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Estimated dietary pesticide exposure from plant-based foods using NMF-derived profiles in a large sample of French adults

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22 Short running head: Dietary pesticides exposure

23 Abbreviations:

24 ADI: Acceptable Daily Intake; ANSES: Agence Nationale de sécurité sanitaire de

25 l'alimentation, de l'environnement et du travail ; CNIL: Commission Nationale de

26 l'Informatique et des Libertés ; CVUA: Chemisches und Veterinäruntersuchungsamt;

27 EAT: Etude de l'Alimentation Totale; EDI: Estimated Daily Intake; EFSA: European Food

28 and Safety Authority; EudraCT: European Union Drug Regulating Authorities Clinical Trials;

29 FFQ: Food Frequency Questionnaire; IRB INSERM: Institutional Review Board of the

30 French Institute for Health and Medical Research; MESA: Multi-Ethnic Study of

31 Atherosclerosis; MUFA: Mono Unsaturated Fatty Acids; NMF: Non-negative Matrix

32 Factorization; PUFA: Poly Unsaturated Fatty Acids; SFA: Saturated Fatty Acids.

33 Clinical Trial Registry: NCT03335644

34

35 **Abstract:**

36 Purpose: This study, conducted in participants of the NutriNet-Santé cohort, aims to identify
37 dietary pesticide exposure profiles (derived from Non-negative Matrix Factorization) from
38 conventional and organic foods among a large sample of general population French adults.
39 Methods: Organic and conventional dietary intakes were assessed using a self-administered
40 semi-quantitative food frequency questionnaire. Exposure to 25 commonly used pesticides
41 was evaluated using food contamination data from Chemisches und
42 Veterinäruntersuchungsamt Stuttgart accounting for farming system (organic or
43 conventional). Dietary pesticide exposure profiles were identified using Non-Negative Matrix
44 factorization (NMF), especially adapted for non-negative data with excess zeros. The NMF
45 scores were introduced in a hierarchical clustering process.
46 Results: Overall, the identified clusters (n=34,193) seemed to be exposed to the same
47 compounds with gradual intensity. Cluster 1 displayed the lowest energy-intake and estimated
48 dietary pesticide exposure, high organic food (OF) consumption (23.3%) and a higher
49 proportion of male participants than other groups. Clusters 2 and 5 presented intermediate
50 energy intake, lower OF consumption and intermediate estimated pesticide exposure. Cluster
51 3 showed high conventional fruits and vegetable (FV) intake, high estimated pesticide
52 exposure, and fewer smokers. Cluster 4 estimated pesticide exposure varied more across
53 compounds than for other clusters, with highest estimated exposures for acetamiprid,
54 azadirachtin, cypermethrin, pyrethrins, spinosad. OF proportion in the diet was the highest
55 (31.5%).
56 Conclusion: Estimated dietary pesticide exposures appeared to vary across the clusters and to
57 be related to OF proportion in the diet.
58 **Keywords:** dietary exposure; pesticides; organic farming; epidemiology.

59 **Introduction:**

60 Plant protection products also referred hereafter as pesticides are used in large quantities in
61 current agriculture all over Europe [1]. France is one of the countries presenting the highest
62 use of pesticides in Europe, with between 60 000 and 80 000 tons sold in 2016 [2, 3] and the
63 fifth highest European country, in terms of average use of pesticides by surface area, in 2001-
64 2003 [4].

65 Current use of pesticides raises environmental and health concerns. On the environmental
66 side, pesticides can have detrimental effects on biodiversity, soil quality, and water quality
67 [5]. In toxicological studies, a wide range effects have been reported for pesticide active
68 substances and/or metabolites [6] such as alteration of genetic material, neurotransmission
69 interference, endocrine disrupting effects, deregulation of cellular apoptosis, and oxidative
70 stress induction, causing neurological, respiratory, dermatological, reproductive or
71 developmental disorders, and cancers [4, 7, 8]. Considering human health, several
72 epidemiological studies have found associations between occupational exposure to pesticides
73 in agricultural settings and diverse diseases including Parkinson disease [9], lymphomas and
74 Alzheimer's disease [4, 10]. However, the general population is also exposed to cocktail of
75 these compounds or their metabolites at very low doses, mainly through the dietary pathway
76 [11], and data on this type of exposure in the general population is lacking .

77 More than 400 active substances are currently authorized as plant protection products within
78 the European Union (EU) according to the EU Pesticides database [12], to which must be
79 added corresponding metabolites, and pesticide formulants., Thus, the assessment of the
80 dietary exposure to pesticide is complex and has a high financial burden because of the range
81 of food commodities to sample and test, in addition to the multiresidues analyses to carry out.
82 The French Agency for Food, Environmental and Occupational Health Safety (*Agence*
83 *Nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail*, ANSES)
84 has described dietary exposures, by merging contamination data and consumption levels, in

85 the general population in the Total Diet Studies (*Etude de l'Alimentation Totale*) published
86 for the periods 2000-2004 and 2006. From these data, exposures to some pesticides were
87 largely related to fruits and vegetables consumption [13, 14]. However, in this study, farming
88 system (i.e. conventional versus organic) to produce foods was not taken into account while
89 non-use of synthetic fertilizers and pesticides in organic farming leads to less (in frequency
90 and concentration) or absence of pesticides residues in organic foods compared to
91 conventional ones by regulation (less than 100 active substances compared to 400 in
92 conventional farming) [15, 16].

93 Given the increase in Europe of organic food consumption over the last years and the
94 differences between farming practices (synthetic pesticides and fertilizers use) used to
95 produce organic food versus “conventional” food, it is important to take this parameter into
96 account in order to discriminate more effectively human exposure profiles.

97 The purpose of this study was to identify dietary pesticide exposure profiles (derived from
98 Non-negative Matrix Factorization) from conventional and organic foods among a large
99 sample of the French web-based cohort NutriNet-Santé.

100

101 **Material and Methods:**

102 *Study population:*

103 NutriNet-Santé study is an on-going web-based prospective cohort of French adult volunteers
104 launched in May 2009 [17]. Participants completed at baseline a set of self-administered
105 questionnaires repeated every year, regarding socio-economic status, anthropometrics,
106 lifestyle, physical activity, and dietary intakes. This set of web-based questionnaires has been
107 validated against traditional methods [18–20]. Complementary questionnaires on dietary
108 behaviors, nutritional and health status were also proposed to participants during follow-up.
109 The NutriNet-Santé study is conducted in accordance with the Declaration of Helsinki, and all
110 procedures were approved by the Institutional Review Board of the French Institute for
111 Health and Medical Research (IRB Inserm 0000388FWA00005831) and the Commission
112 Nationale de l'Informatique et des Libertés (CNIL 908,450 and 909,216). All participants
113 provided their informed consent with an electronic signature, and this study is registered in
114 EudraCT (European Union Drug Regulating Authorities Clinical Trials; no. 2013-000929-31)
115 and in ClinicalTrials.gov (NCT03335644).

116 *Dietary intake assessment:*

117 Dietary intake of organic and conventional foods was assessed using a 264-item web-based
118 self-administered semi-quantitative organic food frequency questionnaire (Org-FFQ) between
119 June and December 2014. The Org-FFQ was constructed according to an existing validated
120 FFQ [21] to which a 5-point ordinal scale was added to measure the frequency of organic
121 food consumption. For each of the 264 questionnaire items, participants provided their
122 frequency of consumption and the quantity consumed for the previous year. For organic-
123 labelled food and beverages, participants were asked “How often was the product of organic
124 origin?” by selecting 1 of the 5 following frequency modalities: never, rarely, half-of-time,
125 often, or always. The organic food consumption parameter was then obtained by attributing
126 the respective percentages, 0, 25, 50, 75, and 100, to the modalities. Full details regarding the

127 Org-FFQ and sensitivity analyses as regards the weighting have been published elsewhere
128 [22].

129 All food and beverage items were aggregated into 16 food groups. Nutritional values were
130 obtained from a published food composition database [23]. The global proportion of organic
131 food in the diet was calculated by computing the ratio between the sum of all organic items
132 (in g/d) and the sum of all items (organic and conventional) excluding water (in g/d). The
133 proportion of organic food for each of the 16 food groups (organic food ratios) was calculated
134 using the same method.

135 *Dietary scores :*

136 PANDiet Score was initially developed by Verger et al.[24], and updated by De Gavelle et al.
137 2018 [25]. It measures the probability of adequate nutrient intake based on current nutrient
138 reference values. It is composed of two subscales, one referring to adequacy and the other to
139 moderation. The following nutrients were included in the score: protein, total carbohydrate,
140 total fat, added simple carbohydrates, saturated fatty acids, poly-unsaturated fatty acids, n-3
141 fatty acids, n-6 fatty acids, cholesterol, fiber, vitamins A, B1, B2, B3, B5, B6, B9, B12, C, D
142 and E, Ca, Mg, Zn, P, K, Fe, I, Se and Na. The final score (/100) is the arithmetic mean of the
143 two subscores. The provegetarian score, developed by Martinez et al. was computed as
144 follows [26] : 7 vegetable food groups and 5 animal food groups (22) were defined and sex-
145 specific quintiles adjusted for total energy intake were calculated. For each plant component,
146 1 to 5 points were allocated to quintile 1 to 5 and for animal food groups the scoring was
147 reversed. The provegetarian score was obtained by summing each quintile value of vegetable
148 food group and each reverse quintile value of animal food group thus ranging from 12 (low
149 plant food consumption) to 60 (high plant food consumption).

150 *Pesticide exposure assessment:*

151 Dietary pesticide exposure was evaluated by combining concentration values with dietary
152 intakes of each adult using contamination data from the Chemisches und
153 Veterinäruntersuchungsamt Stuttgart (CVUAS) database on pesticides, designated as a
154 European Union reference laboratory for pesticide measurements requiring single residue
155 methods for analysis [27]. CVUAS aims to analyze plant products from more than 88
156 countries (in the European Union and outside) and the database includes a wide variety of
157 contaminants (pesticides, hormones etc.). It contains more than 6.7 million datapoints (i.e. a
158 result for a pesticide residue and a product), with 1 million referring to organic data. In the
159 present work, four year data (2012-2015) were pooled. Twenty-five commonly used
160 pesticides were selected, given the data availability in the CVUAS database (some pesticides
161 widely used were excluded from the analysis due to lack of data, *e.g.* dithiocarbamates) and
162 on data presented in the 2015 EFSA Report on pesticide residues in food (most frequently
163 quantified or most frequently exceeding ARfD/ADI compounds)[28]. Three pesticides
164 commonly used in organic agricultural systems (azadirachtin, pyrethrins and spinosad) were
165 included. The 264 Org-FFQ items were decomposed into ingredients and all ingredients
166 present in a proportion of at least 5% in at least one food item (i.e. 442 ingredients) were
167 considered in this study. Animal-based ingredients were excluded, as CVUAS database only
168 encompassed plant-based ingredients. Indeed, plant-based foods have markedly frequent and
169 higher pesticides residues levels than foods of animal origin [29]. The resulting 180 plant
170 ingredients were matched to CVUAS database and then were attributed a contamination value
171 in organic and conventional farming modes (as the mean of corresponding data point). A
172 flowchart of the different steps for the decomposition and matching is shown in Supplemental
173 Material 2.

174 For each ingredient/pesticide couple in conventional and organic agriculture we determined a
175 frequency of detection and a frequency of quantification using the formula as follows:

$$176 \quad \text{Frequency of detection} = 100 \times \frac{\text{Number of analyses} - \text{Number of undetected}}{\text{Number of analyses}}$$

$$177 \quad \text{Frequency of quantification}$$

$$178 \quad = 100 \times \frac{\text{Number of analyses} - \text{Number of unquantified}}{\text{Number of analyses}}$$

179 Treatment of undetected data has been extensively described elsewhere [30].

180

181 As food consumption data from NutriNet-Santé referred to edible foods (bone-free, peeled or
182 cooked products), edibility and cooking factors were allocated to each ingredient when
183 necessary [31, 32]. However, potential concentration or dilution effects during washing or
184 cooking on pesticide residue levels were not accounted for. The same conversion factors were
185 used for both conventional and organic products.

186 For each pesticide, the estimated daily intake (EDI) (in $\mu\text{g}/\text{kg bw}/\text{d}$) under both lower- and
187 upper-bound scenarios was calculated using methods recommended by EFSA and WHO
188 workshop [33, 34].

189 *Statistical Analyses:*

190 For the present study, participants who completed the Org-FFQ between June and December
191 2014 (N = 37,685), with no missing covariates (N = 37,305), who were not detected as under-
192 or over-reporters (N = 35,196), who lived in mainland France (N=34,193) to permit the
193 computation of a weighting procedure described below were selected. The detection method
194 for under and overreporters was based on the comparison between energy intake and energy
195 requirement and is extensively described in a previous article by Baudry et al.[35]. Moreover,
196 in order to make the study sample more representative of the French population, for each
197 gender, weighting was calculated using the iterative proportional fitting procedure of the
198 %CALMAR macro [36] using 2009 national census reports [37] on age, occupational

199 category, educational level, area of residence and marital status and all analyses were
200 weighted.

201 Dietary pesticide exposure profiles were identified using Non-Negative Matrix factorization
202 (NMF) (see Supplemental material 1), a specially adapted method for non-negative data with
203 excess zeros developed by Lee et al [38]. NMF was performed on the 25 pesticide exposure
204 variables. Optimal number of NMF components, K , was chosen after running NMF for
205 different values of K , and evaluating criteria such as the residual sum of squares, as suggested
206 by Zetlaoui et al.[39]. Four components were retained. The NMF scores for these four
207 components were then introduced into a two-step clustering process : Ward's hierarchical
208 clustering using the four dimensions was performed, followed by a non-hierarchical, K-means
209 clustering procedure based on the earlier hierarchical clustering. The number of clusters was
210 determined using standard criteria (Cubic Clustering Criterion, PseudoF, Pseudo T²) [40].

211 NMF was performed using R's NMF package [41], and the clustering procedure was
212 performed using SAS® PROC CLUSTER and PROC FASTCLUS. Identified clusters were
213 described in terms of sociodemographics, dietary patterns and exposure to pesticides.

214 Participant characteristics across clusters are reported as means (SD). P values refer to Chi-
215 square tests and ANCOVA models for food groups are adjusted for energy intake.

216 Relative mean differences of estimated dietary pesticide exposure, compared to the mean of
217 the whole sample were calculated for each cluster.

218 For the 16 food groups, adjusted means for energy intake were computed and corrected for
219 multiple comparisons using Tukey procedure. Energy adjustment was conducted using the
220 residual method for nutrient intake [42]. For information, crude average of food consumption
221 across clusters are shown in **Supplemental Table 3**.

222 Two-sided tests were used, and a P value of <0.05 was considered significant. Data

223 management and statistical analyses were performed using SAS (version 9.4; SAS Institute,

224 Inc.).

225

226 **Results:**

227 Sociodemographic characteristics of the weighted sample are presented in **Table 1**. All the
228 descriptive statistics presented in this section are weighted. Given the small size of cluster 6,
229 statistical tests were performed only between the 5 first clusters for sociodemographic and
230 nutritional characteristics.

231 The total analyzed population was constituted of 34,193 individuals, 76% of them were
232 women and the average age was 50 years (SD=16). When weighting procedure was applied,
233 most represented monthly income (per household unit, obtained using the income by month in
234 the household and the composition of the household) categories were 1,200 to 1,800€ (29%)
235 and 1,800 to 2,700€ (26%) categories. One third of the population was retired. Most
236 participants had a high-school diploma (49%) and lived in an urban setting of more than
237 200,000 inhabitants (41%).

238 After the hierarchical clustering process, six clusters were identified. Relative mean
239 differences (compared to whole sample mean) for estimated dietary pesticide exposure for
240 each cluster are presented in **Table 2**. For information purpose, absolute values are presented
241 in **Supplemental Table 1**. Estimated pesticide exposure under the lower-bound scenario were
242 all inferior to ADI except for two individuals for chlorpyrifos and imazalil pesticides (data not
243 shown). Globally, in our estimation, all clusters were exposed to the same pesticide moieties,
244 with gradual intensity. Nutritional characteristics are presented in **Table 3** and dietary intakes
245 for food groups in **Table 4**.

246 The cluster 1 constituted 51% of our sample. Regarding estimated dietary pesticide exposure,
247 this cluster was overall the less exposed (except for anthraquinone and pyrethrins pesticides).

248 Participants in this cluster were younger and more often men than in other clusters.

249 Predominantly represented monthly income category was 1200 to 1800€ per household unit
250 (29%). This cluster comprised the most often sedentary participants (23%). The proportion of
251 overweight in this cluster was the highest among all clusters (40%). This population group

252 displayed the lowest energy intake of all clusters, and intermediate proportion of pescetarians,
253 vegetarians and vegans (see **Table 3**). They also exhibited high consumptions of alcoholic
254 beverages, fast food, sweetened foods and meat/poultry/processed meat (see **Table 4**). They
255 presented an intermediate global proportion of organic food in their diet (23%), a relatively
256 low Provegetarian score but organic proportions for plant-based food groups were high
257 (41%).

258 The cluster 2 included 28% of the sample. Estimated dietary pesticide exposure was lower
259 than for clusters 3 to 6. However, they showed higher exposure to methamidophos. This
260 cluster was constituted of 76% of women, 36% of retired persons, and a high proportion had
261 obtained a high school diploma (51%). They had intermediate energy intake and a low
262 organic food proportion in their diet (14%). Organic food proportion for the 16 food groups
263 were lower than cluster 1. Similarly to the 1st cluster, they showed high consumptions of
264 alcoholic beverages, fast food, sweetened foods and meat/poultry/processed meat.

265 The highest estimated pesticide exposures for anthraquinone, chlorpropham, fenhexamid,
266 methamidophos were observed in the 3rd cluster (representing 2% of the sample). This cluster
267 was the second most highly exposed of the 6 clusters for other pesticides. Cluster 3 was
268 composed of the highest proportion of unemployed subjects (12%), of employees (25%) and
269 of participants with a high school diploma (57%). This group had the highest proportion of
270 subjects living in a city with more than 200,000 inhabitants (44%). The proportion of
271 overweight individuals was the lowest compared to other clusters (19%). The proportion of
272 never-smokers was the lowest (48%). Individuals from this group had intermediate energy
273 intake and the lowest average organic food proportion in the diet (12%). Relatively high
274 proportions of pescetarians, vegetarians and vegans were observed in this group (2 to 4%).
275 They showed the highest consumption of seafood and extra food groups and the lowest
276 consumption of whole-grain products. Organic food proportion for food groups were low,

277 eggs being the most consumed food group as organic (31%).

278 In cluster 4 (8% of the sample), estimated pesticide exposure varied more across compounds
279 than for other clusters. Participants showed the highest exposures across clusters for
280 acetamiprid, azadirachtin, cypermethrin, pyrethrins, spinosad pesticides. Exposures to
281 anthraquinone, carbendazim, dimethoate were intermediate. This group was composed of
282 87% women, had the highest proportion of individuals with a monthly income superior to
283 2700€ per household unit (21%) and of self-employed/farmer occupational category (4%).
284 The highest proportion of subjects living in a rural setting (29%) and of former smokers
285 (40%) was found in this group. This cluster had relatively low energy intake, the highest
286 average proportion of organic food in the diet (32%) and high proportions of pescetarians,
287 vegetarians and vegans. The provegetarian score was high. Highest consumptions of non-
288 alcoholic drinks, whole grain products, oil and soy, and lowest consumption of dairy products
289 were observed in this group. Organic food proportion for vegetable food groups were the
290 highest compared to other clusters: more than 40% organic for whole grain products, fruits
291 and vegetables and starchy foods.

292 Cluster 5 (11% of sample) was intermediate in terms of estimated pesticide exposure; higher
293 than clusters 1 and 2 and lower than clusters 3 and 6, apart from exposure to methamidophos.
294 This group had the highest proportion of never-smokers (55%). Cluster 5 dietary intakes were
295 characterized by intermediate energy intake and low organic food proportion in the diet
296 (12%). Low consumption can be underlined for whole-grain products group and soy-based
297 products. Organic food proportion for food groups were low (less than 18%) except for Oil
298 and Eggs.

299 Cluster 6 was constituted of 16 individuals only (less than 1% of the sample). Participants
300 exhibited very distinctive characteristics : 97% were women, 66% were retired. Given the
301 small number of individuals in this cluster, we have chosen not to comment further on their

302 characteristics and exposure, as estimation for such small clusters might be unreliable [43].

303 Descriptive statistics of upper-bound scenario data are presented in **Supplemental Table 2**.

304 The gradient observed for lower-bound scenario has been also observed for upper-bound

305 scenario.

306

307 **Discussion:**

308 This study identified different dietary pesticide exposure profiles (derived from Non-negative
309 Matrix Factorization) among a large sample from the French web-based cohort NutriNet-
310 Santé. Using a specially adapted method for this type of left-censored data, our analysis
311 established 6 clusters as regards estimated dietary exposure to 25 commonly used pesticides.
312 It is the first study to estimate exposure on a large population sample accounting for different
313 farming practices using or not synthetic pesticides (conventional versus organic farming). Our
314 analysis showed that the less exposed group was the one with the most individuals (51% of
315 the whole sample for cluster 1). On the other side, the most exposed cluster (cluster 3) had
316 high energy intake, high intakes of conventional fruits and vegetables and low organic
317 proportion for plant-based food groups. It was constituted of much less individuals (2% of
318 whole sample). The global proportion of organic food in the diet was inversely correlated
319 with estimated levels of exposure to pesticides.

320 Few studies have examined dietary exposures to pesticides in general population.
321 The Etude de l'Alimentation Totale (EAT) [13, 14, 44] studies, conducted by the French
322 Agency for Food, Environmental and Occupational Health Safety (ANSES) have analyzed
323 exposure to pesticides and chemicals from food but did not consider the potential role of
324 farming practices to produce foods. Indeed, the production system can influence the pesticide
325 residue levels in food, as shown in EFSA's last report on pesticide residues in food [28] but
326 also in the MESA Study, in United States [45] and in a review of scientific articles [46]. Not
327 accounting for farming practice thus makes difficult to compare the EAT study findings with
328 our study. In addition, the EAT study used data from 2006, eight years prior to the
329 BioNutriNet questionnaire (2014) and considered pesticides were different, due to changes in
330 legislation on the use of pesticides (prohibitions, limitations of use). However, high estimated
331 levels of Imazalil (fungicides used, for instance, in citrus and potatoes production) were found
332 in our study, especially for clusters with high fruit and vegetables intakes, in accordance with

333 the EAT Study analyses of 2013 [44].

334 Herein, we used a factorization method specially adapted for this type of data which allowed
335 us to describe data using a “*profile approach*” to capture the exposure towards all 25
336 pesticides concomitantly rather than individual compounds as it is classically done in
337 toxicological studies. Our data can be helpful to design future studies investigating the
338 possible synergistic effects of mixtures of pesticide residues, based on realistic and
339 comprehensive exposure scenarios.

340 Our analysis showed that the less exposed cluster (cluster 1) had a high proportion of organic
341 food in the diet and conversely the most exposed cluster (cluster 6) had the lowest proportion
342 of organic food in the diet. This is consistent with other studies showing that organic eaters
343 are usually less exposed to synthetic pesticides [30, 45, 47].

344 For example, in another study conducted in the NutriNet-santé cohort we found that regular
345 organic eaters had lower urinary levels of organophosphorus and pyrethrynoïd pesticides
346 metabolites and lower dietary pesticide exposure, which is consistent with EFSA’s
347 surveillance differentiated (organic vs conventional) data [30, 47].

348 However, some nuances to this gradient can be drawn: cluster 1 was the less exposed cluster
349 but it was also the cluster with the lowest consumption of fruit and vegetables. This quantity
350 was nevertheless higher than the World Health Organization and official French Dietary
351 Guidelines recommending more than 400 grams of fruit and vegetables per day.

352 Cluster 4 individuals consumed the highest proportion of organic food in their diet (31.5%)
353 but exhibited high range of exposure levels depending on the compounds. This could be
354 explained by relatively high intakes of non-alcoholic drinks (fruit juices), fruits and
355 vegetables and whole foods, as exposure levels to pesticides used for fruit and vegetables
356 (acetamiprid, azadirachtin, cypermethrin) were particularly high. Pyrethrins and spinosad
357 exposure levels were also high in this group where proportion of organic food was important.

358 This is consistent with agricultural practices, as these two pesticides are authorized in organic
359 farming.

360 Overall, it seems like all clusters were exposed to all pesticides but with gradual intensity.

361 This is not surprising as diet is constituted from very varied foods with different level of
362 consumption constituting a continuum that can be observed in the pesticide exposure derived
363 from foods with variable proportions from conventional and organic agriculture.

364 We elected to primarily consider the lower-bound scenario, as upper-bound scenario imputes
365 data even when values are null or almost null. As organic food contain less and less
366 frequently pesticide residues [28], use of upper-bound scenario would have artificially
367 overestimated pesticide exposure. However, similar trends were found in both scenarios in
368 terms of exposure.

369 Some limitations related to our sample should be mentioned. The NutriNet-Santé cohort
370 includes volunteers, probably more interested in food and health issues than the general
371 population, with a majority of women and highly educated individuals [48]. The weighting
372 process was done in order to limit selection bias but it cannot be completely dismissed.

373 Dietary intakes were self-reported and the use of the organic food consumption scale and food
374 frequency questionnaire may have led to an overestimation of intakes of organic food.

375 However, the FFQ was derived from another validated FFQ [21] and used the same structure.

376 Indeed, proportion of organic food in the diet was higher than that mentioned in the Kantar
377 purchase data published in 2017 [49]. This can be due to our specific population and/or the
378 FFQ but it should also be mentioned that the Kantar study does not include some purchase
379 places such as fresh produce markets. However, when looking at the percentage of non-
380 consumers of organic foods, statistics from our study are consistent with the survey conducted
381 by the French Organic Agency, and the survey question “Have you consumed any organic
382 products over the past year?” where 12% of the 506 respondents reported never consuming

383 any organic foods in 2015 [50]. In our study, the percentage of non-consumers was 10% in
384 2014. The dietary exposure in the general French population might be higher for synthetic
385 pesticides, as organic consumption is lower, but this can be balanced by the fact that NutriNet
386 population has higher intakes for fruits and vegetables therefore potentially a higher exposure.
387 This type of data, linked to health outcomes could be integrated to benefit/risk analyses,
388 which are currently lacking on this topic. Available literature to date, is leaning more in the
389 direction of numerous benefits of fruit and vegetable consumption compared to dietary
390 pesticide risks [51, 52] . However, scarcity of data does not make it possible to firmly draw
391 conclusion.

392 Other limitations can be mentioned.

393 Firstly, it is noteworthy that the descriptive aim of this study limits the possibility to establish
394 associations between different characteristics of the diet and dietary pesticide exposure.

395 Cluster analysis allowed us to explore the exposure of different groups within the population.

396 However, the clusters that we identified are **complex making it difficult to describe and**
397 **characterize them**. Only global trends and relative comparison could be commented on.

398 Secondly, data was not available for animal-based products, which could have led to an
399 underestimation of the exposure levels and some disparities in the coverage of plant food.

400 However, residues of currently authorized pesticides are usually found in plant-based food
401 and less frequently in food of animal origin [28]. In the EAT 2 Study, the clusters with the
402 highest exposure to pesticides were those with elevated intakes of fruit and vegetables or
403 plant-based foods. This is concordant with our findings, namely exposures observed in cluster
404 3 and 6, which in addition have low organic fruits and vegetables rates.

405 It is possible that organic producers would use larger quantities of some pesticides authorized
406 in organic production systems in order to compensate the reduced number of unauthorized
407 pesticides although this phenomenon is not yet documented. This could be the case for

408 mineral-based pesticides such as copper or sulfur (authorized both in organic and
409 conventional system), that we could not include as no data were available. However, no
410 convincing adverse health effects for the general population have been reported until now
411 while issues on the environmental level have been highlighted in recent years [53].

412 Pesticide data were from Germany but covered foods of all European Union's countries. It is
413 noticeable that pesticide regulations are the same for France and Germany and should not
414 have modified results. Analyzed products were products marketed in the whole European
415 Union.

416 Finally, potential concentration or dilution effects during washing or cooking on pesticide
417 residue levels were not taken into account., These aspects would be very interesting to be
418 accounted for given their influences on residue concentration [54]. However, such factors are
419 not available yet for a sufficient number of food/pesticide couples. In addition, this would
420 require precise information on participants' peeling and washing practices.

421 **Conclusion:**

422 This study reports the characterization of dietary exposure to pesticides of French adults with
423 variable proportion of organic food in their diet. In our sample, we have observed an inverse
424 correlation between exposure to pesticides from diet and the proportion of organic food in the
425 diet. It should be kept in mind that the less exposed individuals constitute the largest cluster,
426 which is reassuring on a public health perspective.

427 Our study provides information on dietary pesticide exposure in a sample of the general
428 population, which is not well-documented. It is a necessary first step before
429 studying the specific role, independently of the nutritional quality of diets, of pesticide
430 exposure on health. It would be also interesting to integrate the distinction between
431 organically versus conventionally produced food in national and European pesticide exposure
432 surveillance studies in order to have more accurate exposure measurement in representative

433 populations.

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438 Contributions

439 The authors' contributions are as follows:

440 EK-G, MT, and SH conducted the study.

441 RV, DL, JB and EK-G conducted the research and implemented databases.

442 PR performed statistical analyses and drafted the manuscript.

443 All authors critically helped in the interpretation of results, revised the manuscript and

444 provided relevant intellectual input. They all read and approved the final manuscript. EK-G

445 supervised the study, had primary responsibility for the final content, she is the guarantor.

446

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Tables :**Table 1: Characteristics of the participants (weighted), NutriNet Santé Study, 2014 (N=34,193)**

	Whole Population	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6 ¹	P-value ²
Unweighted, <i>n</i>	34,193	16,922	9,328	684	3,471	3,772	16	
Weighted, % of whole sample		50.70	27.58	2.20	8.27	11.20	0.05	
Age, years	50.1 (16.1)	48.6 (16.0)	51.0 (16.5)	52.8 (17.0)	52.4 (13.1)	52.1 (17.0)	56.94 (17.2)	<0.0001 ²
Sex								<0.0001
Women, %	75.5	71.40	75.74	86.71	87.08	82.74	96.48	
Monthly income per household unit, %								<0.0001
<€1200	18.80	19.30	18.04	19.59	17.27	19.21	2.84	
€1200-1800	28.70	28.7	29.6	33.52	26.65	27.34	51.03	
€1800-2700	26.10	26.48	25.71	20.77	26.81	25.63	25.21	
>€2700	18.70	18.21	19.15	17.31	20.66	18.26	11.77	
Unwilling to answer	7.80	7.31	7.51	8.80	8.61	9.56	9.16	
Occupational status, %								<0.0001
Retired	32.10	28.25	35.77	38.06	33.31	38.47	65.84	
Employee, manual worker	24.10	24.8	23.36	24.85	22.58	23.5	2.03	
Intermediate profession	15.60	17.12	14.86	9.82	14.62	12.72	5.65	
Managerial staff, intellectual profession	11.10	12.58	9.93	6.41	11.22	6.97	7.99	
Unemployed	9.80	10.03	8.83	12.47	11.61	9.02	7.01	
Never employed (students)	4.70	4.1	5.16	6.47	2.87	7.23	11.48	
Self-employed, farmer	2.80	3.11	2.1	1.91	3.79	2.09	0	
Educational level, %								<0.0001
Less than high-school diploma	17.80	17.72	17.95	19.56	16.46	18.68	0	
High school diploma	48.80	46.34	50.75	56.87	49.11	53.04	61.11	
Post Graduate	33.40	35.94	31.3	23.56	34.43	28.28	38.89	
Physical activity, %								<0.0001
High	33.10	30.44	33.16	43.81	41.39	36.32	59.76	
Moderate	34.20	34.96	34.40	28.86	31.04	33.48	9.60	
Low	19.90	22.56	18.49	14.06	15.35	16.11	9.16	
Missing data	12.80	12.04	13.95	13.27	12.21	14.08	21.48	
Body Mass Index (kg/m²)	24.40 (4.90)	24.95 (5.29)	24.45 (4.63)	22.33 (3.95)	22.98 (3.52)	23.46 (4.09)	22.45 (3.00)	
≥25, %	36.10	40.27	36.91	18.97	23.03	27.84	38.76	<0.0001
Place of residence, %								<0.0001
Rural community	24.70	25.25	23.71	22.59	29.07	22.24	2.84	
Urban unit with a population <20,000 inhabitants	16.20	16.23	16.52	13.44	17.37	14.46	65.95	
Urban unit with a population between 20,000 and 200,000 inhabitants	17.90	18.12	17.32	19.75	16.22	19.41	3.55	
Urban unit with a population >200,000 inhabitants	41.20	40.40	42.45	44.22	37.33	43.89	27.66	
Smoking habits, %								<0.0001
Never smoker	50.40	49.39	51.08	48.27	49.18	54.77	50.58	
Former smoker	37.50	37.12	37.93	39.31	40.38	36.14	12.68	
Current smoker	12.10	13.49	10.99	12.41	10.44	9.09	36.74	
Ethanol, grams/day	7.50 (12.10)	7.54 (12.05)	7.81 (11.77)	6.19 (14.65)	6.97 (8.74)	6.77 (14.75)	2.82 (5.23)	<0.0001 ²

¹:The results for this group should be treated with caution as the small sample size can lead to unreliable estimates ²: p-values for comparisons between five first clusters using Chi-square tests ³: p-values for comparisons between five first clusters using linear regression

Table 2: Relative mean differences¹ (compared to whole sample mean) for pesticide dietary exposure, lower-bound scenario, NutriNet Santé Study, 2014 (N=34,193)

Pesticide active substances	Cluster 1 (50.70%)²	Cluster 2 (27.58%)²	Cluster 3 (2.20%)²	Cluster 4 (8.27%)²	Cluster 5 (11.20%)²	Cluster 6³ (0.05%)²
Acetamiprid	-0.45	-0.03	1.00	1.95	0.47	1.92
Anthraquinone	-0.06	0.05	0.20	0.03	0.09	-0.21
Azadirachtin	-0.09	-0.11	0.17	0.90	-0.03	0.54
Azoxystrobin	-0.43	0.33	2.33	-0.25	0.83	5.41
Boscalid	-0.36	0.29	1.53	-0.11	0.67	3.30
Carbendazim	-0.38	-0.01	0.91	1.49	0.43	1.76
Chlorpropham	-0.16	0.22	0.60	-0.31	0.30	0.35
Chlorpyrifos	-0.50	0.12	2.69	0.48	1.06	10.50
Lambda Cyhalothrin	-0.39	0.27	1.80	-0.05	0.76	5.72
Cypermethrin	-0.43	-0.07	0.97	1.99	0.45	1.94
Cyprodinil	-0.38	0.31	1.62	-0.14	0.73	3.10
Difenoconazole	-0.37	0.21	1.43	0.31	0.61	3.30
Dimethoate Ometoate	-0.46	0.05	1.43	1.49	0.57	2.73
Fenhexamid	-0.44	0.38	2.01	-0.16	0.79	1.35
Glyphosate	-0.21	0.16	1.03	-0.09	0.38	1.85
Imazalil	-0.68	0.23	4.74	-0.46	1.82	21.15
Imidacloprid	-0.43	0.27	1.38	0.38	0.74	1.50
Iprodione	-0.43	0.34	1.89	-0.15	0.83	7.06
Malathion	-0.41	0.18	2.79	-0.14	0.95	10.15
Methamidophos	-0.12	0.14	0.31	-0.15	0.25	-0.12
Profenofos	-0.66	0.33	3.97	-0.45	1.67	14.92
Pyrethrins	-0.07	0.01	0.10	0.24	0.08	-0.48
Spinosad	-0.27	-0.27	0.24	2.51	-0.04	1.12
Tebuconazole	-0.43	0.33	1.99	-0.15	0.84	6.23
Thiabendazole	-0.64	0.30	4.14	-0.43	1.60	15.78

¹: Relative mean differences were calculated as follows : $(\text{mean}_{\text{cluster}} - \text{mean}_{\text{whole sample}}) / \text{mean}_{\text{whole sample}}$

²: Weighted percent of whole sample

³: The results for this group should be treated with caution as the small sample size can lead to unreliable estimates

Table 3: Nutritional characteristics of participants' diets (weighted), NutriNet Santé study, 2014 (n=34,193)

	Cluster 1 (50.70%) ¹ Mean (SD)	Cluster 2 (27.58%) ¹ Mean (SD)	Cluster 3 (2.20%) ¹ Mean (SD)	Cluster 4 (8.27%) ¹ Mean (SD)	Cluster 5 (11.20%) ¹ Mean (SD)	Cluster 6² (0.05%) ¹ Mean (SD)
Energy intake without alcohol (kcal/day)	1845.8 (621.3)	2053.4 (642.2)	2297.1 (716.5)	1972.2 (549.4)	2125.3 (648.3)	2833.5 (610.1)
PANDiet Score(/100)	63.7 (8.0)	64.6 (8.1)	66.3 (8.7)	66.6 (7.2)	65.0 (8.3)	70.5 (6.5)
Provegetarian Score	35.5 (6.2)	35.5 (5.8)	37.4 (6.3)	37.9 (5.9)	35.7 (5.9)	37.2 (7.1)
Proportion of organic food in the diet, %	23.3 (22.5)	14.4 (15.2)	11.7 (14.4)	31.5 (21.6)	12.1 (14.8)	9.2 (12.9)
Proportion of organic food for plant-based food groups, %	41.0 (31.6)	23.0 (21.5)	15.0 (17.7)	49.9 (31.4)	18.6 (19.6)	14.3 (17.2)
Proportion of individuals with organic food in the diet ≥ 50%	14.7	3.2	1.8	23.1	2.2	2.3
Special diet, %						
Omnivorous	94.4	96.5	91.3	90.1	95.0	87.7
Pesco-vegetarian diet	1.8	1.4	2.6	3.9	1.7	0.00
Vegan diet	1.5	0.8	3.2	3.3	1.7	11.5
Vegetarian diet	2.3	1.3	2.9	2.7	1.6	0.8
Protein types						
Animal / Vegetal protein ratio	2.6 (1.7)	2.6 (1.4)	2.0 (1.2)	2.0 (1.2)	2.4 (1.3)	1.3 (1.0)
Vegetal / total protein ratio	0.3 (0.2)	0.3 (0.1)	0.4 (0.2)	0.4 (0.2)	0.3 (0.2)	0.5 (0.2)
Lipids (% of alcohol-free energy intake)	41.8 (7.3)	39.9 (9.6)	37.0 (7.8)	41.9 (5.1)	38.9 (1.7)	27.0 (8.6)
Carbohydrates (% of alcohol free energy intake)	39.1 (7.8)	40.9 (7.5)	45.2 (9.5)	39.6 (7.6)	42.2 (7.7)	57.2 (11.7)
Protein (% of alcohol-free energy intake)	18.9 (4.0)	18.8 (3.7)	17.2 (3.8)	18.1 (3.6)	18.3 (3.6)	14.6 (4.1)

¹: Weighted percent of whole sample

²:The results for this group should be treated with caution as the small sample size can lead to unreliable estimates

SD : Standard Deviation

All p-values for comparisons between 5 first clusters using linear regression were <0.0001

Table 4: Daily intakes of sixteen food groups (weighted), NutriNet-Santé study, 2014 (N=34,193)

Food groups (grams/day)	Cluster 1 (50.70%)¹ Mean² (CI)	Cluster 2 (27.58%)¹ Mean² (CI)	Cluster 3 (2.20%)¹ Mean² (CI)	Cluster 4 (8.27%)¹ Mean² (CI)	Cluster 5 (11.20%)¹ Mean² (CI)	Cluster 6³ (0.05%)¹ Mean² (CI)
Alcoholic beverages	94.5 (92.4, 96.8)	90.3 (87.4, 93.3)	63.1 (52.6,73.5)	82.1 (76.7, 87.5)	76.3 (71.7, 80.9)	8.7 (-63.8;81.2)
Other fats (including mayonnaise, fresh cream, vegetable fresh cream)	3.7 (3.7, 3.8)	3.5 (3.4, 3.6)	3.0 (2.7,3.4)	3.6 (3.4, 3.8)	3.1 (2.9, 3.2)	0.4 (-2.2; 3.0)
Non-alcoholic drinks	1675.6 (1663.9, 1687.3)	1706.2 (1690.3, 1722.1)	1838.1 (1781.9, 1894.3)	2082.6 (2053.7, 2111.5)	1758.4 (1733.5, 1783.4)	1794.1 (1405.0; 2183.1)
Butter	6.9 (6.7, 7.1)	6.6 (6.4, 6.7)	4.8 (4.3, 5.3)	5.7 (5.5, 6.0)	6.1 (5.9, 6.3)	1.7 (-1.7; 5.1)
Whole-grain products	54.4 (53.4,55.4)	45.2 (43.8, 46.5)	42.9 (38.1,47.7)	68.3 (65.8,70.8)	45.5 (43.3,47.6)	63.2 (29.9;96.5)
Extra food (including snacks, chips, salted biscuits, dressing and sauces)	17.9 (17.7,18.1)	16.1 (15.7,16.4)	18.2 (17.0,19.4)	17.8 (17.2,18.4)	15.8 (15.3,16.4)	7.0 (-1.0;15.0)
Fruit and vegetables (including juices and soups)	571.1 (565.7, 576.6)	784.9 (777.5, 792.4)	1307.8 (1281.5,1334.0)	895.9 (882.4, 909.4)	962.3 (950.6, 974.0)	2955.9 (2774.0;3137.8)
Starchy foods	186.3 (184.8, 187.8)	174.4 (172.4, 176.4)	152.7 (145.6, 159.7)	163.8 (160.2, 167.5)	158.1 (155.0, 161.3)	52.9 (4.0; 101.7)
Oil	18.8 (18.6,19.1)	18.0 (17.7,18.3)	19.8 (18.7,20.9)	24.4 (23.8, 24.9)	18.5 (18.0,18.9)	10.1 (2.7; 17.5)
Sweetened foods	74.5 (73.7,75.2)	70.7 (69.7, 71.8)	54.0 (50.2,57.7)	60.9 (59.0,62.8)	65.3 (63.7, 67.0)	35.6 (9.7; 61.5)
Fast food	36.7 (36.1,37.3)	33.0 (32.2,33.8)	21.2 (18.4,24.0)	27.2 (25.7,28.6)	29.7 (28.5, 30.9)	0.5 (-18.7; 19.7)
Seafood	40.9 (40.3,41.6)	44.0 (43.1,44.8)	47.3 (44.3,50.3)	45.3 (43.7,46.8)	44.0 (42.6, 45.3)	10.5 (-10.6; 31.5)
Dairy products	251.7 (248.5, 254.8)	280.1 (275.9, 284.4)	265.1 (250.0, 280.3)	233.5 (225.8, 241.3)	287.4 (280.7, 294.1)	384.5 (279.7; 489.3)
Eggs	11.1 (10.8,11.2)	11.5 (11.3,11.8)	11.8 (10.9,12.7)	11.5 (11.1, 12.0)	11.9 (11.5,12.3)	11.8 (5.5; 18.1)
Soy-based products	36.0 (34.5,37.6)	21.9 (19.8,24.0)	32.1 (24.9,39.4)	53.7 (49.9,57.4)	30.9 (27.7,34.1)	45.9 (-4.5; 96.4)
Meat, poultry, processed meats	121.0 (119.8, 122.1)	119.8 (118.2, 121.4)	75.9 (70.4, 81.5)	93.5 (90.6,96.3)	108.2 (105.7, 110.6)	2.1 (-36.4; 40.5)
Percentage of organic food for 16 food groups (%)						
Alcoholic beverages	17 (17, 17)	10 (9, 10)	6 (4, 7)	20 (20, 21)	7 (6, 8)	-1 (-10; 10)
Other fats (including mayonnaise, fresh cream, vegetable fresh cream)	28 (28, 29)	16 (16, 17)	12 (9, 14)	35 (34, 36)	13 (12, 14)	10 (-10; 30)
Non-alcoholic drinks	13 (13, 14)	8 (8, 8)	8 (7, 9)	17 (16, 18)	7 (6, 7)	2 (-10; 10)
Butter	29 (29, 30)	17 (17, 18)	10 (7, 12)	32 (31, 34)	14 (13, 15)	12 (-10; 30)
Whole-grain products	34 (33, 34)	21 (21, 22)	16 (14, 19)	42 (41, 44)	18 (17, 19)	14 (0; 30)
Extra food (including snacks, chips, salted biscuits, dressing and sauces)	25 (25, 26)	13 (13, 14)	10 (8, 12)	33 (32, 34)	11 (10, 12)	6 (-10; 20)
Fruit and vegetables (including juices and soups)	39 (39, 39)	21 (20, 21)	12 (10, 14)	51 (50, 53)	15 (14, 16)	7 (-10; 20)
Starchy foods	32 (31, 32)	19 (18, 19)	16 (14, 18)	42 (41, 43)	15 (14, 16)	38 (20; 50)
Oil	41 (40, 41)	26 (26, 27)	21 (18, 24)	49 (48, 51)	22 (20, 23)	7 (-10; 30)
Sweetened foods	27 (27, 28)	16 (16, 17)	14 (12, 16)	36 (35, 37)	15 (14, 16)	16 (10;30)
Fast food	20 (20, 21)	11 (10, 11)	6 (4, 7)	25 (24, 26)	9 (8, 10)	7 (-10;20)
Seafood	17 (17, 17)	11 (11, 12)	6 (5, 8)	19 (18, 20)	9 (8, 9)	0 (-10;10)
Dairy products	29 (28, 29)	17 (17, 18)	11 (9, 13)	33 (32, 34)	14 (14, 15)	4 (-10; 20)
Eggs	53 (52, 53)	43 (42,43)	31 (28, 34)	62 (61, 64)	36 (35,38)	43 (20; 60)
Soy	30 (29, 30)	19 (18, 20)	21 (18, 24)	38 (37, 40)	18 (16,19)	53 (30; 70)
Meat, poultry, processed meats	23 (23, 23)	15 (14,15)	8 (6, 10)	28 (27,28)	11 (10,12)	2 (-10; 10)

¹: Weighted percent of whole sample / ²: Adjusted means for energy-intake / ³: The results for this group should be treated with caution as the small sample size can lead to unreliable estimates / Abbreviations: CI: Confidence Interval; MUFA: Mono-Unsaturated Fatty Acids; PUFA: Poly-Unsaturated Fatty Acids; SFA: Saturated Fatty Acids. All p-values for comparisons between 5 first clusters (using ANCOVA) were <0.0001.

Appendix A: Detailed Explanation for the Non-Negative Matrix Factorization procedure

Non-negative Matrix Factorization is a non-supervised data decomposition method, proposed by Lee to deal with non-negative data using non-negativity constraints.

This method is relevant for non-negative data with excess zeros and measurement error such as exposure to pesticides constrained by the detection limits of dosing techniques.

The purpose of NMF is to explain observed data through a limited number of components approximating the original data as accurately as possible.

The matrix representing the basis components and the matrix of mixture coefficients are constrained to have non-negative values, and no orthogonality or independence constraints are imposed on the basis components.

Let X be a matrix ($n \times p$) containing only non-negative values and without a row or column containing only 0 and r a relatively small integer $< n$ and $< p$.

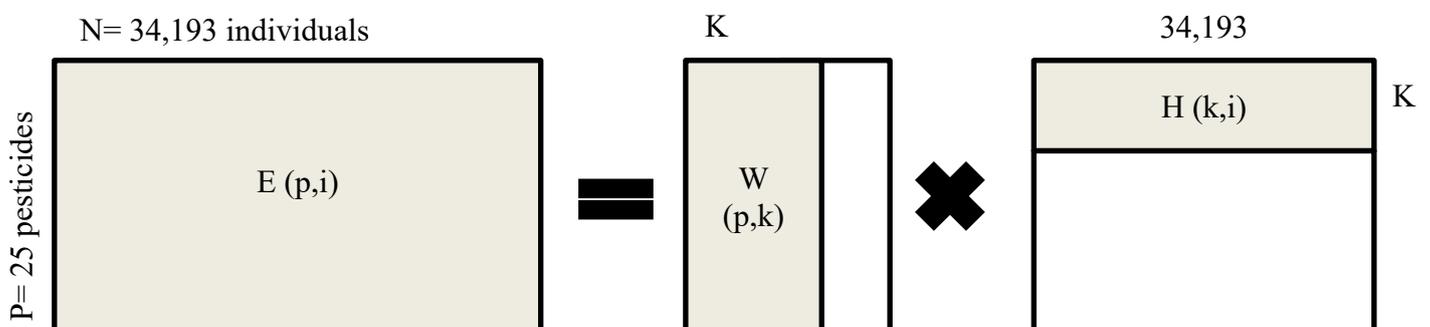
The non-negative factorization of matrix X is the search for two matrices W ($n \times r$) and H ($r \times p$) containing only positive or zero values and whose product approaches X so that $X \approx WH$.

The factorization is solved by searching for a local optimum of the optimization problem:

$$\min_{W, H \geq 0} [L(X, WH)]$$

L is a loss function measuring approximation quality. Since the objective is usually to reduce the dimension of the original data, the factorization rank r is in practice often chosen such that $r \ll \min(n, p)$. This equation is solved by a multiplicative algorithm based on a gradient descent approach.

In this study of dietary pesticide profiles, W would be the total dietary exposure to the 25 selected pesticides (previously obtained after combining contamination values for each food and foods consumed by each participant) and H the number of individuals.



K , the number of NMF Components

adapted from Zetlaoui et al., 2011

Appendix B: Flowchart for the decomposition of ingredients and matching

Selected Ingredients included in the pesticides database :

