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

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Abbreviations

MUP, marker of ultra-processing

A-MUP, additives MUP

FSA, Food Standard Agency

NA-MUP, non-additive ingredients MUP

UPF, ultra-processed food

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

Abstract

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

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

1. Introduction

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

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

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

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

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

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

2. Materials and Methods

2.1 Food selection and data collection

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

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

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

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

2.2 Siga classification

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

- MUP1: obtained by chemical synthesis and is identical to natural substances, by successive processes leading to purification, or by successive processes leading to the high deterioration of the ingredient matrix, such as isolated protein, starches, natural flavouring, and yeast extract.
- MUP2: obtained by artificial chemical synthesis or by successive processes leading to the combined purification and substantial deterioration of the matrix, as is the case for glucose syrup, dextrose, hydrolysed proteins, carboxymethylcellulose, etc.

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

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

2.3 Statistical and machine learning analyses

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

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

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

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

3. Results

3.1 Numbers of MUPs in the different Siga UPF groups

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

3.2 Number of foods according to number of MUPs

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

3.3 Main MUPs among packaged ultra-processed foods

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

3.4 UPF percentages and MUP profiles by food category

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

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

3.5 Decision tree analysis

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

4. Discussion

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

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

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

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

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

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

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

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

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

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

5. Conclusions and perspectives

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

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

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

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

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CRediT authorship contribution statement

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

References

- Allemandi, L., Castronuovo, L., Tiscornia, M.V., Ponce, M., Schoj, V., 2017. Food advertising on Argentinean television: are ultra-processed foods in the lead? Public Health Nutr. 21, 238-246.
- Alonso-Pedrero, L., Ojeda-Rodríguez, A., Martínez-González, M.A., Zalba, G., Bestrolo, M., Martí, A., 2020. Ultra-processed food consumption and the risk of short telomeres in an elderly population of the Seguimiento Universidad de Navarra (SUN) Project. The Am. J. Clin. Nutr. 111, 1259-1266
- Askari, M., Heshmati, J., Shahinfar, H., Tripathi, N., Daneshzad, E., 2020. Ultra-processed food and the risk of overweight and obesity: a systematic review and meta-analysis of observational studies. Int. J. Obes. 44, 2080-2091.
- ANSES, Centre d'information sur la qualité des aliments, 2017. Table CIQUAL. Composition nutritionnelle des aliments. Retrieved July 30, 2020 from the Ciqua database home Page: <http://www.afssa.fr/TableCIQUAL/>.
- Canella, D.S., Levy, R.B., Martins, A.P.B., Claro, R.M., Moubarac, J.C., Baraldi, L.G., Cannon, G., Monteiro, C.A., 2014. Ultra-Processed food products and obesity in Brazilian households (2008-2009). Plos One 9, e92752.
- Canhada, S., Luft, V.C., Giatti, L., Duncan, B.B., Chor, D., Fonseca, M.J.M., Matos, al., e., 2020. Ultra-processed foods, incident overweight and obesity, and longitudinal changes in weight and waist circumference: The Brazilian Longitudinal Study of Adult Health (ELSA-Brasil). Public Health Nutr. 23, 1076-1086

416 Cediël, G., Reyes, M., da Costa Louzada, M.L., Martinez Steele, E., Monteiro, C.A.,
 417 Corvalán, C., Uauy, R., 2018. Ultra-processed foods and added sugars in the Chilean
 418 diet (2010). *Public Health Nutr.* 21, 125-133.

419 Chazelas, E., Deschasaux, M., Srouf, B., Kesse-Guyot, E., Julia, C., Alles, B., Druesne-
 420 Pecollo, N., Galan, P., Hercberg, S., Latino-Martel, P., Esseddik, Y., Szabo, F.,
 421 Slamich, P., Gigandet, S., Touvier, M., 2020. Food additives: distribution and co-
 422 occurrence in 126,000 food products of the French market. *Sci. Rep.* 10, 3980.

423 Daniela Neri, E.M.-S., Carlos Augusto Monteiro, Renata Bertazzi Levy, 2019. Consumption
 424 of ultra-processed foods and its association with added sugar content in the diets of US
 425 children, NHANES 2009–2014. *Ped. Obes.* 14, e12563.

426 Davidou, S., Christodoulou, A., Fardet, A., Frank, K., 2020. The holistico-reductionist Siga
 427 classification according to degree of food processing: An evaluation of ultra-processed
 428 foods in French supermarkets. *Food Func.* 11, 2026-2039.

429 Desquilbet, M., Maigné, E., Monier-Dilhan, S., 2018. Organic food retailing and the
 430 conventionalisation debate. *Ecol. Econ.* 150, 194-203.

431 Dickie, S., Woods, J.L., Lawrence, M., 2018. Analysing the use of the Australian Health Star
 432 Rating system by level of food processing. *Int J Behav Nutr Phys Act.* 15, 128.

433 Eaton, J., 2020. Pillars of the nutrition transition: The global impacts of ultra-processed foods
 434 and beverages on overweight and obesity and national nutrient supplies. The Graduate
 435 School of Washington University, St. Louis, Missouri. PhD thesis.

436 Edalati, S., Bagherzadeh, F., Asghari Jafarabadi, M., Ebrahimi-Mamaghani, M., 2020. Higher
 437 ultra-processed food intake is associated with higher DNA damage in healthy
 438 adolescents. *Brit. J. Nutr.* DOI: 10.1017/S0007114520001981.

439 Egnell, M., Ducrot, P., Touvier, M., Allès, B., Hercberg, S., Kesse-Guyot, E., Julia, C., 2018.
 440 Objective understanding of Nutri-Score Front-Of-Package nutrition label according to

individual characteristics of subjects: Comparisons with other format labels. Plos One
13, e0202095.

Fagerberg, P., Langlet, B., Oravsky, A., Sandborg, J., Löf, M., Ioakimidis, I., 2019. Ultra-processed food advertisements dominate the food advertising landscape in two Stockholm areas with low vs high socioeconomic status. Is it time for regulatory action? BMC Public Health 19, 1717.

FAO, Monteiro, C.A., Cannon, G., Lawrence, M., da Costa Louzada, M.L., Machado, P.P., 2019. Ultra-processed foods, diet quality, and health using the NOVA classification system, Rome, Italy.

Fardet, A., Boirie, Y., 2014. Associations between food and beverage groups and major diet-related chronic diseases: an exhaustive review of pooled/meta-analyses and systematic reviews. Nutr. Rev. 72, 741-762.

Fardet, A., Rock, E., 2019. Ultra-processed foods: a new holistic paradigm? Trends Food Sci. Technol. 93, 174-184.

Gupta, S., Hawk, T., Aggarwal, A., Drewnowski, A., 2019. Characterizing ultra-processed foods by energy density, nutrient density and cost. Front. Nutr. 28, 70.

Hall, K.D., Ayuketah, A., Brychta, R., Cai, H., Cassimatis, T., Chen, K.Y., Chung, S.T., Costa, E., Courville, A., Darcey, V., Fletcher, L.A., Forde, C.G., Gharib, A.M., Guo, J., Howard, R., Joseph, P.V., McGehee, S., Ouwerkerk, R., Raisinger, K., Rozga, I., Stagliano, M., Walter, M., Walter, P.J., Yang, S., Zhou, M., 2019. Ultra-processed diets cause excess calorie intake and weight gain: An inpatient randomized controlled trial of ad libitum food intake. Cell Metabol. 30, 67-77.e3.

Jiang, H., Tang, Y., Garg, H. K., Parthasarathy, D. K., Torregrossa, A. C., Hord, N. G., Bryan, N. S., 2012. Concentration- and stage-specific effects of nitrite on colon cancer cell lines. Nitric Oxide. 26, 267-273.

466 Julia, C., Martinez, L., Alles, B., Touvier, M., Hercberg, S., Mejean, C., Kesse-Guyot, E.,
 467 2018. Contribution of ultra-processed foods in the diet of adults from the French
 468 NutriNet-Sante study. *Public Health Nutr.* 21, 27-37.

469 Juul, F., Hemmingsson, E., 2015. Trends in consumption of ultra-processed foods and obesity
 470 in Sweden between 1960 and 2010. *Public Health Nutr.* 18, 3096-3107.

471 Khandpur, N., Neri, D.A., Monteiro, C., Mazur, A., Frelut, M.L., Boyland, E., Weghuber, D.,
 472 Thivel, D., 2020. Ultra-processed food consumption among the paediatric population:
 473 An overview and call to action from the European Childhood Obesity Group. *Ann.*
 474 *Nutr. Metabol.* 76, 109-113.

475 Lane, M.M., Davis, J.A., Beattie, S., Gómez-Donoso, C., Loughman, A., O'Neil, A., Jacka, F.,
 476 Berk, M., Page, R., Marx, W., Rocks, T., 2020. Ultraprocessed food and chronic
 477 noncommunicable diseases: A systematic review and meta-analysis of 43 observational
 478 studies. *Obes. Rev.*, <https://doi.org/10.1111/obr.13146>.

479 Lawrence, M.A., Pollard, C.M., Vidgen, H.A., Woods, J.L., 2019. The Health Star Rating
 480 system - is its reductionist (nutrient) approach a benefit or risk for tackling dietary risk
 481 factors? *Public Health Res. Pract.* 9, 2911906.

482 Louzada, M.L., Baraldi, L.G., Steele, E.M., Martins, A.P., Canella, D.S., Moubarac, J.C.,
 483 Levy, R.B., Cannon, G., Afshin, A., Imamura, F., Mozaffarian, D., Monteiro, C.A.,
 484 2015. Consumption of ultra-processed foods and obesity in Brazilian adolescents and
 485 adults. *Prev. Med.* 81, 9-15.

486 Luiten, C.M., Steenhuis, I.H., Eyles, H., Ni Mhurchu, C., Waterlander, W.E., 2016. Ultra-
 487 processed foods have the worst nutrient profile, yet they are the most available
 488 packaged products in a sample of New Zealand supermarkets. *Public Health Nutr.* 19,
 489 530-538.

490 Machín, L., Aschemann-Witzel, J., Curutchet, M.R., Giménez, A., Ares, G., 2018. Does front-
 491 of-pack nutrition information improve consumer ability to make healthful choices?
 492 Performance of warnings and the traffic light system in a simulated shopping
 493 experiment. *Appetite* 121(Suppl. C), 55-62.

494 Mallarino, C., Gomez, L.F., Gonzalez-Zapata, L., Cadena, Y., Parra, D.C., 2013. Advertising
 495 of ultra-processed foods and beverages: children as a vulnerable population. *Rev. Saude*
 496 *Publica* 47, 1006-1010.

497 Martínez Steele, E., Baraldi, L.G., Louzada, M.L.d.C., Moubarac, J.-C., Mozaffarian, D.,
 498 Monteiro, C.A., 2016. Ultra-processed foods and added sugars in the US diet: evidence
 499 from a nationally representative cross-sectional study. *BMJ Open* 6, e009892.

500 Monro, J., Mishra, S., Redman, C., Somerfield, S., Ng, J., 2016. Vegetable dietary fibres
 501 made with minimal processing improve health-related faecal parameters in a valid rat
 502 model. *Food Funct.* 7(6), 2645-2654.

503 Monteiro, C., Cannon, G., (2019). The role of the transnational ultra-processed food industry
 504 in the pandemic of obesity and its associated diseases: problems and solutions. *World*
 505 *Nutr.* 10, 89-99.

506 Monteiro, C.A., (2009). Nutrition and health. The issue is not food, nor nutrients, so much as
 507 processing. *Public Health Nutr.* 12, 729-731.

508 Monteiro, C.A., Cannon, G., Levy, R.B., Moubarac, J.-C., Louzada, M.L.C., Rauber, F.,
 509 Khandpur, N., Cediel, G., Neri, D., Martinez-Steele, E., Baraldi, L.G., Jaime, P.C.,
 510 2019. Ultra-processed foods: what they are and how to identify them? *Public Health*
 511 *Nutr.* 22, 936-941.

512 Moore, M., Jones, A., Pollard, C.M., Yeatman, H., 2019. Development of Australia's front-of-
 513 pack interpretative nutrition labelling Health Star Rating system: lessons for public
 514 health advocates. *Aust. N. Z. J. Public Health* 43, 352-354.

515 Moubarac, J.-C., Parra, D.C., Cannon, G., Monteiro, C.A., 2014. Food classification systems
516 based on food processing: Significance and implications for policies and actions: A
517 systematic literature review and assessment. *Curr. Obes. Rep.* 3, 256-272.

518 Nardocci, M., Leclerc, B.-S., Louzada, M.-L., Monteiro, C.A., Batal, M., Moubarac, J.-C.,
519 2019. Consumption of ultra-processed foods and obesity in Canada. *Can. J. Public*
520 *Health.* 110, 4-14

521 Pagliai, G., Dinu, M., Madarena, M.P., Bonaccio, M., Iacoviello, L., Sofi, F., 2020.
522 Consumption of ultra-processed foods and health status: a systematic review and meta-
523 analysis. *Brit. J. Nutr.* 125, 308-318.

524 Rauber, F., da Costa Louzada, M.L., Martinez Steele, E., de Rezende, L.F.M., Millett, C.,
525 Monteiro, C.A., Levy, R.B., (2019). Ultra-processed foods and excessive free sugar
526 intake in the UK: a nationally representative cross-sectional study. *BMJ Open* 9,
527 e027546.

528 Rauber, F., Steele, E.M., da Costa Louzada, M.L., Millett, C., Monteiro, C.A., Levy, R.B.,
529 2020. Ultra-processed food consumption and indicators of obesity in the United
530 Kingdom population (2008-2016). *Plos One* 15, e0232676.

531 Ritz, E., Hahn, K., Ketteler, M., Kuhlmann, M. K., Mann, J., 2012. Phosphate Additives in
532 Food-a Health Risk. *Dtsch. Arztebl. Int.* 109, 49-U29.

533 Satija, A., Bhupathiraju, S.N., Spiegelman, D., Chiuve, S.E., Manson, J.E., Willett, W.,
534 Rexrode, K.M., Rimm, E.B., Hu, F.B., 2017. Healthful and unhealthful plant-based
535 diets and the risk of coronary heart disease in U.S. Adults. *J. Am. Coll. Cardiol.* 70,
536 411-422.

537 Shaw, I.C., 2014. Chemical residues, food additives and natural toxicants in food the cocktail
538 effect. *Int. J. Food Sci. Technol.* 49, 2149-2157.

539 U.S. Department of Agriculture, Agricultural Research Service, Nutrient Data Laboratory,
540 2005. USDA National Nutrient Database FoodData Central. Retrieved July 30, 2020
541 from the USDA database home Page: <https://fdc.nal.usda.gov/>.

542 Vitaglione, P., Napolitano, A., Fogliano, V., 2008. Cereal dietary fibre: a natural functional
543 ingredient to deliver phenolic compounds into the gut. *Trends Food Sci. Technol.* 19,
544 451-463.

545 WHO, 2017. Incentives and disincentives for reducing sugar in manufactured foods. An
546 exploratory supply chain analysis. A set of insights for Member States in the context of
547 the WHO European Food and Nutrition Action Plan 2015–2020. WHO Regional office
548 for Europe. Copenhagen, Denmark.

Captions to figures

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

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

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

Fig. 4 The percentages of UPFs by food category.

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

Fig. 6 Plot of the CHAID decision tree algorithm for C1 (blue) versus C2 (orange) versus C3 (green) UPF groups: < 0.5 indicates absence of the MUP, and ≥ 0.5 indicates presence of the 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			
A1					Low High
Nutritionally balanced processed foods		Adding culinary ingredients (A2) to a preparation			
B1			Only one MUP1	No at risk substances 	Low High
High salt, sugar and/or fat level processed foods					
B2					
Nutritionally balanced ultra-processed foods level 0		Ultra-processed foods with only one MUP1			Low High
C01			Limitation of the number of MUP1		
High salt, sugar and/or fat level ultra-processed foods level 0			Not taken into account		
C02				Presence of MUP1 Possible presence of MUP2	Possible presence of substances evaluated at risk
Ultra-processed foods level 1		Ultra-processed foods with multiple MUP1	Not taken into account		
C1				Presence of MUP1 Possible presence of MUP2	Possible presence of substances evaluated at risk
Ultra-processed foods level 2		Ultra-processed foods which may present several MUP1 and/or MUP2 and/or additives evaluated at risk	Not taken into account		
C2				Presence of MUP1 Possible presence of MUP2	Possible presence of substances evaluated at risk
Ultra-processed foods level 3			Not taken into account		
C3					

Figure 2

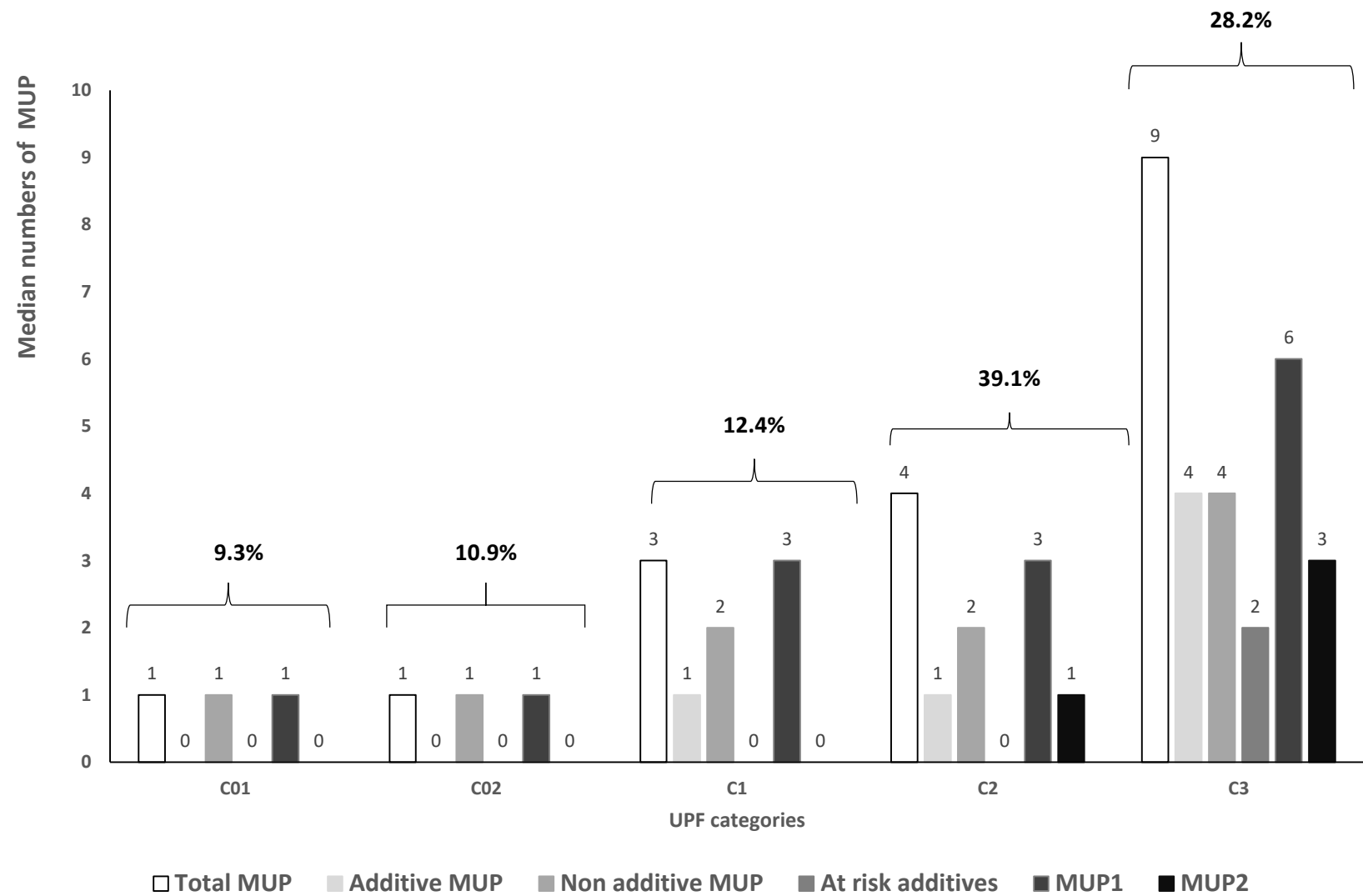


Figure 3

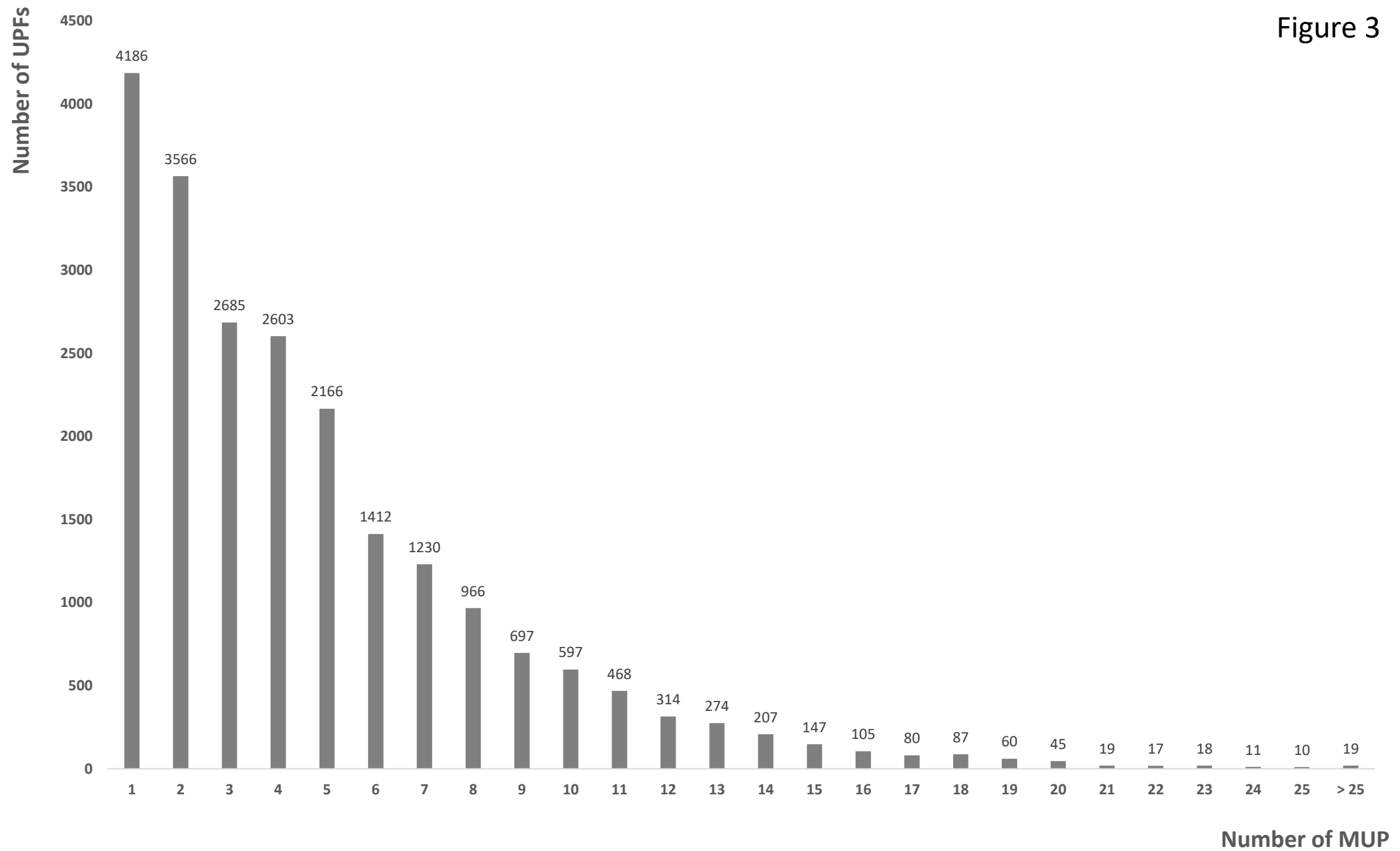


Figure 4

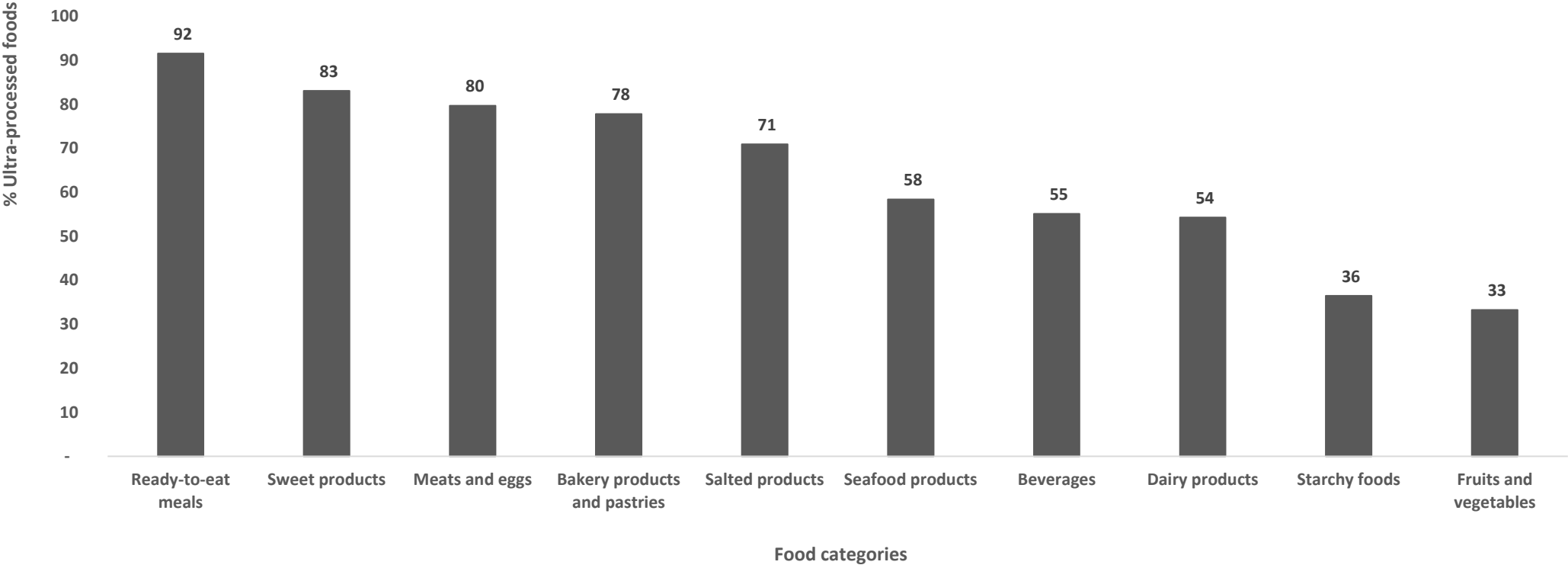
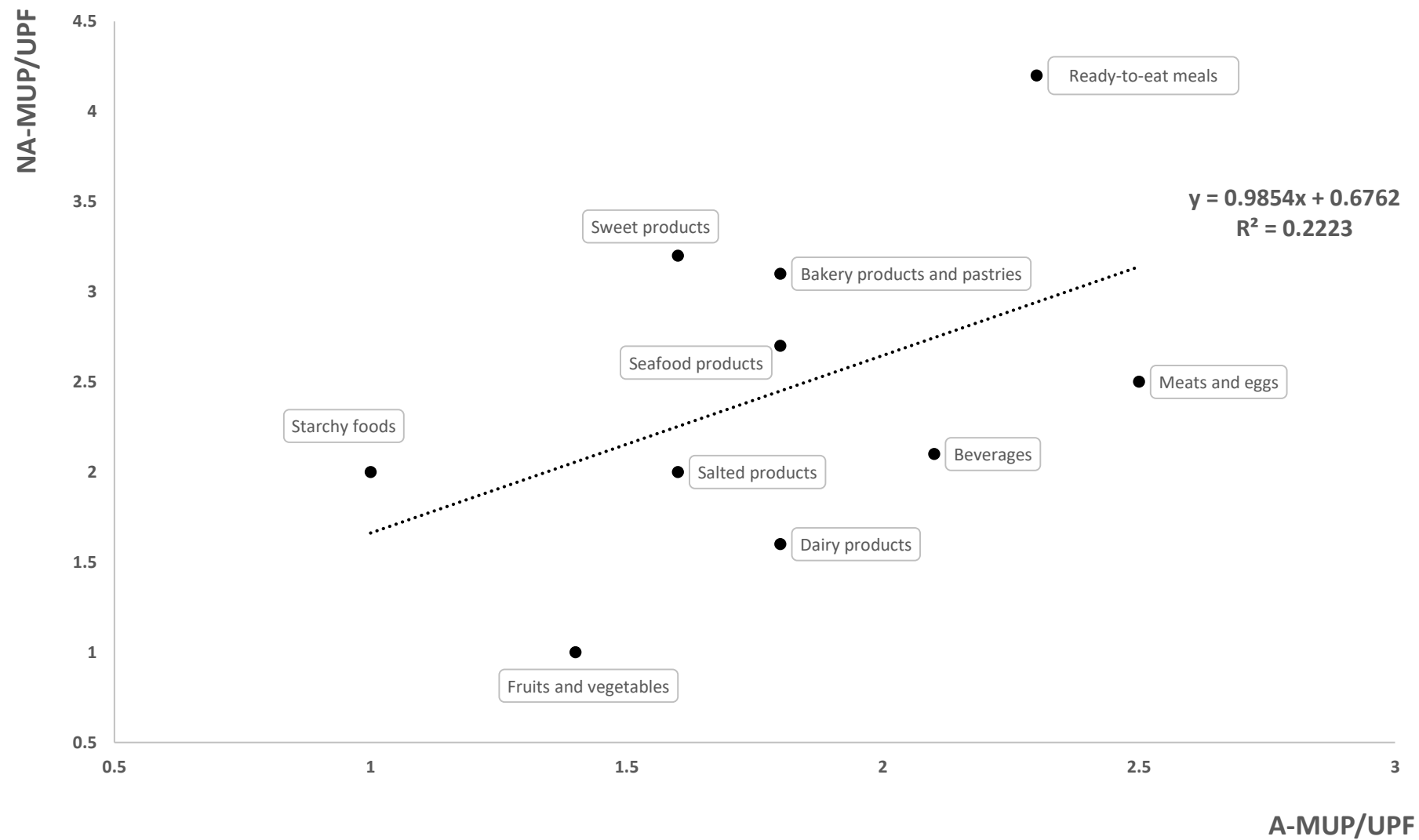


Figure 5

(a)



(b)

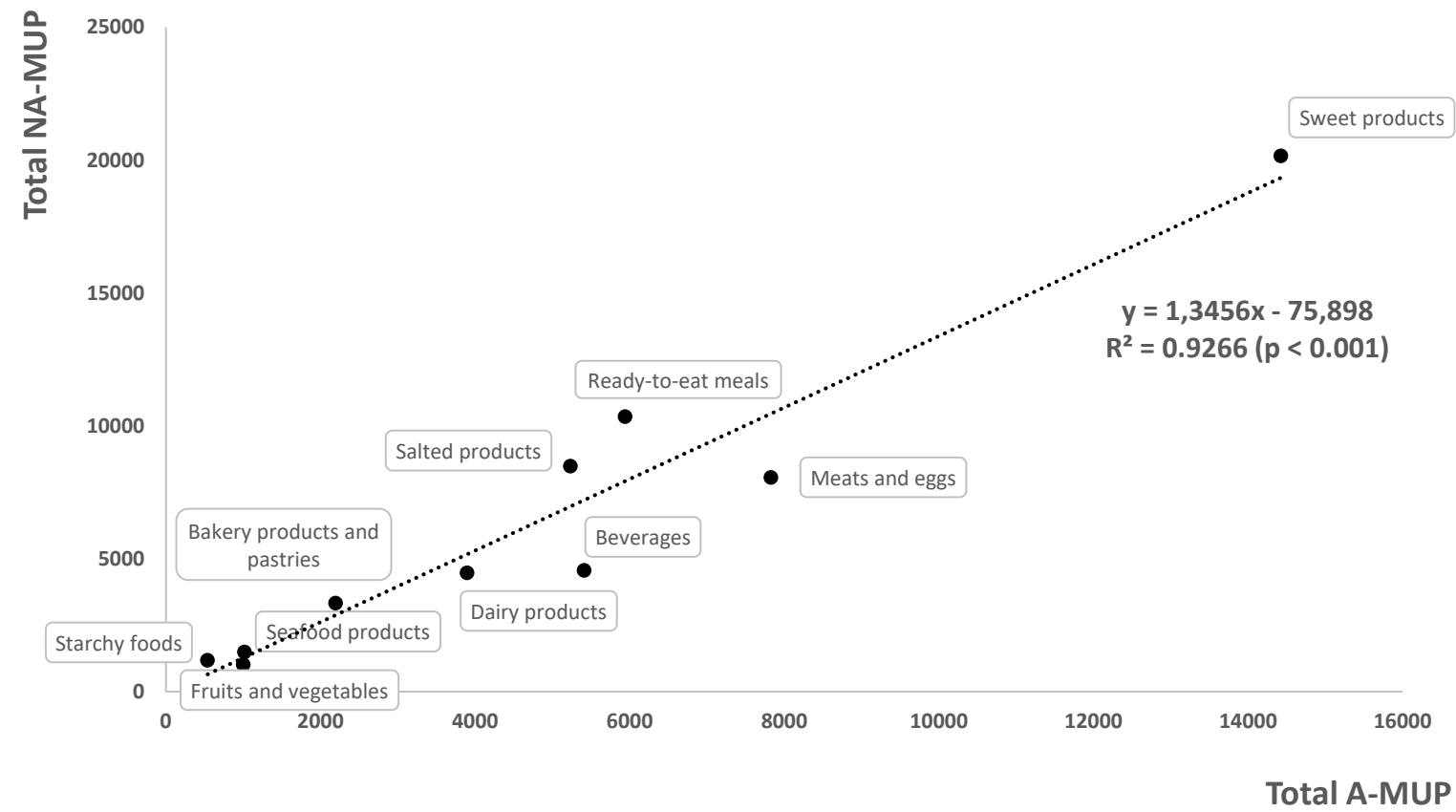
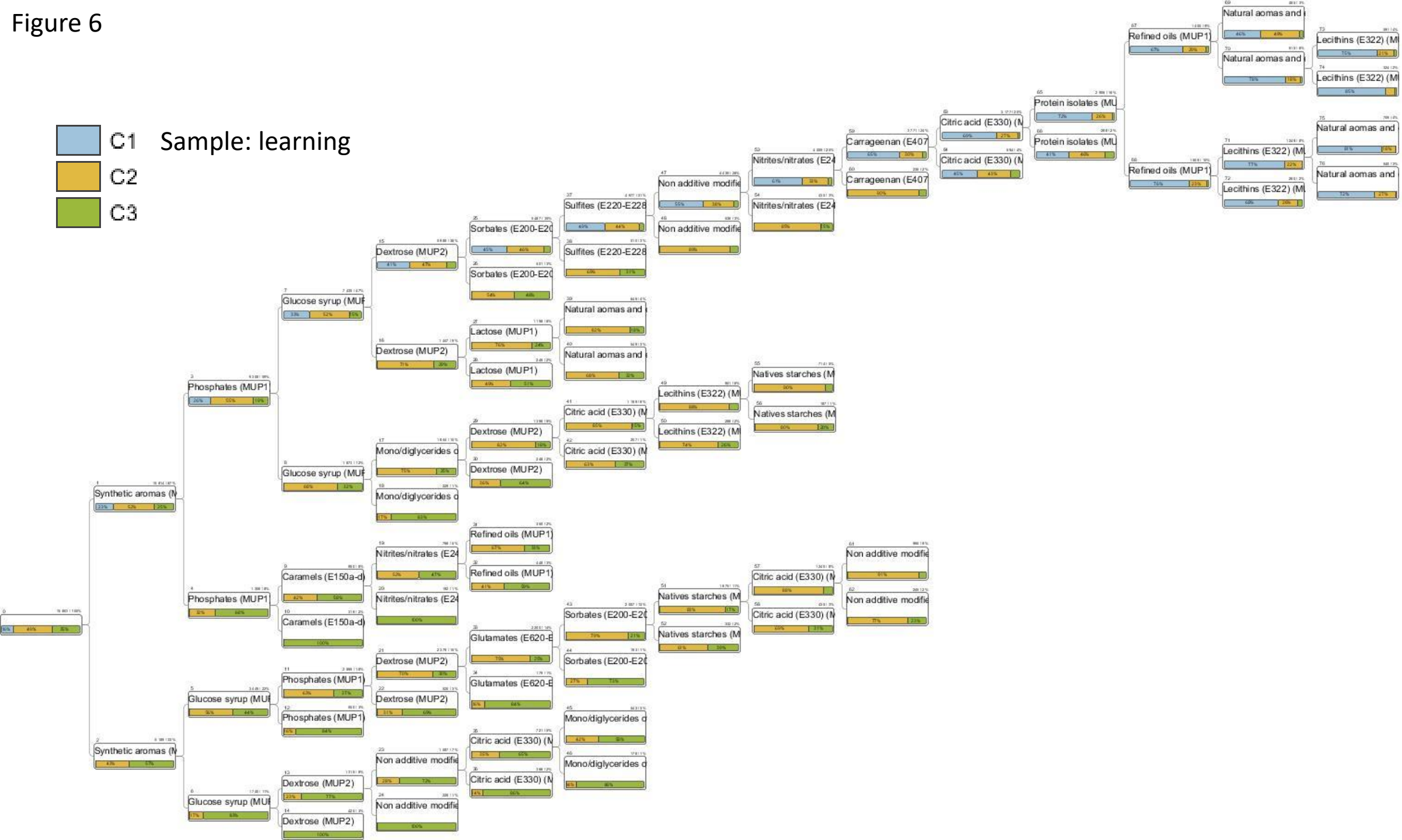


Figure 6

C1 Sample: learning
C2
C3



N = 22,028 ultra-processed foods

