## Metabolomic Data Analysis with MetaboAnalyst 5.0

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### 1 Background

MSEA or Metabolite Set Enrichment Analysis is a way to identify biologically meaningful patterns that are significantly enriched in quantitative metabolomic data. In conventional approaches, metabolites are evaluated individually for their significance under conditions of study. Those compounds that have passed certain significance level are then combined to see if any meaningful patterns can be discerned. In contrast, MSEA directly investigates if a set of functionally related metabolites without the need to preselect compounds based on some arbitrary cut-off threshold. It has the potential to identify subtle but consistent changes among a group of related compounds, which may go undetected with the conventional approaches.

Essentially, MSEA is a metabolomic version of the popular GSEA (Gene Set Enrichment Analysis) software with its own collection of metabolite set libraries as well as an implementation of user-friendly web-interfaces. GSEA is widely used in genomics data analysis and has proven to be a powerful alternative to conventional approaches. For more information, please refer to the original paper by Subramanian A, and a nice review paper by Nam D, Kim SY. <sup>1</sup>. <sup>2</sup>

#### 2 MSEA Overview

Metabolite set enrichment analysis consists of four steps - data input, data processing, data analysis, and results download. Different analysis procedures are performed based on different input types. In addition, users can also browse and search the metabolite set libraries as well as upload their self-defined metabolite sets for enrichment analysis. Users can also perform metabolite name mapping between a variety of compound names, synonyms, and major database identifiers.

### 3 Data Input

There are three enrichment analysis algorithms offered by MSEA. Accordingly, three different types of data inputs are required by these three approaches:

- A list of important compound names entered as a one column data (Over Representation Analysis (ORA));
- A single measured biofluid (urine, blood, CSF) sample- entered as tab separated two-column data with the first column for compound name, and the second for concentration values (Single Sample Profiling (SSP));

 $<sup>^1</sup>$ Subramanian Gene set enrichment analysis: A knowledge-based approach for interpreting genome-wide expression profiles., Proc Natl Acad Sci USA. 2005 102(43): 15545-50

<sup>&</sup>lt;sup>2</sup>Nam D, Kim SY. Gene-set approach for expression pattern analysis, Briefings in Bioinformatics. 2008 9(3): 189-197.

• A compound concentration table - entered as a comma separated (.csv) file with the each sample per row and each metabolite concentration per column. The first column is sample names and the second column for sample phenotype labels (Quantitative Enrichment Analysis (QEA))

You selected Over Representation Analysis (ORA) which requires a list of compound names as input.

# 4 Data Process

The first step is to standardize the compound labels. It is an essential step since the compound labels will be subsequently compared with compounds contained in the metabolite set library. MSEA has a built-in tool to convert between compound common names, synonyms, identifiers used in HMDB ID, PubChem, ChEBI, BiGG, METLIN, KEGG, or Reactome. **Table 1** shows the conversion results. Note: 1 indicates exact match, 2 indicates approximate match, and  $\theta$  indicates no match. A text file contain the result can be found the downloaded file  $name\_map.csv$ 

	Query	Match
1	HMDB0000123	Glycine
2	HMDB0014691	Acetohydroxamic Acid
3	HMDB0031239	Ethyl nitrite
4	HMDB0161401	NA
5	HMDB0000925	Trimethylamine N-oxide
6	HMDB0142449	NA
7	HMDB0140038	NA
8	HMDB0012136	1-Amino-propan-2-ol
9	HMDB0062143	NA
10	HMDB0031558	Methyloxirane
11	HMDB0031652	Allyl alcohol
12	HMDB0003366	Propanal
13	HMDB0001659	Acetone
14	HMDB0144632	NA
15	HMDB0062140	NA
16	HMDB0034203	N-(2-Methylpropyl)acetamide
17	HMDB0031651	N-(3-Methylbutyl)acetamide
18	HMDB0062041	NA
19	HMDB0012296	Trimethylaminoacetone
20	HMDB0031404	Cyclohexylamine
21	HMDB0032416	2-Methylpiperidine
22	HMDB0031544	3-Methylcyclopentene
23	HMDB0062716	NA
24	HMDB0033971	2-Diethylaminoethanol
25	HMDB0002994	Erythritol
26	HMDB0004136	D-Threitol
27	HMDB0094689	NA
28	HMDB0165469	NA
29	HMDB0165470	NA
30	HMDB0062640	NA
31	HMDB0126088	NA
32	HMDB0000710	4-Hydroxybutyric acid
33	HMDB0000442	(S)-3-Hydroxybutyric acid
34	HMDB0000357	3-Hydroxybutyric acid
35	HMDB0000336	(R)-3-Hydroxyisobutyric acid
36	HMDB0000011	(R)-3-Hydroxybutyric acid
37	HMDB0000023	(S)-3-Hydroxyisobutyric acid
38	HMDB0000729	Alpha-Hydroxyisobutyric acid
39	HMDB0031212	Ethoxyacetic acid
40	HMDB0059748	NA
41	HMDB0000008	2-Hydroxybutyric acid
42	HMDB0015507	Gamma Hydroxybutyric Acid
43	HMDB0000630	Cytosine
44	HMDB0031335	2-Chloro-1-propanol
45	HMDB0061966	NA
46	HMDB0062141	NA
47	HMDB0013716	Norvaline
48	HMDB0003355	5-Aminopentanoic acid
49	HMDB0001382	Vaporole
50	HMDB0002141	N-Methyl-a-aminoisobutyric acid
51	HMDB0002111	Amyl Nitrite
52	HMDB0000883	L-Valine
53	HMDB0000009	Glutaral
54	HMDB0025555 HMDB0000509	Senecioic acid
55	HMDB0000303	Tiglic acid
56	HMDB0001470	2-Ethylacrylic acid
57	HMDB0001802	3-Methylbutyrolactone
58	HMDB0002107	2,4-Pentanedione
59	HMDB0031040	Dihydro-5-methyl-2(3H)-furanone
0.0	111111111111111111111111111111111111111	z.m., aro o momy i-2(oii)-iaranone

```
HMDB0031178
 60
                       Dihydro-2-methyl-3(2H)-furanone
      HMDB0031602
                       4-Pentenoic acid
 61
      HMDB0031598
                       2,3-Pentanedione
 62
 63
      {\rm HMDB0033978}
                       Ethyl acrylate
 64
      {\rm HMDB0032385}
                       Methyl methacrylate
      HMDB0029608
 65
                       Angelic acid
      HMDB0032351
                       Isopropenyl acetate
 66
 67
      HMDB0035143
                       Dihydro-3-methyl-2(3H)-furanone
      {\rm HMDB0032459}
 68
                       2-Pentenoic acid
 69
      {\rm HMDB0180166}
 70
      {\rm HMDB0170858}
                       NA
 71
      HMDB0132474
HMDB0129418
                       NA
 \frac{72}{73}
                       NΑ
      HMDB0130837
                       NA
 74
      HMDB0149276
                       NA
      {\rm HMDB0163712}
                       NA
 75
 76
      HMDB0163713
                       NA
 77
78
      {\rm HMDB0163714}
                       NΑ
      HMDB0059606
                       NA
      HMDB0000043
 79
                       Betaine
      HMDB0039806
 80
                       NA
      HMDB0031431
                       Dipropyl sulfide
 82
      {\rm HMDB0029579}
                       Diisopropyl sulfide
 83
      HMDB0011601
                       3- \\ Methyl cytosine
      HMDB0004339
                       2-O-Methylcytosine
 84
      HMDB0002894
                       5-Methylcytosine
 85
      {\rm HMDB0172056}
 86
                       NA
      HMDB0172059
 87
                       NA
 88
      {\rm HMDB0172058}
                       NA
 89
      {\rm HMDB}0172057
                       NA
 90
      HMDB0159225
                       NA
      HMDB0159223
 91
                       NΑ
      HMDB0159222
                       NA
 92
      HMDB0159224
 93
                       NA
      HMDB0005785
                       Indole-3-carbinol
 95
      HMDB0030204
                       1-(2-Furanylmethyl)-1H-pyrrole
 96
      HMDB0040009
                       ΝÀ
      HMDB0040011
 97
                       NA
      HMDB0011664
                       3-Methylene-indolenine
 98
      HMDB0033731
 99
                       Quinoline
100
      HMDB0034244
                       Isoquinoline
101
      {\rm HMDB0161116}
                       NA
102
      {\rm HMDB0161115}
                       NΑ
103
      HMDB0163679
                       NA
      HMDB0061652
104
                       3-hydroxyhexanoic acid
105
      HMDB0171222
                       NA
      HMDB0165043
106
                       NA
107
      {\rm HMDB0165041}
                       NA
108
      {\rm HMDB0165042}
                       NA
      HMDB0163681
109
                       NA
      HMDB0163682
110
                       NA
      HMDB0163680
                       NA
111
112
      HMDB0000525
                       5-Hydroxyhexanoic acid
113
      HMDB0000624
                       D-Leucic acid
114
      HMDB0040409
      HMDB0000665
                       Leucinic acid
115
      HMDB0000746
                       Hydroxyisocaproic acid
116
      HMDB0001624
                       2-Hydroxycaproic acid
117
      HMDB0032158
                       (+/-)-1-Acetoxy-1-ethoxyethane
118
119
      HMDB0032456
                       Paraldehyde
                       \operatorname{2-Ethyl-\check{2-Hydroxybutyric}}acid
120
      HMDB0001975
121
      HMDB0033851
                       4,4-Dimethoxy-2-butanone
      HMDB0000409
                       (5R)-5-Hydroxyhexanoic acid
122
      HMDB0000317
                       2-Hydroxy-3-methylpentanoic acid
123
      HMDB0012843
                       6-Hydroxyhexanoic acid
124
      HMDB0059770
126
      HMDB0041844
                       NA
127
      HMDB0029166
                       2-Methyl-3-hydroxyvaleric acid
      HMDB0165040
128
                       NΑ
      HMDB0010718
                       (R)-3-Hydroxyhexanoic acid
129
      {\rm HMDB0062045}
130
                       ΝÁ
      HMDB0062118
                       NA
132
      HMDB0128943
                       NA
133
      {\rm HMDB0132477}
                       NA
134
      HMDB0129097
                       NΑ
      HMDB0168839
135
                       NΑ
      HMDB0128916
136
                       NA
137
      HMDB0012233
                       Glutarate semialdehyde
138
      HMDB0029172
                       3-keto-2-Methylbutyrate
139
      {\rm HMDB0001865}
                       2-Oxovaleric acid
      HMDB0000310
140
                       Methylacetoacetic acid
      HMDB0031643
                       Ethyl pyruvate
Alpha-ketoisovaleric acid
141
      HMDB0000019
142
      HMDB0003771
                       2-Methylacetoacetic acid
143
144
      HMDB0000720
                       Levulinic acid
145
      HMDB0034466
                       Acetoxyacetone
146
      HMDB0128917
                       NΑ
```

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HMDB0129096
147
                       NA
                       NA
148
      HMDB0129098
      HMDB0168838
149
                       NA
150
      {\rm HMDB}0177210
                       NA
151
      {\rm HMDB0169666}
                       NA
      HMDB0177209
HMDB0171727
152
                       NA
153
                       NA
      HMDB0032356
                       N-Lactovl ethanolamine
154
      HMDB0039499
155
156
      HMDB0031658
                       L-2-Amino-5-hydroxypentanoic acid
157
      {\rm HMDB0039790}
                       NA
158
      HMDB0038974
                       NA
      HMDB0039789
159
                       NΑ
      HMDB0000786
160
                       Oxypurinol
161
      HMDB0000292
                       Xanthine
      {\rm HMDB0001182}
                       6,8-Dihydroxypurine
162
163
      HMDB0000744
                       Malic acid
      HMDB0031518
HMDB0000156
                       D-Malic acid
L-Malic acid
164
165
      HMDB0032872
166
                       Velcorin
      HMDB0061971
167
                       NA
168
      HMDB0166738
                       NA
169
      {\rm HMDB0164724}
                       NA
170
      HMDB0165094
                       NA
      HMDB0165096
171
                       NA
      HMDB0165095
                       NA
172
      HMDB0165097
173
                       NA
      HMDB0166737
174
                       NA
175
      {\rm HMDB0031484}
                       2-Heptenoic acid
176
      {\rm HMDB0038962}
                       NA
                       Methyl 2E-hexenoate
      HMDB0031500
177
      HMDB0166739
178
                       NΑ
      HMDB0029314
179
                       Isopentenyl acetate
      HMDB0031477
                       3,4-Heptanedione
180
      {\rm HMDB0031476}
                       2,3-Heptanedione
181
182
      {\rm HMDB0031504}
                       Methyl (Z)-3-hexenoate
183
      HMDB0031603
                       Ethyl 4-pentenoate
      HMDB0040214
184
                       NA
      HMDB0031342
                       Cyclohexanecarboxylic acid
185
      HMDB0038271
186
      HMDB0031174
                       4-Methyl-5-hexanolide
188
      {\rm HMDB0031681}
                       {\bf Dihydro-5-propyl-2(3H)-furanone}
                       4-Heptenoic acid
5-Methyl-2,3-hexanedione
189
      HMDB0033793
      HMDB0031593
190
      HMDB0039819
191
                       NA
192
      HMDB0166736
                       NA
      HMDB0173760
193
                       NA
194
      {\rm HMDB0173761}
                       NA
195
      {\rm HMDB}0173762
                       NA
      HMDB0173763
196
                       NA
      HMDB0180322
197
                       NA
      HMDB0180323
198
                       NA
199
      HMDB0029165
                       1,3-Diacetylpropane
200
      HMDB0031351
                       Cyclohexyl formate
201
      {\rm HMDB0032460}
                       4-Pentenyl acetate
      HMDB0032391
                       3-Methyl-3-butenyl acetate
202
      HMDB0030330
203
                       1-Methoxy-3-methylene-2-pentanone
      HMDB0059876
204
                       NA
      HMDB0040591
205
                       NA
206
      HMDB0145113
                       NA
207
      {\rm HMDB0145114}
                       NA
      HMDB0145115
208
                       NA
      HMDB0145125
209
                       NA
      HMDB0145116
210
                       NA
      HMDB0094649
                       2-Amino-heptanoic acid
211
212
      HMDB0001161
                       4-Trimethylammoniobutanoic acid
213
      HMDB0006831
                       3-Dehydroxycarnitine
      HMDB0000895
214
                       Acetylcholine
      HMDB0013811
215
                       1-Nitroheptane
216
      HMDB0041477
                       NA
      HMDB0031660
217
                       Dibutyl sulfide
218
      HMDB0240251
219
      HMDB0061880
                       NA
      HMDB0059659
HMDB0002113
220
                       Trans-3-hydroxy-L-proline
221
                       3-Hydroxy-L-proline
Propionylglycine
      HMDB0000783
222
      HMDB0000766
223
                       N-Acetyl-L-alanine
224
      HMDB0000725
                       4-Hydroxyproline
225
      HMDB0036576
                       5-Aminolevulinic acid
226
      {\rm HMDB0001149}
      HMDB0002104
227
                       L-Glutamic gamma-semialdehyde
      HMDB0006055
                       \hbox{4-Hydroxy-L-proline}
228
      HMDB0060460
229
                       cis-4-Hydroxy-D-proline
      HMDB0006272
                       5-Amino-2-oxopentanoic acid
230
231
      HMDB0177404
                       NA
232
      HMDB0014389
                       Mesalazine
233
      HMDB0164041
                       NA
```

```
HMDB0059749
234
                       NA
      HMDB0001972
                       3-Aminosalicylic acid
235
      HMDB0014378
                        Aminosalicylic Acid
236
237
      {\rm HMDB0001476}
                        3-Hydroxyanthranilic acid
238
      {\rm HMDB0059811}
                        NA
      HMDB0012289
                        Tetrahydrodipicolinate
239
240
      HMDB0001280
                       2-Aminomuconic acid semialdehyde
      HMDB0031670
                        1-(Hydroxymethyl)-5,5-dimethyl-2,4-imidazolidinedione
241
      {\rm HMDB0028696}
242
                        Alanyl-Serine
                        Serylalanine
243
      HMDB0029032
244
      {\rm HMDB0145395}
                       NA
245
      HMDB0029061
HMDB0028851
                        Threoninyl-Glycine
                       Glycyl-Threonine
246
247
      HMDB0169117
                       NA
248
      HMDB0125105
                       NA
      {\rm HMDB0038987}
249
                       NA
250
      HMDB0032029
                       2-Isopropylphenol
      HMDB0032149
HMDB0032625
251
                       1-Methoxy-2,4-dimethylbenzene
252
                       4-Propylphenol
      HMDB0029667
                       2,3,6-Trimethylphenol
253
      HMDB0039782
254
                       ŃΑ
255
      HMDB0038986
                       NA
256
      {\rm HMDB0032624}
                       \hbox{2-Propylphenol}
257
      HMDB0038988
                       NA
      HMDB0032621
                        (2-Methoxyethyl)benzene
258
      HMDB0038985
259
                       ŇΑ
      HMDB0031312
260
                        Benzyl ethyl ether
      HMDB0033962
261
                       3-Phenyl-1-propanol
262
      HMDB0031627
                        1-Phenyl-1-propanol
      HMDB0034378
                       (Âś)-1-(4-Methylphenyl)ethanol
263
264
      HMDB0031628
                        2-Phenyl-1-propanol
^{265}
      {\rm HMDB0038984}
                       NA
                       2,4,6-Trimethylphenol
266
      HMDB0032544
                       p-Isopropylphenol
Nona-2,4,6-trienal
      HMDB0031446
267
      HMDB0032441
268
269
      HMDB0059896
                       NA
270
      HMDB0169118
                       NA
271
      {\rm HMDB0156380}
                        NA
      HMDB0000259
HMDB0001046
272
                       {\bf Serotonin}
273
                        Cotinine
      HMDB0156382
274
                       NA
      HMDB0156381
275
                       NA
276
      HMDB0156383
                       NA
277
      {\rm HMDB0040299}
                        NA
278
      HMDB0029727
                       5-Ethyl-2,3-dimethylpyrazine
      HMDB0040000
279
                       NΑ
      HMDB0041252
280
                       NΑ
      HMDB0015644
                       Betahistine
281
282
      HMDB0036584
                       NA
283
      HMDB0036808
                        NA
284
      HMDB0014918
                        Phenelzine
                       2-Ethyl-3,(5 or 6)-dimethylpyrazine
285
      HMDB0032276
      HMDB0041253
286
                       NA
      HMDB0036809
287
                       NA
      HMDB0037151
288
                       NA
      {\rm HMDB0030410}
                        L-2-Amino-3-methylenehexanoic acid
289
290
      {\rm HMDB0004827}
                        Proline betaine
291
      HMDB0038949
                       NA
      HMDB0032332
292
                       Hydroxylated lecithin
293
      HMDB0145430
                       NA
      {\rm HMDB0128078}
                       NA
294
      HMDB0134039
295
                       NA
296
      {\rm HMDB0135273}
                        NA
297
      {\rm HMDB0135648}
                       NA
298
      HMDB0135274
                       NΑ
      HMDB0135275
299
                       NA
300
      {\rm HMDB0035243}
                        1-Phenyl-1,2-propanedione
      HMDB0000930
301
                        trans-Cinnamic acid
302
      {\rm HMDB0000567}
                        Cinnamic acid
303
      {\rm HMDB0036626}
                        NA
      HMDB0040986
                        (E)-3-(4-Hydroxyphenyl)-2-propenal
304
      HMDB0031725
                       (E)-3-(2-Hydroxyphenyl)-2-propenal
Di-2-furanylmethane
305
      HMDB0032947
306
      HMDB0062407
307
                       NA
308
      HMDB0004992
                        Benzocaine
309
      HMDB0001007
                       3-Pyridinebutanoic acid
      HMDB0059934
310
                       NΑ
      HMDB0033589
                       Ethyl 2-aminobenzoate
311
      HMDB0033485
                        Gentiatibetine
312
      HMDB0034169
                        Methyl N-methylanthranilate
313
      HMDB0006044
314
                        Norsalsolinol
315
      {\rm HMDB0000159}
                        L-Phenylalanine
316
      HMDB0159744
                       NA
      HMDB0062402
                       NΑ
317
      HMDB0155168
                       NA
318
319
      HMDB0029455
                        Ginkgotoxin
      HMDB0000068
                        Epinephrine
```

```
HMDB0000819
                       Normetanephrine
321
      HMDB0002832
322
                       Methylnoradrenaline
      HMDB0015652
                       Levonordefrin
324
      {\rm HMDB0062515}
                       NA
325
      {\rm HMDB0061679}
                       NA
      HMDB0154785
326
                       NA
327
      HMDB0000232
                       Quinolinic acid
328
      HMDB0033161
                       2.6-Pyridinedicarboxylic acid
      HMDB0185628
329
330
      HMDB0001330
                       2-Amino-3-carboxymuconic acid semialdehyde
331
      {\rm HMDB0062578}
                       NA
332
      HMDB0060260
HMDB0001552
                       NA
                       2-Keto-glutaramic acid
333
      HMDB0000289
334
                       Uric acid
335
      HMDB0166108
                       NA
      {\rm HMDB0171094}
                       NA
336
337
      HMDB0172092
                       NA
      \begin{array}{c} {\rm HMDB0062005} \\ {\rm HMDB0124926} \end{array}
338
                       NA
339
                       NΑ
      HMDB0168664
340
                       NA
      HMDB0150437
                       NA
341
      HMDB0125528
                       NA
343
      {\rm HMDB0137457}
                       NA
344
      HMDB0146870
                       NA
      HMDB0146889
345
                       NA
      HMDB0166106
                       NA
346
      HMDB0166109
347
                       NA
      HMDB0182861
348
                       NA
349
      HMDB0166107
                       NA
350
      {\rm HMDB0183905}
                       NA
351
      HMDB0183904
                       NA
      HMDB0036907
352
                       NΑ
      HMDB0029660
353
                       2',6'-Dihydroxyacetophenone
      HMDB0029657
                       2,4'-Dihydroxyacetophenone
354
      {\rm HMDB0029659}
                       2',4'-Dihydroxyacetophenone
355
356
      HMDB0029658
                       2',3'-Dihydroxyacetophenone
357
      HMDB0032594
                       2-(Hydroxymethyl)benzoic acid
                       1-(5-Methyl-2-furanyl)-1,2-propanedione
      HMDB0033003
358
      HMDB0032629
                       2',5'-Dihydroxyacetophenone
359
      HMDB0032572
360
                       Methylparaben
361
      HMDB0029662
                       3',5'-Dihydroxyacetophenone
362
      {\rm HMDB0029661}
                       3',4'-Dihydroxyacetophenone
363
      HMDB0032604
                       2-Methoxybenzoic acid
      HMDB0034172
364
                       Methyl 2-hydroxybenzoate
365
      HMDB0032606
                       3-Methoxybenzoic acid
366
      HMDB0041283
      HMDB0004815
                       4-Hydroxy-3-methylbenzoic acid
367
368
      {\rm HMDB0012308}
                       Ethyl 2-furanyl diketone
369
      {\rm HMDB0032919}
      HMDB0172091
370
      HMDB0032399
                       Methyl furfuracrylate
371
      HMDB0000703
372
                       Mandelic acid
373
      HMDB0000669
                       Ortho-Hydroxyphenylacetic acid
374
      HMDB0060390
375
      HMDB0003791
                       3,4-Dihydroxyphenylacetaldehyde
      HMDB0062635
376
                       NA
      HMDB0031609
377
                       Phenoxyacetic acid
      HMDB0000440
                       3-Hydroxyphenylacetic acid
378
      HMDB0001101
                       p-Anisic acid
379
380
      HMDB0000020
                       p-Hydroxyphenylacetic acid
381
      HMDB0002390
                       3-Cresotinic acid
      HMDB0000216
382
                       Norepinephrine
      HMDB0035178
                       6-Acetyl-2,3-dihydro-2-(hydroxymethyl)-4(1H)-pyridinone
383
      HMDB0037685
                       NA
384
      HMDB0155164
385
                       NA
      HMDB0001537
386
                       6-Hydroxydopamine
387
      {\rm HMDB0000239}
                       Pyridoxine
                       5-Hydroxydopamine
388
      {\rm HMDB0004817}
      HMDB0012150
389
                       2-Keto-6-acetamidocaproate
390
      HMDB0168723
                       NA
      {\rm HMDB0168724}
391
                       NA
392
      HMDB0142963
393
      {\rm HMDB0061157}
                       NA
394
      {\rm HMDB0029449}
                       (2R,3R,4R)-2-Amino-4-hydroxy-3-methylpentanoic acid
395
      HMDB0033453
                       Fagomine
396
      HMDB0032354
                       S-Isopropyl 3-methylbut-2-enethioate
397
      HMDB0162077
                       NA
398
      HMDB0162076
                       NA
399
      HMDB0162073
400
      {\rm HMDB0031797}
                       2-Isopropylphenyl methylcarbamate
      HMDB0003892
401
                       (S)-N-Methylsalsolinol
      HMDB0003626
                       (R)-N-Methylsalsolinol
402
      HMDB0036906
403
      HMDB0012484
                       (R)-1,2-dimethyl-5,6-dihydroxy-tetrahydroisoquinoline
404
405
      HMDB0012469
406
      HMDB0035072
                       2-Methylpropyl 2-aminobenzoate
407
      HMDB0037698
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408
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                       (2-Naphthyl)methanol
409
      HMDB0032861
                       2-Methoxynaphthalene
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411
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                       1-Hydroxymethylnaphthalene
412
      {\rm HMDB0061285}
                       NA
      HMDB0040768
413
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      HMDB0000671
                       Indolelactic acid
414
      HMDB0032755
                       Methyl 1-methoxy-1H-indole-3-carboxylate
415
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416
                       Cinnamoylglycine
417
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                       5-Methoxyindoleacetate
418
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                       Edulitine
419
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                       NΑ
420
421
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422
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                       Indoleacrylic acid
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      HMDB0033249
                      6-Chloro-N-(1-methylethyl)-1,3,5-triazine-2,4-diamine
432
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                      2,5-Dimethyl-3-furanthiol acetate
433
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434
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      HMDB0094704
435
                      N-Propionylmethionine
436
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437
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                       NA
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442
443
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                       (Z)-1-(Methylthio)-5-phenyl-1-penten-3-yne
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451
                       NA
      HMDB0038791
452
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453
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454
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455
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456
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      {\rm HMDB0163470}
472
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474
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      HMDB0040439
476
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      HMDB0039685
                       NA
477
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478
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479
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                       (S,Z)-Lyratol acetate
480
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                       (2S,4R)-p-Mentha-1(7),5-dien-2-ol acetate
                       Ethyl (2E,4E,7Z)-Decatrienoate
Ethyl (2E,4Z,7Z)-Decatrienoate
481
      HMDB0035375
482
      HMDB0035376
      HMDB0132986
483
                       NΑ
484
      HMDB0034450
                       Neocnidilide
485
      HMDB0032567
                       Hexylresorcinol
      HMDB0035126
486
                       (Âś)-Myrtenyl acetate
      HMDB0041610
487
                       ŇΑ
      HMDB0038046
                      NA
488
489
      {\rm HMDB0037018}
                       NA
490
      HMDB0037231
                       NA
      HMDB0035085
                       Vulgarole
491
      HMDB0041572
492
                      NA
493
      HMDB0029388
                       Cucurbic acid
      HMDB0037326
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495
                       Dihydrojasmonic acid
      HMDB0040195
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497
      HMDB0035723
                        (1R,2S,3S,4R)-p-Menthane-2,3-diol
                        Propyl heptanoate
498
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499
      {\rm HMDB0061987}
                       NA
      HMDB0062146
500
                       NA
      HMDB0038038
                       NA
501
502
      HMDB0036228
                       2-Methylpropyl hexanoate
      HMDB0040167
503
504
      {\rm HMDB0036136}
505
      {\rm HMDB0187563}
                       NA
506
      HMDB0037387
HMDB0000511
                       NA
                        Capric acid
507
      HMDB0031264
508
                       Methyl nonanoate
509
      HMDB0094654
                        1-Methylethyl heptanoic acid
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510
511
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      HMDB0180501
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525
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      HMDB0061805
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      HMDB0180097
527
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      HMDB0032302
                        Heptanal propyleneglycol acetal
528
529
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                        Acetaldehyde 1,3-octanediol acetal
530
      {\rm HMDB0032264}
                        Ethyl 2-ethylhexanoate
531
      HMDB0032315
                        Hexanal butane-2,3-diol acetal
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                        Pentyl 3-methylbutanoate
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533
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                       4-Methylnonanoic acid
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                        Hexyl 2-methylpropanoate
535
536
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537
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                       trans-p-Menthane-1,8-diol
1,1-Diethoxy-2-hexene
538
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540
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                        Isooctyl acetate
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541
542
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                       NA
543
      {\rm HMDB0038783}
                       NA
      HMDB0036145
544
                       NA
      HMDB0039218
545
                       NA
      HMDB0038602
546
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                        Isopentyl isopentanoate
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      HMDB0031739
                        7-Hydroxy-3,7-dimethyloctanal
549
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                        N-Methyl-1-deoxynojirimycin
      HMDB0029741
                       \hbox{2-Isopropyl-3,5-dimethoxy-6-methylpyrazine}
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551
      HMDB0240493
552
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      HMDB0029224
553
                        N-methylphenylalanine
554
      HMDB0029223
                        alpha-Methylphenylalanine
555
      {\rm HMDB0005199}
                        (R)-Salsolinol
      HMDB0031811
556
                        3,5-Dimethylphenyl methylcarbamate
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557
                       NA
      HMDB0030372
                       Maltoxazine
558
      HMDB0040021
559
                       NA
      HMDB0033763
                        Ethyl N-methylanthranilate
560
561
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562
      {\rm HMDB0001189}
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      HMDR0041931
563
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      HMDB0029135
                        Valyl-Proline
564
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565
                       Dethiobiotin
566
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                        Prolyl-Valine
567
      HMDB0036683
                       NA
      HMDB0059826
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569
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      HMDB0061824
570
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      HMDB0013287
571
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572
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                        Citrulline
573
      HMDB0003148
                        Argininic acid
574
      {\rm HMDB0003269}
                       Nicotinuric acid
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      HMDB0176142
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                       NA
577
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                       NA
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                        2-Hydroxy-3-methyl-9H-carbazole
580
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581
      HMDB0033487
                        1\hbox{-Hydroxy-}3\hbox{-methyl-}9\hbox{H-carbazole}
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592
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                       NA
593
      HMDB0060878
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594
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                       (Âs´)-Tryptophan
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                       ŇΑ
      HMDB0014892
                      Ethotoin
596
      HMDB0000929
597
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                       Isoeugenol acetate
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649
650
      HMDB0035071
                       Verimol I
651
      HMDB0031973
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652
      HMDB0135898
                       ŇΑ
      HMDB0132972
653
                       NA
      HMDB0033594
654
                       Cuelure
      HMDB0030762
                       Ethyl trans-p-methoxycinnamate
655
656
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                       Isoeugenyl acetate
657
      HMDB0034122
                       Aceteugenol
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      HMDB0164281
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703
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704
      {\rm HMDB0037135}
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705
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                       Jasmonic acid
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707
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      HMDB0041573
                       NA
708
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                       NΑ
      HMDB0039669
712
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      HMDB0033640
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714
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715
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                       (R)-3-Hydroxydecanoic acid
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717
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                       9-Hydroxydecanoic acid
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      HMDB0180589
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763
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765
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                       Dodecanoic acid
766
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768
                       Octyl 2-methylpropanoate
      HMDB0036225
769
                       NΑ
770
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                       Isopropyl nonanoate
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773
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      HMDB0040431
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3862 3863 3864 3865 3866 3867	HMDB0099600 HMDB0099602 HMDB0099603 HMDB0099601 HMDB0099453 HMDB0099337 HMDB0099338	NA NA NA NA NA NA
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3862 3863 3864 3865 3866 3867 3868	HMDB0099600 HMDB0099602 HMDB0099603 HMDB0099601 HMDB0099453 HMDB0099337 HMDB0099338 HMDB0099259	NA NA NA NA NA NA NA
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3862 3863 3864 3865 3866 3867 3868 3869 3870 3871	HMDB0099600 HMDB0099602 HMDB0099603 HMDB0099601 HMDB0099453 HMDB0099337 HMDB0099259 HMDB0099261 HMDB0099260 HMDB0099263	NA
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3862 3863 3864 3865 3866 3867 3868 3870 3871 3872 3873 3874 3875 3876	HMDB0099600 HMDB0099602 HMDB0099601 HMDB0099601 HMDB0099337 HMDB0099238 HMDB0099259 HMDB0099261 HMDB0099263 HMDB0099262 HMDB0099264 HMDB0099327 HMDB0099327 HMDB0099329	NA N
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	HMDB0105306	NA
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3939	HMDB0108347	NA
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3943	HMDB0107828	NA
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	HIVIDBUTU(874	
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3945	HMDB0107876	NA NA
$3945 \\ 3946$	HMDB0107876 HMDB0107878	NA NA NA
	HMDB0107876	NA NA
$3946 \\ 3947$	HMDB0107876 HMDB0107878 HMDB0107875	NA NA NA NA
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3946 3947 3948 3949 3950 3951 3952	HMDB0107876 HMDB0107878 HMDB0107875 HMDB0107877 HMDB0107879 HMDB0108054 HMDB0108052 HMDB0108053	NA NA NA NA NA NA NA NA
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3946 3947 3948 3950 3951 3952 3953 3954 3955 3956 3957 3958 3959 3960 3961 3962 3963 3963	HMDB0107876 HMDB0107878 HMDB0107875 HMDB0107877 HMDB0108054 HMDB0108053 HMDB0108055 HMDB0108055 HMDB0108056 HMDB0108344 HMDB0108344 HMDB0108345 HMDB0102355 HMDB0102355 HMDB0102355 HMDB0102355 HMDB0102356 HMDB0102356 HMDB0102356	NA N
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4351
       HMDB0007634
                         DG(22:1(13Z)/20:4(5Z,8Z,11Z,14Z)/0:0)
4352
       {\rm HMDB0007607}
                         DG(22:0/20:5(5Z,8Z,11Z,14Z,17Z)/0:0)
       HMDB0007381
                         \begin{array}{l} DG(20:0/22:5(7Z,10Z,13Z,16Z,19Z)/0:0) \\ DG(20:0/22:5(4Z,7Z,10Z,13Z,16Z)/0:0) \\ DG(20:1(11Z)/22:4(7Z,10Z,13Z,16Z)/0:0) \end{array}
4353
       HMDB0007380
4354
       HMDB0007408
4355
       HMDB0007465
                         DG(20:3(5Z,8Z,11Z)/22:2(13Z,16Z)/0:0)
4356
       HMDB0007494
                         DG(20:3(8Z,11Z,14Z)/22:2(13Z,16Z)/0:0)
4357
4358
       {\rm HMDB0007522}
                         DG(20:4(5Z,8Z,11Z,14Z)/22:1(13Z)/0:0)
4359
       HMDB0007551
                         DG(20:4(8Z,11Z,14Z,17Z)/22:1(13Z)/0:0)
       HMDB0007579
4360
                         DG(20:5(5Z,8Z,11Z,14Z,17Z)/22:0/0:0)
       HMDB0144337
4361
                         NA
       HMDB0144336
4362
                         NA
4363
       HMDB0035940
                         Mulberrofuran T
                         Tetrahydrofolyl-[Glu](n)
4364
       HMDB0006826
4365
       HMDB0012290
                         Tetrahydropteroyltri-L-glutamate
       HMDB0165036
4366
                         NA
       HMDB0165033
4367
                         NA
4368
       HMDB0184675
                         NA
       HMDB0127557
                         NA
4369
4370
       {\rm HMDB0127589}
                         NA
4371
       {\rm HMDB}0127593
                         NA
       HMDB0127594
4372
                         NA
       HMDB0127595
4373
                         NA
       HMDB0127608
4374
                         NA
4375
       HMDB0127607
                         NA
4376
       HMDB0127609
                         NA
4377
       {\rm HMDB0127556}
                         NA
       HMDB0127550
4378
                         NA
       HMDB0127551
4379
                         NA
       HMDB0127549
4380
                         NA
       HMDB0127588
                         NA
4381
4382
       HMDB0127587
                         NA
4383
       {\rm HMDB0127583}
                         NA
       HMDB0127563
4384
                         NA
       HMDB0127562
4385
                         NA
       HMDB0127564
                         NA
4386
       HMDB0127570
4387
                         NA
       HMDB0127571
4388
                         NA
4389
       {\rm HMDB0127569}
                         NA
4390
       {\rm HMDB}0127576
                         NA
       HMDR0127575
4391
                         NA
       HMDB0127577
4392
                         NA
       {\rm HMDB0127555}
4393
                         NA
4394
       HMDB0127581
4395
       {\rm HMDB0127582}
                         NA
       HMDB0031938
HMDB0030261
4396
                         Arachisprenol 10
4397
                         NΑ
       HMDB0163756
4398
                         NΑ
       HMDB0040745
4399
                         NA
4400
       HMDB0164979
                         NA
4401
       HMDB0164980
                         NA
4402
       {\rm HMDB0164978}
                         NΑ
       HMDB0164977
4403
                         NΑ
       HMDB0061054
4404
                         NA
       HMDB0061057
                         NA
4405
       HMDB0012092
                         SM(d18:0/22:1(13Z))
4406
4407
       HMDB0012103
                         SM(d18:1/22:0)
4408
       HMDB0061669
                         NA
4409
       HMDB0112209
```

```
HMDB0042752
4410
                       NA
       HMDB0043401
                       NA
4411
4412
       HMDB0042975
                       NA
4413
       {\rm HMDB0042982}
                       NA
4414
       {\rm HMDB0043177}
                       NA
       HMDB0047755
4415
                       NA
       HMDB0042542
                       NA
4416
       HMDB0042114
4417
                       NA
       HMDB0042107
4418
                       NA
4419
       {\rm HMDB0144075}
                       NA
4420
       {\rm HMDB0182203}
                       NA
4421
       HMDB0036708
                       NA
       HMDB0164984
                       NΑ
4422
4423
       HMDB0164986
                       NA
4424
       HMDB0164987
                       NA
       {\rm HMDB0164985}
                       NA
4426
       {\rm HMDB0055799}
       HMDB0010560
                       TG(22:6(4Z,7Z,10Z,13Z,16Z,19Z)/20:5(5Z,8Z,11Z,14Z,17Z)/22:6(4Z,7Z,10Z,13Z,16Z,19Z))
4427
       HMDB0046646
4428
                       NA
       HMDB0038431
4429
                       NΑ
       HMDB0047508
                       NA
4430
4431
       HMDB0051662
                       NA
4432
       {\rm HMDB0052140}
                       NA
4433
       HMDB0051902
                       NA
       HMDB0047715
4434
                       NA
       HMDB0054410
                       NA
4435
       HMDB0004879
4436
                       Trihexosylceramide (d18:1/16:0)
       HMDB0051659
4437
                       NA
4438
       {\rm HMDB0054167}
                       NA
4439
       {\rm HMDB0047434}
                       NA
       HMDB0054486
4440
                       NA
       HMDB0051643
                       NΑ
4441
       HMDB0047682
                       NA
4442
       HMDB0047505
                       NA
4444
       {\rm HMDB0046964}
                       NA
4445
       {\rm HMDB0051851}
                       NA
4446
       HMDB0047664
                       NA
       HMDB0047452
4447
                       NA
       HMDB0052106
                       NA
4448
       HMDB0047643
                       NA
4449
4450
       HMDB0052227
                       NA
4451
       {\rm HMDB0052101}
                       NA
4452
       HMDB0052196
                       NA
       HMDB0052150
4453
                       _{\rm NA}^{\rm NA}
       HMDB0051995
4454
4455
       {\rm HMDB0053728}
                       NA
       HMDB0052137
                       NA
4456
4457
       {\rm HMDB0047429}
                       NA
4458
       {\rm HMDB0051638}
                       NA
       HMDB0052242
4459
                       NA
       HMDB0046946
4460
                       NA
       HMDB0047515
4461
                       NA
4462
       HMDB0046821
                       NA
4463
       HMDB0046773
                       NA
4464
       {\rm HMDB0046604}
                       NA
       HMDB0046215
4465
                       NA
       HMDB0045865
4466
                       NA
       HMDB0050816
                       NA
4467
       HMDB0050577
                       NA
4468
4469
       {\rm HMDB0050431}
                       NA
4470
       HMDB0047291
                       NA
       HMDB0052248
4471
                       NA
       HMDB0046778
4472
                       NA
       HMDB0051756
                       NA
4473
4474
       {\rm HMDB0054393}
                       NA
4475
       HMDB0050721
                       NA
4476
       {\rm HMDB0050582}
                       NA
       {\rm HMDB0050986}
4477
                       NA
       HMDB0053352
4478
                       NA
       HMDB0053450
                       NA
4479
       HMDB0053347
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4481
       HMDB0054407
                       NA
4482
       HMDB0051772
                       NA
      HMDB0047521
HMDB0047544
4483
                       NA
4484
                       NA
       HMDB0054472
4485
                       NΑ
       HMDB0047308
4486
                       NA
4487
       HMDB0052256
                       NA
4488
       {\rm HMDB0054398}
                       NA
4489
       {\rm HMDB0051782}
                       NA
       HMDB0051867
4490
                       NA
       HMDB0052323
4491
                       NA
       HMDB0039422
                       NA
4492
       HMDB0047520
                       NA
4493
4494
       HMDB0052115
                       NA
4495
       HMDB0047636
                       NA
4496
       HMDB0051989
                       NA
```

4497	HMDB0047290	NA
4498	HMDB0052211	NA
4499	HMDB0047619	NA
4500	HMDB0047475	NA
4501	HMDB0046598	NA
4502	HMDB0046939	NA
4503	HMDB0051658	NA
4504	HMDB0046915	NA
4505	HMDB0046772	NA
4506	HMDB0047123	NA
4507	HMDB0052151	NA
4508	HMDB0051523	NA
4509	HMDB0051834	NA
4510	HMDB0051994	NA
4511	HMDB0047504	NA
4512	HMDB0054079	NA
4513	HMDB0047285	NA
4514	HMDB0052136	NA
4515	HMDB0051502	NA
4516	HMDB0046404	NA
4517	HMDB0052009	NA
4518	HMDB0051732	NA
4519	HMDB0052241	NA
4520	HMDB0052100	NA
4521	HMDB0054406	NA
4522	HMDB0046814	NA
4523	HMDB0047538	NA
4524	HMDB0046603	NA
4525	HMDB0047428	NA
4526	HMDB0046059	NA
4527	HMDB0045859	NA
4528	HMDB0045864	NA
4529	HMDB0046189	NA
4530	HMDB0045657	NA
4531	HMDB0046207	NA
4532	HMDB0054392	NA
4533	HMDB0051507	NA
4534	HMDB0047498	NA
4535	HMDB0046796	NA
4536	HMDB0052130	NA
4537	HMDB0051637	NA
4538	HMDB0051231	NA
4539	HMDB0050430	NA
4540	HMDB0051129	NA
4541	HMDB0050576	NA
4542	HMDB0050702	NA
4543	HMDB0053346	NA
4544	HMDB0050425	NA
4545	HMDB0046956	NA
4546	HMDB0052301	NA
4547	HMDB0054541	NA
4548	HMDB0046627	NA
4549	HMDB0047658	NA
4550	HMDB0053823	NA
4551	HMDB0047337	NA
4552	HMDB0051765	NA
4553	HMDB0051652	NA
4554	HMDB0054391	NA
	HMDB0046732	
4555		NA
4556	HMDB0047300	NA
4557	HMDB0046771	NA
4558	HMDB0046397	NA
4559	HMDB0047496	NA
4560	HMDB0052128	NA
4561	HMDB0046420	NA
4562	HMDB0052157	NA
4563	HMDB0046619	NA
4564	HMDB0047323	NA
	HMDB0051636	NA
4565		
4566	HMDB0046715	NA
4567	HMDB0047144	NA
4568	HMDB0045650	NA
4569	HMDB0047138	NA
4570	HMDB0047158	NA
4571	HMDB0047565	NA
4572	HMDB0046882	NA
4573	HMDB0047397	NA
4574	HMDB0047444	NA
4575	HMDB0052015	NA
4576	HMDB0052013	NA
4577	HMDB0051650	NA
4578	HMDB0047116	NA
4579	HMDB0047427	NA
4580	HMDB0052099	NA
4581	HMDB0046426	NA
4582	HMDB0046025	NA
4583	HMDB0053345	NA

```
NA
NA
4584
         HMDB0050961
4585
         HMDB0047167
4586
         {\rm HMDB0046565}
                               NA
4587
         {\rm HMDB0046613}
                               NA
         HMDB0051515
HMDB0047351
HMDB0047329
4588
                               NA
                               NA
NA
\begin{array}{c} 4589 \\ 4590 \end{array}
4591
         HMDB0051698
                               NA
4592
         {\rm HMDB0052142}
                               NA
4593
         {\rm HMDB0050683}
                               NA
         HMDB0050978
HMDB0050575
HMDB0052001
4594
                               NA
4595 \\ 4596
                               NA
NA
NA
4597
         HMDB0047581
4598
         HMDB0051748
                               NA
4599
         {\rm HMDB0046781}
                               NA
         HMDB0047667
HMDB0051660
HMDB0052259
HMDB0052133
4600
                               NA
                              NA
NA
NA
NA
\frac{4601}{4602}
4603
4604
         HMDB0047501
4605
         {\rm HMDB0051525}
                               NA
4606
         {\rm HMDB}0052011
                               NA
         HMDB0051783
HMDB0051868
HMDB0046965
4607
                               NA
4608
4609
                               NA
NA
4610
         {\rm HMDB0047684}
                               NA
4611
         HMDB0052333
                               NA
4612
         {\rm HMDB0047547}
                               NA
         HMDB0051655
HMDB0052153
HMDB0047339
4613
                               NA
                               NA
NA
4614
4615
4616
         HMDB0052138
                               NA
4617
         {\rm HMDB0054408}
                               NA
4618
         {\rm HMDB0047506}
                               NA
         HMDB0046629
HMDB0054482
HMDB0052244
4619
                               NA
\frac{4620}{4621}
                               NA
                               NA
4622
         HMDB0054403
                               NA
4623
         HMDB0002071
                               O-2-(acetylamino)-2-deoxy-a-D-Gal-(1->3)-O-[6-deoxy-a-L-Gal-(1->2)]-O-b-D-Gal-(1->3)-O-2-(acetylamino)-2-deoxy-b-D-
4624
         {\rm HMDB0015601}
                               Vapreotide
4625
         {\rm HMDB0112241}
```

The second step is to check concentration values. For SSP analysis, the concentration must be measured in umol for blood and CSF samples. The urinary concentrations must be first converted to  $umol/mmol\_creatinine$  in order to compare with reported concentrations in literature. No missing or negative values are allowed in SSP analysis. The concentration data for QEA analysis is more flexible. Users can upload either the original concentration data or normalized data. Missing or negative values are allowed (coded as NA) for QEA.

## 5 Selection of Metabolite Set Library

Before proceeding to enrichment analysis, a metabolite set library has to be chosen. There are seven built-in libraries offered by MSEA:

- Metabolic pathway associated metabolite sets (currently contains 99 entries);
- Disease associated metabolite sets (reported in blood) (currently contains 344 entries);
- Disease associated metabolite sets (reported in urine) (currently contains 384 entries)
- Disease associated metabolite sets (reported in CSF) (currently contains 166 entries)
- Metabolite sets associated with SNPs (currently contains 4598 entries)
- Predicted metabolite sets based on computational enzyme knockout model (*currently contains 912 entries*)
- Metabolite sets based on locations (currently contains 73 entries)
- Drug pathway associated metabolite sets (currently contains 461 entries)

In addition, MSEA also allows user-defined metabolite sets to be uploaded to perform enrichment analysis on arbitrary groups of compounds which researchers want to test. The metabolite set library is simply a two-column comma separated text file with the first column for metabolite set names and the second column for its compound names (**must use HMDB compound name**) separated by "; ". Please note, the built-in libraries are mainly from human studies. The functional grouping of metabolites may not be valid. Therefore, for data from subjects other than human being, users are suggested to upload their self-defined metabolite set libraries for enrichment analysis.

## 6 Enrichment Analysis

Over Representation Analysis (ORA) is performed when a list of compound names is provided. The list of compound list can be obtained through conventional feature selection methods, or from a clustering algorithm, or from the compounds with abnormal concentrations detected in SSP, to investigate if some biologically meaningful patterns can be identified.

ORA was implemented using the *hypergeometric test* to evaluate whether a particular metabolite set is represented more than expected by chance within the given compound list. One-tailed p values are provided after adjusting for multiple testing. **Figure 2** below summarizes the result.

## **Enrichment Overview (top 25)**

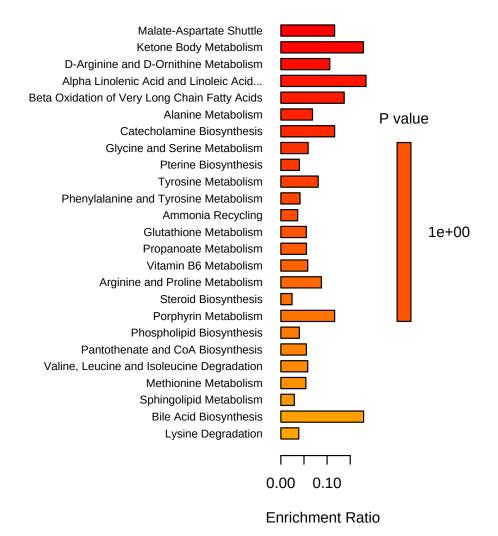


Figure 1: Summary Plot for Over Representation Analysis (ORA)

Table 2: Result from Over Representation Analysis

	total	expected	hits	Raw p	Holm p	FDR
Malate-Aspartate Shuttle	10	8.60	1	1.00E+00	1.00E+00	1.00E+00
Ketone Body Metabolism	13	11.20	2	1.00E+00	1.00E+00	1.00E+00
D-Arginine and D-Ornithine Metabolism	11	9.46	1	1.00E+00	1.00E+00	1.00E+00
Alpha Linolenic Acid and Linoleic Acid	19	16.30	3	1.00E+00	1.00E+00	1.00E+00
Metabolism						
Beta Oxidation of Very Long Chain Fatty	17	14.60	2	1.00E+00	1.00E+00	1.00E+00
Acids						
Alanine Metabolism	17	14.60	1	1.00E+00	1.00E+00	1.00E+00
Catecholamine Biosynthesis	20	17.20	2	1.00E+00	1.00E+00	1.00E+00
Glycine and Serine Metabolism	59	50.80	3	1.00E+00	1.00E+00	1.00E+00
Pterine Biosynthesis	29	25.00	1	1.00E+00	1.00E+00	1.00E+00
Tyrosine Metabolism	72	61.90	5	1.00E+00	1.00E+00	1.00E+00
Phenylalanine and Tyrosine Metabolism	28	24.10	1	1.00E+00	1.00E+00	1.00E+00
Ammonia Recycling	32	27.50	1	1.00E+00	1.00E+00	1.00E+00
Glutathione Metabolism	21	18.10	1	1.00E+00	1.00E+00	1.00E+00
Propanoate Metabolism	42	36.10	2	1.00E+00	1.00E+00	1.00E+00
Vitamin B6 Metabolism	20	17.20	1	1.00E+00	1.00E+00	1.00E+00
Arginine and Proline Metabolism	53	45.60	4	1.00E+00	1.00E+00	1.00E+00
Steroid Biosynthesis	48	41.30	1	1.00E+00	1.00E+00	1.00E+00
Porphyrin Metabolism	40	34.40	4	1.00E+00	1.00E+00	1.00E+00
Phospholipid Biosynthesis	29	25.00	1	1.00E+00	1.00E+00	1.00E+00
Pantothenate and CoA Biosynthesis	21	18.10	1	1.00E+00	1.00E+00	1.00E+00
Valine, Leucine and Isoleucine Degrada-	60	51.60	3	1.00E+00	1.00E+00	1.00E+00
tion						
Methionine Metabolism	43	37.00	2	1.00E+00	1.00E+00	1.00E+00
Sphingolipid Metabolism	40	34.40	1	1.00E+00	1.00E+00	1.00E+00
Bile Acid Biosynthesis	65	55.90	10	1.00E+00	1.00E+00	1.00E+00
Lysine Degradation	30	25.80	1	1.00E+00	1.00E+00	1.00E+00
Glycerolipid Metabolism	25	21.50	1	1.00E+00	1.00E+00	1.00E+00
Pyrimidine Metabolism	59	50.80	3	1.00E+00	1.00E+00	1.00E+00
Nicotinate and Nicotinamide Metabolism	37	31.80	1	1.00E+00	1.00E+00	1.00E+00
Purine Metabolism	74	63.70	3	1.00E+00	1.00E+00	1.00E+00
Fatty acid Metabolism	43	37.00	1	1.00E+00	1.00E+00	1.00E+00
Folate Metabolism	29	25.00	1	1.00E+00	1.00E+00	1.00E+00
Fatty Acid Elongation In Mitochondria	35	30.10	2	1.00E+00	1.00E+00	1.00E+00
Citric Acid Cycle	32	27.50	1	1.00E+00	1.00E+00	1.00E+00
Starch and Sucrose Metabolism	31	26.70	1	1.00E+00	1.00E+00	1.00E+00
Urea Cycle	29	25.00	1	1.00E+00	1.00E+00	1.00E+00
Pyruvate Metabolism	48	41.30	1	1.00E+00	1.00E+00	1.00E+00
Tryptophan Metabolism	60	51.60	9	1.00E+00	1.00E+00	1.00E+00
Aspartate Metabolism	35	30.10	1	1.00E+00	1.00E+00	1.00E+00
Androgen and Estrogen Metabolism	33	28.40	1	1.00E+00	1.00E+00	1.00E+00
Glutamate Metabolism	49	42.20	1	1.00E+00	1.00E+00	1.00E+00
Retinol Metabolism	37	31.80	5	1.00E+00	1.00E+00	1.00E+00
Arachidonic Acid Metabolism	69	59.40	4	1.00E+00	1.00E+00	1.00E+00
Betaine Metabolism	21	18.10	1	1.00E+00	1.00E+00	1.00E+00
Gluconeogenesis	35	30.10	1	1.00E+00	1.00E+00	1.00E+00
Steroidogenesis	43	37.00	10	1.00E+00	1.00E+00	1.00E+00
Fatty Acid Biosynthesis	35	30.10	7	1.00E+00	1.00E+00	1.00E+00
Carnitine Synthesis	22	18.90	2	1.00E+00	1.00E+00	1.00E+00
Transfer of Acetyl Groups into Mitochon-	22	18.90	1	1.00E+00	1.00E+00	1.00E+00
dria	07	02.00	,	1.000	1.000	1.005 : 00
Mitochondrial Beta-Oxidation of	27	23.20	1	1.00E+00	1.00E+00	1.00E+00
Medium Chain Saturated Fatty Acids		40.00	١.	1.000.00	1.000.00	1.000.00
Warburg Effect	58	49.90	1	1.00E+00	1.00E+00	1.00E+00
Estrone Metabolism	24	20.60	1	1.00E+00	1.00E+00	1.00E+00

## 7 Appendix: R Command History

```
[1] "mSet<-InitDataObjects(\"conc\", \"pathora\", FALSE)"
 [2] "cmpd.vec<-c(\"HMDB0000123\",\"HMDB0014691\",\"HMDB0031239\",\"HMDB0161401\",\"HMDB0000925\",\"
 [3] "mSet<-Setup.MapData(mSet, cmpd.vec);"
 [4] "mSet<-CrossReferencing(mSet, \"hmdb\");"</pre>
 [5] "mSet<-CreateMappingResultTable(mSet)"
 [6] "mSet<-SetKEGG.PathLib(mSet, \"hsa\", \"current\")"</pre>
 [7] "mSet<-SetMetabolomeFilter(mSet, F);"
 [8] "mSet<-CalculateOraScore(mSet, \"rbc\", \"hyperg\")"
 [9] "mSet<-PlotPathSummary(mSet, F, \"path_view_0_\", \"png\", 72, width=NA)"
[10] "mSet<-SaveTransformedData(mSet)"
[11] "UpdateDataObjects(\"conc\", \"msetora\", FALSE)"
[12] "mSet<-SetMetabolomeFilter(mSet, F);"</pre>
[13] "mSet<-SetCurrentMsetLib(mSet, \"smpdb_pathway\", 2);"
[14] "mSet<-CalculateHyperScore(mSet)"
[15] "mSet<-PlotORA(mSet, \"ora_0_\", \"net\", \"png\", 72, width=NA)"
[16] "mSet<-PlotEnrichDotPlot(mSet, \"ora\", \"ora_dot_0_\", \"png\", 72, width=NA)"
[17] "mSet<-CalculateHyperScore(mSet)"
[18] "mSet<-PlotORA(mSet, \"ora_1_\", \"net\", \"png\", 72, width=NA)"
[19] "mSet<-PlotEnrichDotPlot(mSet, \"ora\", \"ora_dot_1_\", \"png\", 72, width=NA)"
[20] "mSet<-SaveTransformedData(mSet)"
[21] "mSet<-PreparePDFReport(mSet, \"guest17850890059438804150\")\n"
```

The report was generated on Mon May 24 12:54:45 2021 with R version 4.0.2 (2020-06-22).