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Michele Eliza Cortazzo Menis-Henrique, Natália Soares Janzantti, Isabelle Andriot, Etienne Semon, Olivier Berdeaux, Pascal Schlich, Ana Carolina Conti-Silva

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1   **Cheese-flavored expanded snacks with low lipid content: oil effects on the *in vitro* release**

2   **of butyric acid and on the duration of the dominant sensations of the products**

3   Michele Eliza Cortazzo Menis-Henrique[1*], Natália Soares Janzantti[1], Isabelle Andriot[2],

4   Etienne Sémon[2], Olivier Berdeaux[2], Pascal Schlich[2], Ana Carolina Conti-Silva[1]

5   [1]São Paulo State University (Unesp), Institute of Biosciences, Humanities and Exact Sciences

6   (Ibilce), Department of Food Engineering and Technology, Rua Cristóvão Colombo, 2265,

7   CEP 15054-000, São José do Rio Preto, SP, Brazil.

8   [2]INRA, UMR 1324 Centre des Sciences du Goût et de l'Alimentation (CSGA), 17 Rue de

9   Sully, 21065, Dijon, France.

10   [*]Corresponding author

11   M. E. C. Menis-Henrique

12   Telephone: +55 17 32212565

13   E-mail address: micheleecmenis@gmail.com

14 **Abstract**

15 With the aim of producing snacks with reduced lipid content, the effect of lipids on the *in*

16 *vitro* release of butyric acid and on the duration of the dominant sensations of cheese-flavored

17 expanded snacks were investigated. For that, snacks were obtained through pre-extrusion

18 addition of aroma precursors of cheese to corn grits (butyric acid and cysteine) and sprinkled

19 with sunflower oil in different proportions (6, 12, 18 and 24 g/100 g). The snack sprinkled

20 with 6 g/100 g of sunflower oil showed higher release of butyric acid, compared to the other

21 snacks with oil, when a chewing simulator was employed (simulation of aroma perception),

22 and practically the same release in relation to the other snacks when the dynamic headspace of

23 products was obtained (i.e. simulation of odor perception). All snacks with sunflower oil were

24 described by the duration of salty taste, crunchy/crisp, cheese flavor, umami taste and oil

25 flavor, indicating that the low use of sunflower oil (6 g/100 g) did not alter or prejudice the

26 dominant sensations of the snacks. Therefore, the production of snacks with low addition of

27 lipids is feasible, improving the nutritive value of these products that are so criticized because

28 of the high lipid content.

29

32   **1. Introduction**

33   Expanded snacks are widely consumed around the world and are obtained through a

34   thermoplastic extrusion process. After extrusion, the snacks are flavored in the conventional

35   way by food industries (post-extrusion flavoring), when a mixture of a lipid vehicle (oil or

36   hydrogenated vegetal fat), salt and additives (commercial aroma and flavor enhancers) is

37   sprinkled on the snacks (Maskan & Altan, 2012). This flavoring process increases the lipid

38   and salt content in the snacks, as well the caloric value, reasons why these products are much

39   criticized. Corn snacks marketed in Brazil presents total lipid content from 11 to 30 g/100 g

40   and energy values from 408 to 500 kcal per 100 g product (values observed at labels). These

41   values are similar to those presented in the Brazilian Table of Food Composition (Tabela

42   Brasileira de Composição de Alimentos, 2018), in which commercial corn snacks have a lipid

43   content from 15 to 35 g/100 g and an energy from 448 to 555 kcal per 100 g product.

44   Healthier versions of this product may be obtained using pre-extrusion flavoring, by adding

45   many types of flavoring agents to the raw material to be extruded (Bhandari, D'Arcy, &

46   Young, 2001; Yuliani, Torley, D'Arcy, Nicholson, & Bhandari, 2006; Menis, Milani,

47   Jordano, Boscolo, & Conti-Silva, 2013). With this technique of flavoring, the use of a lipid

48   vehicle can be minimized. However, the suppression of lipids may compromise the sensory

49   quality of the products because of the important contributions of lipids to the flavor of foods.

50   The flavor of a food is the manifestation of interactions between taste, aroma and oral

51   sensations, since taste and oral sensations are associated with non-volatile compounds, while

52   aroma is associated with volatile compounds. The release of volatile compounds from foods

53   during chewing depends on their interaction with the food matrix and both static and dynamic

54   factors are involved in this release. The static equilibrium of the volatile compounds is

55   distributed in the food between the solid matrix, the hydrophilic liquid phase, the liquid

56   lipophilic phase and the gas phase. This distribution is controlled by the partition coefficient

57 of the molecules of the volatile compounds, which affects their volatility. In addition, the

58 mass transfer (a dynamic factor) depends on the viscosity of the food matrix and its interfaces,

59 in which more viscous products release the volatile compounds more slowly (Gaonkar &

60 McPherson, 2006; Reineccius, 2006). In this way, lipids act as transporters and modulators of

61 volatile compounds in food. Even in products with reduced lipid content, the release of

62 volatile compounds can also be altered, negatively affecting the perception of the odor and

63 aroma of foods and, consequently, the flavor (Taylor & Linforth, 2010; Voilley & Etiévant,

64 2006). Moreover, lipids have been investigated as the 6th basic taste (Dramane, Akpona,

65 Besnard, & Khan, 2014), given their importance to the flavor of food. The reduction in or

66 even elimination of lipid content in food is still a challenge.

67   Therefore, with the aim of producing snacks with better nutritive value through

68 reduction of lipids for flavoring, using the pre-extrusion flavoring method, butyric acid and

69 cysteine were added as aroma precursors of cheese to corn grits (Martínez-Cuesta, Peláez, &

70 Requena, 2013) and sunflower oil was sprinkled in different quantities onto the snacks.

71 Butyric acid is a volatile compound that contributes to cheese odors, and considering that

72 lipids influences odor, aroma and flavor of foods, the *in vitro* release of butyric acid was

73 monitored in this work because of the different quantities of oil sprinkled onto the snacks.

74 Moreover, techniques that allow a dynamic sensory evaluation of foods, such as the Temporal

75 Dominance of Sensations (TDS), provide complete information about how dominant

76 sensations vary during the consumption (Lawless & Heymann, 2010; Pineau et al., 2009).

77 Thus, TDS is an interesting technique to be applied to snacks, both for providing information

78 about dominant sensory sensations, which may be related to lipid content, and also because

79 studies about the application of TDS to snacks were not found in the literature.

80 **2. Material and Methods**

81 **2.1 Material**

82   Corn grits (Capela do Alto, Brasil), salt (Cisne, Cabo Frio, Brasil), flavor enhancer

83 monosodium glutamate (Ajinomoto, Limeira, Brasil) and sunflower oil (Liza, Mairinque,

84 Brasil) were used to produce the expanded snacks. Food-grade butyric acid (Sigma-Aldrich,

85 Milwaukee, USA, code W222119, purity >99 g/100 g) and amino acid cysteine (L-cysteine

86 HCL anhydrous, Infinity Pharma, Campinas, Brazil, purity >98.5 g/100 g) were used as

87 aroma precursors of cheese on the expanded snacks.

88   The reagents $NaHCO_3$, $K_2HPO_4 \cdot 3H_2O$, $NaCl$, KCl, $CaCl_2 \cdot 2H_2O$, NaN_3, bovine mucin

89 (reference Sigma: M3895), and porcine alpha-amylase (reference Sigma: A4268), all from

90 Sigma-Aldrich (Milwaukee, USA), were used for production of artificial saliva.

91 **2.2 Preparation of corn grits and extrusion processing**

92   Butyric acid and cysteine (addition of 0.4 g/100 g and 0.2 g/100 g, respectively) were

93 added to corn grits (previously an adjusted to 15 g/100 g moisture content in dry basis). The

94 addition of butyric acid (liquid compound) was performed in volume based on the density,

95 i.e., the mass of butyric acid to be added to the corn grits was converted to volume using its

96 density. The addition of cysteine (powder) was done in mass. The mixture of corn grits with

97 butyric acid and cysteine was performed through manual agitation of the bags, which were

98 sealed and kept under refrigeration for 24 h, for better distribution of butyric acid in the corn

99 grits. Then, the mixture was kept at room temperature for 2 h before extrusion.

100   Corn grits with the aroma precursors added was extruded in an RXPQ Labor 24 single

101 screw extruder (INBRAMAQ, Ribeirão Preto, Brazil) with five independent heating zones.

102 Extrusion conditions were: helicoidally grooved barrel; screw with a compression ratio of

103 2.3:1 and length-to-diameter ratio of 15.5:1; pre-die extruder with holes of 3.01 mm; extruder

104 die with a diameter of 2.93 mm (round hole); feed rate of 265 g/min; screw speed at 192 rpm;

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

106   respectively.

107   After extrusion, salt (1.4 g/100 g) and monosodium glutamate (0.6 g/100 g) were added

108   to the snacks and then sunflower oil was sprinkled on the snacks in the proportions of 6, 12,

109   18, or 24 g/100 g. Two control snacks were produced under the same extrusion conditions: 1)

110   a snack with salt and monosodium glutamate, but without aroma precursors and sunflower oil

111   (control evaluated only through TDS), and 2) snack with aroma precursors, salt and

112   monosodium glutamate, but without sunflower oil (0 g/100 g). The amounts of salt,

113   monosodium glutamate and sunflower oil correspond to the addition of these ingredients in

114   100 g of snack.

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

116   The butyric acid was added to corn grits as an aroma precursor of cheese in the

117   expanded snacks, being a volatile compound that has an important contribution to the

118   odor/aroma of cheese (Martínez-Cuesta, Peláez, & Requena, 2013). The *in vitro* release of

119   butyric acid was monitored using a Proton Transfer Reaction Time-of-Flight Mass

120   Spectrometer (PTR-ToF-MS) connected to two different devices: chewing simulator and

121   valve system.

122   In the chewing simulator, the snacks were mixed with artificial saliva to reproduce

123   mastication. In this way, this system may represent the release of butyric acid inside the

124   mouth, i.e., retronasal olfaction. The valve system allows the evaluation of the dynamic

125   headspace from the snack, representing orthonasal olfaction. Therefore, considering the

126   operation of the two devices, and for better understanding of our results, the two evaluations

127   of *in vitro* release were called *via* aroma (chewing simulator) and *via* odor (valve system),

128   respectively.

129   2.3.1 Evaluation of *in vitro* release of butyric acid *via* aroma

130   The chewing simulator was developed with the aim of reproducing mastication and is

131   composed of an active cell, where the mastication process is performed, an electronic control

132   box and a computer to monitor and adjust each parameter (Salles et al., 2006; Salles, Tarrega,

133   Mielle, Maratray, & Gorria, 2007). The active cell is formed by a mobile lower jaw, a mobile

134   tongue, and a fixed upper jaw. The lower and upper jaws are ring-shaped cylinders composed

135   only of molar teeth made of polyether ether ketone (PEEK), and the tongue is also made of

136   PEEK, in the shape of a cylinder with a 4.5 cm diameter (Salles et al., 2007).

137   Artificial saliva used during the chewing simulation was prepared according to the

138   protocol used by the Centre des sciences du goût et de l'alimentation at the Institut National de

139   la Recherche Agronomique (CSGA/INRA), adapted from Friel and Taylor (2001), Munoz-

140   González et al. (2014) and Ruth, Grossmann, Geary, and Delahunty (2001). The following

141   materials were used: NaHCO (5.208 g), $K_2HPO_4.3H_2O$ (1.369 g), NaCl (0.877 g), KCl (0.477

142   g), $CaCl_2.2H_2O$ (0.441 g), NaN_3 (0.500 g), bovine mucin (2.160 g), and porcine and 200,000

143   units of alpha-amylase (12 units/mg). All the products, except for alpha-amylase, were added

144   to one liter of distilled water. The solution was agitated for 30 min to complete

145   homogenization and then the alpha-amylase was added. The artificial saliva was maintained at

146   -20 °C until use.

147   The chewing simulator parameters were defined according to previous studies (Mielle

148   et al., 2010; Tarrega, Yven, Sémon, & Salles, 2011; Yven, Guessasma, Chaunier, Valle, &

149   Salles, 2010) and, after preliminary tests, the parameters were fixed as follows: mandible and

150   tongue forces of 30 daN; shearing force of 35 daN; shearing angle value of 1/8th tooth; 15

151   chewing cycles (about 50 s of chewing); artificial saliva flow of 2 mL initial and 1 mL/min

152   after the chewing starts; and humid air at a flow of 135 mL/min.

153   Although in human consumption the whole snack may be placed in the mouth, snacks

154   of 2 cm in length were weighed (to guarantee that they all had the same mass) and broken into

155   four parts for chewing. Preliminary tests performed to determine the best snack arrangement

156   in the chewing simulator showed the arrangement presented in Fig. 1A as the most adequate,

157   which, after chewing, presented a food bolus similar to that of a human being (Fig. 1B).

158   Analyses in the chewing simulator were performed in duplicate and data on the release of

159   butyric acid was obtained from 17 to 27 s when the chewing simulator was used,

160   corresponding to the period of increase in signal intensity from the start of chewing (linear

161   part of the graph – Fig. 2A).

162   2.3.2 Evaluation of *in vitro* release of butyric acid *via* odor

163   Fifty milligrams of milled snack were added to a 20-mL hermetically sealed vial and

164   immersed in a bath for 30 min at 40 °C (Conti-Silva, Bastos, & Arêas, 2012). The vial

165   containing the sample was inserted in the valves device and maintained for another 15 min,

166   also at 40 ºC, for the headspace equilibrium. The valves device was activated automatically,

167   operating as follows: for 30 s, valves were open allowing the passage of room air through an

168   empty vial (reference) to the PTR-ToF-MS. After that, the valves were switched, closing the

169   connection of the reference vial to the MS at the same time as the vial containing the snack

170   sample was connected to the MS for 180 s. Analyses were performed in duplicate and data on

171   the release of butyric acid was obtained from 40 to 80 s when the valve system was used,

172   corresponding to the period of increase in signal intensity after the opening of the valves

173   (linear part of the graph – Fig. 2B).

174   2.3.3 Study of butyric acid release using the PTR-ToF-MS

175   The study of butyric acid release from the expanded snacks was performed using an

176   Ionicon PTR-TOF-MS 8000 detector (Ionicon Analytik, Innsbruck, Austria). The drift tube

177   conditions used were: temperature maintained at 80 ºC, operation voltage of 480 V and

178   pressure of 2.3 mBar, resulting in an E/N ratio of 112 Townsends (1 Td $=10^{-17}$ $V.cm^2$) (E:

179   electric field strength; N: density). The headspace was admitted in the PTR-ToF-MS with a

180   flow rate fixed at 100 mL/min. The scan speed was 500 ms for a mass range m/z 0-250. For

181   mass calibration, the mass/charge ratios for H_3O^+ (m/z 21.022086), NO^+ (m/z 29.997440),

182   and acetone (m/z 59.049141) were monitored. Results were obtained evaluating the

183   protonated butyric acid ion (MH^+ ion m/z 89.0616). As calibration curves were not produced,

184   the data were expressed in normalized CPS (nCPS) using primary ions $H_3O^+$and $H_3O^+(H_2O)$

185   as recommended by the manufacturer to account for primary ion fluctuations using the PTR-

186   MS Viewer software (version 3.1.0.31). The PTR-ToF-MS was connected to the two different

187   devices *via* a 1-mm internal diameter, 600-mm length, 1/16-in external diameter polyether

188   ether ketone (PEEK) capillary (maintained at 75 ºC).

189   Data from the PTR-ToF-MS, obtained through both the chewing simulator and the

190   valve system, was analyzed from the linear part of the butyric acid release plot. During the

191   analyses, humid air was introduced into the chewing simulator and the vials via one opened

192   valve as the headspace was admitted in the PTR-ToF-MS with a flow rate fixed at 100

193   mL/min. The drift tube pressure had to be strictly constant to have stable ionization

194   conditions, and to avoid a decreasing of the drift tube pressure (increase of the E/N ratio

195   parameter) due to the closing of the chewing simulator and the vials, a gas flow was needed to

196   flush them. Thus, we analyzed only the linear part of the graph that corresponds to the

197   headspace from the chewing simulator and the vials.

198   **2.4 Evaluation of the sensory profile of the expanded snacks**

199   The sensory profile of the snacks was evaluated through the multi-intake Temporal

200   Dominance of Sensations (TDS) test. This study was approved by the Research Ethics

201   Committee of the Institute of Biosciences, Literature, and Exact Sciences at São Paulo State

202   University (Decision No. 360.800).

203   The test was performed in the Sensory Analysis Laboratory of the Department of Food

204   Engineering and Technology at the same Institute, in individual booths with white light and at

205   a temperature of approximately 22 °C, using the TimeSens® software (CSGA/INRA, Dijon,

206   France). Nine panelists, who previously participated of an Optimized Descriptive Profile

207   (Silva et al., 2012) of cheese-flavored snacks, were recruited for the test. Of the nine panelists,

208   five were male, all were aged from 24 to 29 years and like little or too much of cheese-

209   flavored snacks, and six consume this product once every 15 days or once a month. The

210   panelists defined seven attributes in the snacks: two for texture (crunchy/crispy and hard), and

211   five for flavor (cereal flavor, cheese flavor, oil flavor, salty taste, and umami taste). Before

212   performing the test, the panelists were familiar with the software and were instructed that the

213   dominant sensation is that one that captures the attention, not necessarily the most intense

214   sensation (Pineau et al., 2009).

215   Multi-intake TDS analysis was conducted in triplicate for each snack, and each replicate

216   was performed with three intakes (three units of the same snack, with 2 cm in length each

217   one). In each intake of each replicate, the panelists clicked on the 'START' button on the

218   computer screen as soon as they had the snack in the mouth. Next, they selected the attribute

219   that attracted their attention from the list of seven attributes and only one attribute could be

220   selected at a time. However the same attribute could be selected several times. When the

221   panelists perceived that no more sensation was dominant, they clicked on the 'STOP' button

222   to indicate the end of the TDS evaluation of this unit (intake). After this, panelists performed

223   the same task for the other intakes and replicates, and there was no time limit for each sample

224 evaluation. All samples were presented in plastic cups encoded with random three-digit

225 numbers in balanced and monadic manner and following a Williams Latin square.

226 **2.5 Data analysis**

227 2.5.1 Butyric acid *in vitro* release

228   Results from the PTR-ToF-MS tests were analyzed in two ways: first, curves showing

229 the signal intensity against release time were fitted using a linear model and the inclination

230 coefficient for the release of butyric acid was obtained; then, the area below this curve was

231 calculated using the midpoint integration rule. These data were submitted to analysis of

232 variance followed by the Tukey test, at significant level of 0.05, using the Statistica 7.0

233 software (StatSoft Inc., Oklahoma, EUA).

234 2.5.2 Temporal Dominance of Sensations

235   TDS curves were built, standardizing the time for each intake between 0 (START) and

236 1 (STOP) (Galmarini, Loiseau, Debreyer, Visalli, & Schlich, 2017; Galmarini, Visalli, &

237 Schlich, 2017; Galmarini, Loiseau, Visalli, & Schlich, 2016). TDS curves show the

238 dominance rate of each attribute over time, as well as the lines corresponding to 'chance

239 level' and to 'significance level'. The 'chance level' is the dominance rate that an attribute

240 can be obtained by chance, while the 'significance level' is the minimum value of the

241 dominance rate considered as significant (Pineau et al. 2009). Therefore, an attribute is

242 considered dominant at that moment when the curve is above the significance level. However,

243 if the curve is in-between the chance and the significance level, the attribute can be

244 considered as having a tendency towards dominance (Galmarini et al., 2017).

245   The TDS data was also treated in order to compare dominance durations statistically.

246 Each intake was first time-standardized between 0 and 1 and then the 3 consecutive intakes

247 were concatenated. Thus time of the 3 intakes varies between 0 and 1 for the first, 1 and 2 for

248 the second and 2 and 3 for the third one. Dominance durations were computed from this

249 standardized data and submitted to a two-way ANOVA model including sample, panelist and

250 their interaction as factors, followed by Tukey test (significance level of 0.05). The same data

251 was submitted to the canonical variate analysis (CVA). All analyses were performed using

252 TimeSens® software (INRA, CSGA, Dijon, France).

3. Results and discussion

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

255   Fig. 2 shows that all snacks presented a similar release profile for butyric acid, both *via*

256 aroma (Fig. 2A) and *via* odor (Fig. 2B). However, statistical differences were observed

257 between the inclination coefficients of butyric acid release (Table 1) and to areas under the

258 curve (Table 2). For butyric acid release *via* aroma, the control snack (without sunflower oil)

259 presented the highest ($p \leq 0.05$) inclination coefficient (Table 1), as well as the highest ($p \leq$

260 0.05) area under the curve (Table 2), followed by the snack with 6 g/100 g of sunflower oil,

261 and then by the other snacks (12, 18 and 24 g/100 g of sunflower oil). However, for butyric

262 acid release *via* odor, the opposite was observed, because all snacks with sunflower oil

263 presented higher ($p \leq 0.05$) inclination coefficients (Table 1) and areas under the curve (Table

264 2) in relation to the control snack.

265   As butyric acid was added to the corn grits before extrusion, our hypothesis is that its

266 retention by the final product probably occurred through encapsulation inside the snack and

267 interaction with the sunflower oil sprinkled on the product. During consumption of products

268 without lipid, lipophilic volatile compounds, such as butyric acid, tend to be released rapidly

269 after the food is ruptured because of mastication. In products containing lipids, the release of

270 lipophilic volatile compounds occurs more slowly, since such compounds first need to be

271　released from the food matrix (encapsulation inside the snack) and migrate through the oil

272　interfaces (sunflower oil sprinkled on the product) to the saliva, and then released to the

273　headspace inside the mouth (Leland, 1997; Madene, Jacquot, Scher, & Desobry, 2006; Roos,

274　1997; Yuliani, Torley, & Bhandari, 2009). This is related to the partition coefficient of the

275　volatile compound representing the thermodynamic behavior of the compound in an organic

276　phase and in an aqueous phase ($P_{ow} = C_o/C_w$, where: C_o and C_w, concentration of volatile

277　compounds in the organic phase and in the water phase, respectively) (Roos, 1997;

278　Bortnowskaa, & Goluch, 2018). According IPCS (2018), octanol/water partition coefficient of

279　butyric acid as log P_{ow} is 0.79, showing the higher affinity of this compound by the organic

280　phase than by the aqueous phase. Thus, in the control snack (without sunflower oil), the

281　butyric acid was probably released quickly with the break-up of the snack structure during

282　mastication through the chewing simulator, shown by higher inclination coefficient of release

283　(Table 1) and area under the curve (Table 2), which corresponds to the amount of butyric acid

284　released over the time period analyzed. In the snacks that were sprayed with sunflower oil, the

285　release was supposedly slower, explaining the lower inclination coefficients of release and

286　areas under the curve in relation to the control snack. Therefore, the absence of lipids, or the

287　low quantity of lipids in the case of the snack with 6 g/100 g of sunflower oil, may result in a

288　momentary perception of butyric acid *via* aroma (inside the mouth), because the release is

289　fast, different from a longer perception when the amount of lipid is higher and the release of

290　butyric acid is slower.

291　　　　In the case of butyric acid release *via* odor, it seems that the sunflower oil protected the

292　snacks from the loss of butyric acid. This may have occurred due to interactions of butyric

293　acid with lipids, requiring more time to be released due to greater resistance to mass transfer

294　of the butyric acid in oil than in air. Moreover, this effect was independent of the amount of

295　oil sprinkled on the snacks because the linear coefficients of release were statistically equal

296   for snacks with added oil (Table 1) and the areas under the curve little discriminated between

297   the snacks with oil (Table 2). Regarding the snacks without oil addition, we observed a lower

298   release coefficient (Table 1) and area under the curve (Table 2), probably because during the

299   preparation of the sample (milled), part of the butyric acid was released precisely because

300   there was no oil to increase the mass transfer resistance and act as a protector of butyric acid.

301   Comparing the snacks with oil addition, the sprinkling of 6 g/100 g of sunflower oil

302   caused higher release of butyric acid *via* aroma and practically the same release *via* odor in

303   relation to the other snacks, besides not raising the lipid content very much when compared to

304   others. In this study, these results were complemented with the Temporal Dominance of

305   Sensations technique providing information about the perception of the dominant sensation of

306   the flavor of the snacks over time.

3.2 Temporal Dominance of Sensations of the expanded snacks

307

308   The Fig. 3 shows the TDS curves for each snack over the three intakes. For both the

309   control snacks (C1 and C2), a total of three attributes reached significant dominance rates

310   over the three intakes: crunch/crispy, hard and cereal flavor. The beginning of intake was

311   characterized by hard and crunchy/crispy followed by the cereal flavor that persisted until the

312   end of each intake. Therefore, the absence of aroma precursors and sunflower oil (C1) and of

313   sunflower oil (C2) allowed the dominance of the cereal flavor, coming from the extruded corn

314   grits. Although the C2 snack had been produced with aroma precursors, the cheese flavor did

315   not reach a significant dominance rate for its characterization. This is due to the importance of

316   the lipids in releasing the volatile compounds from a food (Taylor & Linforth, 2010; Voilley

317   & Etiévant, 2006), and, consequently, on the perception of flavor of the product. Although C1

318   had added salt and monosodium glutamate, the salty taste and umami taste did not reach a

319 significant dominance rate for its characterization. This can also probably be explained by the

320 influence of the lipids on the perception of non-volatile compounds (Dramane et al., 2014).

321 In general, the snacks with sunflower oil had significant dominance rates of all

322 attributes. All snacks were described as crunchy/crisp, showing its importance as a dominant

323 attribute of expanded snacks, independent of the formulation of the product. Different from

324 the control snacks, the cheese flavor was dominant in all snacks with oil, although it was not

325 dominant at the intake 3 of the snack with 6 g/100 g oil. Snacks with oil were differentiated

326 regarding umami and salty taste, because the umami taste had significant dominance rate for

327 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,

328 while both attributes described the snack with 24 g/100 g oil. The snack with 12 g/100 g oil

329 was the only snack with oil that was not described by the oil flavor, although this attribute

330 appears as dominant only at the end of the third intake for the other three snacks with oil.

331 These results are justified in the same way as previously, due to the influence of lipids on the

332 release of volatile compounds (Taylor & Linforth, 2010; Voilley & Etiévant, 2006), and on

333 the perception of non-volatile compounds (Dramane et al., 2014). Therefore, the presence of

334 sunflower oil aggregates dominant sensations to snacks, expanding and enriching their

335 sensory profiles.

336 In the same way, the canonical variate analysis splits snacks in function of the presence

337 or absence of oil (Fig. 4). The control snacks (C1 and C2), both without oil, were described

338 regarding the longer duration of the attributes hard and cereal flavor, while snacks with oil

339 were described by the longer duration of salty taste, crunchy/crisp, cheese flavor, umami taste

340 and oil flavor. Moreover, the overlap of the ellipse of the snack with 6 g/100 g of sunflower

341 oil and the ellipses of the other snack (12, 18 and 24 g/100 g) indicates similarity in the

342 duration of the dominant attributes of these products. Indeed, when the duration of the

343 dominant sensations are compared statistically, the snack with 6 g/100 g of oil was

344 statistically equal to the others with oil (Table 3). Therefore, the low use of sunflower oil does

345 not alter the dominant sensations of the snacks.

346 **4. Conclusions**

347   The monitoring of *in vitro* release of butyric acid showed that the snack sprinkled with 6

348 g/100 g of sunflower oil conferred a higher release of butyric acid *via* aroma and practically

349 the same release *via* odor in relation to the other snacks. Moreover, all snacks with sunflower

350 oil were described by the duration of salty taste, crunchy/crisp, cheese flavor, umami taste and

351 oil flavor, indicating that the low use of sunflower oil (6 g/100 g) did not alter or prejudice the

352 dominant sensations of the snacks. The production of snacks with low addition of lipids is

353 feasible and more studies about reducing the lipid content could be conducted in order to

354 further increase the nutritive value of this product. It must be emphasized that lipids are

355 macronutrients and lipophilic vitamin carriers, and so they are fundamental to human health.

356 Therefore, along with the improvement of the nutritive value of snacks by lipid reduction, the

357 population must be educated about the benefits of lipids to health, preventing health problems

358 through their elimination from the diet.

362

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455 **Legends of the figures**

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

457 **Fig. 2.** Profile of release of butyric acid from the expanded snacks *via* aroma (A) and *via* odor

458 (B). Legend: C2 - Control 2 (with addition of aroma precursors and without sunflower oil); 6 g/100 g - snack

459 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

460 g/100 g of sunflower oil; 24 g/100 g - snack with 24 g/100 g of sunflower oil.

461 **Fig. 3.** Multi-intake TDS curves for the expanded snacks. Legend: C1 - Control 1 (snack with salt

462 and monosodium glutamate, but without aroma precursors and sunflower oil); C2 - Control 2 (with addition of

463 aroma precursors and without sunflower oil); 6 g/100 g - snack with 6 g/100 g of sunflower oil; 12 g/100 g -

464 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

465 with 24 g/100 g of sunflower oil. The x-axes represent the standardized time between 0 and 1.

466 **Fig. 4.** Canonical Variate Analysis for the duration of dominant attributes for the expanded

467 snacks. Legend: C1 - Control 1 (snack with salt and monosodium glutamate, but without aroma precursors and

468 sunflower oil); C2 - Control 2 (with addition of aroma precursors and without sunflower oil); 6 g/100 g - snack

469 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

470 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	$14.05^a \pm 1.63$	$I = 2.32 \cdot 10^9t - 8.85 \cdot 10^{10}$	0.94	$2.32^b \pm 0.49$
6 g/100 g	$I = 8.91 \cdot 10^9t - 1.56 \cdot 10^{11}$	0.85	$8.91^b \pm 0.63$	$I = 7.87 \cdot 10^9t - 2.74 \cdot 10^{11}$	0.95	$7.87^a \pm 1.66$
12 g/100 g	$I = 3.70 \cdot 10^9t - 6.02 \cdot 10^{10}$	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	$I = 2.15 \cdot 10^9t - 3.52 \cdot 10^{10}$	0.46	$2.15^c \pm 0.28$	$I = 9.89 \cdot 10^9t - 3.33 \cdot 10^{11}$	0.95	$9.89^a \pm 0.30$
24 g/100 g	$I = 4.20 \cdot 10^9t - 7.13 \cdot 10^{10}$	0.66	$4.20^c \pm 0.01$	$I = 9.45 \cdot 10^9t - 9.66 \cdot 10^{11}$	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	$32.6^a \pm 3.57$	$1.78^c \pm 0.27$
6 g/100 g	$25.3^b \pm 0.76$	$4.64^b \pm 0.79$
12 g/100 g	$9.08^c \pm 0.57$	$6.53^a \pm 0.21$
18 g/100 g	$7.03^c \pm 0.32$	$5.87^{ab} \pm 0.26$
24 g/100 g	$7.57^c \pm 0.03$	$6.06^{ab} \pm 0.56$

[*]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.
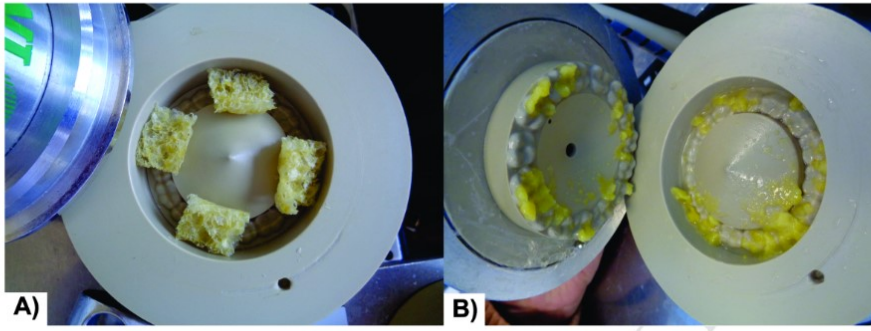[***]Values of area (arbitrary units) were divided by 10^{13}.
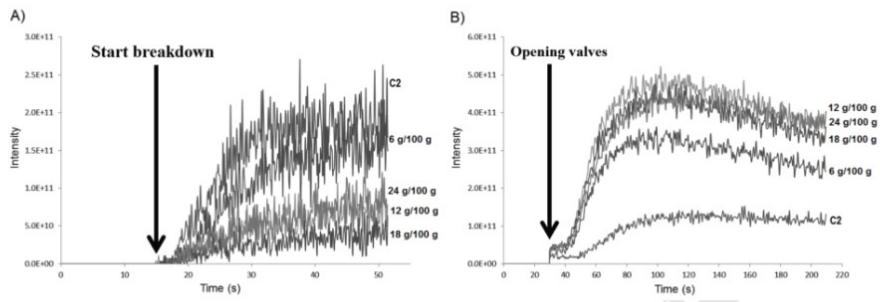Different letters in the same column indicate a significant difference between the samples by the Tukey test ($p \leq 0.05$).

Table 3

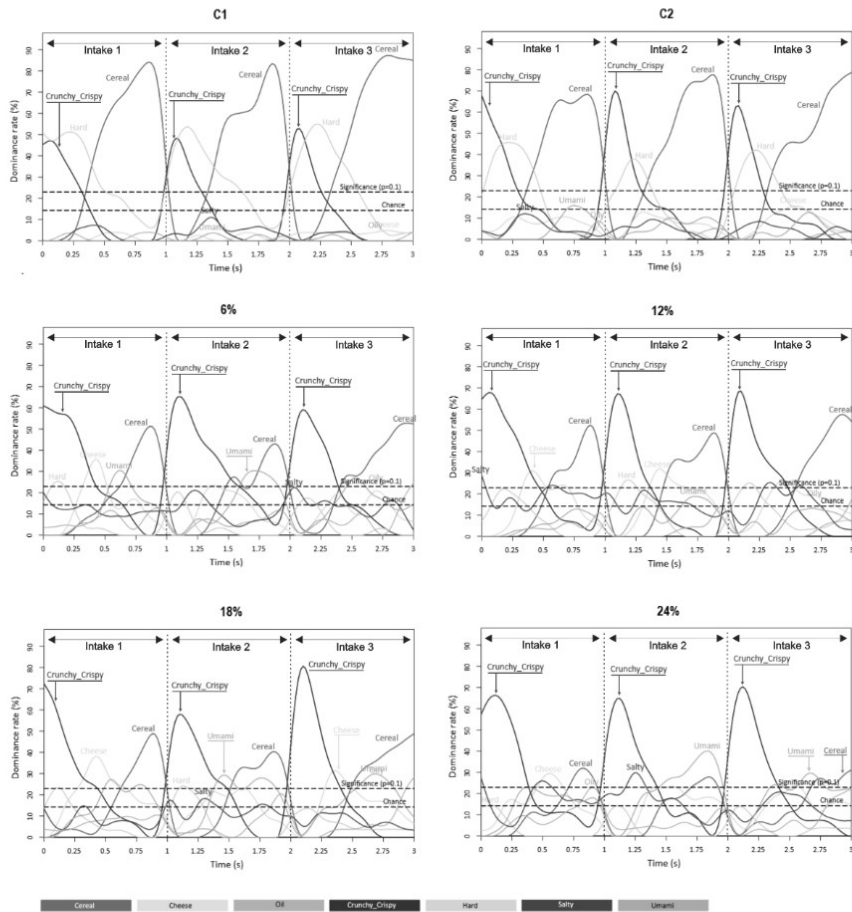Proportional duration (means ± SD) of the dominant sensations.

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 without 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.
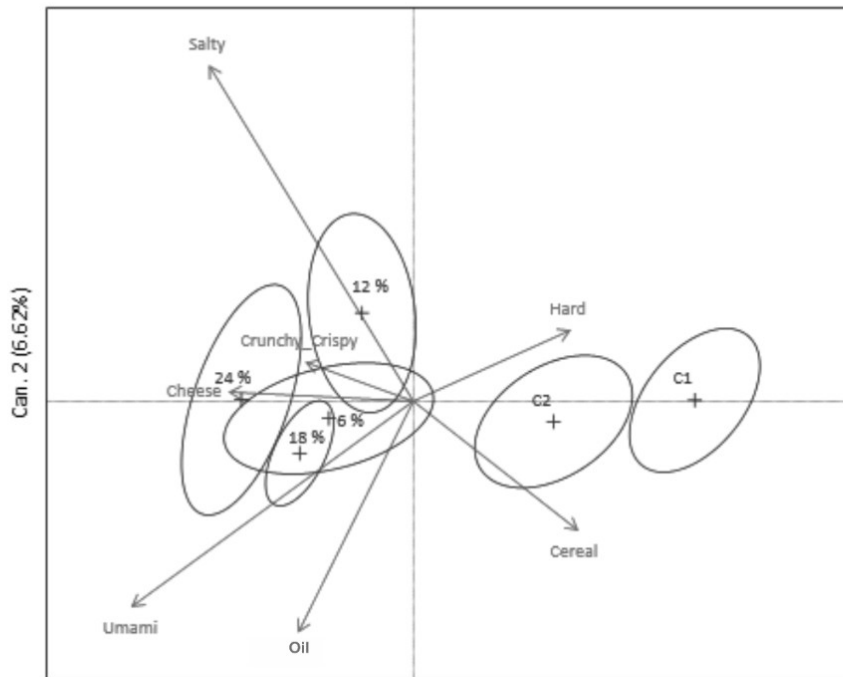Different letters in the same line indicate a significant difference between the samples by the Tukey test (p ≤ 0.05).

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.