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1 **A study of ultra-processing marker profiles in 22,028 packaged ultra-**
2 **processed foods using the Siga classification**

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15 **Abbreviations**

16 MUP, marker of ultra-processing

17 A-MUP, additives MUP

18 FSA, Food Standard Agency

19 NA-MUP, non-additive ingredients MUP

20 UPF, ultra-processed food

21

22

23 **Short title:** Profile of ultra-processing markers in packaged foods

24

25

26 **Abstract**

27 Ultra-processed foods (UPFs) are characterized by the presence of markers of ultra-processing
28 (MUP), either additives (A-MUP) or non-additive ingredients (NA-MUP). The present study
29 aims to characterize the MUP profile of approximately 22,000 UPFs, representative of
30 assortments in French supermarkets. UPFs were ranked according to Siga classification
31 within five UPF technological groups, from C01 to C3, depending on the nature and number
32 of MUPs (MUP1 and MUP2), presence of risk-associated additives, and contents of salt,
33 sugar and/or fat. Then, UPFs were categorized within 10 food categories. The results showed
34 that UPFs contain more NA-MUPs than A-MUPs, on average 1.3 more by UPF. The main
35 MUPs are NA-MUPs, i.e., refined oils (52.5% of UPFs), extracts and natural aromas (42.7%),
36 synthetic aromas (26.5%), glucose syrup (20.0%), native starches (19.1%), and dextrose
37 (16.2%). The NA-MUP/UPF and A-MUP/UPF ratios were not correlated in the 10 food
38 categories. Among UPFs, 19% contained only one MUP, and 31% contained more than five
39 MUPs. In conclusion, additives are not a sufficient marker of ultra-processing. It is proposed
40 that NA-MUPs in UPFs should be taken into greater consideration and that foods be scored
41 with indices based on the degree of processing, not compositional scores, which fail to filter
42 MUPs.

43

44

45 **Keywords:** Packaged foods, markers of ultra-processing, additives, ultra-processed

46 ingredients

47 **1. Introduction**

48 More than forty-three epidemiological studies have shown that excessive and regular
49 consumption of ultra-processed foods (UPFs) was positively associated with several chronic
50 diseases, notably overweight/obesity, type 2 diabetes, cardiovascular diseases and total
51 cancers, and all-cause mortality (Lane et al., 2020; Pagliai et al., 2020; Askari et al., 2020;
52 FAO et al., 2019), and UPF consumption has also been associated with DNA damage (Edalati
53 et al., 2020) and shorter telomeres (Alonso-Pedrero et al., 2020). Prior to the development of
54 the UPF concept in 2009 (Monteiro, 2009), other studies also showed the importance of the
55 degree of food processing for health, e.g., whole-grain *versus* refined cereals, fruits *versus*
56 100% fruit juice *versus* sweetened fruit juices, red *versus* processed meats, and minimally
57 *versus* highly processed plant-based foods (Fardet and Boirie, 2014; Satija et al., 2017).

58 Ultra-processed foods were assessed using the NOVA classification according to the
59 extent and purpose of processing in four technological groups: un/minimally processed foods,
60 culinary ingredients, processed foods and UPFs (Moubarac et al., 2014). The Siga
61 classification extends the NOVA classification with additional subgroups, taking into account
62 added salt, sugar and fat contents; “at risk” additives; “matrix” effects; ultra-processed
63 ingredients; and the number of markers of ultra-processing (MUPs), where UPFs are defined
64 as “*characterized by the presence of at least one deliberately added substance obtained by*
65 *synthesis or by a succession of physical, chemical and/or biological processes leading to its*
66 *purification and/or substantial deterioration compared to the original material in the list of*
67 *ingredients. UPFs can also be created by the direct application of a deterioration process*
68 *(e.g., extrusion-cooking) to the food matrix. These substances are named MUPs and can be*
69 *indifferently an ingredient or an additive, most of which are obtained by technological*
70 *processes relating to cracking or synthesis*” (pages 2031-2032) (Davidou et al., 2020).
71 Therefore, Siga distinguishes additive MUPs (A-MUPs) and non-additive MUPs (NA-

72 MUPs). Finally, the Siga classification distinguishes, from the least to the highest processed,
73 nine technological groups combining previous NOVA groups with five more specific sub-
74 groups; then foods are ranked according to an algorithm based on a decision tree including
75 criteria mentioned in **Figure 1**.

76 NA-MUPs are mainly aromas (synthetic, extracts and natural aromas), and ultra-
77 processed carbohydrates, fats and proteins; for example, hydrolysed sugars, hydrogenated fats
78 and protein isolates. Additives that are minimally processed are not included in the definition
79 of UPFs (Davidou et al., 2020). Therefore, A-MUPs are highly processed additives such as
80 lecithins and diacetyl tartaric acid ester of mono- and diglycerides (i.e., DATEM); additives
81 such as sodium bicarbonate or acacia gum are not A-MUPs. Finally, the risk assessment of
82 additives is complementary to the evaluation of the degree of processing, and some “at risk”
83 additives may also send foods into the UPF category, but were not considered as MUPs (*e.g.*,
84 talc or E553b) (Davidou et al., 2020). They correspond to additives that have been noted to
85 present a risk for health (safety concerns of the European Food Safety Authority reports,
86 EFSA), notably when regularly consumed, *e.g.*, phosphate additives (Ritz et al., 2012) and
87 sodium nitrite (Jiang et al., 2012).

88 In a previous study on 24,932 packaged foods representative of the food supply in
89 French supermarkets, it was found that 67% of foods were UPFs, of which 13% contained
90 only one MUP, and that among foods with more than 5 ingredients, there was more than a
91 75% probability of being a UPF (Davidou et al., 2020). Therefore, if MUPs are generally
92 perceived as only additives (i.e., texture agents, taste exhausters, sweeteners and colouring
93 agents), sometimes evaluated as associated with risk, they are also NA-MUPs. The main
94 objective of this study was therefore to analyse the MUP profiles of approximately 22,000
95 packaged UPFs (except for organic products) representative of French supermarket

96 assortments and to distinguish between A-MUPs and NA-MUPs. This is the first study
97 addressing this issue, notably with a human health perspective as the background.

98

99 **2. Materials and Methods**

100 *2.1 Food selection and data collection*

101 The Siga database is built from information provided by its partners (manufacturers and
102 retailers – 65% of data) and that collected within the framework of the partnership with the
103 "Consumer Transparency program" of Alkemics (i.e., a retail collaborative platform that helps
104 retailers and brands managing, collaborating and sharing product data – 35% of data). To
105 establish the Siga score, data notably include the brand name, the list of ingredients, and the
106 nutrient fact panels.

107 Packaged foods were extracted from the Siga database according to ten food categories
108 (i.e., beverages, bakery products and pastries, starchy foods, fruits and vegetables, ready-to-
109 eat meal, seafood products, dairy products, salted products, sweet products, and meats and
110 eggs), containing a total of 31,967 items. The UPFs were extracted from them, corresponding
111 to 22,028 food items (i.e., 69%). Baby foods, alcoholic beverages and food supplements were
112 not considered in this study because they are generally reserved as part of special diets and
113 because alcoholic beverages are not foods.

114 The percentages of UPFs for each of the five UPF groups (C01–C3, **Figure 1**) were
115 calculated directly from the Siga database based on the list of ingredients (crude results,
116 excluding fresh fruits and vegetables, bread and cheeses, delicatessen, unlabelled seafood
117 packaged in advance). Beyond A-MUP and NA-MUP ingredients, processes of only industrial
118 use directly applied to the foods and highly modifying their matrix (e.g., extrusion-cooking or
119 puffing) are also considered as MUPs (Monteiro et al., 2019; Davidou et al., 2020). However,

120 in this analysis, they were not considered because they were not mentioned on the packaging
121 as legal information that Siga could check.

122

123 *2.2 Siga classification*

124 The Siga classification and its methodology have been previously described in detail
125 (Davidou et al., 2020). In this study, for a better description and analysis, the UPF group,
126 initially described by three technological groups (C01, C02, C1), was subdivided into five
127 groups according to the number and nature of MUPs, the presence of “risk-associated
128 additives”, and the added sugar, salt and/or fat contents, *i.e.*, C01, C02, C1, C2 and C3
129 (**Figure 1**). In addition, although A1 and A2 groups (minimally-processed foods and culinary
130 ingredients, respectively) were distinguished in our previous paper (Davidou et al., 2020), in
131 this study they were merged in the A1 group only (Figure 1), leading to a total of nine groups.
132 Concerning MUPs, they have been grouped into 152 different families with 92 MUP1 (*e.g.*,
133 ascorbates, fibre isolates) and 60 MUP2 (*e.g.*, polyols, hydrogenated oils):

134 – MUP1: obtained by chemical synthesis and is identical to natural substances, by successive
135 processes leading to purification, or by successive processes leading to the high deterioration
136 of the ingredient matrix, such as isolated protein, starches, natural flavouring, and yeast
137 extract.

138 – MUP2: obtained by artificial chemical synthesis or by successive processes leading to the
139 combined purification and substantial deterioration of the matrix, as is the case for glucose
140 syrup, dextrose, hydrolysed proteins, carboxymethylcellulose, etc.

141 MUP1s and MUP2s are equal to total MUPs and include A-MUPs as well as NA-MUPs. C01
142 (nutritionally balanced UPF) contains only one MUP1 with low levels of salt, sugar and/or
143 fats (according to the medium Food Standard Agency threshold, FSA); C02 contains only one
144 MUP1 with high levels of salt, sugar and/or fats (according to the medium FSA threshold);

145 C1 contains less than 5 MUP1s; and C2 contains more than 5 MUP1 and/or 1 MUP2 and/ or 1
146 at-risk additive. Beyond these criteria, foods and beverages are classified in the C3
147 technological group. The medium FSA nutritional thresholds are 1.5 g salt/100 g, 12.5 g
148 sugars/100 g and 17.5 g fat/100 g for foods, and 0.75 g salt/100 g, 6.25 g sugars/100 g and
149 8.75 g fat/100 g for beverages. When added sugars, fats and/or sugars were not detected
150 within the list of ingredients of packaged foods, the above-mentioned thresholds were not
151 taken into consideration for calculations.

152

153 *2.3 Statistical and machine learning analyses*

154 The distribution of MUPs in each UPF category was controlled for normality
155 (Lilliefors and Kolmogorov-Smirnov tests). Since not following a normal distribution ($p >$
156 0.05), the average number of MUP by category was therefore expressed as the median. Other
157 calculations were based on simple analytical indices such as ratios and percentages. The
158 results were expressed based on the number of total MUPs, percentages of main MUPs in the
159 UPFs, the number of foods according to the number of MUPs, the MUP/UPF ratio, the
160 MUP/UPF ratio among food subcategories, and the presence of A-MUPs, NA-MUPs and
161 “risk-associated” additives. The numbers of A-MUPs and NA-MUPs in UPFs among
162 categories were correlated using Pearson’s correlation coefficient, and the effect was
163 considered significant at the $p < 0.05$ level.

164 Decision tree analysis was applied to the “152 MUP \times 17,571 UPFs” matrix to define
165 rules for foods belonging to UPF groups with more than one MUP (i.e., C1, C2 and C3, with
166 C01 and C02 removed), and to unravel potential co-occurrence of MUPs within UPFs.
167 Among machine learning algorithms, the chi-square automatic interaction detector (CHAID)
168 was chosen, instead of classification and regression trees (CARTs) and C4.5 algorithms,
169 because it is more adapted to an exploratory study with a big sample. A total of 90% of the

170 foods were used for the learning sample ($n = 15,814$ UPFs), and the remaining 10% were used
171 for the test sample (model validation). In the final analysis, “ < 0.5 ” indicates the absence of
172 the MUP and “ ≥ 0.5 ” indicates the presence of the MUP.

173 Statistical and decision tree analyses were all performed on a PC with SPAD9.1
174 software (Coheris©, Suresnes, France).

175

176 **3. Results**

177 *3.1 Numbers of MUPs in the different Siga UPF groups*

178 Among the 22,028 UPFs, the median contents of total MUPs, A-MUPs, NA-MUPs,
179 “risk-associated” additives, MUP1s and MUP2s increased with Siga UPF categories from
180 C01 to C3 (**Figure 2**). As defined by Siga, the C01–C02 groups contain only one MUP,
181 which is almost exclusively an NA-MUP of the MUP1 type; indeed, some A-MUPs may be
182 found in UPFs in the C01 and C02 groups, as observed when using the mean number of
183 MUPs, which is 1.3, whereas the median is 1. The C1 group does not contain “risk-
184 associated” additives or MUP2s, with a median of 3 MUP1s with 2 NA-MUPs and 1 A-MUP.
185 The median number of “risk-associated” additives in the C2 group was 0, but the average
186 number was 0.4 (indicating the presence of “risk-associated” additives in less than 50% of
187 UPFs in this group); C2 contains a median of 3 MUP1s and 1 MUP2, with 2 NA-MUPs and 1
188 A-MUP. The C3 group contains a median total of 9 MUPs with 6 MUP1s, a median of 3
189 MUP2s, a median of 2 “risk-associated” additives and an equal median content of A-MUPs
190 and NA-MUPs. Finally, all taken together, the C0–C3 categories contains a median number of
191 4 MUPs/UPF (result not shown).

192

193 *3.2 Number of foods according to number of MUPs*

194 Thirty-nine UPFs contained “risk-associated additives” not classified as MUPs (e.g.,
195 iron oxide E172 or talc E553b), so these UPFs were removed from these calculations. Among
196 the remaining 21,989 UPFs, 19.0% contained only one MUP (4,186 products), 16.2%
197 contained two MUPs (3,566 products), 12.2% contained three MUPs (2,685 products), 11.8%
198 contained four MUPs (2,603 products), 9.9% contained five MUPs (2,166 products) and
199 30.9% contained more than five MUPs (6,783 products) (**Figure 3**).

200

201 *3.3 Main MUPs among packaged ultra-processed foods*

202 Among UPFs, the most representative MUPs ($\geq 10\%$ of all UPFs) were NA-MUPs such
203 as refined oils, extracted/natural aromas, synthetic aromas, and glucose syrup (**Table 1**). A
204 total of 132 other MUPs were found in less than 10% of UPFs (results not shown). Among the
205 12 most representative MUPs, 9 NA-MUPs (i.e., 75%) were found.

206

207 *3.4 UPF percentages and MUP profiles by food category*

208 The ten food categories contain varied levels of UPFs (**Figure 4**), as shown here in
209 decreasing order: ready-to-eat meals, sweet products, meat/egg-based products, bakery
210 products/pastries, salted products, seafood, beverages, dairy products, starchy foods and
211 fruits/vegetables categories, which contain 92, 83, 80, 78, 71, 58, 55, 54, 36.5 and 33% of
212 UPFs, respectively (**Figure 4**). Within the ten categories, the average “A-MUP/UPF” and
213 “NA-MUP/UPF” ratios were not significantly correlated ($R^2 = 0.22$, $p = 0.17$), although a
214 tendency is observable, i.e., the higher the level of an A-MUP in a UPF, the higher the
215 number of NA-MUPs (**Figure 5a**). Besides, 3 food categories exhibited at least 2 “A-
216 MUPs/UPF”, with meats and eggs being the category with the highest “A-MUPs/UPF” ratio
217 (= 2.5), and 3 food categories exhibited at least 3 “NA-MUPs/UPF”, with ready-to-eat meals
218 being the category with the highest “NA-MUPs/UPF” ratio (= 4.2) (**Figure 5a**). However, the

219 total number of A-MUPs was highly correlated with the total number of NA-MUPs among
220 the ten food categories ($R^2 = 0.93$, $p < 0.001$) with a 1.35 higher number of NA-MUP (**Figure**
221 **5b**). Overall, among the ten food categories, the median content of “NA-MUPs/UPF” was 1.3
222 higher than the median content of “A-MUPs/UPF” (results not shown).

223

224 *3.5 Decision tree analysis*

225 Among the 15,803 foods (90%, learning sample, Root/Racine), while 33% of C2-C3
226 UPFs had synthetic aromas (MUP2), C1 UPFs did not (**Figure 6a-b**). Among these 33%, 425
227 UPFs of the C3 group (approximately 2.7%) had a co-occurrence of three MUP2s, *i.e.*,
228 dextrose, glucose syrup and synthetic aromas. Other strong co-occurrences of MUPs within
229 C1–C3 UPFs may be deduced from the decision tree and the different branches: 1) within the
230 C3 group: non-additive modified starch/glucose syrup/synthetic aroma in 228 UPFs, citric
231 acid/glucose syrup/synthetic aromas in 366 UPFs, caramels/phosphates in 316 UPFs, and
232 nitrites-nitrates/phosphates in 192 UPFs; 2) within the C2 group, there was no MUP co-
233 occurrence strongly characteristic of the group; 3) within both the C2 and C3 groups: refined
234 oils/phosphates in 448 UPFs, mono-diglycerides of fatty acid/glucose syrup in 229 UPFs,
235 dextrose/glucose syrup in 248 UPFs, lactose/dextrose in 249 UPFs, and natural aromas and
236 extracts/dextrose in 549 UPFs; and 4) within the C1 group: natural aromas and
237 extracts/refined oils in 540 UPFs, lecithins/refined oils in 260 UPFs, and lecithins/natural
238 aromas and extracts in 324 UPFs.

239

240

241 **4. Discussion**

242 The objective of this study was to describe the profiles of MUPs among a sample of
243 packaged UPFs, which corresponds to 69% of the initial sample of all foods ($n = 31,967$)

244 representative of supermarket assortments, subdivided into 10 categories. This value of 69%
245 is very close to the value of 67% previously reported by Siga classification on 24,932
246 packaged foods (Davidou et al., 2020). Both values are, however, lower than those reported in
247 New Zealand supermarkets (83% of 19,426 packaged products) using NOVA classification
248 (Luiten et al., 2016). In France, based on the Kantar Worldpanel database and NOVA
249 classification, sales in conventional and organic stores among 7,883 households were reported
250 to be at a level of 39% and 27% UPFs, respectively, but all foods were considered, including
251 fresh foods, rather than industrial packaged ones only (Desquilbet et al., 2018).

252 Concerning food categories, bakery products/pastries, ready-to-eat meals, salted products,
253 sweet products, and meats/egg-based products contain the highest levels of UPFs (> 70%).
254 These foods, and other UPF categories, are generally high in added fat, salt and/or sugars
255 (Cediel et al., 2018; Daniela Neri, 2018; FAO et al., 2019; Martínez Steele et al., 2016;
256 Rauber et al., 2019) and may result in the consumption of more calories than necessary.
257 Indeed, in 20 weight-stable adults, a 20% increase in calorie intake was observed with UPF
258 consumption over two weeks, mainly in the form of fat and carbohydrates (Hall et al., 2019).
259 Since minimally processed and ultra-processed diets were matched for presented calories,
260 energy density, macronutrients, sugar, sodium, and fibre, the increased consumption may be
261 mainly due to their hyperpalatable and artificialised matrices (Fardet and Rock, 2019).
262 Therefore, it is not surprising that UPFs have been consistently associated with increased risks
263 of overweight/obesity among adults and children (Canella et al., 2014; Canhada et al., 2019;
264 Eaton, 2020; Juul and Hemmingsson, 2015; Khandpur et al., 2020; Louzada et al., 2015;
265 Monteiro and Cannon, 2019; Nardocci et al., 2019; Rauber et al., 2020), children being
266 particularly targeted by advertising for sweet UPFs (including beverages) (Allemandi et al.,
267 2017; Fagerberg et al., 2019; Mallarino et al., 2013).

268 The median number of total MUPs in the UPF C3 category was 9, with equal median
269 numbers of A-MUPs ($n = 4$) and NA-MUPs ($n = 4$), and C3 includes 28.2% of all UPFs and
270 19.5% of all packaged foods in supermarkets, *i.e.*, *one* out of five. Therefore, knowing that
271 daily UPF consumption in France has been evaluated to be at least 18.4% daily by weight and
272 35.9% daily by calories (Julia et al., 2018), this suggests that French people may potentially
273 consume quite high levels of MUPs daily if we cluster all UPFs from C01 to C3, at least with
274 a median number of 4 MUPs/UPF. Therefore, although combinations are infinite, more
275 research is probably needed to explore the potential health risk of long-term cocktail effects
276 linked to MUPs, not only additives (without counting chemical residues and natural toxicants)
277 (Shaw, 2014).

278 The results also showed that the most representative MUPs (present in $\geq 10\%$ of all
279 UPFs) were refined oils, extracts/natural aromas, synthetic aromas, glucose syrup, native
280 starches, citric acid, dextrose, lecithin, phosphates modified starches, nitrites/nitrates, and
281 protein isolates, which is in agreement with our previous results (Davidou et al., 2020).
282 Refined oil and aroma (both extract/natural and synthetic) are extensively used in UPFs, being
283 present in more than 25% UPFs. For aroma, this can be explained by their very low prices
284 compared to less processed ingredients, *e.g.*, natural fruits, allowing UPFs to be provided at a
285 very low cost for the consumer (Gupta et al., 2019). The high use of glucose syrup (20% of
286 UPFs) is also of concern because this is a hidden sugar with a high glycaemic index (*i.e.*,
287 approximately 100) that may substantially increase the consumption of added sugars within a
288 day. The WHO recommends not exceeding 10% of free sugars daily from fruit juices, added
289 sugars and honey (WHO, 2017). Therefore, glucose syrup (together with added fructose
290 present in 2.1% of UPFs, result not shown) may potentially and significantly increase this
291 percentage daily, potentially contributing to the obesogenic potential of UPFs (Askari et al.,
292 2020). In addition, the frequencies of additives in our study were compared with those

293 obtained in 126,556 foods collected from the collaborative Open Food Facts database
294 (<https://fr.openfoodfacts.org/>), in which citric acid (14.5%) and lecithin (10.4%) were the
295 most frequently used additives (Chazelas et al., 2020).

296 Beyond total MUPs, MUPs were also clustered as NA-MUPs and A-MUPs. The main
297 results showed a higher use of NA-MUPs than A-MUPs in UPFs, and no significant
298 correlation between NA-MUPs/UPF and A-MUPs/UPF ratios among the 10 categories. This
299 result is relevant because this means that organic food products do not escape ultra-
300 processing, despite the reduction in use of additives (e.g., 48 in France), allowing for a rate of
301 UPFs of approximately 27% among all foods in organic stores (Desquilbet et al., 2018).
302 Therefore, because of NA-MUPs, decreasing the use of additives in organic foods is not
303 sufficient to make the product healthier. This indicates the need to regulate NA-MUPs in
304 organic foods to limit UPFs, not only additives. Otherwise, some modified starches are NA-
305 MUPs, and are not identified as additives contrary to other chemically modified starch. These
306 NA-MUP modified starches are starches fluidised by hydrolysis and heat treatment, which
307 can be used in confectionery, pastry creams, etc. (or bleached). This would support the fact
308 that the regulations should be reviewed with regard to uses or to legislate on the definition of
309 a UPF based on MUPs, and to propose an on-pack indicator for consumers.

310 NA-MUPs are therefore still more characteristic of UPFs than A-MUPs, and unlike
311 additives, they supply calories, either in the form of added sugar with a high glycaemic index
312 (i.e., invert sugar, dextrose (16.2% UPFs), maltodextrins and dextrans (4.5%), glucose syrup
313 (20% UPFs), fructose (2.1% UPFs) and/or lactose (7.2% UPFs)), refined oils of generally
314 lower nutritional quality than corresponding virgin oils (ANSES, 2017; U.S. Department of
315 Agriculture, 2005), or protein isolates (10% of UPFs in this study and 3.5% for protein
316 hydrolysates, result not shown). In addition, there are insufficient data on the health effects of
317 protein-based MUPs when consumed for a long time in high amounts, e.g., pea/soybean

318 protein isolates and gluten. Finally, concerning the addition of isolated fibre (4.9% of UPFs)
319 that allows artificial improvement of food compositional scores, they are different from
320 natural fibre in foods and of lower quality, notably with respect to fibre co-passengers, such as
321 antioxidants associated with fibre in minimally processed food matrices (Vitaglione et al.,
322 2008), and with respect to their inferior physico-chemical properties reported in rats (Monro
323 et al., 2016). Similar to protein-based MUPs, the long-term physiological effects of fibre-
324 based MUPs remain unexplored.

325 Concerning the rules for categorizing UPFs into C1–C3 groups (decision tree
326 analysis), synthetic aromas are the most discriminant MUPs; among the strongest co-
327 occurrences of MUPs within C1-C3 UPF groups, we notably found dextrose, glucose syrup
328 and synthetic aromas, dextrose and synthetic aromas, dextrose and glucose syrup, citric acid
329 and glucose syrup, phosphates and synthetic aromas, native starches and synthetic aromas,
330 lecithins and refined oils, caramels and phosphates, and natural aromas and extracts co-
331 occurring in at least 2% of UPFs. We suppose that such associations within UPFs have a
332 technological meaning—although currently unknown for us—and may be characteristic of
333 specific food categories. Nevertheless, these results clearly show that the association of
334 dextrose with glucose syrup and synthetic aromas is frequently used in very highly processed
335 foods, i.e., C3 UPFs. In contrast, the concomitant use of lecithins with refined oils appears to
336 be more characteristic of the UPF C1 group. In the end, NA-MUP co-occurrences are largely
337 more discriminating for UPF sub-groups than A-MUP co-occurrences, again emphasising the
338 importance of these NA-MUP ingredients in the definition of UPFs. In the end, such analyses
339 may also help detect strong additive co-occurrences, and that may be potentially associated
340 with an unknown cocktail effect (Shaw, 2014).

341

342 **5. Conclusions and perspectives**

343 There are more NA-MUPs than A-MUPs in UPFs, and additives are therefore not a sufficient
344 indicator of ultra-processing. In addition to NA-MUPs and A-MUPs, MUPs may also be
345 drastic processes directly apply on raw food matrices, e.g., puffing or extrusion-cooking
346 (Davidou et al., 2020; Monteiro et al., 2019). These MUPs were not considered in this study
347 because technological processes are not indicated on packaging. Therefore, characterising the
348 health potential of foods with reductionist compositional food scores (e.g., Traffic Light
349 (Machín et al., 2018), Health Star rating (Moore et al., 2019), Nutri-score (Egnell et al., 2018)
350 and other nutritional warnings worldwide) is clearly insufficient for allowing an informed
351 choice for the consumer confronted with industrial packaged foods. Indeed, by definition,
352 compositional scores based on a few nutrients “to limit” or “to encourage” obviously fail to
353 distinguish NA-MUPs and A-MUPs, and they score numerous UPFs containing many MUPs
354 as “high/good”. For example, in Australia, the Health Star Rating System was compared to
355 NOVA, from which the Siga classification is derived, and it was shown that this system
356 resulted “*in 3 out of 4 instances of these UPF displaying at least 2.5 so-called health stars*”
357 (Dickie et al., 2018). Other Australian researchers added that “*the Health Star Rating System*
358 *frequently is inadvertently contradicting Australian Dietary Guidelines (ADG)*
359 *recommendations, and promoting the marketing of discretionary and UPFs*” (Lawrence et al.,
360 2019).

361 As perspectives, this study emphasises the need for manufacturers to replace MUPs by
362 real and minimally-processed food ingredients, generally associated with a higher nutritional
363 density in fibre and micronutrients. For example, citric acid may be replaced by citrus juice,
364 soya protein isolate by whole soybean, etc., notably to preserve the crucial “matrix” effect.
365 Indeed, this study clearly showed that the use of one MUP generally leads to the use of
366 another MUP – and so on – to correct the deleterious effect of the first MUP on organoleptic
367 properties of the food, like in a vicious circle. Therefore, ultra-processing (the cause)

368 inevitably leads to ultra-formulation (the effect), both being clearly linked, as shown in this
369 study.

370 In addition, the results obtained in this study on MUP profiles of UPFs, combined with
371 results obtained regarding UPFs and health risks (FAO et al., 2019), should also prompt
372 public health policies to take the issue of UPFs into greater consideration, to propose food
373 scoring with scores based on the degree of processing such as NOVA (Moubarac et al., 2014)
374 and/or Siga (Davidou et al., 2020), and also to prompt super- and hypermarkets to rearrange
375 food offers according to the degree of processing. This would be faster and more efficient
376 than reviewing food additive legislation.

377

378

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381

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385

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387 **CRedit authorship contribution statement**

388 **Sylvie Davidou:** Conceptualization, Methodology, Investigation, Validation, Formal
389 analysis, Writing – review. **Aris Christodoulou:** Conceptualization, Methodology, Data
390 formatting, Validation. **Kelly Frank:** Conceptualization, Formal analysis, Validation.
391 **Anthony Fardet:** Conceptualization, Methodology, Investigation, Validation, Formal
392 analysis, Writing – review.

393

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549 Captions to figures

550 **Fig. 1** The Siga[®] food classification involving ten technological groups (including minimally
551 processed culinary ingredients, e.g., table sugar, virgin oils, salt, spices).

552
553 **Fig. 2** Median numbers of total MUPs, additives (A-MUP), non-additive MUPs (NA-MUP),
554 risk-associated additives, MUP1s and MUP2s for the five different UPF groups ($n = 22,028$
555 UPF products). Foods classified as UPFs because they contained non-MUP “risk-associated
556 additives” were included. Median numbers are indicated above the bars, and the percentages
557 of foods in each Siga UPF group (C01 to C3) are indicated above the horizontal parentheses.

558
559 **Fig. 3** Number of UPFs according to number of MUPs, Siga database ($n = 21,989$ products).
560 Thirty-nine UPFs were removed because they contained non-MUP “risk-associated additives”
561 (see *Materials and Methods*).

562
563 **Fig. 4** The percentages of UPFs by food category.

564
565 **Fig. 5** Spearman’s correlation coefficient between (a) A-MUP/UPF and NA-MUP/UPF ratios
566 among the 10 food categories, and (b) between total A-MUPs and total NA-MUPs among the
567 10 food categories.

568
569 **Fig. 6** Plot of the CHAID decision tree algorithm for C1 (blue) versus C2 (orange) versus C3
570 (green) UPF groups: < 0.5 indicates absence of the MUP, and ≥ 0.5 indicates presence of the
571 MUP

Figure 1

	Definition	Degree of processing	Substance assessed at risk	Nutritional thresholds
Unprocessed foods				
A0	No process except cutting or peeling	No MUP ✓	No at risk substances ✓	Not taken into account
Minimally processed (including culinary ingredients)	Physical and/or thermal treatment without purification or denaturation			
Nutritionally balanced processed foods				
B1	Adding culinary ingredients (A2) to a preparation	No MUP ✓	No at risk substances ✓	Low
High salt, sugar and/or fat level processed foods				High
B2				
Nutritionally balanced ultra-processed foods level 0				
C01	Ultra-processed foods with only one MUP1	Only one MUP1	No at risk substances ✓	Low
High salt, sugar and/or fat level ultra-processed foods level 0				High
C02				
Ultra-processed foods level 1				
C1	Ultra-processed foods with multiple MUP1	Limitation of the number of MUP1	Possible presence of substances evaluated at risk	Not taken into account
Ultra-processed foods level 2				
C2	Ultra-processed foods which may present several MUP1 and/or MUP2 and/or additives evaluated at risk	Presence of MUP1 Possible presence of MUP2		
Ultra-processed foods level 3				
C3				

Figure 2

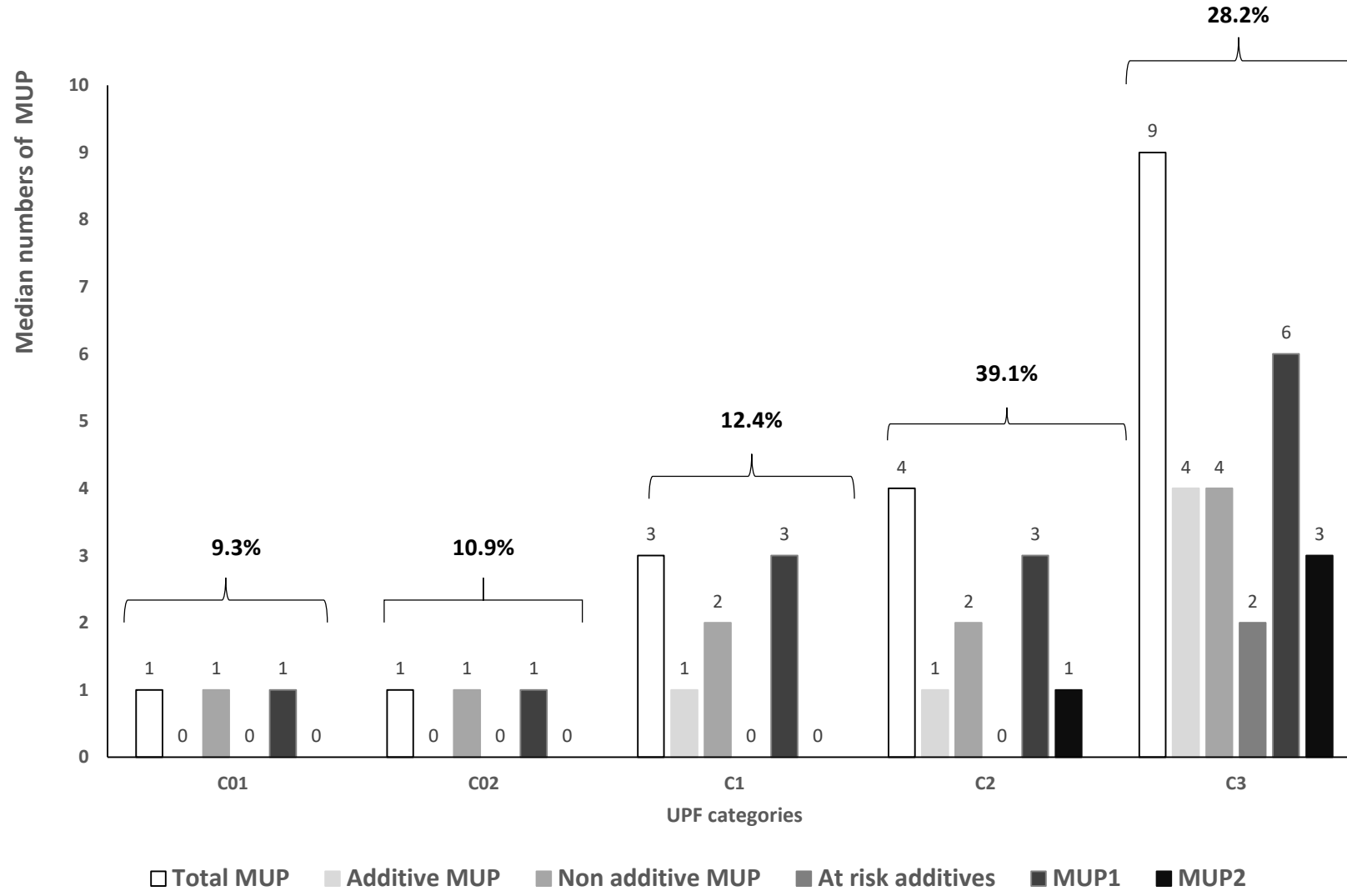


Figure 3

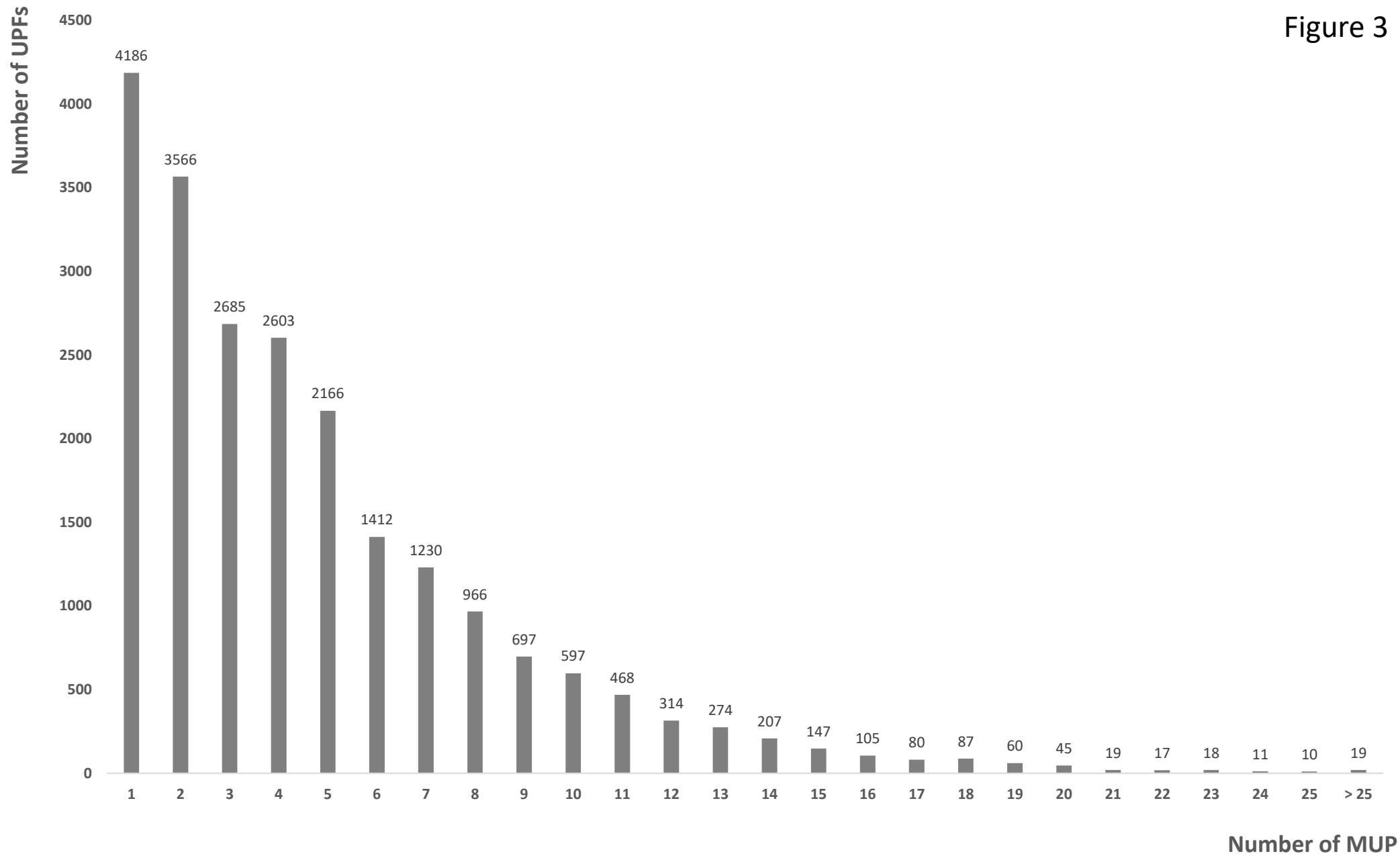


Figure 4

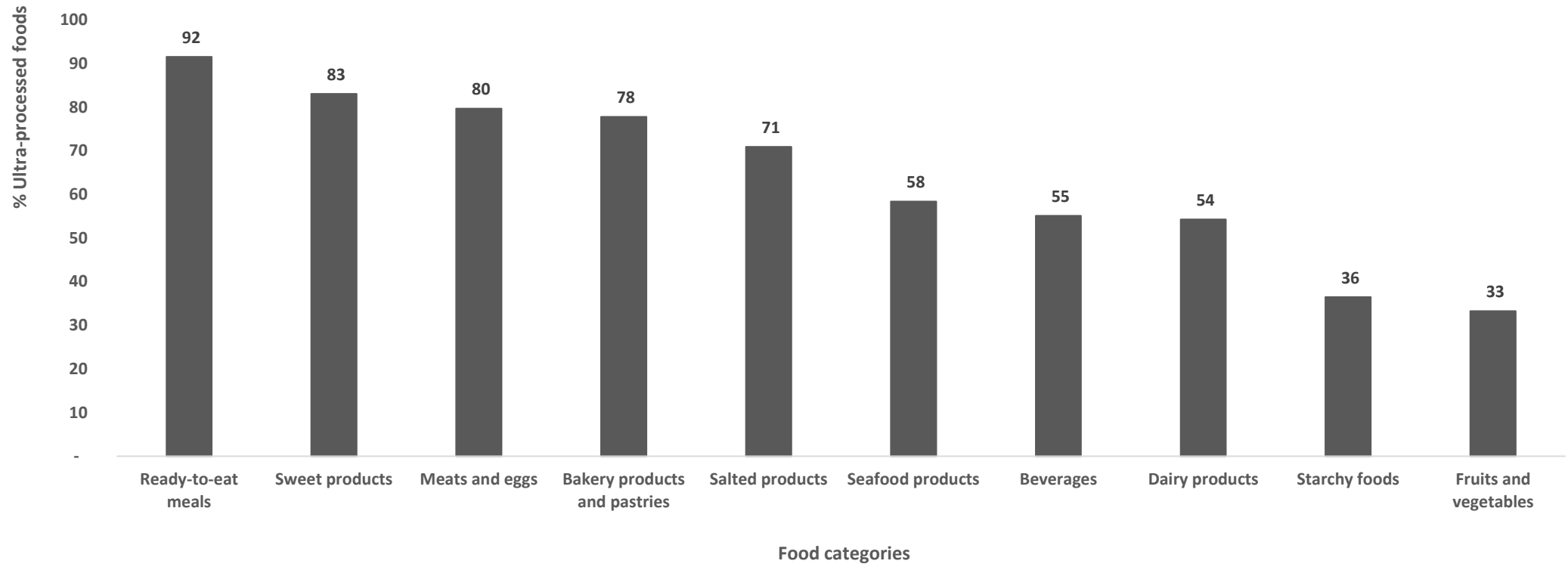
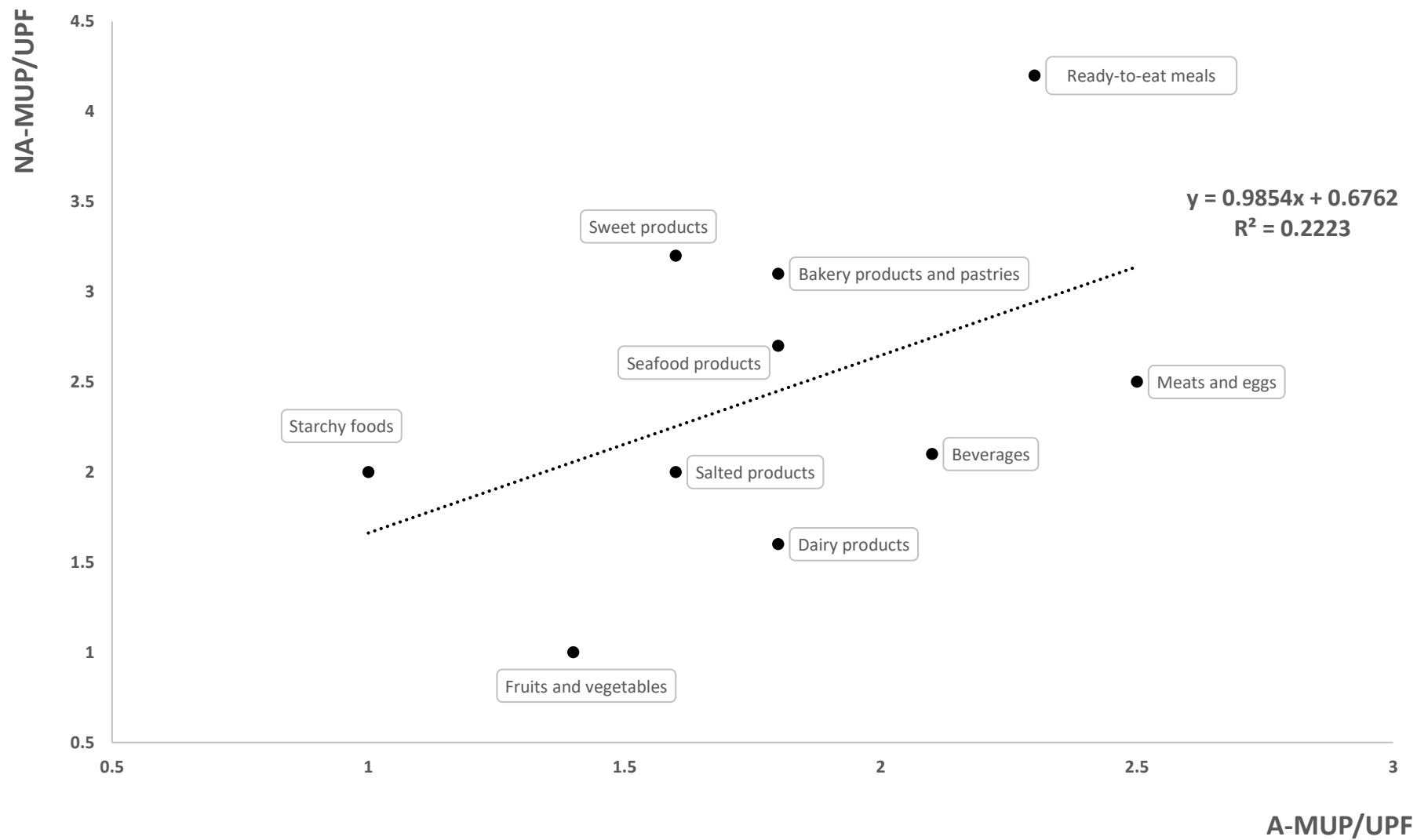
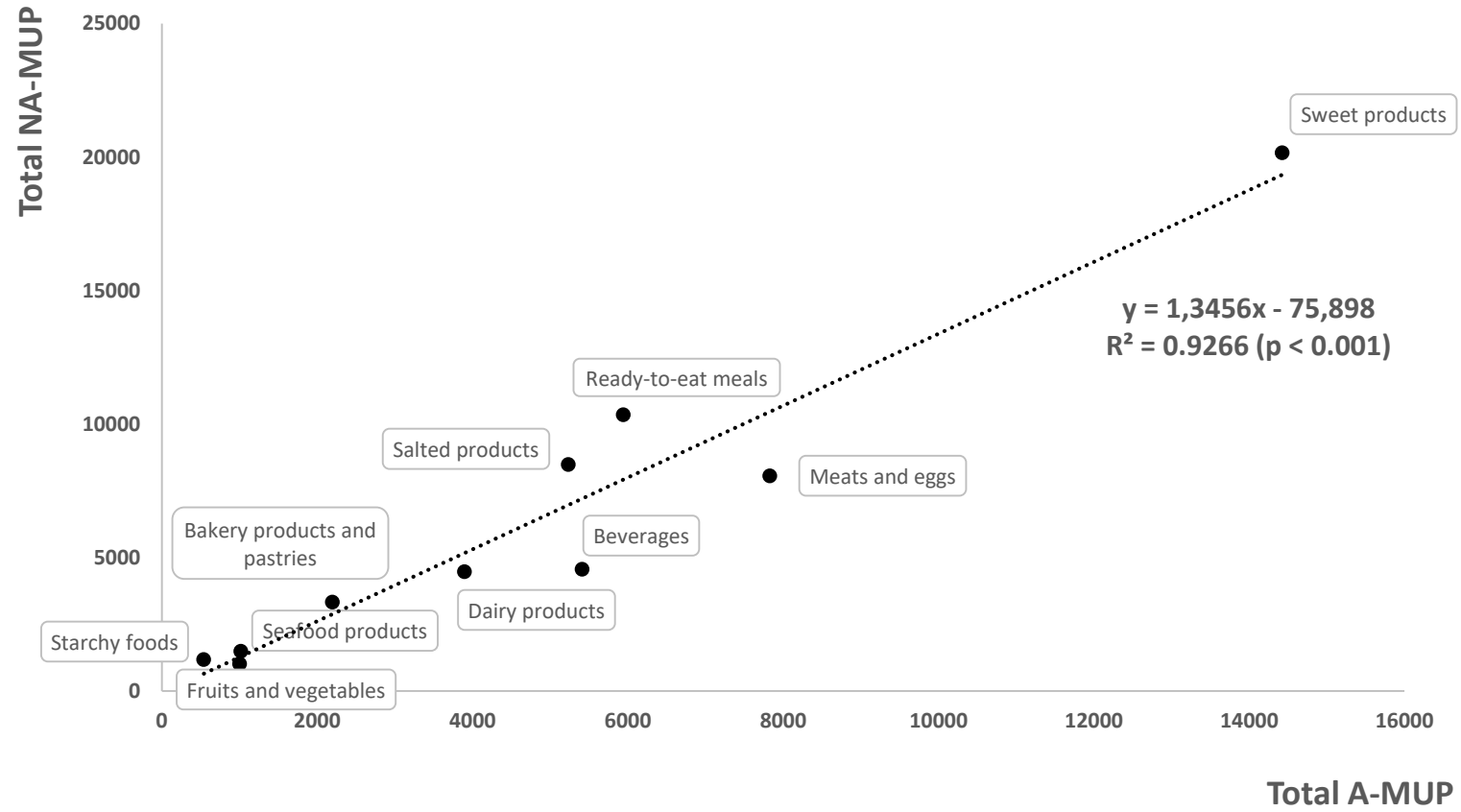


Figure 5

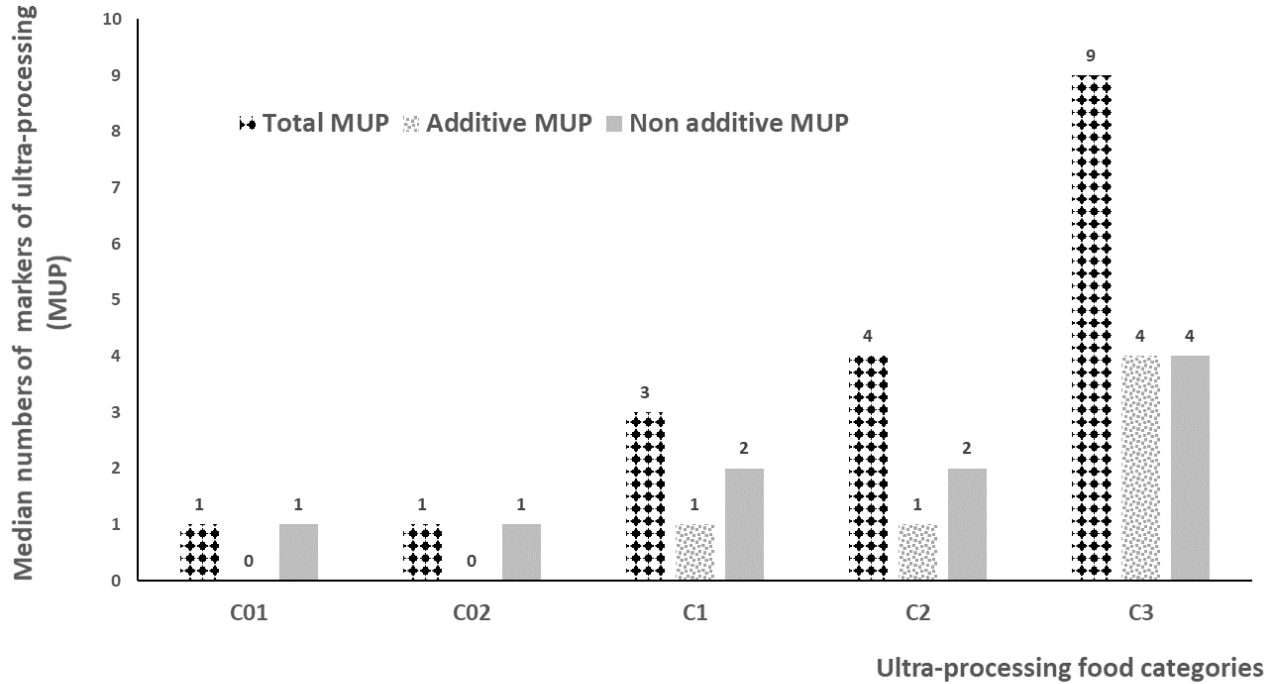
(a)



(b)



N = 22,028 ultra-processed foods



C1 C2 C3

