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## 1 **Sensory acceptability of new plant protein meat substitutes**

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### 8 **Abstract**

9 Consumers have been encouraged to reduce their consumption of meat for health and  
10 environmental reasons. A possible way is to substitute meat with plant protein alternatives;  
11 however, consumer acceptance of these products is far from settled, which might be due to  
12 taste. Therefore, it is important to identify sensory attributes that should be optimized to improve  
13 palatability. This paper is based on two consumer tests. In the first experiment, three recipes,  
14 each prepared with two or three different plant protein meat substitutes and with meat, were  
15 compared by 91 consumers using a liking scale and Check-All-That-Apply characterizations. An  
16 optimized variant of one of the meat substitutes was then produced by adding a flavor. During  
17 the second experiment, this new variant was prepared by following a single recipe and was  
18 tested by 69 consumers against a meat and two other plant protein meat substitutes from the  
19 market. Unlike in the first experiment, the consumers evaluated a full portion of each product  
20 during four different meals. They performed multiple-intake Temporal Dominance of Sensations  
21 (TDS) measurements, alternating with liking scales. The TDS evaluations also alternated texture  
22 measurements and flavor measurements over the intakes. Regarding both experiments, the  
23 meat was generally preferred; however, one plant protein meat substitute was truly appreciated,  
24 even more than the meat. Acceptance of the plant protein products depended on their  
25 composition and on the recipe. Sensory interpretations of these liking differences were  
26 proposed, and sensory drivers of liking were highlighted, which could lead to better acceptance  
27 of the products.

### 28 **Keywords**

29 Novel Protein Foods, Meat substitutes, Consumer, Acceptance, CATA, TDS

### 30 **1. Introduction**

31 Many epidemiological studies (e.g., Cummings and Binham, 1998; Norat et al., 2002; Boutron-  
32 Ruault et al., 2017) have shown that the excessive consumption of meat, especially red meat

33 and processed meat, is a risk factor for health (increased occurrence of digestive cancers,  
34 cardiovascular diseases and hypercholesterolemia). Therefore, it seems important to seek  
35 preventive strategies to decrease the incidence of these diseases without decreasing the  
36 consumption of proteins, which would lead to deficiencies. In addition, in a global food  
37 consumption context in which animal proteins being depleted and the financial and  
38 environmental cost of their production is unfavourable, developing alternative solutions based on  
39 proteins of plant origin seems obvious.

40 In recent years, new foods made from vegetable proteins have emerged. The main sources of  
41 the plant protein meat substitutes in current use are soy, wheat, legumes and fungi (Kumar et  
42 al., 2017; Kyriakopoulou et al., 2019; Bohrer, 2019). Most of these meat substitutes have clear  
43 nutritional and health benefits, although this assertion has to be qualified depending on the  
44 source of vegetable protein, on the ingredients added to the product and on the process used to  
45 make them (Bohrer, 2019). Meat substitutes are becoming increasingly popular, especially in  
46 Europe; however, few consumers regularly buy these foods (Weinrich, 2018).

47 In fact, although it is now well accepted that more consumption of plant-based protein foods  
48 should be encouraged to reduce the global consumption of meat and although a large number of  
49 new meat substitutes are launched on the market every year, their acceptability by consumers is  
50 far from assured. Thus, in occidental countries, there is still a relative lack of interest from  
51 consumers in these foods. Several hypotheses, among others, may explain that assessment:

52 i) Consumers like the sensory characteristics of meat (Verbeke et al., 2010; Weinrich 2018), and  
53 they perceive a lower sensory attractiveness in plant protein meat substitutes compared to meat  
54 (Hoek et al., 2011a).

55 ii) Meat consumption is based on a cultural preference in occidental countries (de Boer et al.,  
56 2006), or it is a matter of habit.

57 iii) Some consumers do not accept any product that is presented as an alternative to meat  
58 (Lemken et al., 2019).

59 iv) Other consumers prefer replacing meat with natural vegetables rather than ultra-processed  
60 products (Lemken et al., 2019).

61 v) It could also be a matter of familiarity, or neophobia (Weinrich, 2018; Hoek et al., 2011a;  
62 Schösler et al., 2012; Grahl et al., 2020).

63 vi) There is a lack of knowledge among consumers regarding the negative aspects of meat

64 (Hartmann & Siegrist, 2017).

65 Furthermore, Weinrich (2019) conducted a review of empirical research published until the  
66 spring of 2018 on the adoption by consumers of meat substitutes. The author studied 27 papers  
67 focused on plant protein meat substitutes as well as insect proteins or cultured meat. The author  
68 concluded that the taste and appearance perception was one of the main drivers of persuasion  
69 to consume meat substitutes, regardless of the country.

70 Therefore, taste and appearance seem to be crucial factors in the adoption of meat substitutes  
71 by consumers, yet these sensory aspects have still been little studied; some experiments were  
72 performed with focus groups to understand consumer choices better (e.g., Apostolidis and Mc  
73 Leay, 2016; Weinrich, 2018; Collier et al., 2021). Other studies analyzed consumer attitudes and  
74 intentions through questionnaires and surveys (e.g., Bosman et al., 2009; Hoek et al. 2011a; De  
75 Boer et al. 2014; Mohamed et al., 2017; Michel et al., 2021). Other protocols were based on  
76 photos, either to perform a sorting task of different meat products and meat substitutes (Hoek et  
77 al. 2011b), to measure consumer willingness to buy burgers made from beef, plant-based  
78 proteins and cultured meat (Slade 2018), or to assess the appropriateness of different dishes for  
79 the use of meat substitutes (Elzerman et al. 2015).

80 However, to our knowledge, quite a few studies have been conducted to assess consumers'  
81 sensory perceptions of plant protein meat substitutes specifically, including taste testing  
82 sessions. For example, Elzerman et al. (2011) focused on the influence of the recipe on the  
83 acceptance of meat substitutes. They tested 28 samples of various meat substitutes  
84 (mycoproteins or soy) in different recipes, with 93 participants in the Netherlands, and they  
85 highlighted a significant effect of the recipe. They also compared the acceptance of the  
86 substitutes with the acceptance of chicken pieces, although this measure was performed during  
87 a separate and later part of the study, using the same participants: chicken in the rice dishes  
88 was significantly more appreciated than all meat substitutes. However, an overall 'similarity to  
89 meat', rated by the consumers, did not appear to be crucial for the acceptance of the meat  
90 substitutes. Another study conducted by Elzerman et al. (2013) on 46 consumers in the  
91 Netherlands combined focus group discussions and tasting sessions to determine consumer  
92 experiences and sensory expectations towards meat substitutes. They also assessed the  
93 appropriateness of meat substitutes in various meals. They found that the main negative aspects  
94 of meat substitutes were uniform taste, compactness, dryness and softness, whereas the  
95 positive aspects were neutral taste, crispiness, chicken-like texture and granular texture. Then,  
96 Hoek et al. (2013) performed in-home tests on two meat substitutes and chicken with 89

97 consumers in the Netherlands for 20 meals over 10 weeks to study the evolution of their liking  
98 scores over time. Again, liking was significantly higher for chicken than for the meat substitutes.  
99 More recently, Grahl et al. (2020) performed a conventional sensory profiling (N=12 trained  
100 panelists) and a consumer liking test of pasta filled with spirulina, with different added levels of  
101 flavors, in Germany (N=139 consumers), the Netherlands (N=137) and France (N=144). To our  
102 knowledge, apart from these papers and as underlined in 2017 by Hartmann & Siegrist in their  
103 review, there is a lack of sensory research focused on meat substitutes, including plant-based  
104 protein foods.

105 However, if most consumers have shown little interest in these foods thus far, it might be a matter  
106 of taste. It is therefore important to address this question, because when the taste of a product is  
107 not appreciated, the product is not bought again (Terlet et al., 2018). It is important to identify the  
108 sensory attributes that should be optimized to improve the acceptance of these substitutes. Thus,  
109 the research reported in this paper is based on two consumer tests. The first one, held in winter  
110 2016, was an exploratory step. It aimed to compare the same recipes made with either meat or  
111 plant protein meat substitutes including meat substitutes from the market and an experimental  
112 meat substitute (*Wheat-Chickpea*) available in four variants. The use of these four experimental  
113 variants made it possible to evaluate the effect of a change in aroma and/or color, and to enrich  
114 the variety of sensations perceived in the product space. The objectives of this first experiment  
115 were i) to obtain an idea of the acceptability and perceptions of some plant protein meat substitutes  
116 compared to meat in classical food recipes, ii) to select a relevant recipe for the second experiment,  
117 and iii) to choose one of the four experimental variants – the most appreciated one – to use it in  
118 the second experiment.

119 In the second experiment, held in winter 2017, this optimized experimental variant was cooked  
120 according to a single recipe and was tested against a meat and a few other plant protein meat  
121 substitutes from the market. The objective of this second experimental step was to study the  
122 acceptance and sensory perceptions of plant protein meat substitutes including the optimized  
123 experimental variant, compared to meat, in the context of a full meal to be as close as possible to  
124 real consumption habits. Another objective was to identify sensory drivers to improve the  
125 acceptance of plant protein meat substitutes. For this second phase, a dynamic description with  
126 multi-intake evaluation was adopted, with alternating evaluations of liking. In fact, in classic  
127 sensory analysis methods, which are generally static, the time-dependent evolution of the sensory  
128 properties and hedonic responses throughout the tasting is not taken into account. Measuring  
129 sensory perceptions with a single intake of the product does not reflect the real conditions of  
130 consumption and may mask some potential boredom effects, some aftertastes, or some changes

131 that may occur in the texture/aroma sensations throughout the tasting. When comparing meat  
132 substitutes and meat, it seems particularly important to consider the time-dependent evolution of  
133 the sensory properties throughout the tasting, especially with regard to texture, because meat  
134 texture has long been recognized as an important driver of consumer preference (Zimoch &  
135 Findlay, 1998; Font-i-Furnols & Guerrero, 2014). The perception of the texture is strongly related  
136 to the chewing process in the mouth and it changes throughout the tasting. For example, the  
137 tenderness of meat has an obvious time-dependent evolution during the tasting (Zimoch & Findlay,  
138 1998). Therefore, such an evolution is important to capture here, as it may explain some  
139 differences in liking between meat and plant protein meat substitutes. Moreover, the alternating  
140 evaluations of liking may allow for the identification of the sensory attributes that should be  
141 optimized to improve the acceptance of meat substitutes.

## 142 **2. Material and methods**

### 143 **2.1. Products**

#### 144 **2.1.1. First experiment**

145 Three culinary preparations (*White Sauce*, *Chop Suey* and *Lasagna* recipes) were prepared  
146 either with plant-based protein chunks (soy or a mix of wheat and chickpea) or with meat chunks  
147 (veal, chicken or ham), as described in Table 1. For the *White Sauce* and *Chop Suey* recipes,  
148 the products were prepared with a side dish, namely quinoa and vegetables, respectively. These  
149 very different recipes and side dishes were selected after internal pre-tests to provide a variety  
150 of perceived sensations in terms of tastes, flavors, textures and aftertastes. The *White Sauce*  
151 recipe was chosen because it is a traditional French meat dish. The *Chop Suey* recipe, which is  
152 a mix of fried vegetables and meat with sweet-and-sour sauce, was interesting because of its  
153 distinctive sweet and umami sensations. Lastly, the *Lasagna* recipe was interesting because of  
154 the composition of its recipe, which allowed for the chunks to be completely mixed into the pasta  
155 and sauce. The side dishes were chosen to be common and harmonious with each recipe. They  
156 were also selected to be very different in order to obtain a variety of perceived sensations  
157 between the recipes. Regarding the meat substitutes studied in this first step, apart from the  
158 experimental product *Wheat-Chickpea*, the two other commercial plant-based protein products  
159 were selected based on internal pre-tests to ensure different sensory characteristics across the  
160 products. The meat chosen for each recipe was the meat usually cooked for this type of recipe.  
161 Concerning the production and the composition of the experimental product *Wheat-Chickpea*, it  
162 was a mixing and a kneading of wheat proteins with chickpeas (flour or whole chickpeas). The

163 mixture was then baked in an oven at 150°C, then in water, and sterilized in a mixture of broth  
164 and water.

165 As described in Table 1, the three recipes were evaluated during one session each: session 1  
166 for the *White Sauce* recipe, session 2 for the *Chop Suey* recipe, and session 3 for the *Lasagna*  
167 recipe. Furthermore, the *White Sauce* recipe was tested twice, during session 1 and then in  
168 session 4. The specificity of the 4th session is that it was focused on four experimental products:  
169 *Wheat-Chickpea* and three variants of *Wheat-Chickpea*, which were either spiked with a meat  
170 flavor (*WhtChp-Aroma*), either less colored (*WhtChp-Color*), or spiked with the flavor and less  
171 colored (*WhtChp-Aro-Col*). It was not possible to test these experimental variants with the three  
172 recipes because of production constraints. Therefore, only one of the three recipes was selected  
173 for session 4. *White Sauce* was the chosen recipe because it is a traditional French meat dish.  
174 Concerning the variants *WhtChp-Color* and *WhtChp-Aro-Col*, it must be noted that the visual  
175 differences from the other two variants were obvious: the color of the less colored variants was  
176 close to the color of boiled chicken, whereas the color of the other two variants was closer to that  
177 of roast beef. The recipe did not mask the color changes, because the sauce did not completely  
178 coat the chunks.

179 All the preparations were delivered by a caterer and were warmed to 65 °C just before the  
180 sessions. Thirty gram portions were served on plastic plates coded with three-digit random  
181 numbers. The subjects were free to consume all or part of the portions served. They were  
182 instructed to taste the chunks coated with sauce and to score their perceptions. Then, they were  
183 allowed to taste the side dish, but they were told that no data would be collected concerning the  
184 side dishes. The role of the side dishes was only to allow the products to be tasted under  
185 conditions close to those of a regular meal, as the products were cooked and presented with the  
186 side dishes. Indeed, plant protein meat substitutes are rarely presented alone; they are usually  
187 cooked with a side dish that is an integral part of the recipe.

188 [\[Insert Table 1\]](#)

### 189 **2.1.2. Second experiment**

190 Based on the results of the liking measurements from the first experiment, one of the four  
191 experimental variants derived from *Wheat-Chickpea* was selected and produced for the second  
192 experiment: it was the variant *WhtChp-Aroma* (consisting of a mix of wheat and chickpeas, with  
193 added flavor). Two other commercial meat substitutes were selected on the basis of internal pre-  
194 tests: a product composed of mycoproteins (this product is called *Mycoprotein*) was selected as

195 a promising meat substitute, and a product made from a mix of wheat and soy (this product is  
196 called *Wheat-Soy*) was also chosen as a well-established product on the French commercial  
197 market. As in the first experiment, the selection of the meat substitutes to ensure sensory  
198 variations across the products was an important criterion in the second experiment. However,  
199 the selection of well-established products on the French commercial market was also an  
200 important criterion, to avoid products that may be strongly rejected by the consumers.

201 In this second step, a single recipe, *White Sauce* with its side dish (quinoa), was selected  
202 because the chunks were easier to evaluate than in the *Lasagna* recipe and because the *White*  
203 *Sauce* recipe is easier to prepare in a reproducible way. However, after internal pre-tests and  
204 discussions coming to a consensus, veal was replaced by chicken because the texture of  
205 chicken thin strips seemed to be closer to the texture of the plant protein meat substitutes.  
206 Therefore, the *White Sauce* recipe was cooked either with chicken chunks (this product is called  
207 *Chicken2*) or with the three different plant-based protein chunks (*Wheat-Soy*, *Mycoprotein* and  
208 *WhtChp-Aroma*).

209 The products were cooked in the lab each morning before the sessions. The objective was to be  
210 as close as possible to a regular consumption context. The consumers tasted a full portion of  
211 each of these four products in four different meals (one meal per session). Each meal consisted  
212 of carrot salad (100 g), then the *White Sauce* dish with its quinoa (125 g of meat or meat  
213 substitute, 100 g of quinoa and 30 g of sauce), then a piece of cheese, and a dessert (either  
214 chocolate cream or apple compote). The consumers also had bread and water. They were free  
215 to consume all or part of the portions served. Data were collected only for the meat and the meat  
216 substitutes (no data were collected for the carrots, quinoa, cheese and dessert). The impact of  
217 the meal components (carrot salad, quinoa, bread, etc.) on the appreciation of the tasted  
218 products (meat or meat substitutes) was not tested here: the meal components being the same  
219 regardless of the tasted product, this impact is assumed to be the same, regarding a given  
220 consumer, for all the products that he or she had to taste. Therefore, this assumption allowed us  
221 to perform comparison analyses of the data obtained for all the products.

## 222 **2.2. Participants**

### 223 **2.2.1. First experiment**

224 Ninety-one naïve French consumers without aversions to meat, sauce dishes or vegetarian  
225 dishes (46 men, 45 women), who were from 18 to 65 years old, participated in this study. They  
226 were recruited from a population registered in the ChemoSens Platform's PanelSens database,

227 which has been declared to the relevant authority (Commission Nationale Informatique et  
228 Libertés—CNIL— authorization n°1148039). The study was conducted according to the  
229 guidelines established in the Declaration of Helsinki and was approved by the local ethics  
230 committee (Comité de Protection des Personnes Est I Bourgogne, 2015-A01419-40). Written  
231 informal consent was obtained from each consumer.

232 Only 82 of the consumers participated in the four sessions, 6 consumers took part in three  
233 sessions, and 3 consumers participated in only one session. The subjects were compensated for  
234 their participation (10 € per one-hour session). Among the participants, 31 were heavy  
235 consumers of meat (every day or almost), 44 were medium consumers (several times a week),  
236 and 10 were light consumers (equal to or less than once a week). Moreover, 26 participants  
237 reported being regular users of plant protein meat substitutes (at least once a week), 36 were  
238 light users (less often) and 23 were non-users. Information about the consumption frequencies  
239 was not collected for 6 participants, because they were absent from the last session.

#### 240 **2.2.2. Second experiment**

241 Sixty-nine other French consumers (36 men, 33 women) from 20 to 65 years old participated in  
242 this study. The recruitment criteria were the same as those used in the first experiment. All the  
243 consumers participated in the four sessions, except one subject who only took part in three  
244 sessions. As in the first experiment, the subjects were compensated for their participation (10 €  
245 per one-hour session).

#### 246 **2.3. Sessions**

247 For both experiments, the sessions occurred at lunchtime, in isolated sensory booths and lasted  
248 approximately one hour. The products were presented under white light. Data were collected  
249 using TimeSens 1.0 software (INRAE, Dijon, France).

##### 250 **2.3.1. First experiment**

251 The consumers participated in one session per week for four weeks. They were told that they  
252 would have to taste “dishes including vegetable ingredients”, without further details as to the  
253 composition of the dishes. The samples were presented monadically, according to Williams Latin  
254 Square experimental designs. Between the samples, the subjects had to eat bread and drink  
255 water to rinse their mouths. Two types of data were collected:

256 Check-All-That-Apply (CATA) measurements (Adams et al., 2007): for each product, a list of  
257 descriptors was displayed on the TimeSens screens. The descriptors were arranged in two  
258 columns, one for textures and one for tastes and flavors. The subjects had to choose all the

259 descriptors corresponding to what they were perceiving in their mouths during the tasting of the  
260 product, including aftertastes. Within each column, the order of the descriptors was randomized  
261 from one subject to another, but for a given subject, the orders were the same throughout the  
262 session to facilitate the selection of descriptors. The descriptors were different from one recipe to  
263 another and were defined thanks to internal pre-tests involving 7 naïve subjects, who were  
264 asked to taste the different products and to generate vocabulary (one session per recipe). The  
265 final lists of descriptors were chosen according to the frequencies of citations for the generated  
266 terms. At the beginning of each CATA session, the descriptors were verbally explained to the  
267 consumers, with definitions or examples for the most complicated descriptors.

268 Table 2 and Table 3 show the descriptors displayed for each recipe.

269 Liking measurement: For each product, the consumers also had to indicate their overall liking on  
270 a continuous hedonic scale ranging from "I do not like it at all" to "I like it very much". The  
271 hedonic ratings were then translated into scores from 0 to 10.

272 [Insert Table 2]

273 [Insert Table 3]

### 274 **2.3.2. Second experiment**

275 The consumers participated in one session per week for four weeks. Each session consisted of  
276 one meal. The consumers were told that they would have to taste "dishes made from vegetable  
277 and animal proteins". One-quarter of the consumers started with the evaluation of the first  
278 product, one-quarter with the second product, etc. Each meal was organized according to the  
279 same procedure. First, while they were tasting the carrot salad, the consumers were familiarized  
280 with the acquisition method (the collected data were not analyzed). Then, they were familiarized  
281 with the descriptors: they had to taste or smell different samples of foods or beverages (samples  
282 of water with added salt, cooked mushrooms, cooked mixed cereals, cooked chicken and veal  
283 meats, soy milk, crème fraiche, toasted sliced bread, cooked chickpeas, and a mix of mustard  
284 and pepper), and they had to read the definitions of the texture descriptors. Then, they evaluated  
285 the meat or the meat substitute in the main course. Lastly, they received cheese and dessert.  
286 Different types of data were collected during each meal. All the liking data were collected on  
287 continuous hedonic scales ranging from "I do not like it at all" to "I like it very much". The hedonic  
288 ratings were translated into scores from 0 to 10:

289 Visual liking: Before tasting, the subjects were asked to score their visual liking of the chunks  
290 coated with sauce.

291 Multiple-intake Temporal Dominance of the Sensations (TDS) alternating with liking  
292 measurements: this approach was adapted from a protocol described in Thomas et al. (2016).  
293 While tasting the main dish, the subjects had to alternate between meat or meat substitute  
294 intake and quinoa intake to be under conditions as close as possible to those of a regular meal,  
295 yet following a standardized procedure to avoid too many differences between the consumers in  
296 the way of tasting the dish. No data were collected for quinoa. Concerning the meat or meat  
297 substitutes, TDS (Pineau et al., 2009) evaluations alternated texture (8 descriptors) and flavor  
298 (10 descriptors) measurements over the intakes: odd intakes were evaluated for texture, while  
299 even intakes were evaluated for flavor. The TDS descriptors, which were previously established  
300 thanks to internal pre-tests, were displayed in the same order for all the consumers. Table 4  
301 shows the list of the TDS descriptors. The concept of a dominant sensation was defined as "the  
302 feeling that attracts the most attention at any given moment" (Pineau et al., 2009). After  
303 swallowing, the subjects had to continue to evaluate the dominant sensations until they no  
304 longer perceived anything. Dynamic liking measurements were captured for each intake just  
305 after each TDS evaluation. Because the subjects were free to consume all or part of the portions  
306 served, with a minimum of two intakes of chunks coated with sauce nonetheless, the number of  
307 intakes and thus data collected varied from one subject to another.

308 Liking measurements after the tasting: At the end of the tasting of the main dish, the subjects  
309 were asked to score their overall liking of the chunks coated with sauce. They also had to rate  
310 their liking with a focus on texture and their liking with a focus on taste.

311 Quantities consumed: The quantities (in grams) of chunks with sauce consumed by each subject  
312 were evaluated (with the weighing of the chunks with sauce at the beginning then at the end of  
313 the session). The consumers were not informed of that measure.

314 Other measurements: In addition, the consumers were interrogated about their hunger feelings  
315 at the beginning of each meal, at the end of the main course, and four hours after the end of the  
316 meal. These latter data are not reported in this paper.

317 [Insert Table 4]

## 318 **2.4. Data analyses**

319 The data treatments were run with R 3.5.1 (R Core Team, 2018) and SAS 9.4 (SAS Institute Inc.,  
320 Cary, North Carolina, USA). TDS curves were produced with TimeSens 1.0 (INRAE, Dijon,  
321 France).

### 322 **2.4.1. First experiment**

323 Analyses of the liking data

324 For each recipe, an analysis of variance was performed on the liking scores given to the different  
325 products using the following model:

326  $Liking = P + A + G + MF + MSF + \text{Second order interactions } (P, A, G, MF, MSF) + \text{Third order}$   
327  $\text{interactions } (A, G, MF, MSF) + C(A*G*MF*MSF) + Error$

328 where *P* corresponds to *Product*, *A* to *Age*, *G* to *Gender*, and *C* to *Consumer*. *MF* is the  
329 individual frequency of meat consumption (heavy, medium or light consumers). *MSF* is the  
330 individual frequency of consumption of plant protein meat substitutes (regular, light or non-  
331 users). *Consumer* is a random effect. *Product*, *Consumer* and all the interactions including  
332 *Product* were tested against the usual error term, whereas the other effects were tested against  
333  $C(A*G*MF*MSF)$ . For each recipe, a graph was produced to compare the mean liking scores  
334 (LSMeans) of the different products visually, with 5% confidence intervals.

335 Analyses of the CATA data

336 The methodology presented by Mahieu et al. (2020) was used. For each session, a contingency  
337 table was constructed, and it contained the numbers of citations of each descriptor for each  
338 product assessed in that session. Chi-square statistics were then performed for each of the four  
339 contingency tables. The p-values of these tests were computed using a Monte Carlo approach  
340 (1000 simulations,  $\alpha = 5\%$ ). Then, a Correspondence Analysis (CA) for each of the four  
341 contingency tables was performed. The results were displayed thanks to the standard CA biplot  
342 (Greenacre, 2006). Confidence ellipses were drawn around the products thanks to bootstrap on  
343 consumers and procrustean rotations, and the number of significant CA axes was determined  
344 with Monte Carlo tests of dependence (simulations = 1000,  $\alpha = 5\%$ ).

345 **2.4.2. Second experiment**

346 Analyses of the non-dynamic liking data (*visual liking* captured before the tasting, *overall liking*  
347 *captured after the tasting, liking of the texture, and liking of the taste*)

348 For each of these four types of liking data, an analysis of variance was performed on the scores  
349 given to the different products using the following model:

350  $Liking\ variable = P + A + G + P*A + P*G + A*G + P*A*G + C(A*G) + Error$

351 where *P* corresponds to *Product*, *A* to *Age*, *G* to *Gender*, and *C* to *Consumer*. *Consumer* is a  
352 random effect. *Product*, *Consumer* and all the interactions including *Product* were tested against

353 the usual error term, whereas the other effects were tested against  $C(A*G)$ . Graphs were  
354 produced to compare the mean liking scores (LSMeans) of the different products visually, with  
355 5% confidence intervals.

#### 356 Repartition of the intakes into three tasting periods

357 Because the number of intakes was different from one consumer to another (on average, 6.5  
358 intakes per consumer and product, with a standard deviation equal to 2.7), the intakes were split  
359 into 3 periods for each consumer and each product (the procedure is described in Thomas et al.,  
360 2016). The first period corresponds to the beginning of the tasting, the second one to the middle  
361 of the tasting and the third one to the end.

#### 362 Analysis of the dynamic liking data

363 The mean liking scores were computed by consumer and period for each product, taking into  
364 account all the dynamic liking scores given by that consumer during that period. Then, an  
365 analysis of variance was performed, using a mixed ANOVA model. *Product, Period, Age,*  
366 *Gender* and their second-order interactions were defined as fixed effects. The random part of the  
367 model consisted of *Consumer, Period\*Consumer* and *Product\*Consumer*. *Period within*  
368 *Consumer\*Product* was the repeated variable. A graph was produced to compare the mean  
369 liking scores (LSMeans) by period for each product visually, with 5% confidence intervals.

#### 370 Analysis of the TDS data: TDS curves

371 For each product, TDS curves were produced by period for each type of TDS descriptor (Texture  
372 or Taste/Flavor) by applying the method presented in Pineau et al. (2009). The different  
373 evaluations of the same consumer in the same period were taken into account as replicates  
374 (Thomas et al., 2016). The dominance rate (%) of each recorded descriptor at each moment was  
375 calculated and plotted over time. For each intake, the times were standardized between 0 (first  
376 citation) and 1 ("no longer perceive any sensation") to align the consumers' responses (Lenfant  
377 et al., 2009).

#### 378 Temporal drivers of liking (TDL)

379 The Temporal Drivers of Liking were computed according to the method described in Thomas et  
380 al. (2015) for texture and then for taste/ flavor: for each product and each descriptor, individual  
381 Liking While Dominant scores (LWDs) were calculated (the LWD of a descriptor is the average  
382 of the liking scores given by the consumer to a product while that descriptor was dominant).  
383 Each individual LWD was then centered towards the mean liking scores given by the consumer  
384 to the product. The individual-centered LWDs were then averaged over the consumers by

385 descriptor and product. The nullity of the centered LWD means was tested using a t-distribution.  
386 The number of degrees of freedom was defined as the number of consumers having selected  
387 the considered descriptor during the consumption of each product, minus 1. Temporal Drivers of  
388 Liking were highlighted as the descriptors for which the centered LWD mean was significantly  
389 smaller or higher than 0 (at  $p < 5\%$ , or  $p < 10\%$ ).

### 390 Analysis of the quantities consumed

391 An analysis of variance was performed on the quantities of each product with sauce consumed  
392 (in grams) using the following model:

$$393 \text{Quantity consumed} = P + A + G + P*A + P*G + A*G + P*A*G + C(A*G) + \text{Error}$$

394 where  $P$  corresponds to *Product*,  $A$  to *Age*,  $G$  to *Gender*, and  $C$  to *Consumer*. *Consumer* is a  
395 random effect. *Product*, *Consumer* and all the interactions including *Product* were tested against  
396 the usual error term, whereas the other effects were tested against  $C(A*G)$ . A graph was  
397 produced to compare the mean quantities (LSMeans) consumed for the different products  
398 visually, with 5% confidence intervals.

## 399 **3. Results**

### 400 **3.1. First experiment**

#### 401 **3.1.1. Liking measurements**

402 Regardless of the recipe, the analysis of variance revealed a significant *Product* effect. Figure 1  
403 shows the mean liking scores (LSMeans) of the different products for each recipe. The meat was  
404 always the most appreciated product (the overall liking ranged from 6.31 for the *White Sauce*  
405 recipe to 7.70 for the *Chop Suey* recipe). However, the plant protein meat substitutes were not  
406 all appreciated equally and their ranking depended on the recipes: *Soy1* was the least  
407 appreciated (its overall liking ranged from 1.72 in the *Chop Suey* recipe to 4.06 in *Lasagna*), and  
408 *Soy2* and *Wheat-Chickpea* were close in the *White Sauce* recipe (Session 1) but not in the *Chop*  
409 *Suey* recipe. The *Lasagna* recipe improved the appreciation of *Wheat-Chickpea* and *Soy1*. The  
410 *Wheat-Chickpea* product in the *White Sauce* recipe, which was tasted twice (in Session 1 then in  
411 Session 4), obtained very close mean scores between the two sessions (3.53 in session 1 then  
412 3.88 in session 4). Interestingly, *WhtChp-Aroma*, which was spiked with a flavor, was preferred  
413 to the original *Wheat-Chickpea* product in the *White Sauce* recipe (session 4). However, the

414 color had no significant effect: *WhtChp-Color* was given approximately the same mean liking  
415 score as *Wheat-Chickpea* in session 4.

416 [Insert Figure 1]

417 We also found a significant *Age* effect regardless of the recipe ( $F=2.85/p=0.0677$  in Session 1;  
418  $F=8.34/p=0.0008$  in Session 2;  $F=3.26/p=0.0474$  in Session 3;  $F=5.51/p=0.0069$  in Session 4):  
419 older consumers were more severe in their ratings than younger consumers. In addition, there  
420 was a slight *Age\*Product* interaction only during Session 1 ( $F=2.11/p=0.0534$ ): older consumers  
421 liked the meat slightly less than the other consumers did. There was also a significant  
422 *Gender\*Product* effect in Session 1 ( $F=5.94/p=0.0006$ ): on average, women gave lower scores  
423 to *Soy1* and *Soy2* and higher scores to *Veal*. Lastly, in Session 2, there was a slight significant  
424 interaction for *Age\*Gender\*MSF* ( $F=2.47/p=0.0565$ ), in which *MSF* is the individual frequency of  
425 consumption of plant protein meat substitutes, but no clear interpretation could be given to this  
426 interaction.

### 427 3.1.2 CATA measurements

428 Figure 2 shows the maps obtained for each recipe.

429 [Insert Figure 2]

430 The maps show that the products were not perceived in the same way, depending on the recipe.  
431 The meat is always well separated from the other products and is projected close to descriptors  
432 such as *Meat*, *Dry*, *Firm*, *Ham*, *Tender*, etc. All of these descriptors are common attributes of  
433 meat or ham. *Soy2* also seems to be different from the other plant-based protein meat  
434 substitutes: it was characterized as having a *Vegetable* aroma in the *White Sauce* recipe, while it  
435 was described as *Spicy*, *Piquant*, *Fat*, and *Umami* in the *Chop Suey* recipe. *Wheat-Chickpea*  
436 and *Soy1* are closer to each other and were characterized by descriptors such as *Tasteless*,  
437 *Gelatinous*, *Spongy*, *Soy*, or *Cereal*. However, these two products are more distant from each  
438 other in the *Lasagna* recipe: *Wheat-Chickpea* was thus characterized as *Spongy*, while *Soy1*  
439 was defined by the descriptors *Tasteless*, *Gelatinous*, *Alga*, etc. Lastly, the fourth map looks  
440 very different from the three others. Only one axis is significant. This axis opposes the variants  
441 spiked with flavor, on the right side of the map, to the variants without flavor on the left side. With  
442 the addition of flavor, the variants were no longer perceived as *Tasteless*: they were  
443 characterized as more *Salty*, with a more intense *Meat* flavor. In addition, color had little effect  
444 on the perception of the variants.

### 445 3.2. Second experiment

446 **3.2.1 Non-dynamic liking data (*visual liking* captured before tasting, *overall liking* captured**  
447 **after tasting, *liking of texture*, and *liking of taste*)**

448 For each of these four liking variables, the analysis of variance revealed a significant *Product*  
449 effect. Figure 3 shows the mean liking scores (LSMeans) of the different products for each liking  
450 variable. Concerning *visual liking* (Figure 3-a), *WhtChp-Aroma* obtained the highest mean score,  
451 even higher than the mean score obtained by the meat. *Mycoprotein* is in the third position.  
452 *Wheat-Soy* was little appreciated visually. Concerning the *overall liking* captured after tasting  
453 (Figure 3-b), *Mycoprotein* and *Chicken2* obtained higher scores. *WhtChp-Aroma* was little  
454 appreciated after the tasting, while its visual aspect was attractive. *Wheat-Soy* was still little  
455 liked. The graphs concerning the *liking of taste* (Figure 3-c) and the *liking of texture* (Figure 3-d)  
456 are quite similar to the graph of *overall liking* (Figure 3-b). The computation of the averages of  
457 the individual Pearson correlation coefficients between these three variables, two by two,  
458 showed that the three variables were strongly correlated with each other: the mean coefficients  
459 were equal to 0.86, 0.84 and 0.73 between *overall liking* and *liking of taste*, between *overall*  
460 *liking* and *liking of texture*, and between *liking of texture* and *liking of taste*, respectively.  
461 However, we can guess slight differences between Figures 3-c and 3-d: for example, *WhtChp-*  
462 *Aroma* seems to be more appreciated for its taste, because it is quite close to the meat in Figure  
463 3-c, but less for its texture.

464 [Insert Figure 3]

465 In addition, there was a slight interaction for *Age\*Product* only concerning the *overall liking*  
466 scores ( $F=2.23/p=0.0417$ ) and the *liking of texture* ( $F=2.16/p=0.0483$ ): younger consumers liked  
467 *Wheat-Soy* more than the older consumers, whereas the 36-50 y-o consumers gave lower  
468 scores to *WhtChp-Aroma* than the other consumers, but no explanation could be found to  
469 interpret this result.

470 **3.2.4 Dynamic liking**

471 The mixed ANOVA highlighted significant *Product* ( $F=12.3/p<0.0001$ ) and *Period*  
472 ( $F=12.71/p<0.0001$ ) effects. Figure 4 shows the mean liking scores (LSMeans) of the different  
473 products by period. The conclusions are similar to those obtained with the *overall liking* captured  
474 after tasting: *Mycoprotein*, then *Chicken2* received the highest scores throughout the tasting.  
475 *Wheat-Soy* was the least liked product. The significant *Period* effect occurred because the liking  
476 scores increased slightly between the beginning and the middle of the tasting and then  
477 decreased slightly at the end of the tasting. There was no *Product\*Period* interaction, which

478 means that the evolution of the liking over the tasting was the same for the four products. There  
479 was little temporality of the liking scores over the periods.

480 [Insert Figure 4]

481 The mixed ANOVA also revealed a slight *Gender\*Period* significant effect ( $F=3.18/p=0.0436$ ).  
482 Women marked a greater difference in their liking between Period 2 and Period 3 than men did.

### 483 3.2.5 TDS curves

484 Figure 5 shows the TDS curves obtained for each product by period, concerning the descriptors  
485 of texture. Figure 6 shows the TDS curves concerning the descriptors of taste/flavor. Regarding  
486 the texture, the meat revealed a *Tender* attack, followed by a *Fibrous* texture, with a *Dry* finish,  
487 regardless of the period of consumption. The three plant-based protein products started with a  
488 *Tender* attack, but their temporal profiles were then different: all had a *Fondant* finish, but  
489 *Wheat-Soy* was dominated at mid-period by a *Spongy* and *Elastic* texture, whereas *WhtChp-*  
490 *Aroma* was dominated only by a *Spongy* texture and *Mycoprotein* by a *Tender* texture.  
491 Regarding taste/flavor, *Chicken2* was largely dominated by *Cream* and *Meat/Poultry* flavors.  
492 Interestingly, *Mycoprotein* was given a fairly similar temporal profile, because it was dominated  
493 by *Cream*, then *Meat/Poultry*, with touches of *Mushroom* and *Broth*. *Wheat-Soy* had a *Broth*  
494 attack and then a succession of *Cream*, *Salty*, *Mushroom* and *Meat/Poultry* flavors. Lastly,  
495 *WhtChp-Aroma* had a *Cream* and *Broth* attack and then a succession of *Meat/Poultry*, *Cereal*,  
496 *Mushroom* and *Soy* flavors. For all the products, there was a clear within-intake temporality but  
497 little between-period temporality, because all the curves were very similar between the three  
498 periods.

499 [Insert Figure 5]

500 [Insert Figure 6]

### 501 3.2.6 Temporal Drivers of Liking

502 Table 5 and Table 6 show the Temporal Drivers of Liking of the four products for texture and  
503 taste/flavors, respectively.

504 [Insert Table 5]

505 [Insert Table 6]

506 Concerning texture, *Chicken2* had a positive TDL, namely *Tender*, and three negative TDLs,  
507 namely *Firm*, *Elastic* and *Dry*. For *Wheat-Soy* and *WhtChp-Aroma*, *Tender* was also a positive  
508 TDL. In addition, *Wheat-Soy* was less appreciated when *Fibrous* was dominant. *WhtChp-Aroma*  
509 had another positive TDL, *Firm*, and a negative TDL, *Spongy*. No TDL was highlighted for

510 *Mycoprotein*. Concerning taste/flavors, few TDLs were highlighted: *Wheat-Soy* was less  
511 appreciated when the descriptor *Chickpea* was dominant, whereas *WhtChp-Aroma* was less  
512 appreciated when the descriptor *Soy* was dominant. No TDL was highlighted for *Mycoprotein*  
513 and *Chicken2*.

### 514 **3.2.6 Quantities consumed**

515 The analysis of variance revealed a significant *Product* effect. Figure 7 shows the mean  
516 quantities (LSMeans) consumed for the different products. The most appreciated products were  
517 also the most consumed on average: the quantities consumed here were higher for the meat,  
518 then for *Mycoprotein*, *Whtchp-Aroma* than for *Wheat-Soy*.

519 [Insert Figure 7]

520 In addition, there was a *Gender\*Product* effect ( $F=4.96/p=0.0025$ ): on average, women  
521 consumed smaller amounts of *Wheat-Soy* and *WhtChp-Aroma* than men did, but there were no  
522 significant differences between them regarding *Chicken2* and *Mycoprotein*.

## 523 **4. Discussion**

### 524 **4.1. Acceptance of plant protein meat substitutes versus meat**

525 Our experiments showed that the plant protein meat substitutes were appreciated differently  
526 depending on their composition and also depending on the recipe. The meat was generally more  
527 liked, regardless of the recipe, with its mean liking scores ranging from 5.98 (*Chicken2* in  
528 Experiment 2, *White Sauce* recipe) to 7.70 (*Chicken1* in Experiment 1, *Chop Suey* recipe) on the  
529 0-10 hedonic scale, whereas the plant protein meat substitutes rarely exceeded 5 for the most  
530 accepted ones. However, one of the plant protein meat substitutes tested was truly appreciated,  
531 even more than the meat: *Mycoprotein* received a mean liking score equal to 6.61 in the *White*  
532 *Sauce* recipe (Experiment 2), whereas *Chicken2* received 5.98. All these results are consistent  
533 with those found in the literature: in Elzerman et al. (2011), the overall liking of meat substitutes  
534 in rice dishes ranged from 43.7 to 64.0 on a 0-100 scale, whereas the acceptance of chicken  
535 pieces was 76.7, which was significantly higher than the acceptance of all the meat substitutes.  
536 As in our study, the product composed of mycoprotein obtained higher overall liking scores than  
537 the other products. The specific texture of *Mycoprotein* could account for that result: in fact,  
538 contrary to the other plant protein products, *Mycoprotein* was not described as *spongy*, a texture  
539 that seemed to be less liked by the consumers.

540 In Experiment 2, we found strong correlations between overall liking, texture liking and taste  
541 liking. Overall liking is assumed to be a holistic hedonic evaluation, taking into account the  
542 appreciation of several sensory modalities, such as odor, taste, and texture (Lawless and  
543 Heymann, 2010). It was interesting to collect the judgments of the consumers towards taste and  
544 texture, to understand the impact of these sensory modalities better. The consumers were  
545 strongly consistent in their evaluations of the different modalities. However, a comparison of the  
546 LSM means of the modalities suggested slight differences: *WhtChp-Aroma* and *Wheat-Soy*  
547 seemed to be less appreciated because of their textures.

548 Furthermore, as expected, Experiment 2 showed that the most appreciated products were also  
549 the most consumed. Interestingly, women consumed smaller amounts of *Wheat-Soy* and  
550 *WhtChp-Aroma* than men did, while they consumed the same amounts of the other products.  
551 This result may suggest that women restricted themselves more than men did when they  
552 disliked a product.

#### 553 **4.2. Temporality of the products**

554 The conclusions from the dynamic liking measurements were similar to the conclusions from the  
555 non-dynamic measurements, and temporality did not affect the overall ranking of the products in  
556 terms of preference. Moreover, there was little temporality of the liking scores throughout the  
557 tasting, which is quite surprising. We could have intended a stronger decrease of the liking  
558 scores of the less-liked products between Period2 and Period3, due to boredom effects,  
559 compared to *Mycoprotein* or *Chicken2*. However, this result may be explained by the  
560 experimental design: because the objective was to be as close as possible to a usual  
561 consumption context, the consumers were free to consume all or part of the portions served.  
562 The analysis of the quantities consumed here showed that the less appreciated products were  
563 also the less consumed on average. If the consumers had to consume the same quantities of  
564 the four products, maybe stronger differences in the temporality of the liking scores would have  
565 been highlighted. A protocol with a fixed quantity of each product would be needed to explore  
566 that question further.

567 Concerning the TDS results, despite a clear within-intake temporality, there was little between-  
568 period temporality. This result is surprising concerning taste/flavor TDS, because these sensory  
569 perceptions are generally impacted by subsequent intakes: within quite similar experimental  
570 protocols, other authors underlined period effects on the sensory perceptions, e.g., Zorn et al. on  
571 orange juices with sweeteners (2014), Thomas et al. on oral nutritional supplements (2016), and  
572 Galmarini et al. on wines (2016). However, in these papers, the consumers evaluated  
573 successive repeated intakes. In our paper, because the protocol was designed to be as close as

574 possible to real consumption habits, the consumers alternated meat or meat substitute intakes  
575 with quinoa intakes. Even if the participants were not asked to rinse their mouths between  
576 intakes, quinoa had a neutral taste, so it may have had the same effect as a washout break on  
577 the taste/flavor TDS measurements.

#### 578 **4.3. Which sensory drivers can improve the acceptance of plant protein meat substitutes?**

579 In our first experiment, the experimental plant-based protein variant spiked with a meat flavor  
580 was preferred to the original *Wheat-Chickpea* product: the mean liking score of the flavored  
581 variant was 5.04 instead of 3.88 without added flavor. This result is consistent with the liking  
582 scores obtained by the meat products, which were generally more liked, regardless of the recipe.  
583 It was thus possible to improve the acceptability of that plant-based protein product, by focusing  
584 on its taste with the addition of a meat flavor. However, changing its color had no effect. In our  
585 second experiment, we showed that plant protein meat substitutes can be visually attractive:  
586 *WhtChp-Aroma* obtained a visual liking score of 6.73, and *Mycoprotein* obtained a score of 5.8,  
587 while *Chicken2* received a score of 6.24. However, sometimes, e.g., concerning *WhtChp-Aroma*,  
588 the visual expectation did not reflect the overall liking after tasting. Two explanations can be  
589 given for this result. First, the meat aroma added to *WhtChp-Aroma* may have positively  
590 influenced the consumers while they were evaluating the visual expectation. However, it seems  
591 also to be a matter of texture: while the results of the CATA and TDS measurements showed  
592 that most of the plant protein meat substitutes had truly different texture and taste profiles from  
593 the meat products, the analysis of the Temporal Drivers of Liking primarily highlighted texture  
594 descriptors: a *Tender* attack seems to be a positive characteristic, whereas the *Spongy* texture  
595 was less accepted. Therefore, the texture could be improved to approach the texture of  
596 *Chicken2* or *Mycoprotein*, for example.

597 It would have been interesting to compare these results with data from other papers to validate  
598 these sensory drivers. However, we did not find any papers in the recent scientific literature,  
599 which would have reported descriptive data optionally related to liking data, for similar plant  
600 protein meat substitutes.

#### 601 **4.4. Should plant protein meat substitutes mimic the appearance, taste and texture of** 602 **meat?**

603 First, it must be noted that the populations studied in the paper were not representative of the  
604 whole French population. However, considering the ameliorative sensory drivers suggested by  
605 our results, it could be tempting to recommend the development of plant protein meat substitutes  
606 with the appearance, taste and texture of meat. However, that could be counterproductive:

607 Regarding the visual aspect, Mancini and Hunt (2005) pointed out that the color of a meat  
608 product is often considered one of the most important attributes for consumers. As a result, the  
609 color of meat substitutes is often modified to mimic a meat-like appearance. In our first  
610 experiment, we did not find any effect from color on participant preferences; however, this result  
611 cannot be generalized because the color was modified for only one of the variants tested here.  
612 Concerning taste and texture, it is also possible to add specific aromas, flavors and texturizing  
613 additives or to use technological processes to obtain meat-like patterns. However, this outcome  
614 is not as easy as it seems: it is necessary to understand what appeals to the consumer in the  
615 taste/texture of meat before trying to reproduce these characteristics. In addition, the use of  
616 specific ingredients or processes should be reasonable and pragmatic to avoid obtaining ultra-  
617 processed foods. It has been shown that an increase in the consumption of such ultra-processed  
618 foods can have unexpected nutritional consequences (Monteiro et al., 2013; Moodie et al., 2013;  
619 Hall et al., 2019). A compromise should be found to avoid the production of ultra-processed  
620 foods, to avoid wiping out the benefits of plant-based protein foods versus animal foods.  
621 Apart from that consideration, a fundamental question arises: is it necessary to mimic the  
622 characteristics of meat for consumers? In our experiment, some of the plant protein meat  
623 substitutes were rejected by the consumers, but others were appreciated, while they were  
624 different from meat in terms of visual aspect, taste or texture. According to Hoek et al. (2011a,  
625 2011b), meat substitutes must be recognized as alternatives to meat to be accepted. They  
626 surveyed 553 consumers in the United Kingdom and the Netherlands to understand how to  
627 attract new consumers to these products and they indicated that the less frequently consumers  
628 were using meat substitutes, the greater they wanted them to be similar to meat. However, this  
629 assessment may be qualified, because, according to Elzerman et al. (2011), 'similarity to meat'  
630 did not seem to be a prerequisite for the acceptance of meat substitutes in a meal context.  
631 However, according to these authors, it seems important that the foods fit in the meal, in  
632 particular with an appropriate shape and appearance. Conducting new studies on that topic  
633 could open up further perspectives, taking into account the recent changes in consumer  
634 attitudes and expectations towards meat and plant protein meat substitutes.

635 In addition, trying to mimic meat-like characteristics can exacerbate consumer dissatisfaction:  
636 the sensory expectations of consumers towards a plant protein meat substitute with visual  
637 patterns similar to that of meat can lead to disappointment after tasting them if the taste and  
638 texture are too far from those of meat. To avoid that issue, another perspective would be to  
639 present the plant protein meat substitutes as products apart, giving them an identity, so that  
640 these foods, so called Novel Protein Foods (Hoek et al., 2011b), are perceived as different from

641 meat as eggs or fish, for example. These Novel Protein Foods should not have to be meat-like to  
642 be accepted by consumers, as long as their sensory characteristics are appreciated and as long  
643 as they fit in the dishes in which they are prepared. Novel Protein Foods should be recognized  
644 by consumers as alternatives to meat but not as substitutes, strictly speaking: they should not be  
645 too similar to meat (to have their own identity) but not too different (to be recognized as an  
646 alternative to meat). An optimum level has to be found (Hoek et al. 2011b).

#### 647 **4.5. Limitations of the study**

648  
649 Concerning the age, gender and the individual frequency of consumption of plant protein meat  
650 substitutes, no clear effect arises on the acceptance of the different products. Some  
651 *Age\*Product* or *Gender\*Product* effects were found, but not in all the sensory sessions;  
652 therefore, no conclusion could be made concerning their possible impacts. In addition, no clear  
653 interpretation could be given regarding the slight significant interaction for *Age\*gender\*MSF*,  
654 which was observed only in Session 2 of the first experiment. Therefore, the study does not  
655 allow us to draw conclusions on a potential impact of individual familiarity with plant protein meat  
656 substitutes. An experiment with a larger panel should be conducted to explore the question of  
657 familiarity and attitudes towards plant protein meat substitutes and to look deeper into the issue  
658 of potential age and gender effects.

659 Moreover, individual familiarity with the conventional version of each recipe was not evaluated.  
660 The more an individual is familiar with a recipe, the more he or she might notice the sensory  
661 changes induced by the plant-based products. Such a question deserves to be clarified with a  
662 dedicated experiment.

#### 663 **5. Conclusion**

664 The present paper investigated consumer acceptance of different plant protein meat substitutes  
665 compared to meat in various recipes. We found that the plant protein meat substitutes were  
666 appreciated differently depending on their composition and depending on the recipe. The meat  
667 was generally more liked regardless of the recipe. However, one of the plant-based protein product  
668 tested here was truly appreciated, even more than the meat. We highlighted some sensory drivers  
669 that could lead to a better acceptance of the products. However, a compromise has to be found  
670 to avoid the production of ultra-processed foods, which might be counterproductive. It is also  
671 important to examine consumers' attitudes and expectations towards Novel Protein Foods further  
672 to determine whether it is necessary to mimic a meat-like appearance, taste and texture for these

673 products. Other strategies could be explored to guide consumer choices while preserving the  
674 identity of the Novel Protein Foods. For example, educating consumers about environmental,  
675 sustainability, health and animal concerns and gradually exposing them to these Novel Protein  
676 Foods so that they can familiarize themselves with their taste and texture could be constructive.

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Figure captions:

Figure 1. Least Square mean liking scores of the different products for each recipe (a: *White Sauce* in Session 1; b: *Chop Suey* in Session 2; c: *Lasagna* in Session 3; d: *White Sauce* in Session 4). On the bars, different letters indicate significantly different means.

Figure 2. Biplots of correspondence analyses for each recipe (a: *White Sauce* in Session 1; b: *Chop Suey* in Session 2; c: *Lasagna* in Session 3; d: *White Sauce* in Session 4); p-values of dimensionality tests. Two products linked by a dashed line are not significantly different.

Figure 3. Standardized mean liking scores (LSMeans) of the different products for each non-dynamic liking variable (a: *visual liking*; b: *overall liking*; c: *liking of taste*; d: *liking of texture*). On the bars, different letters indicate significantly different means.

Figure 4. Evolution of the mean liking scores (LSMeans) per period for each product. The different letters indicate significantly different means.

Figure 5: Texture TDS curves for the four products and the three periods in standardized time. (a: *Wheat-Soy*; b: *Chicken2*; c: *WhtChp-Aroma*; d: *Mycoprotein*)

Figure 6: Taste/flavor TDS curves for the four products and the three periods in standardized time. (a: *Wheat-Soy*; b: *Chicken2*; c: *WhtChp-Aroma*; d: *Mycoprotein*)

Figure 7. Standardized quantities (LSMeans) consumed for the different products. On the bars, different letters indicate significantly different means.

Figure 1. [Color not required]

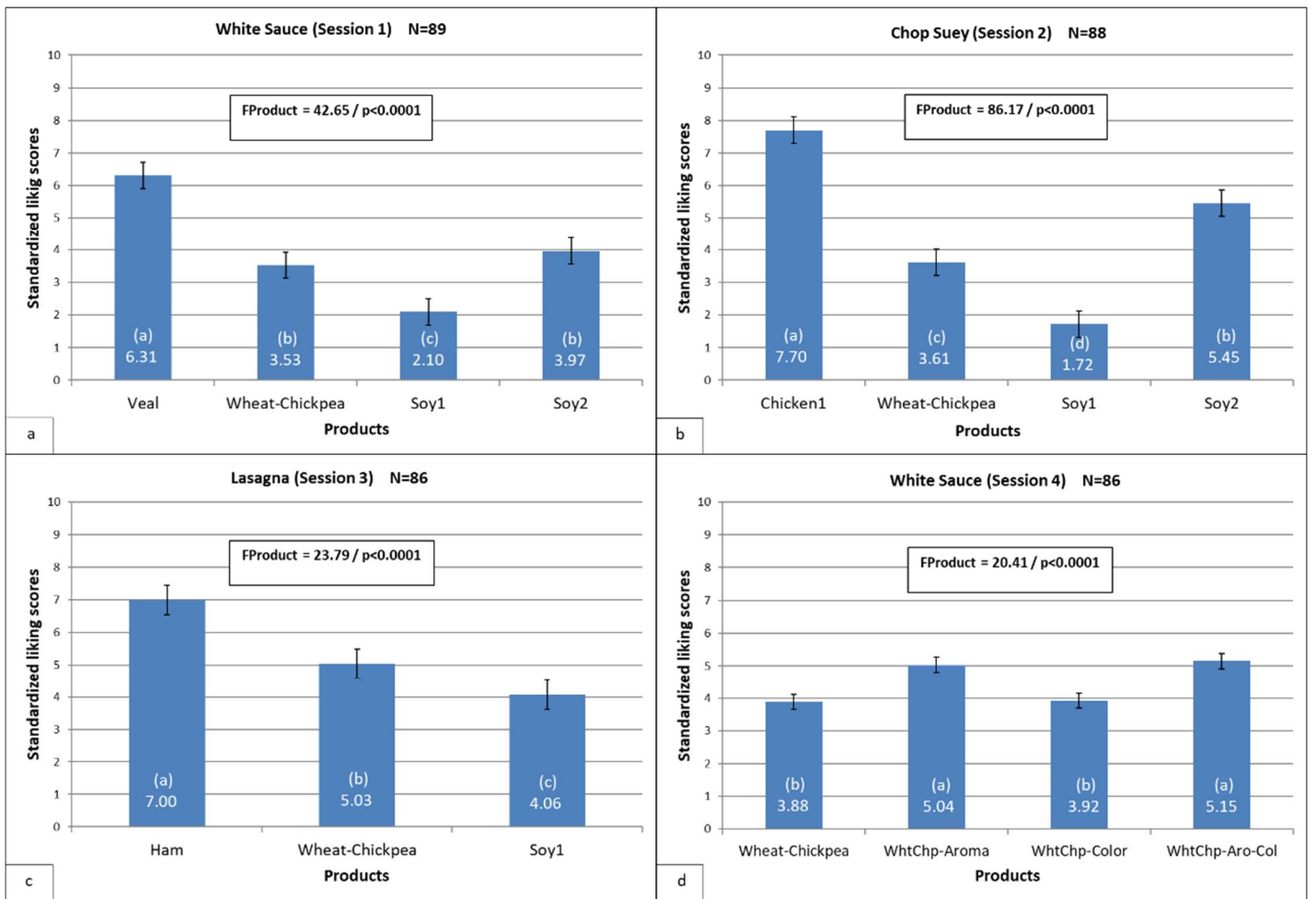


Figure 2. [Color required]

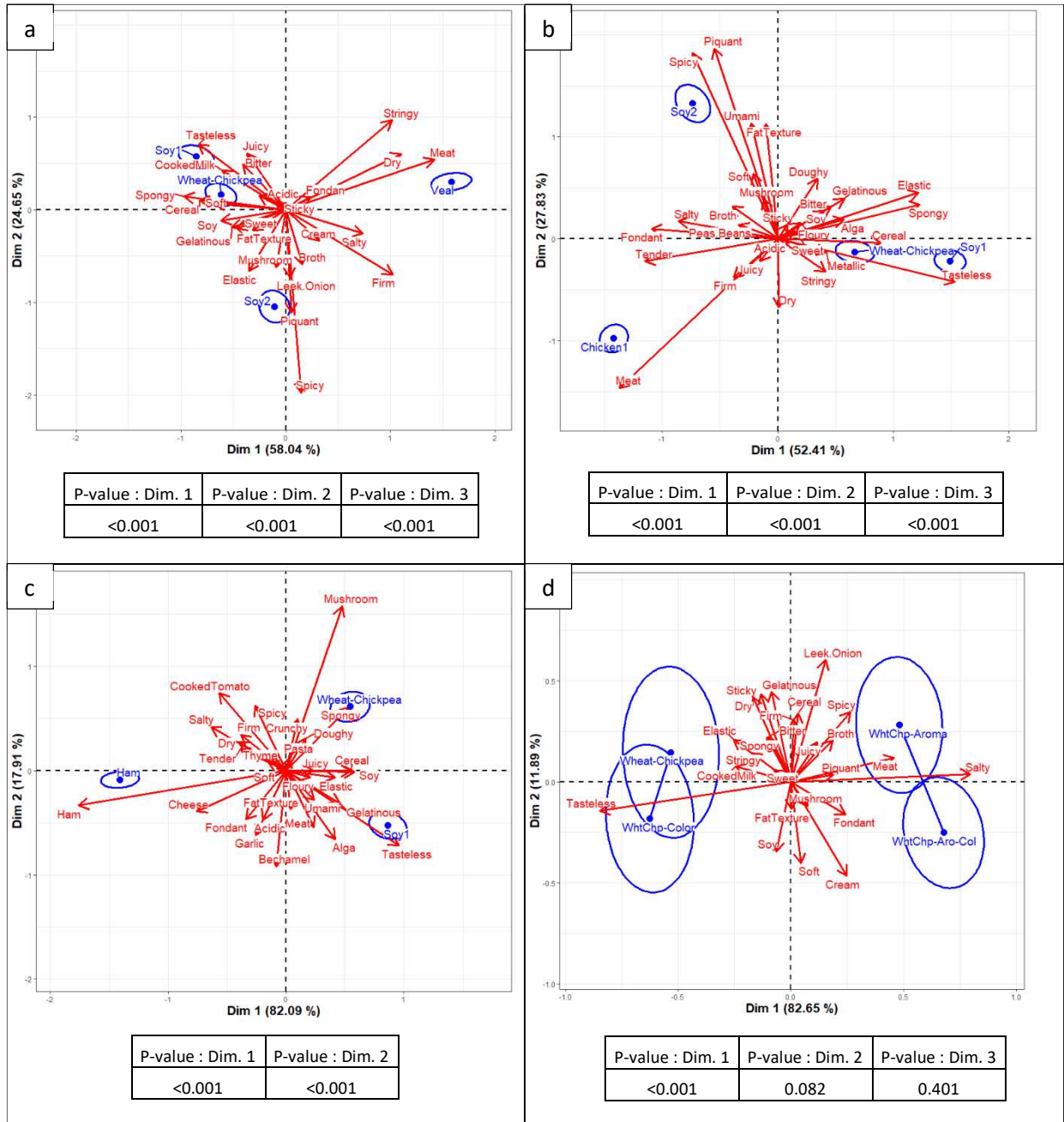


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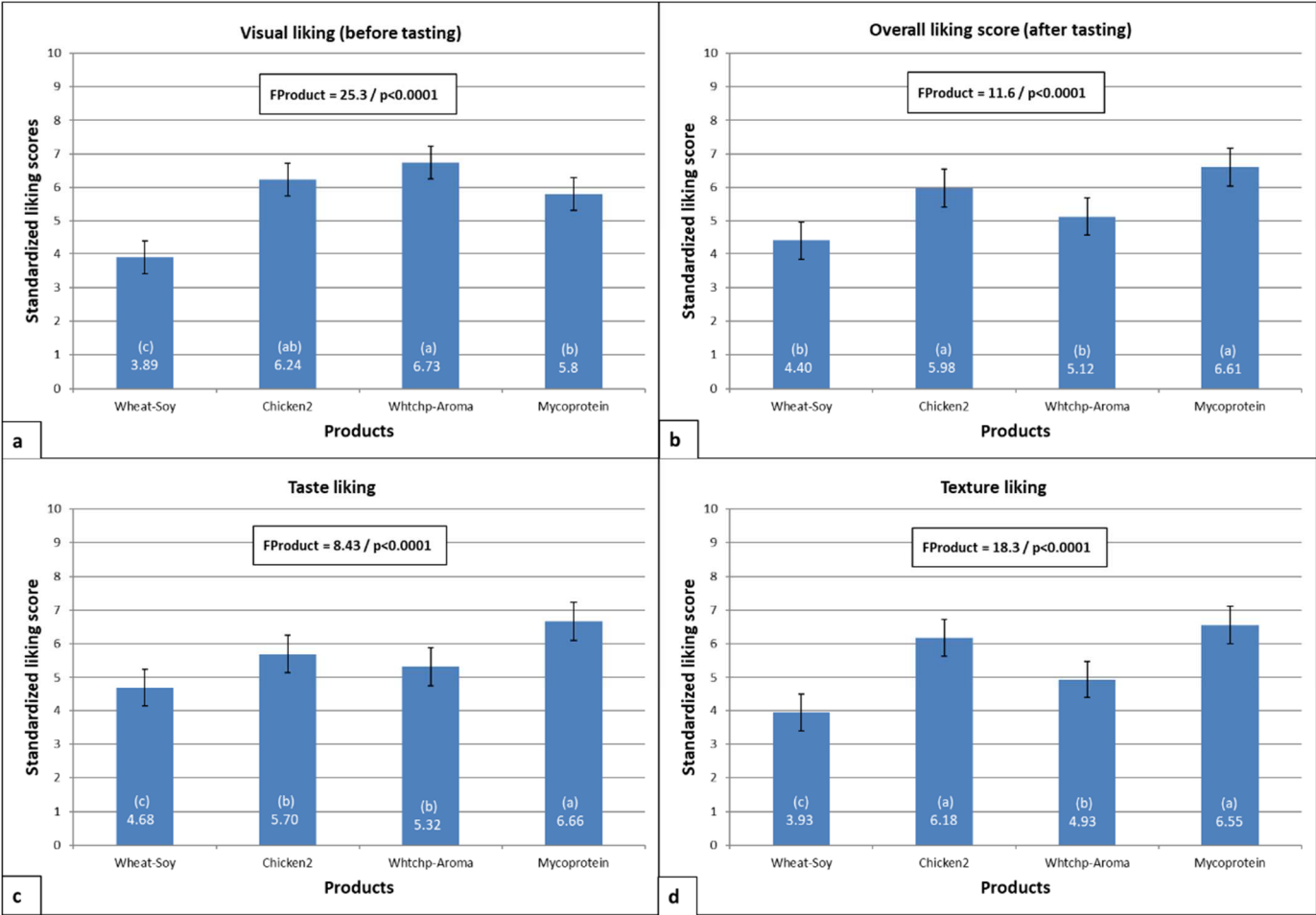


Figure 4. [Color required]

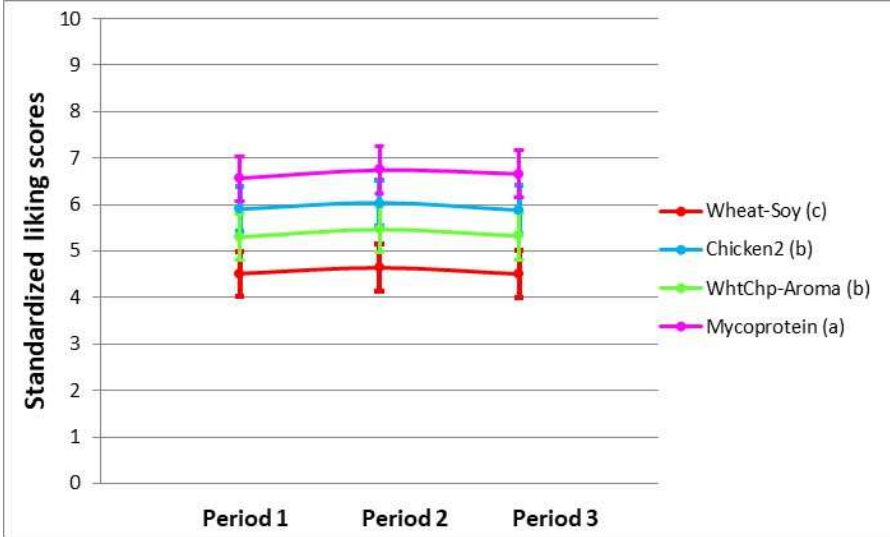


Figure 5. [Color required]

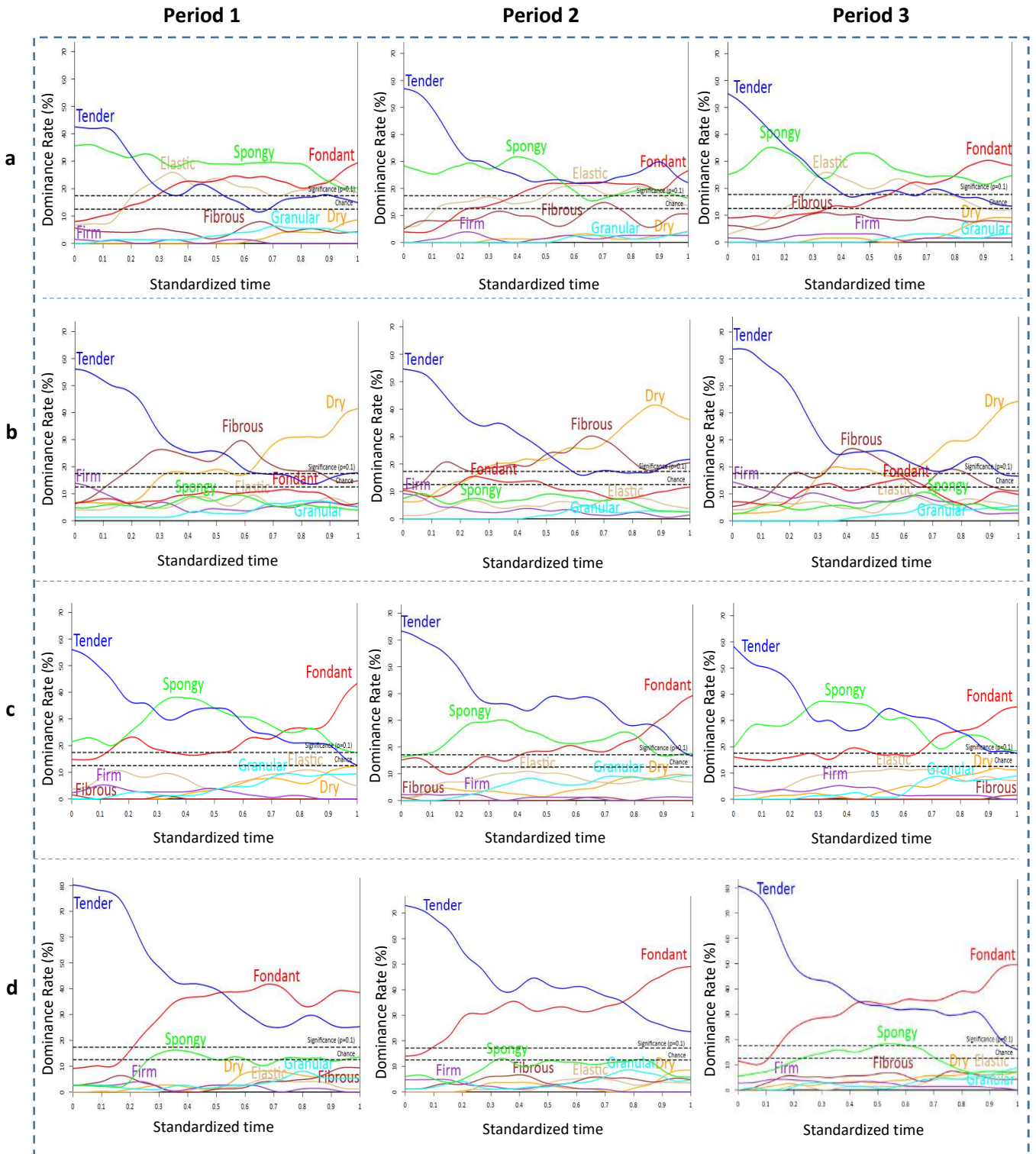


Figure 6. [Color required]

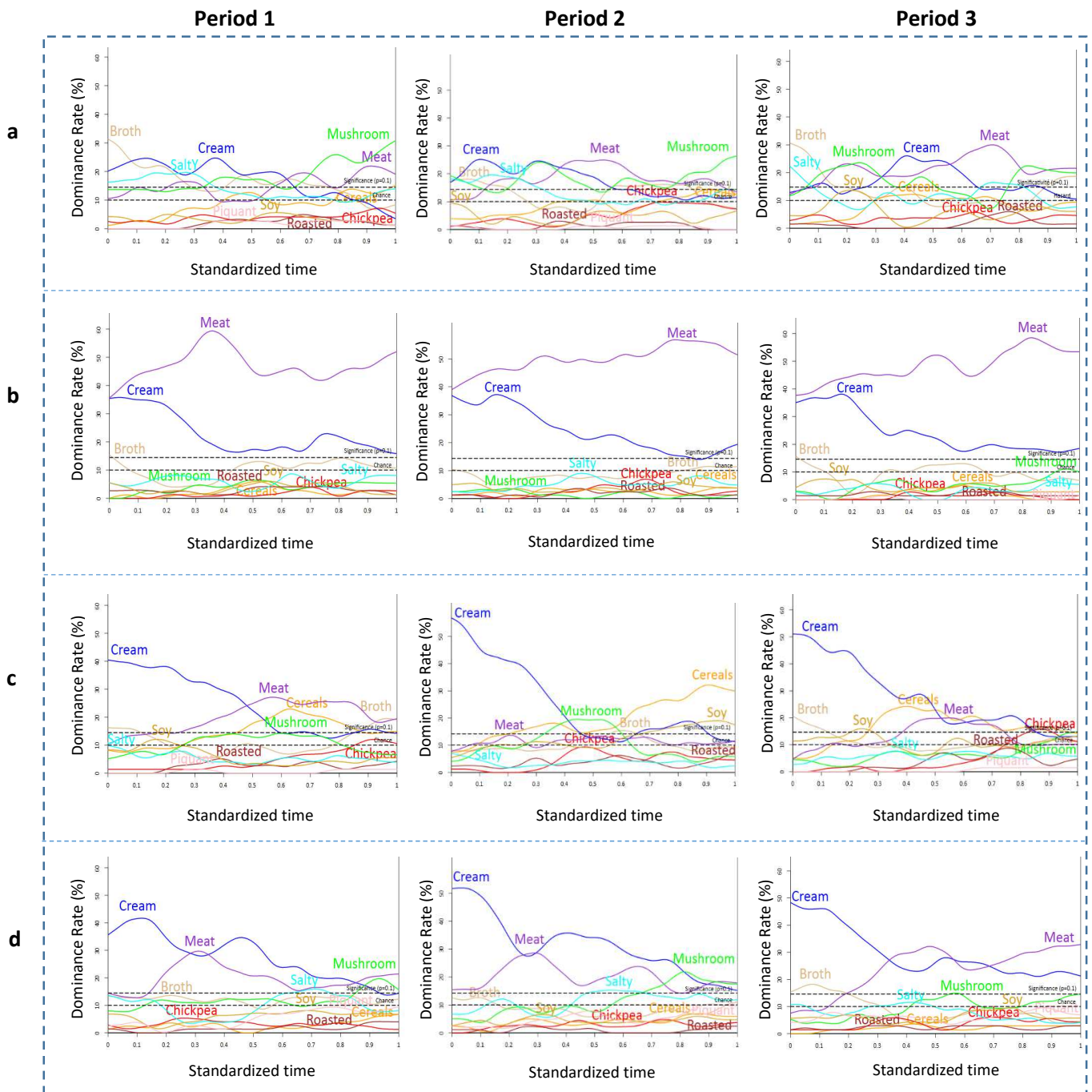
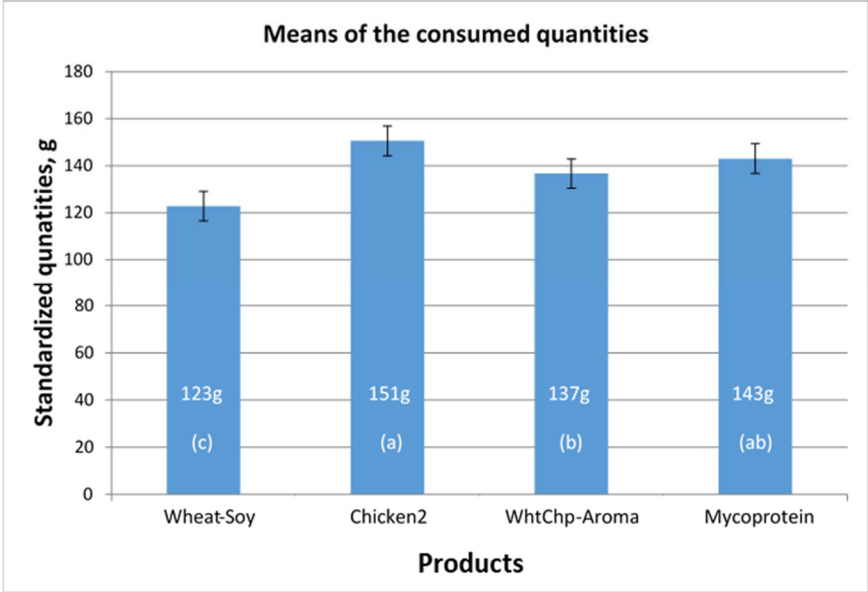


Figure 7. [Color not required]



Tables:

<b>Recipe</b>	<b>1<sup>st</sup> product</b>	<b>2<sup>nd</sup> product</b>	<b>3<sup>rd</sup> product</b>	<b>4<sup>th</sup> product</b>
<b>White Sauce (session 1)</b>	<i>Wheat-Chickpea</i>	<i>Soy1</i>	<i>Veal</i>	<i>Soy2</i>
<b>Chop Suey (session 2)</b>	<i>Wheat-Chickpea</i>	<i>Soy1</i>	<i>Chicken1</i>	<i>Soy2</i>
<b>Lasagna (session 3)</b>	<i>Wheat-Chickpea</i>	<i>Soy1</i>	<i>Ham</i>	/
<b>White Sauce (session 4)</b>	<i>Wheat-Chickpea</i>	<i>WhtChp-Aroma</i>	<i>WhtChp-Color</i>	<i>WhtChp-Aro-Col</i>

Table 1: Names used in this paper to designate the products tested for each recipe in the first experiment. *WhtChp* means Wheat-Chickpea.

<b>Descriptors for textures</b>	<b>Recipes</b>		
	<b>White Sauce</b>	<b>Chop Suey</b>	<b>Lasagna</b>
<i>Dry</i>	X	X	X
<i>Elastic, rubbery</i>	X	X	X
<i>Fat texture</i>	X	X	X
<i>Firm</i>	X	X	X
<i>Fondant</i>	X	X	X
<i>Gelatinous</i>	X	X	X
<i>Juicy, watery</i>	X	X	X
<i>Soft</i>	X	X	X
<i>Spongy</i>	X	X	X
<i>Sticky</i>	X	X	
<i>Stringy, fibrous</i>	X	X	
<i>Doughy</i>		X	X
<i>Floury</i>		X	X
<i>Tender</i>		X	X
<i>Crunchy, crispy</i>			X

Table 2. Texture CATA descriptors displayed for each recipe.

<b>Recipes</b>			
<b>Descriptors for tastes</b>	<b>White Sauce</b>	<b>Chop Suey</b>	<b>Lasagna</b>
<i>Acidic</i>	X	X	X
<i>Cereal, wheat</i>	X	X	X
<i>Mushroom</i>	X	X	X
<i>Salty</i>	X	X	X
<i>Soy</i>	X	X	X
<i>Spicy, peppery</i>	X	X	X
<i>Tasteless</i>	X	X	X
<i>Bitter</i>	X	X	
<i>Broth</i>	X	X	
<i>Meat, poultry</i>	X	X	
<i>Piquant</i>	X	X	
<i>Sweet</i>	X	X	
<i>Alga</i>		X	X
<i>Umami</i>		X	X
<i>Metallic</i>		X	
<i>Veg. (peas, beans)</i>		X	
<i>Cooked tomato</i>			X
<i>Garlic</i>			X
<i>Thyme, Herbs</i>			X
<i>Meat</i>			X
<i>Ham</i>			X
<i>Cheese</i>			X
<i>Bechamel</i>			X
<i>Pasta</i>			X
<i>Cooked milk</i>	X		
<i>Cream</i>	X		
<i>Veg. (leek, onion)</i>	X		

Table 3. Tastes CATA descriptors displayed for each recipe.

Texture descriptors	Taste and flavor descriptors
<i>Soft, tender</i>	<i>Broth</i>
<i>Spongy</i>	<i>Soy</i>
<i>Elastic</i>	<i>Cream</i>
<i>Granular</i>	<i>Roasted</i>
<i>Firm</i>	<i>Piquant, peppery, mustard</i>
<i>Fibrous, stringy</i>	<i>Salty</i>
<i>Dry</i>	<i>Meat, poultry</i>
<i>Fondant</i>	<i>Cereals, wheat</i>
	<i>Chickpea</i>
	<i>Mushroom</i>

Table 4. List of TDS descriptors in their presentation order.

Descriptors	<i>Wheat-Soy</i>		<i>Chicken2</i>		<i>WhtChp-Aroma</i>		<i>Mycoprotein</i>	
	N	CLWD	N	CLWD	N	CLWD	N	CLWD
<i>Tender</i>	55	0,11**	59	0,14**	62	0,06*	65	-0,01
<i>Fondant</i>	45	0,04	32	0,08	50	0,06	54	0
<i>Firm</i>	7	-0,01	28	-0,19*	8	0,12*	6	-0,18
<i>Spongy</i>	53	-0,05	19	-0,13	53	-0,16**	37	-0,03
<i>Elastic</i>	45	-0,05	21	-0,26**	21	-0,11	11	0,17
<i>Dry</i>	11	-0,11	52	-0,09*	15	-0,07	9	-0,08
<i>Granular</i>	9	-0,11	12	0,05	11	-0,07	12	-0,02
<i>Fibrous</i>	23	-0,27**	47	-0,09	4	0,32	15	0,06

Table 5. Temporal Drivers of Liking for texture. N is the number of consumers who selected the descriptor while they were tasting the corresponding product. CLWD is the average of the individual centered LWDs. \* corresponds to a 10% significance level, \*\* corresponds to a 5% significance level.

Descriptors	<i>Wheat-Soy</i>		<i>Chicken2</i>		<i>WhtChp-Aroma</i>		<i>Mycoprotein</i>	
	N	CLWD	N	CLWD	N	CLWD	N	CLWD
<i>Piquant</i>	3	0,29	2	0,19	2	0,05	22	-0,03
<i>Meat</i>	47	0,02	67	-0,02	41	-0,03	53	0
<i>Cream</i>	48	0,02	61	0,01	61	-0,01	63	-0,01
<i>Salty</i>	41	0,01	21	0,09	25	0,04	36	-0,01
<i>Roasted</i>	11	-0,03	8	-0,27	16	0,11	8	-0,09
<i>Broth</i>	52	-0,03	39	0,08	38	0,01	39	0
<i>Mushroom</i>	50	-0,03	19	0,07	36	0	35	-0,07
<i>Cereals</i>	35	-0,04	11	0,1	38	0,09	20	0,12
<i>Soy</i>	20	-0,1	18	-0,09	<b>33</b>	<b>-0,1*</b>	19	0,02
<i>Chickpea</i>	<b>17</b>	<b>-0,16*</b>	9	0,05	18	0,04	12	0,08

Table 6. Temporal Drivers of Liking for taste/flavors. N is the number of consumers who selected the descriptor while they were tasting the corresponding product. CLWD is the average of the individual centered LWDs. \* corresponds to a 10% significance level (no significant data at 5%).