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## ► To cite this version:

Sandy Pagès-Hélary Pagès-Hélary, Laurence Dujourdy, Nathalie Cayot. Flavor compounds in blackcurrant berries: Multivariate analysis of datasets obtained with natural variability and various experimental parameters. *LWT - Food Science and Technology*, 2022, 153, pp.112425. 10.1016/j.lwt.2021.112425 . hal-03394363

**HAL Id: hal-03394363**

<https://institut-agro-dijon.hal.science/hal-03394363v1>

Submitted on 16 Oct 2023

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1 **Flavor compounds in blackcurrant berries: multivariate analysis of**  
2 **datasets obtained with natural variability and various experimental**  
3 **parameters**

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9

10

## 11 **Abstract**

12 Berries of blackcurrant are source of vitamin C, flavonoids, beta-carotene, lutein and phenolic acid, with  
13 deep inky blue color and strong flavor. Within the works reported on blackcurrant berries, some studies  
14 suggested that a given cultivar of blackcurrant could yield berries with a specific profile in volatile  
15 compounds. However, in these studies, berries of various cultivars were obtained from different growing  
16 areas throughout the world. Moreover, methods used to study flavor compounds were different, and only few  
17 authors attempted to compare their results to other ones already published.

18 The present review aims to highlight the most important parameters influencing the reported results  
19 concerning aroma compounds in blackcurrant berries. We conducted a complete bibliometric and meta-  
20 analysis. We collected data from published studies, taking into account parameters linked with natural  
21 variability and experimental parameters. We obtained a pool of 351 identified volatile compounds, among  
22 which about twenty molecules we considered as representative of the general volatile profile of blackcurrant  
23 berries.

24 Collected data were analyzed first using Multiple Factor Analysis and Hierarchical Clustering on Principal  
25 Components, and then using Nonmetric MultiDimensional Scaling. We obtained mainly four consolidated  
26 clusters characterized by their richness/poorness in given volatile compounds. None of these clusters was  
27 linked with specific cultivars. Therefore, further research still has to be done to establish clearly the  
28 typicality of given cultivars that are empirically known to give specific organoleptic properties to  
29 manufactured products. Nevertheless, this study allowed identifying the important molecules to target with  
30 appropriate method and the experimental conditions to control.

31

32 **Keywords:** blackcurrant berries, aroma compounds, GC-MS, meta-analysis, multivariate statistical analyses

33

## 34 **1. Introduction**

35 Blackcurrant berries (*Ribes nigrum L.*) are cultivated in different countries for diverse uses. The biggest  
36 producing country of blackcurrant is Poland (Cortez and Gonzalez de Mejia, 2019), where berries are usually  
37 used for juices and jam.

38 Blackcurrant berries and buds are also commonly used for the production of alcoholic beverages (wine,  
39 liqueur and spirits) or for the production of essential oil, especially to make perfumes and food flavoring.  
40 This last commercial sector represents a small volume of production, but an important economical part.  
41 (Gerbaka, 2013)

42 The variety of blackcurrant is chosen according to its use. For juices and jams, variety must yield large and  
43 juicy berries, unlike variety used for liquors, which must have a powerful flavor.

44 Several works have been reported on aroma compounds of blackcurrant berries since many years  
45 ((Andersson and von Sydow, 1964) (Marsol-Vall et al., 2019)). Studied berries were from different growing  
46 areas in different parts of the world and from different cultivars ((Andersson and von Sydow, 1966b), (Jung,  
47 2018)). Nevertheless, some studies suggested that a given cultivar of blackcurrant could yield berries with  
48 typical flavor ((Anjou and von Sydow, 1966), (Jung, 2018)).

49 However, as methods used to study flavor compounds were very different, authors did not succeed to  
50 compare their results to other ones already published. Besides, it was hard to find studies dealing with the  
51 impact of the geographic growing area on the aroma profile of berries. Finally, none of the published studies  
52 clearly highlighted which parameter affected the most the flavor profile of blackcurrant berries.

53 In-depth analysis of published data could permit defining a pool of molecules characteristic of the odor of  
54 blackcurrant berries and selecting molecules that would be more specific of a variety or of a geographic zone  
55 for example. Such results could be useful to prove adulteration or to confirm origin of commercial products.

56 It is thus essential to perform a bibliometric analysis and a meta-analysis using statistical methods to  
57 combine data from multiple experiments, as an objective and quantitative approach for summarizing results  
58 of published studies.

59 Therefore, the present review aimed to highlight the parameters that influenced the more the aroma  
60 compounds recovered from blackcurrant berries. In order to proceed to this study, we compared several  
61 publications, based on:

- 62 - Natural variability: blackcurrant variety, geography and year of growth.
- 63 - Experimental parameters: storage temperature of berries, extraction method for aroma compounds,  
64 berries process (juice, whole fruit...).

65

## 66 **2. Material and methods**

67 The methodology we followed to conduct the present meta-analysis was summed up by the flowchart on  
68 figure 1. Data collection comprised extensive search and data recovery steps. In some cases, it was possible  
69 to complete missing information directly from the authors.

### 70 **2.1. Data collection**

71 We carried out the literature search in the Google scholar and Web of Science databases using the following  
72 search criteria: (blackcurrant) and (volatile compounds). The search included the period from 1950 to March  
73 2020. We retained only studies published in English or in French, and studies retained in our search had to  
74 meet these two criteria: (1) the study concerned berries, and (2) the study reported qualitative and  
75 quantitative data in either the text, figures, tables, or appendices. All these studied reported instrumental  
76 analysis of volatile compounds. Some of them reported also olfactometry data such as (Jung, 2018), or  
77 sensory results such as (Varming et al., 2004a).

78 As many papers were focused on blackcurrant buds or healthy compounds extract from berries and not on  
79 berries, only 22 papers were found eligible and their references were reported in table 1 in a chronological  
80 order. Studies ranged from 1964 to 2019. The reference Varming et al. (2004) was reported several times in  
81 table 1 because the authors reported different extraction methods for volatile compounds.

82 For each study case, we compiled the following information:

- 83 • cultivar of blackcurrant (for example, Ben Lemon),

- 84 • place and year of growth as indicated in the study or deduced from the country of the authors and the
- 85 year of publication,
- 86 • degree of maturity of the berries if indicated in the paper,
- 87 • storage temperature of berries before analysis (for example, frozen),
- 88 • process undergone by fruits before the extraction of volatile compounds (for example, whole fruit of
- 89 juice),
- 90 • extraction method for volatile compounds (for example, solvent extraction or Solid phase micro
- 91 extraction (SPME)), extraction parameters such as temperature and duration
- 92 • type of chromatography column used for the analysis of volatile compounds by gas chromatography
- 93 (GC)
- 94 • main volatile compounds identified and reported with their amount (quantities or area).

95 As it can be seen in table 1, reported studies embraced a wide variety of cultivars more or less specific of the  
96 geographical origin of the authors. For example, German authors studied the Titania cultivar, used for  
97 nectars and jams, and French authors studied the Noir de Bourgogne cultivar, used in liquors. Methods used  
98 to extract the volatile fraction were evolving with technological improvements along years: solvent  
99 extraction was used mainly in the oldest studies and SPME was dominating for the newest ones. The  
100 resulting main aroma compounds reported in studies were thus quite different but consistent. Giving the fact  
101 that different extraction methods could give complementary information, we decided to keep data from all  
102 the different methods.

103 A mind-map was presented on figure 2 to give an overview of differences in the study parameters of the  
104 selected studies. Some of these parameters were missing in the various studies and could not be included in  
105 the multivariate study.

106 As a result, an in-depth analysis of these data was then necessary to be able to draw main conclusions.

## 107 **2.2. Data curation**

108 The 22 selected studies counted for 36 different types of samples. They gave a pool of 351 identified volatile  
109 compounds, among which 22 molecules were the most frequently cited found in significant amount for at

110 least 10 samples among the 36 ones. We considered that these 22 molecules, most frequently cited, were  
111 representative of the general volatile profile of blackcurrant berries (table 2).

112 The most cited compounds were 3-carene, eucalyptol, terpinen-4-ol, *g*-terpinene, *p*-cymene, terpinolene, *b*-  
113 caryophyllene, and limonene. It is noticeable that esters, typical of fruity notes, appeared less frequently.

114 Table 2 compiled the odor descriptors of each compound. In order to facilitate further data analysis, we  
115 regrouped odor descriptors in larger categories, based on definitions from literature and personal knowledge:  
116 for example, citrus, orange, lemon, petit-grain, lime, peel, and rind gave a single category named citrus  
117 (Appendix Table A1).

118 Finally, in order to be able to compare data, we expressed data for one given compound as a percentage of  
119 the total chromatographic area.

## 120 **2.3. Data description**

121 We described data, considering parameters likely to explain variations one by one: blackcurrant cultivar,  
122 country of the study, storage of berries before analysis, sample preparation, extraction method for volatile  
123 compounds, GC column. We studied the evolution of the quality and quantity of volatile compounds as a  
124 function of each of these parameters.

125 For this in-depth analysis, we retained all the reported compounds in case of studies reporting less than 15  
126 compounds, and we retained the 15 most important compounds (based of the relative chromatographic area)  
127 for the other studies. For direct comparison between studies, parameter by parameter, we took into account  
128 the molecules reported in at least 50 % of the samples. This selection of compounds was comforted by  
129 published data on the odor activity of these compounds, found in references indicated in table 1 by an  
130 asterisk (<sup>a</sup>). This was done for each publication. Table 2 compiled all these selected compounds.

### 131 **2.3.1. Cultivars**

132 As previously seen, the studied cultivars were numerous. Nevertheless, only two cultivars were found at least  
133 twice in the different studies and could be used for comparison. The Brödtorp cultivar was reported in three  
134 studies ((Andersson and von Sydow, 1966); (Liu et al., 2018); (Andersson and von Sydow, 1964)) and the

135 Ben Lemond cultivar was reported in four studies ((Mikkelsen and Poll, 2002); (Iversen et al., 1998);  
136 (Marriott, 1986); (Bagger-Jørgensen et al., 2004)).

### 137 **2.3.2. Countries**

138 Nine different countries were represented among the 23 selected studies. Four countries were found in  
139 several studies, and could be used for comparison: Finland ((Marsol-Vall et al., 2018), (Leino and Kallio,  
140 1993), Titinen et al. 2004); Denmark ((Varming et al., 2004), (Mikkelsen and Poll, 2002), (Iversen et al.,  
141 1998), (Bagger-Jørgensen et al., 2004)); Germany ((Hempfling et al., 2013), (Jung et al., 2017), (Harb et al.,  
142 2008)); Great Britain ((Ruiz del Castillo and Dobson, 2002), (Marriott, 1986), (Nursten and Williams,  
143 1969)).

### 144 **2.3.3. Storage of berries**

145 Sometimes, berries were frozen before analysis. As this step could result in aroma loss or modification, it  
146 was important to evaluate this parameter. Data were regrouped in three categories: without freezing, freezing  
147 (-20°C and above), and deep-freezing (below -20°C).

148 Category “without freezing” regrouped samples from (Orav et al., 2002) and (Marriott, 1986) who analyzed  
149 fresh samples, (Nursten and Williams, 1969) who analyzed samples stored at 0°C, and (Jung et al., 2017) and  
150 (Hempfling et al., 2013) who analyzed samples stored at 4°C.

151 Category “freezing” regrouped samples stored at -15°C (Mikkelsen and Poll, 2002), at -18°C (Varming et  
152 al., 2004), (Ohlsson, 2009), (Leino and Kallio, 1993), and at -20°C ((Marsol-Vall et al., 2018), (Latrasse et  
153 al., 1982), (Liu et al., 2018), (Jung et al., 2017), (Bagger-Jørgensen et al., 2004), (Ruiz del Castillo and  
154 Dobson, 2002), (Tiitinen et al., 2004)).

155 Category « deep freezing » regrouped samples stored at -26°C (Iversen et al., 1998), -30°C (Harb et al.,  
156 2008), and -40°C ((Andersson and von Sydow, 1966a), (Andersson and von Sydow, 1966b), (Andersson and  
157 von Sydow, 1964)).

### 158 **2.3.4. Sample preparation**



159 Blackcurrant berries were often processed before analysis. ((Ruiz del Castillo and Dobson, 2002) is the only  
160 study using whole berries.

161 In case of “crushed berries”, we found berries as such ((Marriott, 1986) (Ruiz del Castillo and Dobson,  
162 2002)), but also berries mixed with water ((Latrasse et al., 1982), (Hempfling et al., 2013), (Jung et al.,  
163 2017), (Tiitinen et al., 2004)), or berries mixed with water and salts ((Andersson and von Sydow, 1964),  
164 (Andersson and von Sydow, 1966a), (Andersson and von Sydow, 1966b), (Marsol-Vall et al., 2018), (Harb  
165 et al., 2008).

166 Juices could be pure pasteurized juices ((Varming et al., 2004), (Mikkelsen and Poll, 2002), (Bagger-  
167 Jørgensen et al., 2004), (Ohlsson, 2009)), or pasteurized juices plus NaCl (Liu et al., 2018).

168 Finally, (Leino and Kallio, 1993) and (Nursten and Williams, 1969) studied concentrated juices, and (Iversen  
169 et al., 1998) studied nectar with sucrose.

#### 170 **2.3.5. Extraction method for volatile compounds**

171 We considered four categories of extraction methods that were reported in table 1: solvent extraction (SE),  
172 vacuum-headspace extraction (VE), dynamic headspace extraction (DHS), and solid-phase micro-extraction  
173 of the headspace (HS-SPME).

#### 174 **2.3.6. GC-column**

175 GC-column used in the different studies were classified into three categories of polarity:

- 176 - Low polarity: SE-52 ((Latrasse et al., 1982), DB-5MS (Marsol-Vall et al., 2018), HP-5 (Ruiz del  
177 Castillo and Dobson, 2002), SPB-1 (Orav et al., 2002), VF5-MS (Ohlsson, 2009), RH-5 (Tiitinen et  
178 al., 2004), ApezonN/MS-550 (Nursten and Williams, 1969), OV-101 (Marriott, 1986)
- 179 - Intermediate polarity: Tween-80 (Andersson and von Sydow, 1966), DB-1701 (Leino and Kallio,  
180 1993)
- 181 - High polarity: DB-WAX ((Varming et al., 2004), (Hempfling et al., 2013), (Jung et al., 2017),  
182 (Mikkelsen and Poll, 2002), (Bagger-Jørgensen et al., 2004)), HP-INNOWAX ( (Liu et al., 2018)  
183 (Iversen et al., 1998), ZB-WAX (Harb et al., 2008).

184

## 185        **2.4. Multivariate data analyses**

186        In order to explore more in depth the dataset and reveal the existence of some specific groups, we used  
187        factorial analysis and hierarchical clustering.

188        Multiple factor analysis (MFA) is a multivariate data analysis method for summarizing and visualizing a  
189        complex data table, in which observations are described by several sets of variables (quantitative and /or  
190        qualitative) structured into groups. MFA seeks the common structures present in all or some of these sets. It  
191        is performed in 2 steps: (1) a Principal Component Analysis (PCA) is performed on each data set, which is  
192        then “normalized” by dividing all its elements by the square root of the first eigenvalue obtained from of its  
193        PCA and (2), the normalized data sets are merged to form a unique matrix and a global PCA is performed on  
194        this matrix. The observation datasets are then projected onto the global analysis to explore communalities  
195        and discrepancies. The basis of MFA can be viewed as a weighted PCA applied to the multiple table. (Pagès,  
196        2002, Husson, 2017, Abdi and Valentin, 2007)

197        Clustering can be performed from the principal coordinates without any loss of information by computing  
198        the classical Euclidean distance from the principal coordinates. The HCPC (Hierarchical Clustering on  
199        Principal Components) function allows performing a clustering on individuals. This function combines  
200        principal components methods, hierarchical clustering and partitioning to better visualize and highlight the  
201        similarities between individuals. The simultaneous analysis of a principal component map and a hierarchical  
202        clustering mainly means representing the partition issue from the dendrogram on the map (Bécue-Bertaut,  
203        2008, Husson, 2010).

204        Multidimensional scaling (MDS) is a multivariate statistical technique used to create a map in which the  
205        distances between all pairs of items match the distances in the original distance matrix as closely as possible.  
206        The input to an MDS analysis is the same as the input to hierarchical cluster analysis—a distance matrix.  
207        Conversely, when the distances are converted into rank distances, a nonmetric multidimensional scaling  
208        (NMDS) is used. A benefit of NMDS is that it allows responses that are less precise. Therefore, easier  
209        response tasks can be used to obtain this type of similarity data.

210        The results produced by the MDS methods and clustering techniques are used to describe the interrelations  
211        between observations but cluster analysis is a tool for classifying objects into groups and is not concerned

212 with the geometric representation of the objects in a low-dimensional space. To explore the dimensionality  
213 of the space, the use of multidimensional scaling is preferred. MDS and cluster analysis are not mutually  
214 exclusive both approaches can complement each other (Roskos-Ewoldsen, 2007, Timm, 2002).

215 In the resent study, calculations were done using RStudio Version 1.2.5042 (RStudio\_Team, 2020) with R-  
216 4.0.0 (R\_Core\_Team, 2020) and RStudio 1.2.5042 (RStudio\_Team, 2020) with packages: “FactoMineR” (Lê  
217 et al., 2008), “factoextra” (Kassambara and Mundt, 2020), “ggplot2” (Wickham, 2016), “Hmisc” (Harrell  
218 and others, 2020), “magritt” (Bache and Wickham, 2014), “dplyr” (Hadley Wickham, 2020), “ggpubr “  
219 (Kassambara, 2020) , “MASS” (Venables and Ripley, 2002), “vegan” (Oksanen et al., 2010).

220

### 221 **3. Results - Discussion**

222 In a first step, we undertook a descriptive analysis focused on the impact of each studied parameter on the  
223 volatile profile. Then, we performed multivariate data analyses, using the whole dataset, to highlight the  
224 possible existence of more specific groups.

225 We calculated the mean values of normalized abundance percentages (relative chromatographic area  
226 reported in the different studies) for the different volatile compounds. Figure 3 reported the 21 most  
227 abundant compounds, which we considered for the present meta-analysis as representative of the global  
228 volatile profile for blackcurrant berries. The vast majority of compounds represented in figure 3 (most  
229 abundant) were included in the list of most frequently cited compounds (light grey and dark grey cells in  
230 table 2). It is noticeable that standard deviations were huge and did not allow an easy interpretation of data.

231

#### 232 **3.1. Differences in study parameters and their impact on data**

233 Table 2 regrouped details (CAS n°, odor descriptors) on the volatile molecules discussed in the following  
234 paragraphs. For other molecules (not reported in table 2), details were given in the text.

235 In the following development, we abbreviated molecules names in this way: “*a*” for alpha; “*b*” for beta; “*d*”  
236 for delta; “*g*” for gamma; “*p*” for para. Additionally, we did not make any difference between 3-carene and  
237 *d*-3-carene, because these molecules had the same organoleptic properties and chemical structure.

238 We stated the impact of the different parameters by comparison with the list of molecules representative of  
239 the global profile in volatile compounds based on most abundant compounds (figure 3). We checked that the  
240 list of molecules was consistent with highest odorant impacts reported in publications with olfactometry  
241 measurements.

242

### 243 **3.1.1. Impact of cultivars**

244 The volatile profile of the cultivar Brödttorp was mainly characterized by ethyl acetate, terpinen-4-ol, *p*-  
245 cymen-8-ol, 3-methyl-1-butanol, *cis*-3-hexen-1-ol. Among these five molecules, ethyl acetate (CAS n° 141-  
246 78-6, odor description: ethereal, fruity, sweet, green, rummy) and 3-methyl-1-butanol (CAS n° 123-51-3,  
247 odor description: alcoholic, fusel, banana, molasses, ethereal) did not appear in the global profile of volatile  
248 compounds for blackcurrant berries.

249 The volatile profile of the cultivar Ben Lomond was mainly characterized by methyl butanoate, ethyl  
250 butanoate, ethyl hexanoate, terpinolene, 3-carene, *b*-caryophyllene, ethyl acetate, *cis*-*b*-ocimene, terpinen-4-  
251 ol, *trans*-*b*-ocimene, limonene, *b*-phellandrene, myrcene, *a*-terpinene ((Iversen et al., 1998), (Mikkelsen and  
252 Poll, 2002), (Varming et al., 2004b), (Bagger-Jørgensen et al., 2004), (Marriott, 1986)). Among these 14  
253 molecules, ethyl hexanoate and ethyl acetate did not appear in the global profile of volatile compounds for  
254 blackcurrant berries.

### 255 **3.1.2. Impact of countries**

256 In studies reported for Germany, the following compounds seemed to be specific (found only for this  
257 country): 3-carene, 2-methyl-3-buten-2-ol, *cis*-*b*-ocimene, *trans*-2-hexenal, *b*-phellandrene, *trans*-2-hexen-1-  
258 ol, *trans*-*b*-ocimene ((Harb et al., 2008), (Hempfling et al., 2013), (Jung et al., 2017), (Jung, 2018)).

259 In studies reported for Great Britain, the following 10 compounds were specific: *a*-terpinene, *b*-  
260 caryophyllene, *p*-cymene, sabinene, *g*-terpinene, *a*-pinene, *a*-phellandrene, *a*-humulene (CAS n°6753-98-6,  
261 odor descriptor: sweet, spicy, WOODY), *b*-pinene, ocimene (CAS n°13877-91-3, odor descriptor: sweet,  
262 herbal) ((Nursten and Williams, 1969), (Marriott, 1986)).

263 Ethyl hexanoate was specific for Denmark ((Iversen et al., 1998), (Mikkelsen and Poll, 2002), (Varming et  
264 al., 2004b), (Bagger-Jørgensen et al., 2004), (Christensen and Pedersen, 2006)) , and bornyl acetate was  
265 specific for Finland ((Leino and Kallio, 1993), (Tiitinen et al., 2004), (Marsol-Vall et al., 2018)).

### 266 **3.1.3. Impact of storage of berries**

267 Among the main volatile compounds, some molecules were only present in samples without freezing:  
268 caryophyllene, *b*-phellandrene, *a*-terpineol, *b*-caryophyllene, sabinene, *trans*-2-hexenal, *a*-terpinene.  
269 Nevertheless, the other volatile compounds found in the frozen samples could drive the corresponding odor  
270 descriptors.

### 271 **3.1.4. Impact of sample preparation**

272 The identified volatile compounds reported for the different ways of sample preparation were clearly  
273 different.

274 Compounds with odor descriptors such as terpenic, citrus, and woody characterized whole berries. 2-methyl-  
275 3-buten-2-ol, myrcene, *cis*-*b*-ocimene, *trans*-*b*-ocimene were found only in the case of crushed berries. These  
276 compounds had odor descriptors such as herbal, and green.

277 For more processed samples (juices and nectars), fruity, aldehydic and fatty notes, given by ethyl acetate,  
278 butyric acid, benzyl alcohol, hexanoic acid, *trans*-2-octen-1-olmethyl hexanoate, methyl octanoate, and  
279 hexanal, could be enhanced.

### 280 **3.1.5. Impact of the extraction method for volatile compounds**

281 It seemed that extraction methods using solvents (SE) allowed extracting higher quantities of terpenes and  
282 terpenoids related to sweet and fruity notes, such as *b*-caryophyllene and limonene.

283 Vacuum-headspace extraction (VE) methods gave a higher proportion of alcohols, related with green leaf  
284 and herbal notes, such as 2-methyl-3-buten-2-ol and *trans*-2-hexen-1-ol.

285 Dynamic headspace extraction (DHS) favored esters (fruity notes), such as ethyl hexanoate and methyl  
286 acetate.

287 Finally, solid-phase micro-extraction of the headspace (HS-SPME) was linked with higher amounts of  
288 carboxylic acids, such as butyric acid, acetic acid, and hexanoic acid. These compounds were related with  
289 cheesy, acid, fermented and fatty notes.

### 290 **3.1.6. Impact of GC-column**

291 Molecules identified using low polarity columns were molecules with quite high molecular weights (above  
292 10 carbons), and were mainly terpenes and terpenoids.

293 High polarity columns allowed identifying esters and alcohols together with terpenes and terpenoids.

294 For medium polarity columns, there was no specific molecule or chemical function highlighted.

295

### 296 **3.2. Multivariate analysis and clusters of individuals**

297 Dataset was composed of several categorical variables such as variety of studied blackcurrant berries or  
298 country, and numerical data such as percentages of specific compounds. Due to the variety of data, we  
299 applied a Multiple Factor Analysis (MFA) to the dataset. This analysis had two objectives: first, we searched  
300 to obtain a typology of the various studies and second we wished to know if there were correlated variables.

301 The complete data consisted in three datasets. Each study was an  $I \times J[k]$  rectangular data matrix denoted  
302  $Y[k]$ , where  $I$  was the number of observations and  $J[k]$  the number of variables of the  $k$ -th study.

303 The complete dataset was composed of  $I = 46$  observations corresponding to the studies (in terms of articles)  
304 with 45 variables including descriptive characters,  $J[1] = 7$ : berry variety used, country of the study, storage  
305 type, nature of samples, publications, extraction method, GC column and 18 quantitative data: volatile  
306 molecules ( $J[2] = 18$  variables), and 30 frequency data with chemical family ( $J[3] = 7$  variables), and odor  
307 descriptors ( $J[4] = 13$  variables). These three last groups were named active groups and the group of  
308 qualitative variables ( $J[1]$ ) was named supplementary group.

309 Codes used for factors and observations were given in tables 3 and 4.

310 Cumulative variance of three dimensions counted for more than 53 % of the total variance.

311 The graph in figure 4a revealed the common structure of the observation space (dimension 1 x dimension 2).

312 Squared cosines reflected the representation quality of a variable on a factorial axis. A squared cosine of 1  
313 meant that the observation was on the factorial axis (i.e. the angle is zero) and was perfectly represented,  
314 whereas a squared cosine of 0 indicated that the observation is on an orthogonal direction to the axis. We  
315 considered that observations with a sum of squared cosines on dimension 1 and dimension 2 above 0.6 meant  
316 that observation was correctly represented in the plan. We identified four groups of observations: 15-22-23-  
317 41 (named g1) in the down-right quarter, 26-27-28-38 (g2) in the up-right quarter, 12-31-36 (g3) in the left  
318 side dimension 1-axis, and 29-30 (g4) in the upper side along dimension 2-axis.

319 Figure 4b showed the dimension 1 x dimension 3 plan for observations. We considered that observations  
320 with sum of  $\cos^2$  above 0.6 were correctly represented in the plan. We also obtained four clusters of  
321 observations: 28-38 was confirmed in the up-right quarter; 8-9-39 in the down-left quarter, 31-32-34-35 in  
322 the up-left quarter, and 36 on the left along the dimension 3 axis.

323 As in standard PCA, the variable loadings were the correlation between the original variables and the global  
324 factor scores. These loadings were plotted along with the “circles of correlation” on the left in Figures 5a and  
325 5b. They showed correlation between quantitative variables (group named Mole with “volatile molecules”)  
326 and dimensions.

327 The relationships between the groups and the dimensions were plotted on the right in Figure 5. It meant that  
328 observations, which were along dimension 1 such as g1, were influenced by the chemical family group and  
329 odor descriptors. Terpene molecules and herbal (mint) odor mainly characterized them. At the opposite side,  
330 there was g3, which was mainly characterized by ester molecules and floral odor. On dimension 2, g4 was  
331 mainly characterized by chemical molecules especially M.t4o; on the contrary, g1 was mainly characterized  
332 by M.phi and M.3ca.

333 On figure 5a, the coordinates of the three active groups of frequencies (named Famy and Odor) on the first  
334 dimension were almost identical. This meant that they contributed similarly to the first dimension.  
335 Concerning the second dimension, the two groups - Mole and Quali - had the highest coordinates indicating  
336 a highest contribution to the second dimension.

337 From figure 5b, it could be observed that the variable “Chemical family - Famy” mainly contributed to  
338 dimensions 1 and 3. The variable “odor description - Odor” contributed to dimension 1 mainly and the

339 variable “volatile molecules - Mole” contributed mostly to dimensions 1 and 2. Contribution of the  
340 supplementary group “Quali” was the same along the three dimensions. From “correlation circles”, it could  
341 be observed that variables were rather widespread meaning that they were not correlated between them but in  
342 1x2 plan. Two groups of variables were close: M. bca and M.atp and M.3ca, M. cib and M. trb. It was  
343 confirmed by their correlation coefficients (Appendix. Figure A2).

344 The same type of analysis was done in 2x3 plan.

345

346 To complete the presence of clusters, a hierarchical clustering on principal components (HCPC) was applied  
347 and dendrograms were generated. Finally five clusters were obtained and they were synthetized as a, b, c, d  
348 and e in table 5.

349 Cluster a and cluster b regrouped observations from different studies with different experimental conditions.

350 Cluster c regrouped observations for which samples were all frozen.

351 Cluster d regroups observations for which samples were mainly crushed berries, with freezing as storage, and  
352 from northern countries (Sweden, Denmark, Germany, and Finland).

353 Finally, cluster e regrouped observations from northern countries (Scotland, Germany and mainly Denmark).

354

#### 355 **4. Conclusions**

356 From the pool of 351 identified volatile compounds collected in the present study, our methodology resulted  
357 in the selection of about twenty molecules we considered as representative of the volatile profile of  
358 blackcurrant berries. The most cited compounds were terpinen-4-ol (citation frequency: 61%, mean value of  
359 normalized abundance:  $8\pm 13$ ), terpinolene (53%,  $9\pm 11$ ), limonene (50%,  $4\pm 3$ ), 3-carene (47%,  $15\pm 13$ ),  
360 eucalyptol (44%,  $4\pm 6$ ), *g*-terpinene (28%,  $4\pm 6$ ), *b*-caryophyllene (36%,  $8\pm 8$ ), and *p*-cymene (33%,  $4\pm 4$ ).

361 We considered parameters one by one (blackcurrant cultivar, country of the study, storage of berries before  
362 analysis, sample preparation, extraction method for volatile compounds, GC column) to make an in-depth  
363 description of data.



364 Indications for volatile compounds typical of some cultivars could be given. They concerned volatile  
365 compounds that were representative of a cultivar but that did not appear in the list of the main volatile  
366 compounds given for blackcurrant berries:

- 367 - ethyl acetate and 3-methyl-1-butanol for the cultivar Brödtorp
- 368 - ethyl hexanoate and ethyl acetate for the cultivar Ben Lomond.

369 Other parameters clearly had an impact on the detected volatile compounds but no clear tendency could be  
370 drawn from data description.

371 Linear multivariate analysis was firstly done, but, as representativeness of observations might seem quite  
372 low, we decided to comfort the linear multivariate analysis with another method: non-Metric  
373 Multidimensional Scaling (NMDS).

374 Even though there are similarities in the type of research questions to which MFA+HCPC and NDMS can be  
375 applied, Multidimensional Scaling and Factor Analysis are fundamentally different methods. Factor analysis  
376 requires that the underlying data are distributed as multivariate normal, and that the relationships are linear.  
377 Multidimensional Scaling (MDS) imposes no such restrictions. As long as the rank-ordering of distances (or  
378 similarities) in the matrix is meaningful, MDS can be used. In terms of resultant differences, factor analysis  
379 tends to extract more factors (dimensions) than MDS; as a result, MDS often yields more readily,  
380 interpretable solutions. Most importantly, however, MDS can be applied to any kind of distances or  
381 similarities, while factor analysis requires us to first compute a correlation matrix. MDS can be based on  
382 subjects' direct assessment of similarities between stimuli, while factor analysis requires subjects to rate  
383 those stimuli on some list of attributes (for which the factor analysis is performed) (TIBCO, 2020).

384 In the present study, NMDS gave new clusters, reported as  $\alpha$ ,  $\beta$ ,  $\chi$ ,  $\delta$ ,  $\epsilon$ , and  $\phi$  in table 5.

385 Observations belonging to a same cluster whatever the multivariate analysis were in color other than black.

386 From that, we obtained mainly four consolidated clusters, which were the following ones, characterized by  
387 their richness/poorness in given volatile compounds:

- 388 • 25-26-27-28-38. Observations were characterized by a profile of volatile molecules rich in *a*-  
389 terpinene, *g*-terpene, *p*-cymene, *a*-terpinolene (*b*-caryophyllene)/ poor in methyl and ethylbutanoate.  
390 The profile was poor in aldehydes.
- 391 • 4-10-14: Observations were characterized by a profile of volatile molecules rich in *a*-pinene,  
392 limonene, terpinene, and myrcene. The profile was rich in terpenes. Associated odor descriptors  
393 were poor in alcoholic, fermented, and dairy notes.
- 394 • 1-31-32-33-34-35: Observations were characterized by a profile of volatile molecules poor in 3-  
395 carene, *cis* and *trans-b*-ocimene, phellandrene. The profile was rich in acids, terpenoids and  
396 alcohols. Associated odor descriptors were rich in nuts and fermented notes.
- 397 • 15-23-41-44: Observations were characterized by a profile of volatile molecules rich in sabinene, 3-  
398 carene, phellandrene, *cis* and *trans-b*-ocimene, methyl and ethyl butanoate. The profile was rich in  
399 aldehydes.

400 Unfortunately, none of the clusters of individuals was linked with specific cultivars, which was not obvious  
401 considering raw data.

402 The present bibliometric and meta-analysis study failed to draw main conclusions concerning typicality of  
403 blackcurrant cultivars. Moreover, the different parameters taken into account in the multivariate statistical  
404 analysis did not allow explaining the overall variability within data set. We showed that most of the variables  
405 were not correlated between them. This observation should be considered with caution due to the limits of  
406 the database used to retrieve the studied articles.

407 Nevertheless, this confirms that further research still has to be done to establish clearly the typically of given  
408 cultivars that are empirically known to give specific organoleptic properties to manufactured products. It also  
409 permitted us identifying the important molecules to target, the experimental conditions to control, and  
410 selecting appropriate method for future works.

411

412 **Credit authorship contribution statement**

413 Sandy Pagès-Hélary: data collection and curation, data analysis and interpretation, writing. Laurence  
414 Dujourdy: statistical analysis, data interpretation, writing. Nathalie Cayot: methodology, project  
415 administration, writing,

416

417 **Declaration of Competing Interest**

418 The authors declare that they have no known competing financial interests or personal relationships that  
419 could have appeared to influence the work reported in this paper.

420

421 **Acknowledgement**

422 We want to acknowledge Geoff Langford (brand manager at Bayer New Zealand Limited, New Zealand) for  
423 additional information on publication (Ohlsson, 2009), and Stefanie Sharma (general manager at  
424 International blackcurrant association, France) and Dorota Jarret (fruit breeder and researcher at James  
425 Hutton Limited, Scotland) for details on blackcurrant cultivation.

426

427 **Funding**

428 This work was supported by the Regional Council of Bourgogne – Franche Comté and the “Fond Européen  
429 agricole pour le développement rural” (FEADER) for the project “Pérennité de la filière cassis en  
430 Bourgogne”.

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545

546

547 Table 1. List of the different publications included in the meta-analysis with their specificities and main volatile compounds reported

548

| References                              | Growth area of berries | Variety of berries   | Extraction methods used for volatile compounds analysis | Main aroma compounds reported   |
|---|------------------------|--|---|---|
| <b>(Andersson and von Sydow, 1964)</b>  | Sweden                 | Brödorp  | SE + distillation of the extract                        | myrcene, <i>cis-b-ocimene</i> , <i>trans-b-ocimene</i> , limonene, <i>b-phellandrene</i> , terpinolene, <i>a-pinene</i> , 3-carene, citronellol, terpinen-4-ol, <i>p-cymene</i> , citronellyl acetate, caryophyllene  |
| <b>(Andersson and von Sydow, 1966a)</b> | Sweden                 | Brödorp  | VE: 48°C + distillation of the extract                  | acetone, methyl acetate, ethyl acetate, propanol, 2-methyl-3-buten-2-ol, isobutanol, terpinen-4-ol  |
| <b>(Andersson and von Sydow, 1966b)</b> | Sweden                 | Brödorp, Wellington XXX, Silvergieters Zwart, Cotswold Cross, and two crossing (WellingtonXXX x Brödorp, Cotswold Cross x Brödorp) | SE + distillation of the extract                        | 3-carene, <i>g-terpinene</i> , terpinolene, terpinen-4-ol, citronellyl acetate, caryophyllene   |
| <b>(Nursten and Williams, 1969)</b>     | UK                     | NI (English blackcurrant varieties mix)  | SE + distillation of the extract                        | <i>a-terpinene</i> , <i>b-phellandrene</i> , <i>g-terpinene</i> , <i>p-methylisopropenylbenzene</i> , eucalyptol, 2-hexenal, methanol, ethanol, <i>n-propanol</i> , <i>n-butanol</i> , isobutanol, isopentanol, 2-methylbut-3-en-2-ol, <i>n-hexanol</i> , <i>cis- &amp; trans-2-hexen-1-ol</i> , terpinen-4-ol, ethyl butanoate, methyl <i>n-hexanoate</i> , and methyl benzoate. |

|   |          |  |   |   |
|---|----------|--|---|---|
| <b>(Latrasse et al., 1982)</b>                | France   | Noir de Bourgogne and Royal de Naples                        | SE  | diacetylene, ethyl butanoate, methyl butyrate, eucalyptol, linalool, limonene-4-ol, <i>a</i> -terpineol, terpinen-4-ol  |
| <b>(Marriott, 1986)</b>                       | UK       | Ben Lemond and WellingtonXXX                                 | SE  | sabinene, 3-carene, limonene, linalool, <i>a</i> -terpineol, <i>b</i> -caryophyllene, caryophyllene oxide   |
| <b>(Leino and Kallio, 1993)<sup>b</sup></b>   | Finland  | Öjeby  | DHS: 40°C - deactivated fused silica capillary tubing | Butanoic acid, hexanoic acid, ethyl octanoate, octanoic acid, bornyl acetate, methyl decanoate, ethyl decanoate, ethyl dodecanoate, 2,6-bis(1,1-dimethylethyl)-4-methyl phenol  |
| <b>(Iversen et al., 1998)<sup>a</sup></b>     | Denmark  | Ben Lemond   | DHS: 18°C – 60 min – Poropak trap                     | Methyl butanoate, ethyl butanoate, 3-carene, methyl hexanoate, limonene, ethyl hexanoate  |
| <b>(Ruiz del Castillo and Dobson, 2002)</b>   | Scotland | Ben Tirran, Ben Dorian, Hedda, Ben Avon                      | HS-SPME: 55°C – 20 min – PDMS-DVB fiber               | <i>a</i> -pinene, myrcene, limonene, eucalyptol, <i>a</i> -phellandrene   |
| <b>(Orav et al., 2002)</b>                    | Estonia  | N.I. (Saxifragaceae, wild black currant, from north America) | SE (with simultaneous distillation)                   | 3-carene, <i>cis</i> - <i>b</i> -ocimene, limonene, <i>b</i> -phellandrene, terpinolene, <i>p</i> -cymene, <i>trans</i> - <i>b</i> -caryophyllene   |
| <b>(Mikkelsen and Poll, 2002)<sup>a</sup></b> | Denmark  | Ben Lemond   | DHS: 30°C – 60 min – Tenax trap                       | 3-carene, <i>cis</i> -ocimene, <i>a</i> -terpinolene, <i>b</i> -caryophyllene, ethyl acetate, methyl butanoate, ethyl butanoate   |
| <b>(Varming et al., 2004a)<sup>b</sup></b>    | Denmark  | Ben Lemond   | DHS: 30°C – 45 min – Tenax trap                       | 2-methyl-1-propanol, 2- and 3-methyl-1-butanol, methyl butanoate, ethyl butanoate, 4-terpineol  |
| <b>Varming et al.2004<sup>b</sup></b>         | Denmark  | Ben Lemond   | HS: 30°C – 60 min – Tenax trap                        | ethyl butanoate, 2,3-butanedione, methyl 2-methylbutanoate, 2-methylpropyl acetate, methyl acetate, ethyl hexanoate   |
| <b>Varming et al.2004<sup>b</sup></b>         | Denmark  | Ben Lemond   | DHS: 30°C – 15 et 60 min – Tenax trap                 | ethyl butanoate, methyl butanoate, 2,3-butanedione, 2-methyl-3-furanthiol, cineole, 2-methyl-1-butanol, 3-methyl-1-butanol  |
| <b>Varming et al.2004<sup>b</sup></b>         | Denmark  | Ben Lemond   | SE  | ethyl butanoate, 2-methyl-3-furanthiol, methional, butanoic acid  |
| <b>(Bagger-Jørgensen et al., 2004)</b>        | Denmark  | Ben Lemond   | DHS: 30°C – 60 min – Tenax trap                       | methyl butanoate, ethyl butanoate, furfural, ethyl hexanoate, eucalyptol, <i>cis</i> -3-hexen-1-ol, <i>b</i> -damascenone   |
| <b>(Tiitinen et al., 2004)</b>                | Finland  | NI   | HS-SPME: 25°C – 30 min – triphasic fiber              | <i>a</i> -pinene, <i>b</i> -pinene, sabinene, 3-carene, <i>b</i> -phellandrene, terpinolene, myrcene, limonene, <i>cis</i> -ocimene, <i>trans</i> -ocimene, <i>g</i> -terpinene, linalool, <i>a</i> -terpineol, citronellol |
| <b>(Christensen and</b>                       | Denmark  | NI (13 different   | DHS: 25°C – 90 min –                                  | methyl butanoate, ethyl butanoate, methyl hexanoate, ethyl  |



|   |                        |  |  |   |
|---|------------------------|--|--|---|
| <b>(Pedersen, 2006)</b>                     |                        | organic varieties)   | Porapak trap                             | hexanoate, sabinene, 3-carene, <i>g</i> -terpinene, terpinolene, <i>cis</i> - <i>b</i> -ocimene, eucalyptol   |
| <b>(Harb et al., 2008)</b>                  | Germany                | Titania  | HS-SPME: 30°C – 60 min – PDMS fiber      | terpinen-4-ol, 3-carene, <i>a</i> -pinene, 4-carene, hexanal, <i>b</i> -pinene, limonene, 1-hexanol   |
| <b>(Ohlsson, 2009)</b>                      | New Zealand            | Ben Hope, Magnus   | HS-SPME: 55°C – 20 min – PDMS fiber      | 2-methyl-3-buten-2-ol, methyl butanoate, ethyl butanoate, thujol, linalool, terpinene, <i>a</i> -terpineol, <i>p</i> -cymen-8-ol, eucalyptol, damascenone, <i>a</i> -cadinol  |
| <b>(Hempfling et al., 2013)<sup>a</sup></b> | Germany                | N.I.   | VE: 35°C – 2h at 1-10 mbar               | <i>trans</i> -2-hexenal, <i>trans</i> -2-hexen-1-ol, <i>cis</i> -3-hexen-1-ol, methyl butanoate, ethyl butanoate, 2-methylbut-3-en-2-ol, eucalyptol   |
| <b>(Jung et al., 2017)</b>                  | Germany<br>Deutenkofen | Titania, 8 Bona, Ben Sarek, Rosenthals, Silvergieters, Supernova, Tsema, Ometa         | VE: 35°C – 2h at 1-10 mbar               | 4-methoxy-2-methyl-2-butanethiol, <i>cis</i> -3-hexenal, ethyl butanoate, eucalyptol, oct-1-en-3-one, alkyl-substituted 3-methoxypyrazines  |
| <b>(Marsol-Vall et al., 2018)</b>           | Finland                | Mortti, Ola, Melahati and other crossing cultivar                                      | HS-SPME: 45°C – 30 min – triphasic fiber | undecane, eucalyptol, <i>cis</i> -rose-oxide, terpinolene, terpinen-4-ol, <i>a</i> -terpineol   |
| <b>(Jung, 2018)<sup>a</sup></b>             | Germany                | Andega, 8 Bona, Ben Sarek, Rosenthals, Silvergieters, Supernova, Titania, Tsema, Ometa | VE: 35°C – 2h at 1-10 mbar               | <i>trans</i> -2-hexenal, <i>cis</i> -3-hexenal, ethyl butanoate, methyl butanoate, 3-carene, <i>b</i> -phellandrene, sabinene, terpinen-4-ol, 2-methylbut-3-en-2-ol   |
| <b>(Liu et al., 2018)</b>                   | China                  | Risagar, Fertodi, Brodorp, Sofya, Yadrionaya, Liangye                                  | HS-SPME: 40°C – 30 min – triphasic fiber | butyric acid, hexanal, nonanal, <i>trans</i> -octenal, decanal, methyl 4-hydroxybenzoate, guaiacol, 4-vinylguaiacol, isoamyl acetate, hexyl acetate, <i>cis</i> -3-hexanol acetate, ethyl butanoate, ethyl hexanoate, methyl butanoate, heptanol, <i>trans</i> - <i>b</i> -damascenone, lilac alcohol D |

549

550 SE: solvent extraction, VE: vacuum-headspace extraction, DHS: dynamic headspace extraction, HS-SPME: solid-phase micro extraction of the headspace,  
551 N.I.: not indicated

552 <sup>a</sup> reference with GC-O or GC-sniffing results, <sup>b</sup> reference with sensory results

Table 2. Citation frequencies and descriptors of the main volatile compounds reported in the studied publications

*Aroma compounds are in white cells when reported between 10 and 20 times, in light grey cells when reported between 20 and 30 times, and in dark grey cells when reported more than 30 times.*

*Descriptors were taken from [www.thegoodscentscompany.com](http://www.thegoodscentscompany.com), unless otherwise specified. Descriptors in normal letters are for odor, in italic for flavor, and in capital letters for both odor and flavor.*

| <b>Compounds</b>                 | <b>CAS</b> | <b>Sensory descriptor</b>   |
|----------------------------------|------------|---|
| 3-carene                         | 13466-78-9 | CITRUS, TERPENIC, PINE, HERBAL, RESINOUS, phenolic, medicinal, <i>spicy</i>                   |
| eucalyptol                       | 470-82-6   | Balsamic * / EUCALYPTUS, CAMPHREOUS, MEDICINAL, herbal, <i>cooling</i>                        |
| terpinen-4-ol                    | 562-74-3   | WOODY, EARTHY, CITRUS, SPICY, musty, sweet, mentholic, <i>cooling, clove</i>                  |
| <i>g</i> -terpinene              | 99-85-4    | TERPENIC, LIME, OILY, TROPICAL, CITRUS, herbal, woody, <i>fruity</i>                          |
| <i>p</i> -cymene                 | 99-87-6    | TERPENIC, CITRUS, WOODY, SPICY, ORIGANO, fresh, cilantro, <i>rancid</i>                       |
| terpinolene                      | 586-62-9   | WOODY, CITRUS, fresh, pine, sweet, <i>terpenic, herbal</i>                                    |
| <i>b</i> -caryophyllene          | 87-44-5    | SPICY, WOODY, CLOVE, dry, <i>nutty, powdery, peppery, skin</i>                                |
| limonene                         | 138-86-3   | root * / citrus, herbal, terpenic, camphorated  |
| ethyl butanoate                  | 105-54-4   | Fruity * / FRUITY, TUTTI FRUTTI, SWEET, juicy, pineapple, cognac, <i>fresh, apple</i>         |
| myrcene                          | 123-35-3   | WOODY, spicy, peppery, terpenic, balsamic, herbal, rose, <i>vegetable, tropical, minty</i>    |
| <i>α</i> -pinene                 | 80-56-8    | WOODY, PINE, CAMPHOREOUS, HERBAL, TERPENIC, earthy, <i>tropical</i>                           |
| methyl butanoate                 | 623-42-7   | FRUITY, FUSEL, DAIRY, ESTERY, sweet, fermented, pungent, tropical, <i>acidic</i>              |
| <i>α</i> -phellandrene           | 99-83-2    | TERPENIC, CITRUS, GREEN, woody, black pepper, <i>fresh</i>                                    |
| <i>α</i> -terpinene              | 99-86-5    | WOODY, TERPENIC, CITRUS, SPICY, herbal, medicinal, camphorated, <i>pine, minty</i>            |
| hexanal                          | 66-25-1    | GREEN, GRASSY, FRESH, VEGETABLE, leafy, fruity, <i>citrus, apple</i>                          |
| <i>trans</i> -2-hexen-1-ol       | 928-95-0   | FRUITY, GREEN, FRESH, LEAFY, vegetable, banana, <i>fatty, juicy</i>                           |
| <i>cis</i> -3-hexen-1-ol         | 928-96-1   | GREEN, FRESH, PUNGENT, grassy, vegetable, melon, rind, <i>fruity</i>                          |
| sabinene                         | 3387-41-5  | WOODY, SPICY, CAMPHOREOUS, terpenic, citrus, pine, green, oily                                |
| <i>β</i> -pinene                 | 127-91-3   | PINE, WOODY, RESINOUS, SPICY, MINTY, CAMPHOREOUS, TERPENIC, hay                               |
| <i>β</i> -phellandrene           | 555-10-2   | minty, terpenic   |
| <i>trans</i> -2-hexenal          | 6728-26-3  | apple ** / GREEN, FRUITY, LEAFY, FRESH, cheesy, spicy, aldehydic, <i>vegetable</i>            |
| <i>α</i> -terpineol              | 98-55-5    | CITRUS, FLORAL, WOODY, terpenic, lilac, pine, cooling, <i>soapy</i>                           |
| nonanal                          | 124-19-6   | ALDEHYDIC, CITRUS, FATTY, CUCUMBER, waxy, fresh, rose, iris, <i>nutty, potato</i>             |
| hexanol                          | 111-27-3   | GREEN, FRUITY, OILY, ethereal, sweet, alcoholic, herbal, <i>fruity, apple</i>                 |
| <i>p</i> -cymen-8-ol             | 1197-01-9  | FRUITY, CHERRY, SWEET, camphorated, floral, coumarinic, <i>hay, cereal, bready</i>            |
| methyl hexanoate                 | 106-70-7   | FRUITY, PINEAPPLE, ethereal, <i>fatty, apple, apricot</i>                                     |
| <i>trans</i> - <i>b</i> -ocimene | 3779-61-1  | herbal, sweet   |
| bornyl acetate                   | 76-49-3    | WOODY, CAMPHOREOUS, MENTHOLIC, cedar, spicy, <i>berry, seedy, soapy</i>                       |
| linalool                         | 78-70-6    | Floral * / FLORAL, CITRUS, WOODY, WAXY, blueberry, terpenic, <i>aldehydic</i>                 |
| methyl benzoate                  | 93-58-3    | PHENOLIC, CHERRY, CAMPHOREOUS, almond, floral, cananga  |
| decanal                          | 112-31-2   | citrus *** / WAXY, CITRUS, ORANGE, PEEL, sweet, aldehydic, floral, <i>green, melon</i>        |
| 2-methyl-3-buten-2-ol            | 115-18-4   | herbal, earthy, oily  |
| citronellyl acetate              | 150-84-5   | FLORAL, GREEN, FRUITY, WAXY, citrus, woody, <i>aldehydic, pear, apple</i>                     |
| ethyl benzoate                   | 93-89-0    | SWEET, WINTERGREEN, FRUITY, dry, musty, medicinal, cherry, <i>minty, green</i>                |
| methyl octanoate                 | 111-11-5   | GREEN, WAXY, CITRUS, ALDEHYDIC, vegetal, herbal, <i>fatty, fruity</i>                         |
| ethyl octanoate                  | 106-32-1   | WAXY, FRUITY, SWEET, PINEAPPLE, CREAMY, banana, musty, brandy, <i>fatty, mushroom, cognac</i> |

|                         |            |  |
|-------------------------|------------|--|
| ethyl hexanoate         | 123-66-0   | SWEET, FRUITY, PINEAPPLE, WAXY, GREEN, BANANA, ESTERY, fatty                         |
| pentanol                | 71-41-0    | FUSEL, FERMENTED, BREADY, oily, balsamic, winey, solvent, <i>fruity, cereal</i>      |
| <i>a</i> -caryophyllene | 6753-98-6  | woody, spicy   |
| benzaldehyde            | 100-52-7   | ALMOND, CHERRY, SWEET, NUTTY, bitter, powdery, maraschino, <i>oily, woody</i>        |
| heptanol                | 111-70-6   | GREEN, musty, leafy, fruity, peony, banana, <i>fermented, aldehydic, oily, nutty</i> |
| <i>cis-b</i> -ocimene   | 3338-55-13 | FLORAL, warm, herbal, sweet, <i>green, tropical, spicy, woody</i>                    |
| sabinene hydrate        | 546-79-2   | MINTY, GREEN, COOLING, terpenic, eucalyptus, spicy, <i>camphorated, oily, woody</i>  |

*\*(Latrasse et al., 1982), \*\* (Hempfling et al., 2013), \*\*\*(Jung et al., 2017)*

Table 3. Codes of factors used for figure 4 and table 4

| <b>Factors</b>      | <b>Whole name (code)</b>   |
|---------------------|--|
| <b>Cultivars</b>    | Brödtorp (Bro), BC-group (BCg), BenLoyal (Bly), BenNevis (BNe), Cie5-32 (C32), Cie5-63 (C63), Kristin (Kri), Pasille-group (PaG), Sunniva (Sun), Tenah (Teh), Wellington XXX (Wel), Silvergieters Zwarte (Sil), Cotswold Cross (Cos), WellingtonXXX x Brödtorp (WxB), Cotswold Cross x Brödtorp (CxB), English blackcurrant varieties mix (NiE), Noir de Bourgogne (NB), Royal de Naples (RN), Ben Lomond (BLo), Öjeby (Obj), Géant de Boskoop (GBo), Malvern Cross (MCR), Davison's eight (Da8), Golubka (Gol), Ben Tirran (BTi), Ben Dorian (BDo), Hedda (Hdd), Ben Avon (BAv), black currant, from north America (NiA), NI (NI), Titania (Tit), Ben Hope (BHo), Magnus (Mag), Mortti (Mor), Ola (Ola), Melahati (Mel), Andega (And), 8 Bona (8Bo), Ben Sarek (BSa), Rosenthals (Ros), Supernova (Sup), Tsema (Tse), Ometa (Ome), Risagar (Ris), Fertodi (Fer), Sofya (Sof), Yadrionaya (Yad), Liangye (Lia) |
| <b>Countries</b>    | Sweden (Swe), UK (UK), France (Fra), Finland (Fin), Denmark (Den), Scotland (Sco), Estonia (Est), Germany (Ger), New Zealand (NZ), China (Chi)   |
| <b>Storage</b>      | Frozed (Fro), Unfrozed (UFR)   |
| <b>Samples type</b> | Whole (Who), Crushed (Cru), Juice (Jui), Concentrated juice (Con)  |
| <b>Publications</b> | Andersson and von Sydow 1964 (A64), Andersson and von Sydow 1966a (A66a), Andersson and von Sydow 1966b (A66b), Nursten and Williams 1969 (N69), Latrasse et al. 1982 (L82), Marriott 1986 (M87), Leino and Kallio 1993 (L93), Iversen et al. 1998 (I98), Ruiz del Castillo and Dobson 2002 (C02), Orav et al. 2002 (O02), Mikkelsen and Poll 2002 (M02), Varming et al. 2004a (V04), Varming et al. 2004 (V04b), Bagger-Jørgensen et al. 2004 (B04), Tiitinen et al. 2004 (T04), Christensen and Pedersen 2006 (C06), Harb et al. 2008 (H08), Ohlsson 2009 (O09), Hempfling et al. 2013 (H13), Jung et al. 2017 (J17), Marsol-Vall et al. 2018 (M18), Jung 2018 (J18), Liu et al. 2018 (L18)  |
| <b>Methods</b>      | Solvent extraction (SE), Vacuum extraction (VE), Purge and trap extraction (PT), SPME extraction (SP)  |
| <b>Columns</b>      | Low polarity (LPo), Medium polarity (MPo), High polarity (HPo)   |

Table 4. Correspondence between individuals and factors used for figure 4 and table 5

| <b>Individuals</b> | <b>Varieties</b> | <b>Countries</b> | <b>Storage</b> | <b>Sample type</b> | <b>Publications</b> | <b>Methods</b> | <b>Columns</b> |
|--------------------|------------------|------------------|----------------|--------------------|---------------------|----------------|----------------|
| <b>1</b>           | Bro              | Swe              | Fro            | Cru                | A64                 | SE             | HPo            |
| <b>2</b>           | Bro              | Swe              | Fro            | Cru                | A66a                | VE             | MPo            |
| <b>3</b>           | BTi              | Sco              | Fro            | Cru                | C02                 | SP             | LPo            |
| <b>4</b>           | BDo              | Sco              | Fro            | Cru                | C02                 | SP             | LPo            |
| <b>5</b>           | Hdd              | Sco              | Fro            | Cru                | C02                 | SP             | LPo            |
| <b>6</b>           | BAv              | Sco              | Fro            | Cru                | C02                 | SP             | LPo            |
| <b>7</b>           | Hdd              | Sco              | Fro            | Who                | C02                 | SP             | LPo            |
| <b>8</b>           | Bly              | Den              | Fro            | Cru                | C06                 | PT             | HPo            |
| <b>9</b>           | BNe              | Den              | Fro            | Cru                | C06                 | PT             | HPo            |
| <b>10</b>          | C32              | Den              | Fro            | Cru                | C06                 | PT             | HPo            |
| <b>11</b>          | C63              | Den              | Fro            | Cru                | C06                 | PT             | HPo            |
| <b>12</b>          | Kri              | Den              | Fro            | Cru                | C06                 | PT             | HPo            |
| <b>13</b>          | Sun              | Den              | Fro            | Cru                | C06                 | PT             | HPo            |
| <b>14</b>          | Tse              | Den              | Fro            | Cru                | C06                 | PT             | HPo            |
| <b>15</b>          | Tit              | Ger              | Fro            | Cru                | H08                 | SP             | HPo            |
| <b>16</b>          | BLo              | Den              | Fro            | Con                | I98                 | PT             | HPo            |
| <b>17</b>          | Ros              | Ger              | Fro            | Cru                | J17                 | VE             | HPo            |
| <b>18</b>          | Tit              | Ger              | Fro            | Cru                | J18                 | VE             | HPo            |
| <b>19</b>          | Sup              | Ger              | Fro            | Cru                | J18                 | VE             | HPo            |
| <b>20</b>          | Sup              | Ger              | UFr            | Cru                | J18                 | VE             | HPo            |
| <b>21</b>          | Teh              | Ger              | UFr            | Cru                | J18                 | VE             | HPo            |
| <b>22</b>          | Teh              | Ger              | Fro            | Cru                | J18                 | VE             | HPo            |
| <b>23</b>          | 8Bo              | Ger              | Fro            | Cru                | J18                 | VE             | HPo            |
| <b>24</b>          | BSa              | Ger              | Fro            | Cru                | J18                 | VE             | HPo            |
| <b>25</b>          | Ome              | Ger              | Fro            | Cru                | J18                 | VE             | HPo            |
| <b>26</b>          | Obj              | Fin              | Fro            | Jui                | L93                 | PT             | MPo            |
| <b>27</b>          | Bro              | Chi              | Fro            | Jui                | L18                 | SP             | HPo            |
| <b>28</b>          | Sof              | Chi              | Fro            | Jui                | L18                 | SP             | HPo            |
| <b>29</b>          | Yad              | Chi              | Fro            | Jui                | L18                 | SP             | HPo            |
| <b>30</b>          | Lia              | Chi              | Fro            | Jui                | L18                 | SP             | HPo            |
| <b>31</b>          | Ris              | Chi              | Fro            | Jui                | L18                 | SP             | HPo            |
| <b>32</b>          | Fer              | Chi              | Fro            | Jui                | L18                 | SP             | HPo            |
| <b>33</b>          | BLo              | UK               | UFr            | Cru                | M87                 | SE             | LPo            |
| <b>34</b>          | Wel              | UK               | UFr            | Cru                | M87                 | SE             | LPo            |
| <b>35</b>          | Mor              | Fin              | Fro            | Cru                | M18                 | SP             | LPo            |
| <b>36</b>          | BLo              | Den              | Fro            | Jui                | M02                 | PT             | HPo            |
| <b>37</b>          | NiE              | UK               | UFr            | Con                | N69                 | SE             | LPo            |
| <b>38</b>          | BCg              | NZ               | Fro            | Jui                | O09                 | SP             | LPo            |
| <b>39</b>          | PaG              | NZ               | Fro            | Jui                | O09                 | SP             | LPo            |
| <b>40</b>          | NI               | Est              | UFr            | Cru                | O02                 | SE             | LPo            |
| <b>41</b>          | NI               | Fin              | Fro            | Cru                | T04                 | SP             | LPo            |
| <b>42</b>          | BLo              | Den              | Fro            | Jui                | V04b                | PT             | HPo            |

|           |     |     |     |     |      |    |     |
|-----------|-----|-----|-----|-----|------|----|-----|
| <b>43</b> | BLo | Den | Fro | Jui | V04b | PT | HPo |
| <b>44</b> | BLo | Den | Fro | Jui | V04b | PT | HPo |
| <b>45</b> | BLo | Den | Fro | Jui | V04b | SE | HPo |
| <b>46</b> | BLo | Den | Fro | Jui | V04a | PT | HPo |

Table 5. Comparison and interpretation of NMDS and MFA+HCPC data analyses

Individuals in color are regrouped in the same cluster whatever the multivariate analysis

| Multivariate analysis | Cluster    | Individuals                           | Characteristics of the cluster  |
|-----------------------|------------|---------------------------------------|---|
| MFA + HCPC            | a          | 1-12-31-32-33-34-35-36                | Molecules: rich in ethyl butanoate, phellandrene, terpinen-4-ol/ poor in <i>α</i> -terpinene, myrcene, limonene, <i>b</i> -caryophyllene<br>Varieties concerned: Ojeby, Fertodi, Yadrionaya, Sofya, Risagar, Liangye  |
|                       | b          | 3-5-7-8-9-11-29-30-37-39              | Molecules: rich in ethyl butanoate, phellandrene, terpinen-4-ol/ poor in <i>α</i> -terpinene, myrcene, limonene, <i>b</i> -caryophyllene<br>Varieties concerned: Liangye, Ben Lomond  |
|                       | c          | 13-25-26-27-28-38                     | Molecules: rich in <i>b</i> -caryophyllene, <i>α</i> -terpinene/ poor in ethyl butanoate, methyl butanoate<br>Varieties concerned : Ben tiran, Hedda, Ben Avon  |
|                       | d          | 2-4-10-14-15-22-23-41-44              | Molecules: rich in <i>cis</i> - <i>b</i> -ocimene, <i>trans</i> - <i>b</i> -ocimene, 3-carene, terpinolene/ poor in eucalyptol, <i>b</i> -caryophyllene, <i>α</i> -terpineol, terpinolen-4-ol<br>Varieties concerned: Tenah, Ben Nevis, Wellington, Kristin |
|                       | e          | 6-16-17-18-19-20-21-24-40-42-43-45-46 | Poor graphical representation, it is not possible to draw conclusion  |
| NMDS                  | $\alpha$   | 25-26-27-28-38                        | Molecules: rich in <i>α</i> -terpinene, <i>g</i> -terpene, <i>p</i> -cymene, <i>α</i> -terpinolene ( <i>b</i> -caryophyllene)/ poor in methyl and ethylbutanoate<br>Chemical family: poor in aldehydes  |
|                       | $\beta$    | 4-10-14                               | Molecules: rich in <i>α</i> -pinene, limonene, terpinene, myrcene<br>Chemical family : rich in terpene<br>Odor: poor in alcoholic, fermented, and dairy notes   |
|                       | $\chi$     | (1-5)-31-32-33-34-35                  | Molecules: poor in 3-carene, <i>cis</i> and <i>trans</i> - <i>b</i> -ocimene, phellandrene<br>Chemical family : rich in acids, terpenoids and alcohol<br>Odor: rich in nuts and fermented notes   |
|                       | $\delta$   | 39                                    | Molecules: poor in <i>α</i> -pinene, limonene, terpinene, myrcene<br>Chemical family : rich in ketones  |
|                       | $\epsilon$ | 15- (22)-23-40-41-44-45               | Molecules: rich in sabinene, 3-carene, phellandrene, <i>cis</i> and <i>trans</i> - <i>b</i> -ocimene, methyl and ethyl butanoate<br>Chemical family : rich in aldehydes   |

φ

8-9-12-36

Molecules: poor in  $\alpha$ -pinene, limonene, terpinene, myrcene  
Chemical family : rich in esters  
Odor : rich in fermented, alcoholic, oily, fruity, and dairy notes

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## Figure captions

Figure 1: Flowchart for the methodology of the meta-analysis

Figure 2: Mind-map overview of differences in study parameters of the reviewed studies.

Figure 3: Main flavor compounds reported for Blackcurrant berries

(Among the 351 molecules reported in the different publications, these 21 compounds were reported with the highest contents for at least 10 varieties upon 36). Error bars correspond to standard deviation.

Figure 4: MFA: graphs of individuals. 4a: dimensions 1 x 2 - 4b: dimensions 1 x 3

Figure 5: MFA graphs of variables and plots of the groups of variables

5a: dimensions 1 x 2 - 5b: dimensions 1 x 3

Correspondence of codes for correlation circles

M.t4o = terpinen-4-ol, M.ebu = ethyl butanoate, M.lim = limonene, M.eca = eucalyptol, M.ter = terpinolene, M.3ca = 3-carene, M.mbu = methyl butanoate, M.myr = myrcene, M.cib = *cis*-*b*-ocimene, M.ato = *α*-terpineol, M.gtp = *g*-terpinene, M.sab = sabinene, M.api = *α*-pinene, M.trb = *trans*-*b*-ocimene, M.phl = *b*-phellandrene, M.atp = *α*-terpinene, M.pcy = *p*-cymene, M.bca = *b*-caryophyllene.

Correspondence of codes for groups' representation

Quali = qualitative variables (supplementary variable), Famy = chemical family, Mole = volatile molecules, Odor = odor description.

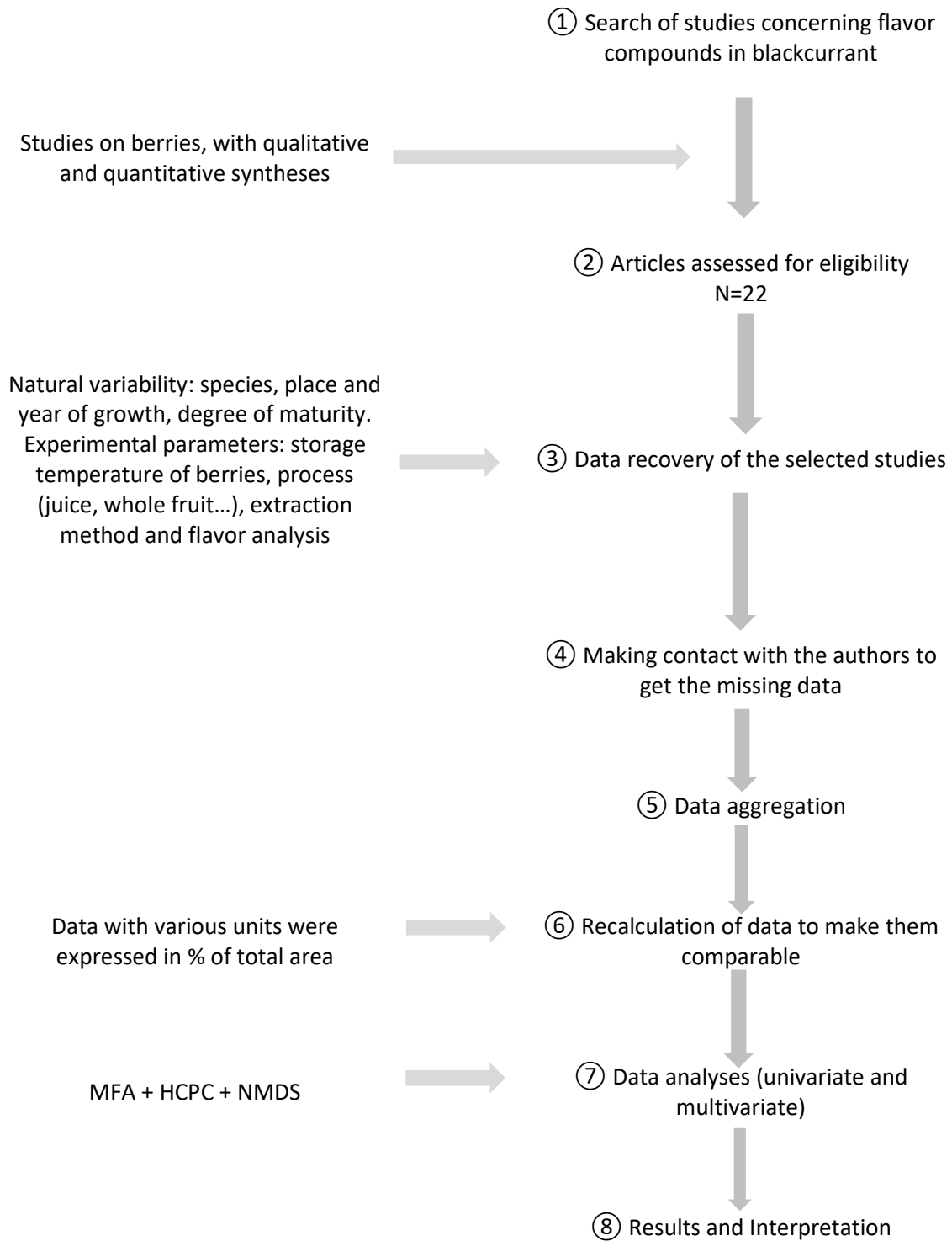


Figure 1.

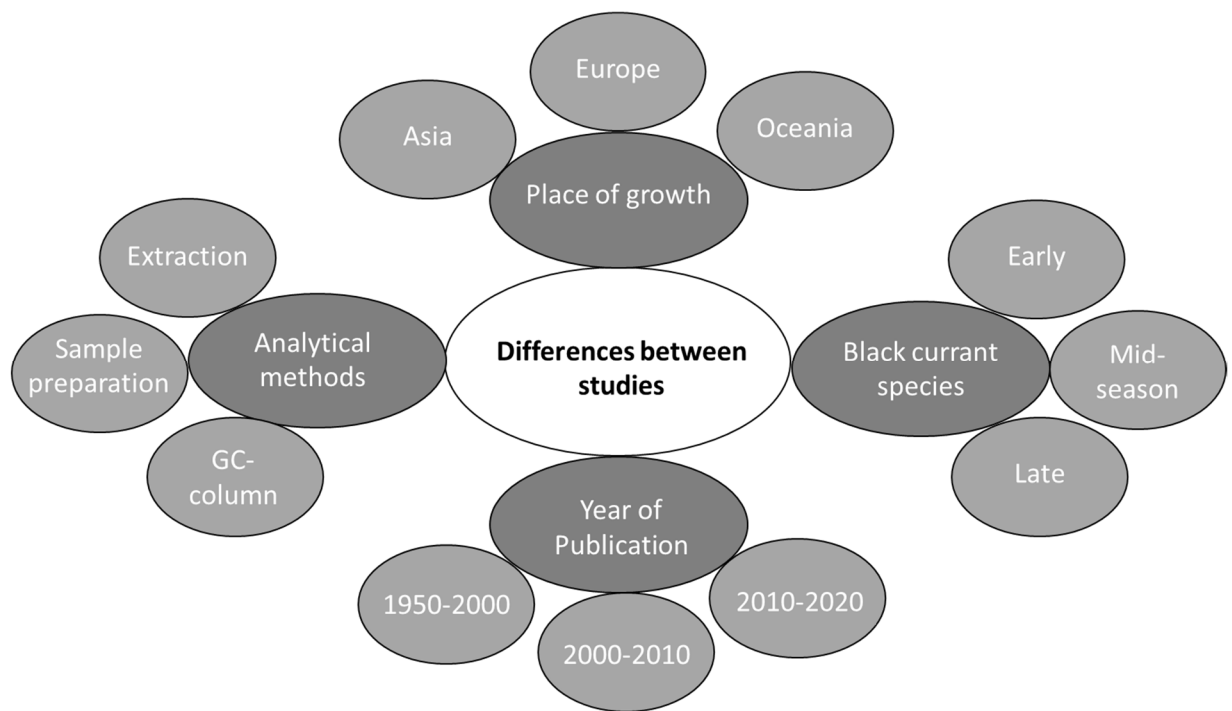


Figure 2.

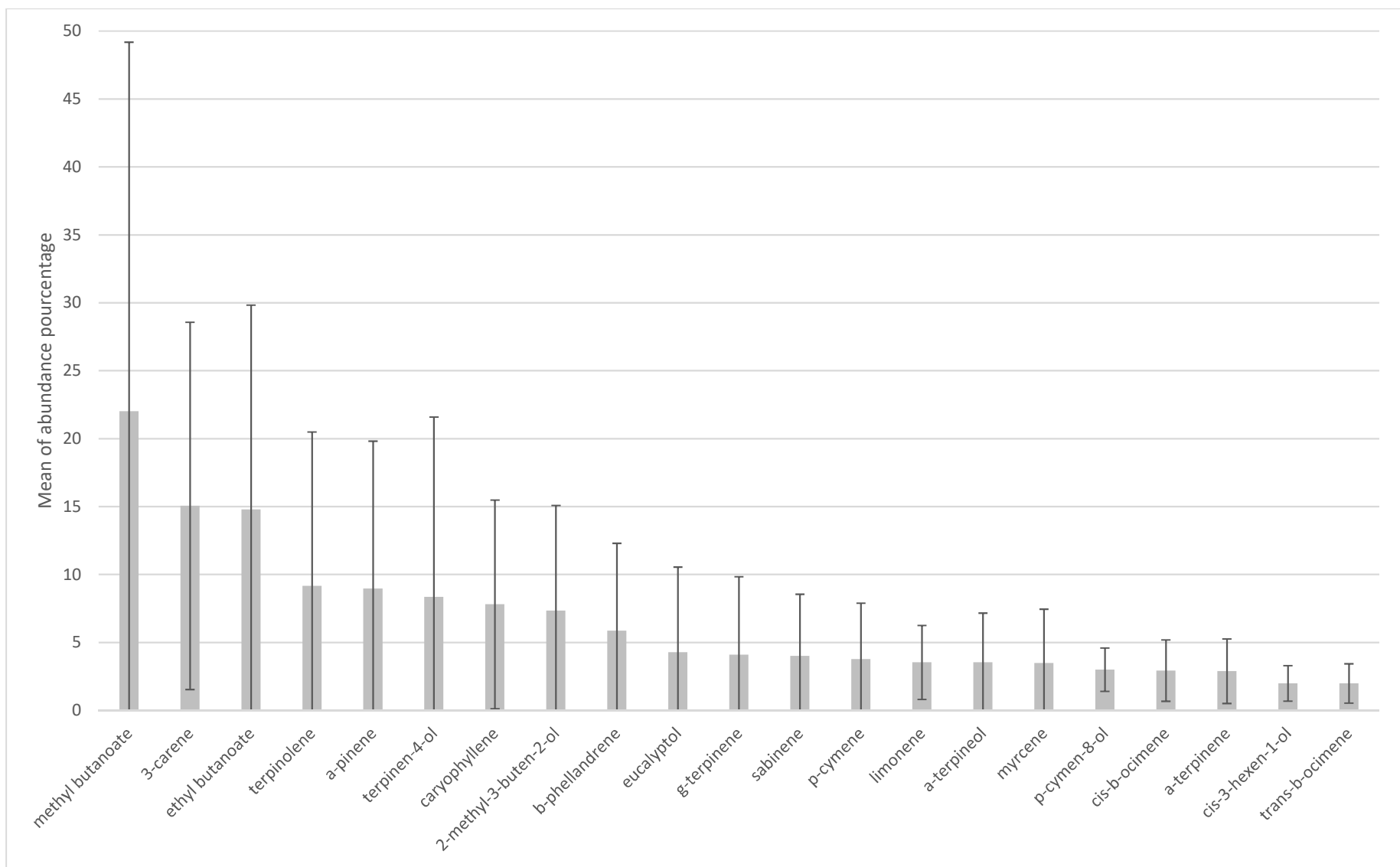


Figure 3.

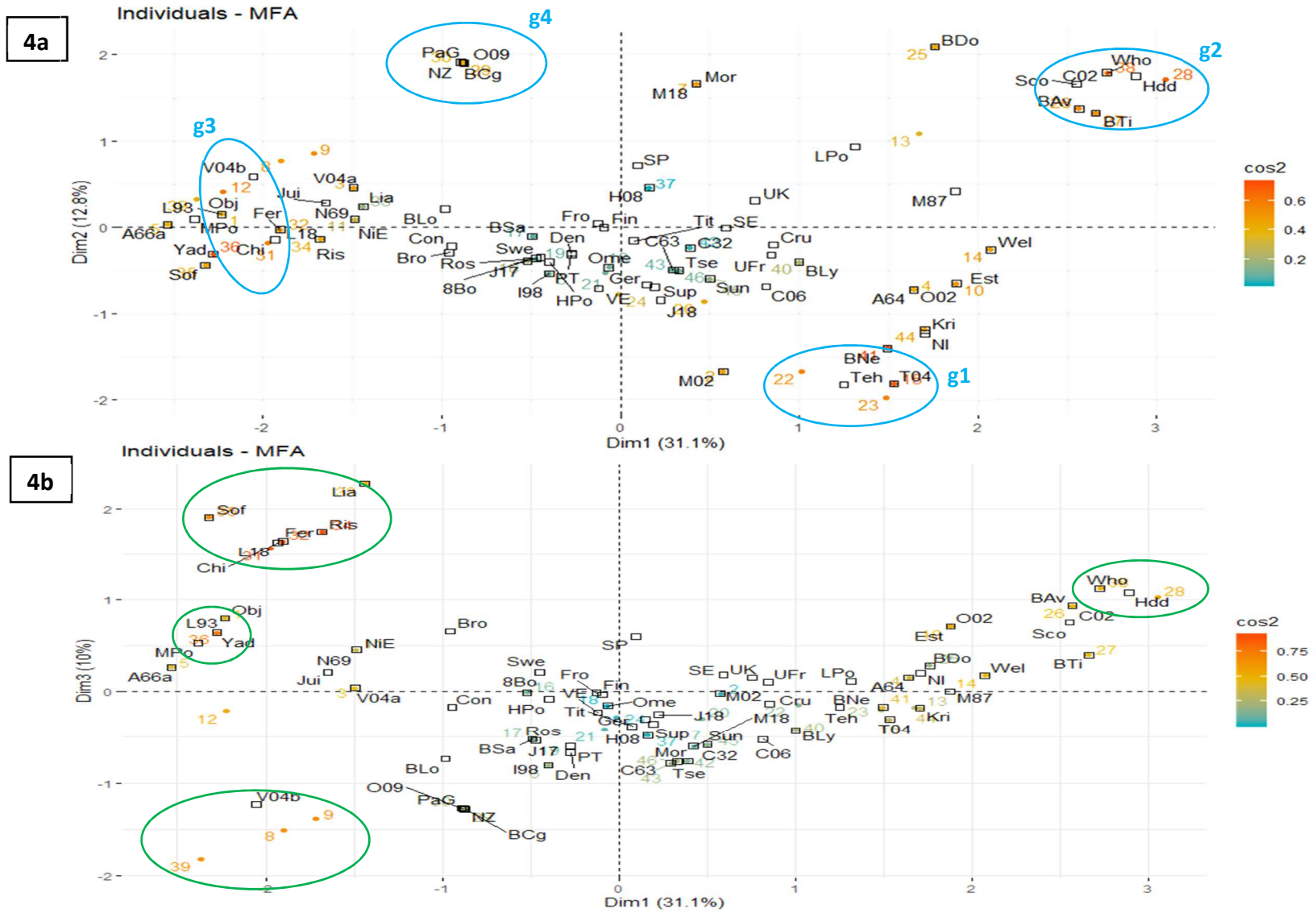
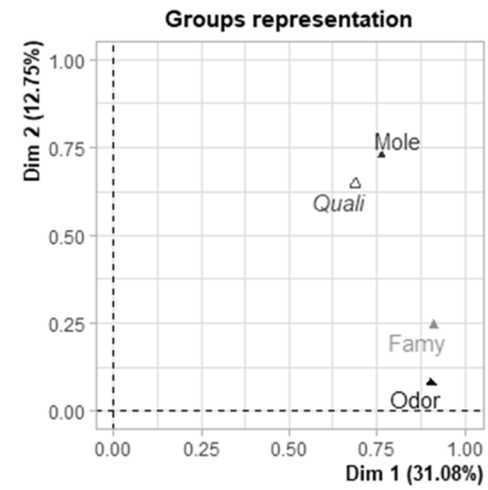
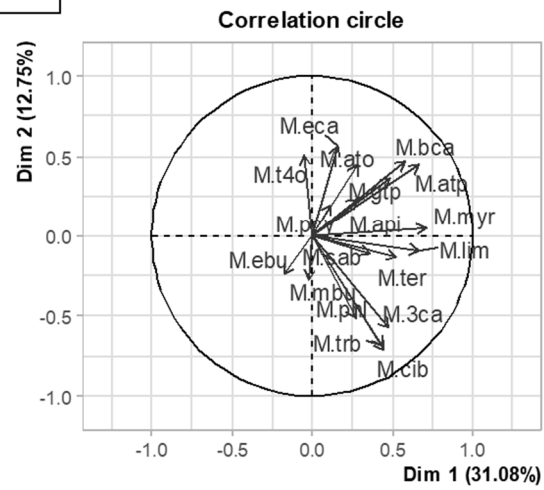


Figure 4.

5a



5b

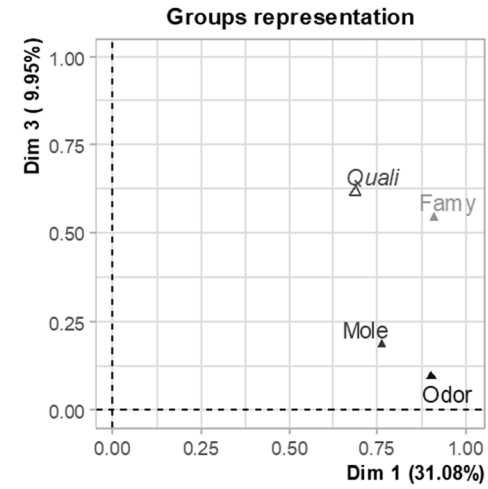
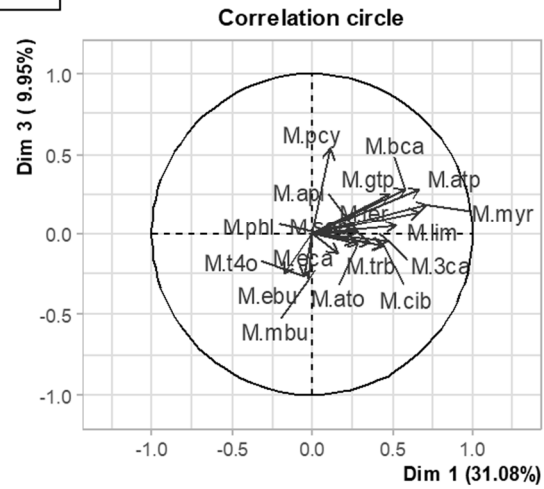


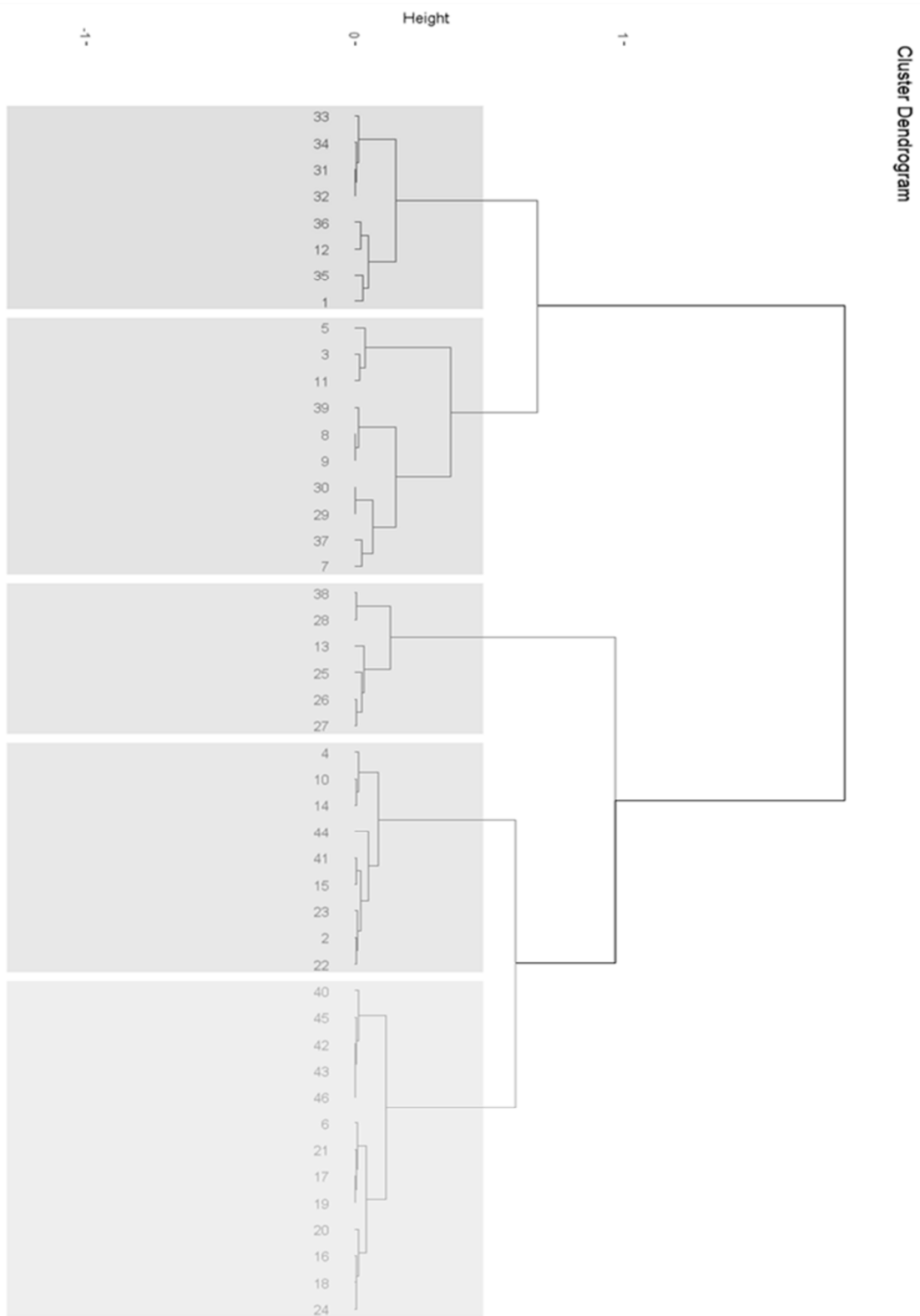
Figure 5.

## Appendices

**Table A.1.**

Odor descriptors regrouped by categories on the basis of personal knowledge and definitions from (\*) (Zarzo, 2013) and (\*\*)(De Rovira, 1999)

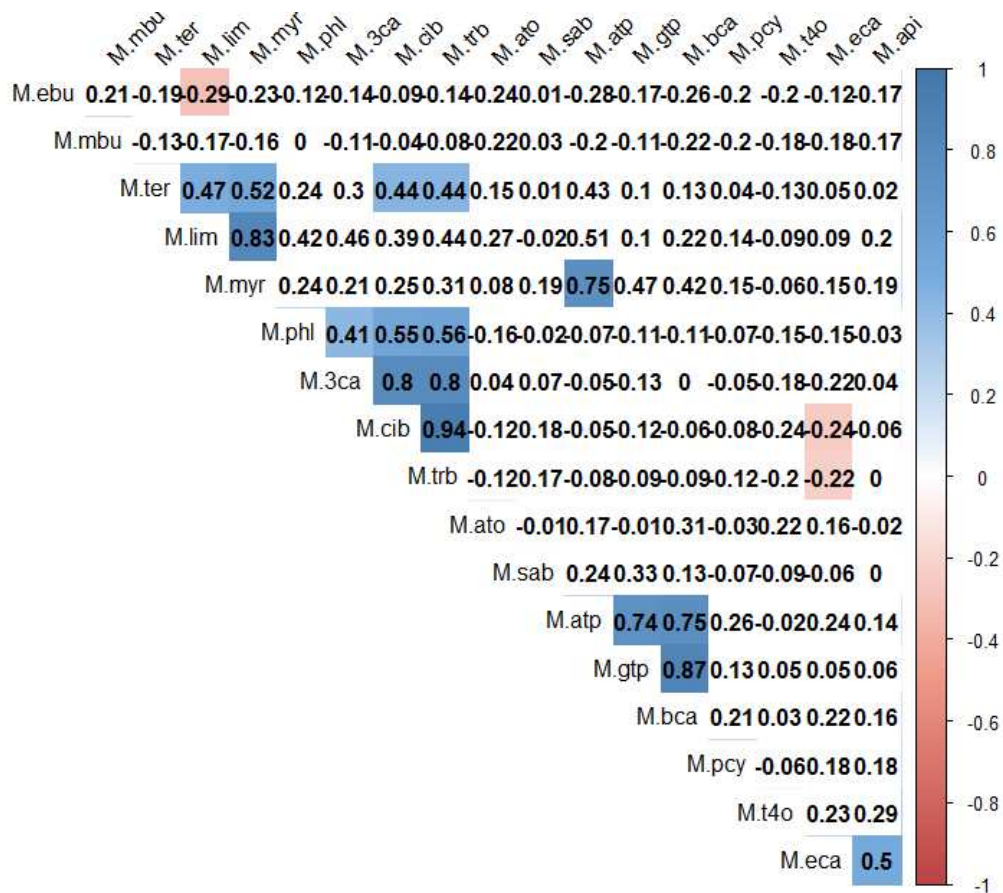
| <b>Category</b>               | <b>Descriptors</b>  |
|-------------------------------|---|
| <b>Citrus</b>                 | Citrus, orange, lemon, petit-grain, lime, peel**, rind                                    |
| <b>Green</b>                  | Green, herbal, leafy, grassy, cucumber  |
| <b>Spicy</b>                  | Spicy, clove, thyme, pepper, cilantro, oregano, cumin, caraway, licorice                  |
| <b>Woody</b>                  | Woody, pine, cypress, cedar, resinous, balsamic*, powdery*                                |
| <b>Dairy</b>                  | Dairy, buttery, milky, cheesy, butyric, creamy  |
| <b>Floral</b>                 | Floral, violet, lilac, rose, geranium, vanilla, soapy, iris, coumarin**, cananga**, honey |
| <b>Minty</b>                  | Minty, fresh, eucalyptus, camphorated, cooling, medicinal, wintergreen                    |
| <b>Alcohol</b>                | Alcohol, winey, cognac, fusel*, maraschino  |
| <b>Fermented</b>              | Fermented, spoiled, bready, yeast   |
| <b>Nutty</b>                  | Nutty, marzipan, almond, walnut, peanut, cereal**, seed**, cocoa                          |
| <b>Cooked</b>                 | Cooked, burnt, roasted, smoky, cooked meat, coffee, caramel                               |
| <b>Fruity</b>                 | Fruity, apple, berry, grape, plum, pear, apricot, juicy, tutti fruity, melon, cherry      |
| <b>Lipid</b>                  | Lipid, fatty, gassy, rancid, oily, frying, waxy   |
| <b>Tropical</b>               | Tropical, pineapple, banana, mango, lychee, coconut                                       |
| <b>Vegetable</b>              | Vegetable, cabbage, onion, garlic, beany, cauliflower, tea, hay, horseradish, potato      |
| <b>Earthy</b>                 | Earthy, moody, dirty, tobacco, root, beetroot, mushroom, musty                            |
| <b>Chemical</b>               | Chemical, solvent, ethereal, aldehydic, estery, phenolic, vitamin, terpenic               |
| <b>Taste &amp; trigeminal</b> | Warm, acidic, sour, pungent, bitter, dry**, Sweet   |



**Figure A.1.**

Dendrogram generated by the hierarchical clustering on principal components (HCPC) showing the different groups of individuals





**Figure A.2.**

Matrix of correlations showing significant p-values

(M.bca/M.atp = 0 / 0.75; M.cib/M.3ca = 0 / 0.8; M.3ca/M.trb = 0 / 0.8; M.cib/M.trb = 0 / 0.94).