Model cheese aroma perception is explained not only by in vivo aroma release but also by salivary composition and oral processing parameters

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1   **Model cheese aroma perception is not only explained by *in vivo* aroma**

2   **release but also by salivary composition and oral processing parameters**

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8

9   **Abstract**

10   The aim of the present paper was to determine, on four model cheeses differing in fat content and firmness consumed by

11   fourteen well characterised subjects, the respective impacts of *in vivo* aroma release, bolus rheology, chewing activity,

12   mouth coating and saliva composition on dynamic aroma perception. The originality of the approach was to consider all the

13   parameters together and to be able to evaluate their relative contribution using multi-block partial least square (MB-PLS)

14   regression. Fruity aroma perception of the more hydrophilic compound (ethyl propanoate) was related to its dynamic

15   release parameters before swallowing whereas blue cheese aroma perception of the more hydrophobic compound (nonan-

16   2-one) was related to its dynamic release parameters after swallowing and was highly impacted by mouth coating.

17   Moreover MB-PLS approach made it possible to evidence the combined effects of saliva composition and cross-modal

18   interactions to understand why in some cases dynamic aroma perception could not be explained by dynamic *in vivo* aroma

19   release data. Subjects with low sodium content in saliva perceived fruity aroma which is not congruent with saltiness as less

20   intense and salt- congruent (blue cheese) aroma as more intense, which was explained by their higher sensitivity to salt.

21   Subjects with a high lipolysis activity perceived fruity aroma which is not congruent to fat as less intense and fat-congruent

22   (blue cheese) aroma as more intense, which should be explained by the link between lipolysis activity and fat sensitivity.

23   These results could be considered for the reformulation of foods towards specific populations taking into account

24   nutritional recommendations.

26 **Introduction**

27   Aroma perception is an important aspect of food acceptability by consumers. However it is often very difficult to

28   directly explain aroma perception during food consumption by the amount of aroma compounds in the food. One

29   explanation is that aroma compounds have first to be released from the food matrix to the vapour phase in the

30   buccal cavity then transferred into the nasal cavity via the velum to reach the olfactory receptors[1]. The partition of

31   aroma compounds between the food matrix and the vapour phase depends on the affinity of aroma compounds

32   for the macromolecules present in the food[2] which can be determined by measuring the vapour/matrix partition

33   coefficients of aroma compounds. These coefficients depend both on the physico-chemical properties of the

34   aroma but also on the food matrix composition. As an example hydrophobic aroma compounds are more soluble

35   in fat than in water and thus are better released in the vapour phase from products with a reduced fat content[3].

36   Proteins are able to form reversible or irreversible binding with aroma compounds which will impact aroma

37   release in the vapour phase[4, 5]. In case of irreversible binding such as the formation of Schiff base between amino

38   groups of proteins and aldehydes[6], the aroma compounds cannot be released in the vapour phase and thus cannot

39   be perceived. In case of reversible binding the aroma perception is lowered[7]. The major effect of hydrocolloids is

40   to increase food viscosity and thus decrease the transfer of aroma compounds from matrix to vapour[8, 9], however

41   inclusion complexes are formed between amylose and specific aroma compounds which also impacts aroma

42   perception[10]. During consumption, food is mixed with saliva and broken down during the masticatory step to form

43   a swallowable bolus. During this step, aroma compounds are transferred from food to saliva before being released

44   in the nasal cavity. This transfer of aroma compounds is highly dependent on food composition and texture but

45   also on subject's physiology[11]. Thanks to the development of on line aroma release technologies, such as

46   atmospheric pressure chemical ionisation (APCI-MS)[12] or proton transfer reaction mass spectrometry (PTR-MS)[13],

47   it was possible to better understand the impact on dynamic *in vivo* aroma release of food matrix composition and

48   structure[14, 15] and of physiological parameters such as chewing, swallowing, saliva flow[16, 17]. Concerning the impact

49   of food matrix, increasing fat content results in a decrease in maximum intensity and overall *in vivo* aroma release

50   together with an increase in aroma remanence as was observed in gelatin gels[18], whey protein gels[15] or model

51   cheeses[19], which was explained by a lower solubility of hydrophobic aroma compounds in fat. Even if food

52   rheology could explain chewing activity during consumption[20], bolus properties and in-mouth bolus rheology

53   better explain *in vivo* aroma release[21]. The amount of cheese remaining in the mouth after swallowing has also

54   been found important to explain *in vivo* aroma release. A higher amount of fat product remaining in the mouth

55   leads to a lower release of the more hydrophobic compounds before swallowing due to their high affinity for the

56   food bolus and to a longer aroma persistence in the breath[16, 22]. The less hydrophobic compounds are less

57 impacted by mouth coating but are more quickly released from firmer cheeses, due to a higher food breakdown[16,]

58 [17]. When consuming solid foods, differences in chewing activities between subjects are responsible for differences

59 in aroma release, an intense chewing work leads to a higher amount of aroma release[17].

60 However despite the development of *in vivo* measurements, results in the literature in the field of dairy products

61 showed that no clear relationship exists between *in vivo* aroma release and aroma perception due to the co-

62 existence of physicochemical and cognitive mechanisms[23]. Cognitive mechanisms are due to cross-modal

63 interactions which vary according to the type of texture[24]. In the case of semi-liquid foods such as yoghurts, an

64 increase in viscosity induced a decrease in both aroma release and aroma perception[25], whereas for solid cheeses

65 aroma perception decreased with firmness without any noticeable difference in aroma release[26]. This finding was

66 explained by the attention paid by the subjects to the texture perception which likely led to a decrease in the

67 aroma perception. By delivering simultaneously different kinds of texture and different odorants, Bult et al.[27]

68 showed that the perceived aroma intensity was reduced with increasing viscosity when the odour was presented

69 either ortho or retronasally. Moreover the perceived thickness was increased only when the odour was presented

70 retronasally simulataneously with swallowing time. An adaptation phenomenon was also evidenced in gel candies

71 as being responsible for the influence of taste and texture on aroma perception[28], by comparing the *in vivo* aroma

72 release curves and sensory time intensity curves which were recorded simultaneously. This study showed that

73 time at maximum chewing activity came first followed by time at maximum in nose concentration then time at

74 maximum perceived intensity. The time delays between release and perception increased when the product

75 remained longer in the mouth. The difficulties to relate results from analytic and sensory approaches was also

76 pointed out in brandies[29] and explained by sensory interactions between fruity and woody aroma[30]. In coffee, the

77 burnt sensory notes could be associated with pyrazines detected by *in vivo* PTR-MS analysis but the effect of

78 adding sugar produced a change in aroma perception from burnt to caramel which could not be associated to any

79 change in aroma composition[31], confirming the existence of sweet-aroma interactions[23]. Odour-taste interaction

80 basically depends on the capacity of the two stimuli to form an appropriate combination in a food product context

81 (congruency)[32]. Thus, odour–taste integrated perception highly depends on learned associations, the context in

82 which the food is consumed and the consumer's previous experience[33]. In experimental situations, odour–taste

83 interactions were found to be affected by the so-called dumping and halo effects[34], which resulted from the

84 tendency for sensory panellists to dump their sensations on several available scales (taste and/or odour).

85 Moreover, in more complex cheese flavour mixtures, NaCl, lactic acid, and aroma were found to be able to

86 enhance cheese flavour intensity and to compensate each other towards cheese flavour intensity[35], thus

87 suggesting complex taste-taste and taste-aroma interactions involved in the overall cheese flavour. So far, no

88 study has investigated cross-modal interactions using parameters related to oral physiology.

89 During the last decade, saliva has gained more and more interest in the field of sensory science. Indeed, due to its

90 role in oral clearance, bolus moisturizing and hydrolytic properties, saliva promotes the disintegration of the

91 matrix and thus the release of palatable active substances during food consumption. For example the salivary flow

92 rate influences aroma release[36] by a dilution effect[37]. Salivary flow has also been positively associated with liking

93 for fat[38]. Moreover, amylase activity can modify the bolus rheological properties[39] and thus modulates the

94 perception of salt in starch-based matrices[40]. Even subject to controversy, lipase might be responsible for

95 hydrolysis of food triglycerides and thus fat perception[41, 42]. Finally the catalytic activity of saliva against some

96 aroma compounds (e.g. esters, aldehydes) has been demonstrated *in vivo* and *in vitro*[43-46] with consequences on

97 aroma release and thus on perception. Saliva is also composed of small and large molecules that contribute to

98 maintain a "salivary homeostasis" whose background level can regulate the dynamics of molecule release and thus

99 their sensory impact (sensory or nutritional)[47]. For instance, it has been shown that a human subject with a high

100 salivary sodium concentration is less sensitive to saltiness[48].

101 A previous paper[22] highlighted the role of bolus rheology and composition of stimulated saliva on aroma release

102 from cheeses varying in fat content and firmness. The aim of the present paper is to better understand the

103 physicochemical and physiological parameters which drive dynamic aroma perception. For that purpose, a group

104 of fourteen subjects were selected as representative of those participating to our previous study in order to

105 evaluate aroma perception as a function of time and to determine, on these well characterised subjects, the

106 respective impacts of *in vivo* aroma release, bolus rheology, chewing activity, mouth coating and saliva

107 composition on dynamic aroma perception.

108 ## Experimental

109 ### Cheese products

110 Four processed model cheeses were used[16]. They were composed of a mixture of cheddar, soft cheese, butter, melting

111 salts, protein powder (casein), salt and water. Two levels of texture (S=soft, F=firm) were obtained by varying the water

112 content and two ratio of fat to dry matter, a low level at 25% for low fat cheeses (lfF and lfS) and a high level at 50% for high

113 fat cheeses (hfF and hfS). The pH ranged from 5.27 to 5.55. The rheological properties of the cheeses were measured in a

114 large deformation at a rotation of 0.01 rad.s^{-1} for 240 s using a Haake Viscotester (VT550 - Thermo electron GmbH,

115 Karlsruhe, Germany), as previously described[16]. The breakdown stress corresponds to the maximum strength necessary to

116 cause cheese breakdown, with the lowest values for the softest cheese (8129 ± 469 Pa for lfS and 8022 ± 1309 Pa for hfS)

117 and the highest values for the firmest cheese (15253 ± 1231 Pa for lfF and 15556 ± 2307 Pa for hfF). The critical strain at

118 breakdown corresponds to the maximum rotation angle required to cause breakdown, with the lowest values for cheeses

119   with the highest fat content (0.273 ± 0.022 rad for hfS and 0.348 ± 0.061 rad for hfF), and the highest values for cheeses

120   with the lowest fat content (0.804 ± 0.056 rad for lfS and 0.836 ± 0.036 rad for lfF). Two aroma compounds were added

121   during cheese production, a hydrophobic ketone, nonan-2-one (NO: logP= 2.9, 6 mg.kg^{-1}) and a hydrophilic ester, ethyl

122   propanoate (EP: logP= 1.4, 25 mg.kg^{-1}).

123

124   **Subjects**

125   In a first step, 48 subjects (23 female and 25 males) were selected from a group of 100 volunteers based on their good

126   dental and oral status, and on the repeatability of physiological parameters (salivary flow rate under resting and stimulated

127   conditions, respiratory flux, salivary composition)[16, 20]. They were characterised for their oral volume, saliva composition

128   and flow, *in vivo* release measurement, chewing activity, bolus saliva content, bolus rheology and mouth coating. From this

129   group of 48 subjects, a subgroup of fourteen subjects (6 females and 8 males, average age: 40 years ± 9) was selected for

130   the sensory analyses, on their ability to detect and recognise the two aroma notes. The subjects were not allowed to

131   smoke, eat or drink starting at least one hour before the different test sessions. All the subjects were informed of the

132   observational nature of this study. They gave their signed consent and received a financial compensation for their

133   participation. The study protocol was submitted to an Ethics Committee and was approved on 17 April 2008 by the Comité

134   de Protection des Personnes Est-1 (N°2008/15) and on 8 August 2008 by the Direction Générale de la Santé - France (N°

135   DGS2008-0196).

136   Subjects were characterised for specific physiological parameters described in the following sections.

137

138   **Oral volume**

139   Oral volume was measured using an Eccovision® acoustic pharyngometer (Hood Laboratories, USA), as described

140   previously[49]. This device consists of two microphones and a horn driver mounted on a wave tube and connected to a PC-

141   compatible computer with signal conversion capabilities. The signal was converted into the surface change (cm^2) as a

142   function of the length of the oral cavity (cm). The subjects held the mouthpiece in their mouth with their teeth against the

143   flange and their tongue in a low position. To prevent air leaks, which could cause measurement errors, the subjects placed

144   their lips over the flange, sealing the mouthpiece. The subjects were instructed to breath with their nose during the

145   experiment. Values are expressed in cm^3 and correspond to the average of 10 measures.

146

147   **Saliva samples and flow**

148   Since our previous study[22] highlighted that resting saliva poorly contributed to explaining aroma release whereas

149   stimulated saliva significantly impacted *in vivo* aroma release from soft cheeses, only results obtained with stimulated saliva

150 are taken into account in the present paper. Stimulated saliva was collected as previously described[49]. The subjects chewed

151 a piece of Parafilm™ (0.5 g ± 0.2 g) for a period of 5 min and spit out the saliva every 30 seconds into a pre weighed cup

152 over a period of 5 minutes. The cups were weighted and the salivary flow rates were expressed in $mL.min^{-1}$. Immediately

153 after collection, the saliva samples were standardized by a first step of centrifugation for 30 min at 15000-x g to remove

154 bacteria and cellular debris. Thereafter the supernatants were stored at -80°C to stop metabolism until subjected to

155 biochemical analyses.

156

157 **Biochemical analyses of saliva samples**

158 **Protein concentrations.** Protein concentrations (Prot) were measured with a standard Quick Start Bradford protein assay

159 (Bio-Rad, France) with bovine serum albumin as the calibration standard.

160 **Enzyme activities.** All enzyme activities were expressed in International Enzyme Activity Units (U) per ml of saliva. One U is

161 defined as the amount of enzyme that catalyses the conversion of 1 micromole of substrate per minute. The lipolytic

162 (Lipolysis), proteolytic (Proteolysis), lysozymal (Lysozyme) and amylolytic (Amylase) activities were determined as

163 previously described[42, 50, 51].

164 **Sodium analysis.** The saliva samples were diluted to 1/20 (50 μL saliva in 950 μL filtered 18 mΩ Milli-Q-water (Millipore,

165 Bedford, MA, USA)) and filtered through a membrane (pore size = 0.45 μm, C.I.L., Sainte-Foy-La-Grande, France). The

166 amounts of sodium (Na) in saliva were determined by HPLC ionic chromatography using a Dionex ICS2500 ion

167 chromatographic system (Dionex, Voisins le Bretonneux, France) as previously described[52]. Quantifications were performed

168 using calibration curves realised with sodium standard solutions ranging from 0.1 to 10 mM in 22 mM sulfuric acid

169 (R^2=0.999).

170

171 **Sensory analyses**

172 All sessions took place in an air-conditioned (21 ± 2°C) sensory testing room of the ChemoSens platform (Centre des

173 Sciences du Goût et de l'Alimentation, INRA, Dijon) using standardized booths equipped with computers. Subjects were

174 instructed to place each piece of cheese (6 g) in the mouth, and freely consume it while keeping the lips closed. The

175 products were presented in a random order at 17° C. All measurements were done in triplicate. Bread, apple and water

176 were used as mouth cleansers between two tests.

177 The subjects were firstly trained during eight sessions to recognise the odour of the two aroma compounds, blue cheese for

178 nonan-2-one (NO) and fruity for ethyl propanoate (EP), using triangular tests and recognition tests. Other training sessions

179 were conducted to familiarize the subjects with the discontinuous time-intensity methodology used. The last training

180   sessions were dedicated to the use of a continuous scale (0 to 10) to score the intensity of the two aroma compounds. Two

181   test sessions were then done using Fizz® software to score the intensity of the two aroma notes during the mastication, to

182   indicate the time of the first swallowing and then to score the intensity of the two aroma notes after each swallowing

183   event, during a total time of 3 min. During mastication and at each swallowing time, the intensity of each aroma note was

184   scored on the continuous scale (0-10). Each of the four cheeses was presented three times, in a random order, at 17°C.

185   From the aroma intensity perception at each swallowing event and the time of each swallowing event, time-intensity curves

186   were reconstituted for each aroma note and the following parameters were extracted: $Imax\_S$ for maximum intensity,

187   $Tmax\_S$ for time to reach maximum intensity, $Ideg\_S$ for intensity at the first swallowing and $Tend\_S$ for time to reach the

188   end of perception (Fig. 1). The rate of perception ($Vmax\_S = Imax\_S/Tmax\_S$) was then calculated as a fifth variable.

189   Insert Figure 1

190   ***In vivo* aroma release measurement**

191   The same protocol was applied for cheese consumption than that described for sensory analysis. The release of the two

192   aroma compounds was followed simultaneously in the nasal cavity as previously described [16] using Atmospheric Pressure

193   Chemical Ionisation-Mass Spectrometry (APCI-MS) with an ion trap Esquire-LC mass spectrometer (Bruker Daltonique,

194   Wissembourg, France) according to their protonated molecular ion (MH^+), which is the main ion: ethyl propanoate

195   ($m/z=103$) and nonan-2-one ($m/z=143$). Air was sampled from the nose at an average flow rate of 37 mL.min^{-1} via a fused

196   silica capillary tubing (i.d. = 0.53 mm) heated at 150 °C and to which a 5 kV positive ion corona pin discharge was applied.

197   Each subject was asked to position the plastic tube in one nostril (the same for all the experiments) and to breathe

198   normally. This period (breath-blank phase) was used to record the potential residual signal of the previous sample until

199   return to the baseline and to control the regularity of breathing.

200   The curves were smoothed using a wavelet decomposition method to eliminate signal fluctuations due to the subjects'

201   breathing patterns. Two release phases were identified, the chewing phase (1) extended from placing the cheese in the

202   mouth to the first swallowing, and the post-swallowing phase (2) extended from the first swallowing to the time at which

203   the signal returned to its baseline level. For both release phases and for each aroma compound, four main parameters were

204   extracted from each individual release curve: the area under the curve ($A1\_P$ and $A2\_P$ (a.u.: arbitrary unit)) representing

205   the quantity of aroma released, the maximum intensity ($IMax1\_P$ and $IMax2\_P$ (a.u.)), the time to reach maximum intensity

206   ($tMax1\_P$ and $tMax2\_P$ (min)) and the release rate ($Vmax\_P= IMax1\_P / tMax1\_P$ (a.u./min)). These data, also not

207   quantitative, allow a direct comparison of the different release curves.

208

209   **Chewing activity**

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210   Chewing activity was monitored during cheese consumption, simultaneously to aroma release. The muscle activity of the

211   superficial masseter and temporis muscles (left and right) during chewing was recorded by electromyography (EMG) using

212   gold surface electrodes (Grass technologies, West Warwick, RI, U.S.A), at 382 Hz, then the signal was amplified and

213   digitalized[53]. The following parameters were extracted from EMG data: number of chewing cycles (Nber_Cycle), chewing

214   duration (Chew_time expressed in s), total muscle work (W_tot expressed in mV.s-1) and mean amplitude of contraction

215   (Ampl expressed in mV) which corresponds to a mean calculated from the amplitude values of each chewing cycle

216   registered in a whole chewing sequence[20].

217

218   **Bolus saliva content**

219   The percentage of dry matter and water content were determined using an infrared dryer for all cheeses and boluses

220   obtained just before swallowing. The percentage of moistening (Moist %) into the bolus was calculated from the bolus

221   water content (Bwc %), the bolus dry matter (Bdm %), the cheese dry matter (Cdm %) and the cheese water content (Cwc

222   %) as follows:

223
$$Moist(\%) = \left(\frac{Bwc}{Bdm} \times Cdm \right) - Cwc$$

224   Three replicates per cheese and per subject were performed.

225

226   **Bolus rheology**

227   The subjects were instructed to chew the cheese samples until swallowing and to spit out the bolus into a truncated

228   syringe. Bolus rheological properties were measured using a compression test on an aliquot of 3 mL of bolus[20]. The test was

229   performed using a mobile circle upper plate and a fixed circle lower plate as compression device, with a compression rate of

230   1 mm.s^{-1}. The bolus was subjected to a force F ranging between 0.01 N and 50 N. From the compression curve, particularly

231   two phases were highlighted. A "flow phase" during which the suspension begins to flow and the particles move

232   significantly in relation to one another at a height denoted as hflow (mm). Yield stress and viscous effects were described

233   respectively by the parameters sflow (Pa) and Kflow (Pa.s). A "particle phase" during which the mechanical response is

234   governed by the particle size which is represented by a height denoted hpart (mm) and the yield stress component denoted

235   spart (Pa). At the end of the compression, hend (mm) denotes the final height and Send (mm^2) the area generated under

236   the maximal force. All measurements were done in triplicate.

237

238   **Mouth coating**

239   The amount of food that sticks to the oral surface after food ingestion (QRB) was quantified by the "mouth rinse" method[54].

240   Curcumin (Naturex, France) was added during cheese production (30 mg.kg^{-1}). Each subject was asked to place a piece of

241   cheese (6 g, at 17°C) in the mouth and to chew normally until swallowing. The subjects swallowed without cleaning

242   movement and then rinsed their mouth (with cleaning movements) with 4 mL of warm water at 50°C for 30 s, and spat it

243   into a vial. This rinsing procedure was applied two times consecutively and the spittle was cumulated in the same vials. The

244   fluorescence intensity of curcumin was quantified using a Perkin Elmer 1420 Multilabel Counter Victor 3V at an excitation

245   wavelength of 450 nm and an emission wavelength of 510 nm. All measurements were done in triplicate.

246

247   **Statistical analyses**

248   Analyses of variance (ANOVA) and Principal Component Analysis (PCA) were performed using XLSTAT® Software (Excel 97,

249   version 8.0, Paris, France). When a significant effect ($p < 0.05$) was revealed by applying ANOVA, the Student-Newman-Keuls

250   test was used to compare the differences in least-squares (LS) means.

251   Statistical treatments for Partial lest Square (PLS) analysis were performed using the free software R 3.3.0 (http://cran. r-

252   project.org/), as already described for the treatment of *in vivo* release data obtained with the same cheeses and 48

253   subjects [22]. The main R package used for multivariate data analyses was «pls 2.5-0» [55]. In a preliminary stage, the statistical

254   treatment consisted in a pre-processing step [56]. More precisely, all the variables are mean centered; then the blocks of

255   variables are set to the same total variance. Finally, in order to explore the systematic variation patterns in the X blocks

256   which are likely to predict the systematic variation patterns in Y, Multiblock -PLSR (MB-PLSR) is applied.

257   The different variables used in the MB-PLS approach are presented in Table 1. They have been divided in six blocks. The Y

258   block corresponds to the variables to be explained that is, the sensory variables. The five other blocks correspond to the

259   explanatory variables (X1-X5). X1 is related to aroma release variables before (1) and after swallowing (2) as previously

260   described. The variables in the subsequent blocks were selected as highly impacting the *in vivo* aroma release[22]. X2 is

261   related to bolus rheological variables and bolus moistening. X3 is related to mouth coating and oral volume. X4 is related to

262   masticatory variables extracted from the EMG signals. X5 is related to the properties of stimulated saliva.

263   Insert Table1

264   **Results**

265

266   **Subjects' physiology**

267   The 14 subjects were selected from the 48 subjects participating to the *in vivo* release measurements[16]. Their physiological

268   characteristics (Table 2) cover the range of variability observed for the 48 subjects as presented in the PCA representation

269 (Fig.2). The principal plan represents 47% of the information. Axis 1 (26.76%) is explained by the salivary flow (Flux_S) and

270 the amount of sodium (Na_S) on its positive part, which are higher for subjects S027 and S094. Axis 2 (20.14%) is explained

271 by the amount of amylase (Amylase_S) , the amount of salivary proteins (Prot_S) and the oral volume (Oral_vol) on its

272 positive part, in relation with subjects S001, S052 and S086. At the opposite, S004 has a very low amount of amylase.

273

274 Insert Table 2.

275 Insert Figure 2

276 **Time intensity perception**

277 From the time intensity curves obtained for the four cheeses, 14 subjects and two odour notes, four variables

278 were extracted namely, maximum intensity (Imax_S), time to reach the maximum intensity (Tmax_S), intensity at

279 the first swallowing (Ideg_S) and time at the end of perception (Tend_S). The fifth variable, rate of perception

280 (Vmax_S = Imax_S/Tmax_S) was calculated. Due to the high inter-individual differences between subjects only two

281 variables show significant differences between the cheeses. Tmax_S is significantly higher ($p = 0.002$) for the blue

282 cheese aroma (NO) detected in low fat cheeses (lfS and lfF) and Vmax_S is significantly higher ($p = 0.07$) for the

283 fruity aroma (EP) detected in high fat soft cheese (hfS). Means and standard deviations for the different cheeses

284 are reported in supplementary Table S1.

285 The high inter-individual variability was also observed on the *in vivo* release variables for the 48 subjects, which

286 was explained by differences in physiological parameters. Results of *in vivo* aroma release have already been

287 published[16], However the data obtained for the 14 subjects selected for the sensory analysis are available in

288 supplementary Table S2. In order to better highlight the subject effect, a multiblock PLS analysis was performed on

289 these 14 subjects to explain sensory perception for each cheese and each aroma compound by the *in vivo* release

290 variables together with the physiological variables (Table 1).

291

292 **Relating sensory perception to *in vivo* aroma release and physiological parameters using MB-PLS**

293 MB-PLS is an extension of the PLS method, a class of regression models attempting to find relationships between

294 explanatory and response variables. In MB-PLS, the predictor variables are separated into subsets or blocks that

295 are standardized in order to balance for the size effect due to the measurement scale. It is a statistical approach

296 particularly relevant when different data sets reflecting different dimensions (physiology, physic, chemistry ..) and

297 with a different number of variables in each set are considered.

298 MB-PLS analyses were conducted on the different data sets to assess the extent to which the X blocks of variables

299 explain sensory perception during cheese matrix consumption (Fig. 3 and Fig. 5). The four cheeses and the two

300   aroma compounds nonan-2-one (NO) and ethyl propanoate (EP) were considered separately for the statistical

301   treatment.

302   Two different results are presented from MB-PLS analysis in the following sections, the importance of the block

303   and the projection of the variables in the correlation circle. At first, the importance of the blocks is calculated from

304   the sum of the beta-weight of the different variables constitutive of the block related to the corresponding

305   component and is expressed in %. It thus reflects the contribution of the block of variables to the determination of

306   the component. Higher is the percentage, higher is the contribution of the block for explaining sensory data.

307   Complementary to the importance of the blocks, the projections correspond to the depiction in a correlation circle

308   of the variables belonging to the different blocks. They thus represent the importance of the variables to the

309   components. Higher a variable is correlated to the components, higher it contributes to the model and thus to

310   explain perception.

311   The choice of the number of MB-PLS components to be retained for the importance of the block and the

312   projections was based on the total variance of block Y recovered by these components. For more details regarding

313   this aspect, we refer to a previous paper[22]. We restrict ourselves to the first two components because they explain

314   between 45.3% and 56% of the total variance of Y for the high fat cheeses and the two aroma compounds and

315   between 36.5 and 50.4% for the low fat cheeses and the two aroma compounds.

316   In order to avoid cumbersome graphical displays on the projections, only the variables with a correlation

317   coefficient with one of the two first components above 0.5 are depicted. The font size for each variable on the

318   projection (Fig. 4 and Fig. 6) reflects the importance of the correlation coefficient with the first two components;

319   with large font size indicating large correlations.

320   The results from the MB-PLS are presented and discussed successively for high fat cheeses and for low fat cheeses.

321

322   ***Relative Importance of the blocks in the projection for high fat cheeses***

323   The importance of the blocks of variables for the two first MB-PLS components is shown in figure 3 for the two

324   high fat cheeses and the two aroma compounds. The release block is important for the high fat firm cheese (hfF)

325   and both molecules and this on the two components (31.7% for NO on component 1 and 37% for EP on

326   component 2) and less important for high fat soft cheeses (with a maximum of contribution of 18.5%). The bolus

327   rheology block is mainly reflected by the second component for EP (25.9% for hfF-EP and 31.5% for hfS-EP) and

328   less reflected for NO. The importance of coating and oral volume is higher for EP than for NO, on the first

329   component. The masticatory variables take an important part in the explanation for both cheeses and both aroma

330   compounds. Notice also the high contribution of stimulated saliva, mainly for hfS-NO (48.9% on component 1 and

331 24.8% on component 2) for which the masticatory variables are less important (12.5% on component 1 and 21.3%

332 on component 2).

333 Insert Figure 3

334 Insert Figure 4

335 ***Projection of the main variables for high fat cheeses***

336 Figure 4 shows the projection of the variables from each block for the two high fat cheeses (hfF and hfS) and the two aroma

337 compounds (EP and NO). The sensory variables from the Y block (variables to be explained) are negatively correlated with

338 component 1 and for the high fat soft cheese, the rate of perception is negatively correlated with component 2. The other

339 variables (explanatory variables) are projected differently according to both the cheese and the aroma compound. For the

340 high fat firm cheese and ethyl propanoate (hfF-EP), the masticatory parameters are correlated with component 1, with the

341 chewing time (Chew_time) and number of chewing cycles (Nber_Cycle) on the positive part and the amplitude (Ampl) on

342 the negative part, the release parameters are correlated with component 2, with a higher correlation coefficient for

343 Vmax_P and Imax1_P, the amount of product remaining in the mouth (QRB) is projected at the opposite of the maximum

344 intensity perceived (Imax_S). Among the salivary parameters, the amount of proteins (Prot_S) is positively correlated with

345 component 1, opposite to the amount of sodium (Na_S) and of amylase (Amylase_S). The amount of lipolysis (Lipolysis_S) is

346 projected close to the QRB. For the high fat soft cheese and ethyl propanoate (hfF-EP), the most correlated explanatory

347 variables are the bolus rheology properties, with Send and Moist negatively correlated with component 1 together with the

348 sensory variables, opposite to hend and hpart. The masticatory parameters are also correlated with component 1, with

349 Chew_time and Nbe_Cycle on the positive part and Ampl on the negative part. Among the release parameters, only

350 Imax1_P and A1_P are positively correlated with component 1 and Vmax_P with a lower correlation. QRB is also projected

351 opposite to Imax_S. Concerning the high fat firm cheese and nonan-2-one (hfF-NO), the masticatory parameters

352 (Chew_time and Nbe_Cycle) are also positively correlated with component 1 and negatively with component 2, the release

353 parameters before swallowing (Imax1_P and A1_P) are positivele correlated with component 1 whereas the release

354 parameters after swallowing (Imax2_P, A2_P) are negatively correlated with component 2. Concerning the high fat soft

355 cheese and nonan-2-one (hfS-NO), the salivary parameters are well represented on the projection, mainly Flux_S and Na_S,

356 positively correlated with component 1 and component 2 and opposite to the maximum intensity perceived. The release

357 parameters have only low correlations with these two components as represented by their small font size, but the time to

358 reach maximum intensities both before and after swallowing (tmax1_P and tmax2_P) are positively correlated with

359 component 2, opposite to the rate of perception. The masticatory parameters and QRB are negatively correlated with

360 component 1.

361

362 ***Relative Importance of the blocks in the projection for low fat cheeses***

363   The importance of the blocks of variables for the two first MB-PLS components is shown in figure 5 for the two low fat

364   cheeses and the two aroma compounds. The relative importance of the release block is always below 28%, it is higher for

365   nonan-2-one and the firm cheese (lfF-NO, 27.5% on component 1 and 14.9% on component 2) and for ethyl propanoate

366   and the soft cheese (lfS-EP, 20.7% on component 1 and 19.8% on component 2). The bolus rheology block is reflected on

367   the two components with a contribution of 19.2% on component 1 and 6.8% on component 2 for lfF-NO, 17.4% on

368   component 1 and 29% on component 2 for lfS-NO and intermediates for EP. Coating and oral volume are highly important

369   for lfF-NO (25.2% on component 1 and 29.8% on component 2) and lfS-EP (48.7% on component 2). The masticatory

370   properties have a high impact on fruity aroma (EP) in the low fat firm cheese (46.5% on component 1 and 47% on

371   component 2), and in the low fat soft cheese (41.3% on component 1) but they seem to impact less blue cheese aroma

372   (NO). For nonan-2-one the salivary parameters are more relevant to explain sensory perception with 22.2% of contribution

373   on component 1 and 28.5% on component 2 for low fat firm cheese and 14.8% on component 1 and 46.5% on component 2

374   for low fat soft cheese.

375   Insert Figure 5

376   Insert Figure 6

377   ***Projection of the main variables for low fat cheeses***

378   Figure 6 shows the projection of the variables from each block for the two low fat cheeses and the two aroma

379   compounds on the two first MB-PLS components.

380   For the low fat firm cheeses (lfF), the sensory variables related to aroma persistence (Tmax_S and Tend_S) are

381   negatively correlated with component 1, whereas the rate of perception (Vmax_S) and the maximum intensity of

382   perception (Imax_S) are negatively correlated with component 2 for ethyl propanoate and positively for nonan-2-

383   one. For the low fat soft cheeses, the rate of perception (Vmax_S) is positively correlated with component 1, the

384   maximum intensity (Imax_S) negatively with component 2, whereas the times (Tmax_S and Tend_S) are negative

385   correlated with component 1 for ethyl propanoate and negatively correlated with component 2 for nonan-2-one.

386   Concerning the explanatory variables, the masticatory parameters (Chew_time and Nber_Cycle) are negatively

387   correlated with component 1 for lfS cheese and the 2 aroma compounds and for lfF cheese and ethyl propanoate

388   but negatively correlated with component 2 for lfF cheese and nonan-2-one, whereas the amplitude is negatively

389   correlated with component 2 only for lfF cheese and ethyl propanoate. Concerning the bolus rheology parameters

390   Hend, hpart and Kflow are always positive correlated with component 1 and component 2 whereas Moist and

391   Send are negatively correlated with component 1 and component 2. Concerning the release parameters, tmax2_P

392   is always negative correlated with component 1, the other parameters have lower correlations on this plan, except

393   Vmax_P on the positive part of component 1 for lfF cheese and ethyl propanoate, Imax1_P on the positive part of

394   component 1 and negative part of component 2 for lfF cheese and nonan-2-one, A2_P and A_P for both cheese

395 and nonan-2-one. The salivary parameters have only small correlations on this plane for the low fat soft cheese

396 but for the low fat firm cheese, the salivary flow (Flux_S) and the amount of sodium (Na_S) are negatively

397 correlated with component 2.

398

399 ***Discussion***

400 Considering the results of MB-PLS on high fat cheeses (Fig. 4), different trends are observed for firm and soft cheeses. For

401 the firm cheeses, the perception of fruity aroma is more related to the release of ethyl propanoate (EP) before swallowing

402 whereas the perception of blue cheese aroma is more related to the release of nonan-2-one (NO) after swallowing. Ethyl

403 propanoate which is less hydrophobic is released faster from the fat cheese matrix[16], and thus perceived at the beginning of

404 the oral processing for the firm cheese whereas nonan-2-one which is hydrophobic is released later and mainly after

405 swallowing[19], which explains the longer time to reach maximum intensity and time to reach the end of perception. For the

406 soft cheeses the same correlations are found for nonan-2-one whereas no such correlation is found between sensory

407 parameters and release parameters for ethyl propanoate. Regarding the masticatory variables, it appears that the mean

408 amplitude of contraction (Ampl) is well correlated with the rate of fruity perception (EP) on component 1 for firm cheese

409 and component 2 for soft cheeses. This variable was already highlighted in our previous paper[22] as responsible for a higher

410 rate of EP release. Thus, we confirm that subjects with high amplitude per burst will release more rapidly the hydrophilic

411 compound (EP) and we demonstate that this higher release rate induce a more rapid perception. The other masticatory

412 variables better explain the blue cheese perception (NO) and more specifically aroma persistence. Subjects with a longer

413 chewing time (Chew_time) and larger number of bursts (Nber_Cycle) have a longer duration of blue cheese aroma (Tmax_S

414 and Tend_S) for both cheeses. This could also be explained by a longer time to reach the maximum NO release intensity

415 after swallowing (tMax2_P). The bolus rheology properties impact fruity perception (EP) more, with a positive relationship

416 between bolus moistening (Moist) and time to reach the end of perception (Tend-S), which could be explained by an

417 important bolus spreadability (Send). Bolus moistening (Moist) impacts EP release intensity (Imax1_P), a high bolus

418 moistening decreases the amount of release before swallowing. This could be explained by dilution with saliva which

419 decreases the rate of release of hydrophilic aroma compounds as already proposed using *in vitro*[57] and *in silico* models[58]

420 and thus will delay the perception by increasing the persistence. The amount of product remaining in the mouth (QRB)

421 explains the perception of both aroma notes. QRB corresponds to the fat coating at the surface of the tongue and oral

422 mucosa after swallowing[54]. For blue cheese perception (NO), it could be thus due to the retention of NO, hydrophobic

423 aroma compounds, in the fat, which delays its release and then enhances its perception. Conversely, the fruity perception

424 (EP) is projected opposite to fat coating in the mouth, i.e. higher is the coating lower is the perception. Many salivary

425 parameters impact aroma perception. Sodium concentration in saliva (Na_S) positively influences fruity perception (EP) and

426 negatively blue cheese perception (NO), whereas it was not found to have a strong impact on *in vivo* aroma release[22].

14

427   Salivary lipolysis (Lipolysis_S) was depicted in the same direction of QRB in three projections (hfF-EP, hfF-NO and hfS-NO)

428   witnessing a different impact on sensory perception depending on the fruity (EP) or blue cheese (NO) note. Salivary flow

429   (Flux_S), protein content (Prot_S), amylase activity (Amylase_S) also impact sensory perception but differently according to

430   the cheese and the aroma notes.

431

432   As for high fat cheeses, different trends are observed between firm and soft low fat cheeses (Fig. 6). For the low

433   fat firm cheese (lfF) aroma persistence (Tmax_S and Tend_S) can be explained by the time to reach maximum

434   aroma release after swallowing (tMax2_P), the amount of product remaining in the oral cavity (QRB) and the oral

435   volume (Oral_Vol) for the two aroma compounds whereas the chewing time (Chew_time) and the number of

436   chewing cycles (Nber_Cycle) mainly explain fruity perception (EP). These correlations are logical because a higher

437   amount of product remaining in the mouth increases the amount of aroma released after swallowing[22] which

438   should increase aroma persistence. Moreover a longer chewing time increases the total amount of aroma

439   released[17] and thus aroma perception. The mean amplitude of contraction (Ampl) is depicted very similarly to the

440   rate of perception (Vmax_S) of the fruity note as it was the case for high fat cheeses. Similar to high fat cheeses,

441   stimulated saliva composition and in particular the sodium content (Na_S) impact aroma perception. High sodium

442   content is related to a high fruity aroma (EP) and low blue cheese aroma (NO) intensity.

443   For the low fat soft cheeses (lfS), similar trends are observed for the fruity aroma (EP) but not for blue cheese

444   aroma (NO). The blue cheese aroma perception (NO) cannot be logically explained by NO release but is related to

445   saliva composition and more precisely to lipolysis (Lypolysis_S). Bolus moistening and bolus rheology highly

446   contribute to the perception of the two aroma notes. A higher aroma perception is related to a higher moistening

447   (Moist) and higher bolus spreadability which is explained by the area at the end of compression (Send). These

448   results are also in line with the higher salivary flow (Flux_S).

449

450   Thanks to MB-PLS statistical approach, some general trends can be highlighted concerning the explanation of

451   sensory perception by release and physiological properties. When consuming solid foods containing fat such as

452   cheeses, masticatory behaviour highly impacts the dynamic of aroma release and thus aroma perception. A large

453   mean amplitude of contraction increases rate of release and rate of perception. A longer chewing time increases

454   the time to reach maximum intensity after swallowing and the time to reach maximum perceived intensity.

455   Concerning the variables from the other blocks, the relationships are not always so simple to interpret, which may

456   be due to interactions between these variables. A high salivary flow leads to a high bolus moistening, a large bolus

457   area at the end of compression indicating a high bolus spreadability, which results in a lower rate of aroma

458   release[22] but the direct consequence on aroma perception is not clearly evidenced.

15

459 However some variables were found to be related to sensory perception and not to aroma release. This is the case

460 for specific variables of saliva composition. The most striking finding is that lipolysis which is depicted in the same

461 direction to fat coating for NO and EP, is also depicted in the NO projection in the same direction to sensory

462 variables, while the opposite is observed for EP. This was particularly emphasized for high-fat cheeses. Salivary

463 lipolysis has been described as a marker of fat sensitivity and liking in human[41]. For example, a positive correlation

464 was found between the level of lipolysis and perceived fat intensity while the opposite was observed for liking in

465 subjects[51] with a normal weight. On obese subjects, *in vivo* inhibition of lingual lipase led to a significant

466 enhancement of their sensory threshold for triolein[59]. Moreover, compared to normal-weight subjects, obese

467 individuals exhibited a significant low level of salivary lipolysis thus reflecting the higher liking for fat as reported in

468 this population[48, 60]. Concerning coating, fatty perception of oil in water emulsions has been previously related to

469 the level of fat retention at the surface of the tongue after consumption[61, 62]. Altogether, these findings tend to

470 substantiate a positive correlation between the level of salivary lipolysis, fat coating and fat perception. These

471 findings support our hypothesis of cross-modal interactions between aroma perception and fattiness that differs

472 depending on the aroma. For NO (blue cheese aroma), the similar depiction of lipolysis, fat coating and sensory

473 variables should indicate a congruency between aroma perception and fat perception. Contrariwise, for EP (fruity

474 aroma), the depiction between lipolysis, fat coating and sensory variables should indicate a negative interaction

475 because of the non-congruency between this aroma and fat perception.

476 A similar hypothesis can be proposed for the effect of sodium content in stimulated saliva on aroma perception.

477 This property is depicted in the same direction as sensory variables for EP whereas it is in the opposite direction

478 for NO. The amount of sodium in saliva has already been described as an important factor which contributes in the

479 sensitivity for salt, i.e. the higher the concentration, the higher the detection threshold[63-66]. As for lipolysis, it is

480 likely that subjects exhibiting a high sodium concentration had a lower saltiness perception. Following our

481 hypothesis regarding the existence of salty-aroma interactions and considering that blue cheese aroma, unlike

482 fruity aroma, could be congruent to saltiness, subjects with a low salivary sodium content may perceive the

483 cheeses as being saltier. Since the subjects were instructed to rate the aroma intensity only and not the salty taste

484 in the cheese products during the sessions, they should have reported their salty perception on the blue cheese

485 aroma which is congruent with salty perception, due to a dumping effect[34]. Contrariwise, the perception of a fruity

486 note may be increased for the subjects with high sodium content who perceived the cheeses as less salty, because

487 this aroma is not congruent with salty.

488 **Conclusions**

489   As a conclusion, this study allowed us to highlight the respective impacts of *in vivo* aroma release and physiological

490   properties on sensory perception. The originality of the approach is to consider all the variables together and

491   evaluate their relative contribution. Our study confirms the important role of masticatory variables for firm

492   cheeses and that of salivary properties for soft cheeses. The perception of the fruity aroma of the more

493   hydrophilic compound (ethyl propanoate) is related to its dynamic release parameters before swallowing whereas

494   the blue cheese aroma of the more hydrophobic compound (nonan-2-one) is related to its dynamic release

495   parameters after swallowing and is highly impacted by mouth coating. Moreover, it was evidenced that dynamic *in*

496   *vivo* aroma release does not always explain sensory perception. MB-PLS approach made it possible to evidence the

497   combined effects of saliva composition and cross-modal interactions to understand why in some cases dynamic

498   aroma perception could not be explained by dynamic *in vivo* aroma release data. Our study confirms the key role

499   of salivary sodium content and lipolysis activity in sensory perception. The main finding is that subjects with a high

500   sodium content in saliva perceive aromas which are not congruent with saltiness as more intense and salt-

501   congruent aromas as less intense and that subjects with a high lipolysis activity perceive aromas which are not

502   congruent to fat as less intense and fat-congruent aromas as more intense. These findings could help to better

503   understand the inter-individual differences in aroma perception and could be considered for the reformulation of

504   foods targeted for specific populations taking into account nutritional recommendations.

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Table 1: presentation of the different blocks of variables used in the –MB-PLS Analyses. Y: variables to be explained, X: explanatory variables. a.u.: arbitrary units

Block	Abbreviation	Definition of the variable
Y: sensory parameters	Imax_S	Maximum intensity perceived (a.u.)
	Tmax_S	Time to reach the maximum intensity (s)
	Vmax_S	Rate of perception (a.u./s)
	Ideg_S	Maximum intensity at swallowing (a.u.)
	Tend_S	Time to reach the end of perception (s)
X1: aroma release parameters	A1_P	Area under the curve before 1st swallowing (a.u.)
	A2_P	Area under the curve after 1st swallowing (a.u.)
	A_P	Total area under the curve (A = A1_P + A2_P)
	IMax1_P	Maximum intensity before 1st swallowing (a.u.)
	tMax1_P	Time to reach maximum intensity before 1st swallowing (s)
	IMax2_P	Maximum intensity after 1st swallowing (a.u.)
	tMax2_P	Time to reach maximum intensity after 1st swallowing (s)
	Vmax _P	Rate of release (a.u./s)
X2: Bolus rheology	Moist	Moistening of the bolus just before the swallowing (%)
	sflow	Yield stress at flow phase of compression curve (Pa)
	spart	Yield stress at particle phase of compression curve (Pa)
	hpart	Bolus height at the beginning of the particle phase of compression curve (mm)
	Kflow	Consistency at the flow phase, which reflects bolus consistency (Pa.s)
	hflow	Bolus height at the beginning of the flow phase of compression curve (mm)
	hend	Bolus height at the end of compression (mm)
	Send	Area at the end of compression (mm^2)
X3: Coating- oral vol	QRB	Amount of product remaining in the oral cavity after swallowing (%)
	Oral_Vol	Volume of the oral cavity (cm^3)
X4: Masticatory parameters	Nber_Cycle	Number of chewing cycle
	Chew_time	Chewing duration (s)
	Ampl	Mean amplitude of contraction (mV)
	W_tot	Energy expended in chewing (mV/s)
X5: Properties of stimulated saliva	Flux_S	Salivary flow stimulated saliva (ml/min)
	Prot_S	Amount of salivary proteins stimulated saliva (mg/ml)
	Lipolysis_S	Amount of Lipolysis in stimulated saliva (mU/ml)
	Amylase_S	Amount of Amylase in stimulated saliva (U/ml)
	Proteolysis_S	Amount of Proteolysis in stimulated saliva (U/ml)
	Na_S	Amount of sodium in stimulated saliva (mM)

Table 2: oral physiological characteristics of the 14 subjects included in the study, mean, standard deviation, minimum and maximum values.

		minimum	maximum	mean	Standard deviation
Oral volume (cm^3)	Oral_Vol	26.85	62.16	39.03	9.73
Stimulated salivary flow (ml/min)	Flux_S	0.73	4.32	2.60	1.40
Protein (mg/ml)	Prot_S	0.57	1.31	1.04	0.31
Lipolysis (mU/ml)	Lipolysis_S	<0.01	1.32	0.90	0.74
Amylase (U/ml)	Amylase_S	1.27	30.6	20.86	11.00
Proteolysis (U/ml)	Proteolysis_S	0.04	0.51	0.13	0.12
sodium content (mM)	Na_S	2.09	37.82	15.82	11.03

Figure captions:

Figure 1. Time intensity curves obtained for one subject for blue cheese aroma (NO: nonan-2-one) for the four cheeses (hfS: high fat soft, hfF: high fat firm, lfS: low fat soft, lfF: low fat firm) showing the extracted parameters (Imax_S: maximum intensity, Tmax_S: time to reach maximum intensity, Ideg_S: intensity at swallowing and Tend_S: time to reach the end of perception.

Figure 2. Bibplot representation from the PCA performed on the 14 subjects and their physiological parameters.

Figure 3. Bar charts representing the relative importance (%) of the different blocks of variables (X1-X5) for the different components obtained by means of MB-PLS analysis performed on fruity aroma (EP) and blue cheese aroma (NO) sensory data set and for the high fat (hfF & hfS) cheese products. Blue chart: X1-Aroma release, Green chart: X2-rheology, Orange chart: X3-coating and oral volume, Red chart: X4-EM data, Violet chart: X5-stimulated saliva composition.

Figure 4. MB-PLS results on dim1/dim2 for high fat (hf) cheeses: relationships between the X-blocks of explanatory variables (Blue arrows: X1-aroma release, Green arrows: X2-rheology, Orange arrows: X3-coating and oral volume, Red arrows: X4-EMG data, Violet arrows: X5-stimulated saliva composition) and the Y block of variables to be explained (Black arrows: sensory data for fruity aroma (EP) and blue cheese aroma (NO). Top: firm high fat cheeses (hfF), bottom: soft high fat cheeses (hfS). The font size for each variable reflects the importance of the correlation coefficient with the two components.

Figure 5. Bar charts representing the relative importance (%) of the different blocks of variables (X1-X5) for the different components obtained by means of MB-PLS analysis performed on fruity aroma (EP) and blue cheese aroma (NO) sensory data set and for the low fat (lfF & lfS) cheese products. Blue chart: X1-Aroma release, Green chart: X2-rheology, Orange chart: X3-coating and oral volume, Red chart: X4-EM data, Violet chart: X5-stimulated saliva composition.

Figure 6. MB-PLS results on dim1/dim2 for low fat (lf) cheeses: relationships between the X-blocks of explanatory variables (Blue arrows: X1-aroma release, Green arrows: X2-rheology, Orange arrows: X3-coating and oral volume, Red arrows: X4-EMG data, Violet arrows: X5-stimulated saliva composition) and the Y block of variables to be explained (Black arrows: sensory data for fruity aroma (EP) and blue cheese aroma (NO). Top: firm low fat cheeses (lfF), bottom: soft low fat cheeses (lfS). The font size for each variable reflects the importance of the correlation coefficient with the two components.

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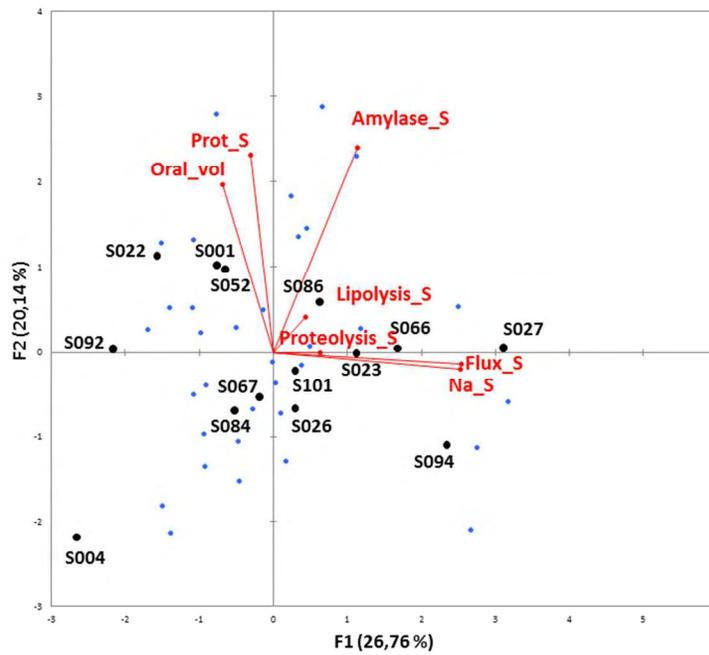
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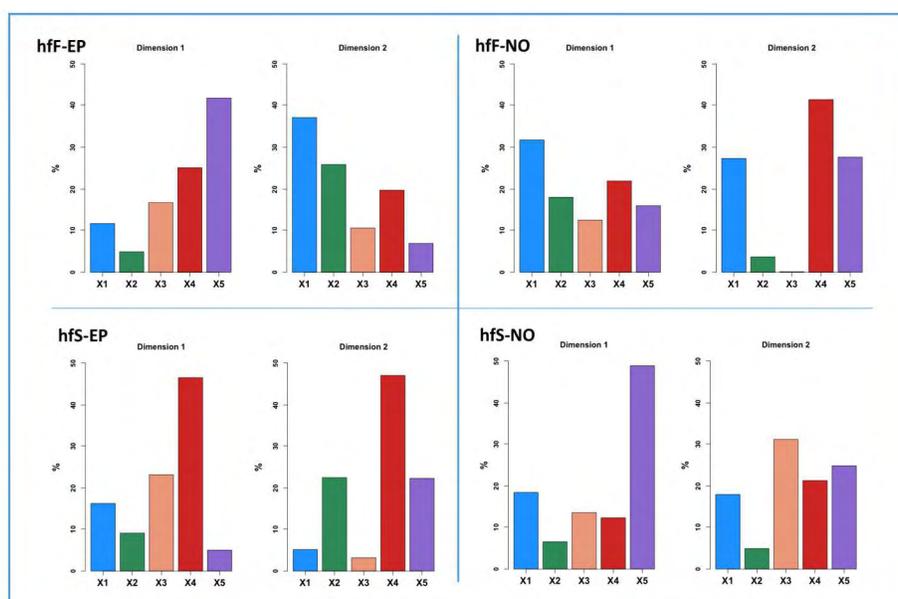
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