Metabolomic Data Analysis with MetaboAnalyst 5.0

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1 Background

The Pathway Analysis module combines results from powerful pathway enrichment analysis with pathway topology analysis to help researchers identify the most relevant pathways involved in the conditions under study.

There are many commercial pathway analysis software tools such as Pathway Studio, MetaCore, or Ingenuity Pathway Analysis (IPA), etc. Compared to these commercial tools, the pathway analysis module was specifically developed for metabolomics studies. It uses high-quality KEGG metabolic pathways as the backend knowledgebase. This module integrates many well-established (i.e. univariate analysis, over-representation analysis) methods, as well as novel algorithms and concepts (i.e. Global Test, Global Ancova, network topology analysis) into pathway analysis. Another feature is a Google-Map style interactive visualization system to deliver the analysis results in an intuitive manner.

2 Data Input

The Pathway Analysis module accepts either a list of compound labels (common names, HMDB IDs or KEGG IDs) with one compound per row, or a compound concentration table with samples in rows and compounds in columns. The second column must be phenotype labels (binary, multi-group, or continuous). The table is uploaded as comma separated values (.csv).

3 Compound Name Matching

The first step is to standardize the compound labels used in user uploaded data. This is a necessary step since these compounds will be subsequently compared with compounds contained in the pathway library. There are three outcomes from the step - exact match, approximate match (for common names only), and no match. Users should click the textbfView button from the approximate matched results to manually select the correct one. Compounds without match will be excluded from the subsequently pathway analysis.

Table 1 shows the conversion results. Note: 1 indicates exact match, 2 indicates approximate match, and θ indicates no match. A text file contain the result can be found the downloaded file $name_map.csv$

	Query	Match	HMDB
1	HMDB0000123	Glycine	HMDB0000123
2	HMDB0014691	Acetohydroxamic Acid	HMDB0014691
3	HMDB0031239	Ethyl nitrite	HMDB0031239
4	HMDB0161401	NA	NA
5	HMDB0001858	p-Cresol	HMDB0001858
6	HMDB0033895	Anisole	HMDB0033895
7	HMDB0003119	Benzyl alcohol	HMDB0003119
8	HMDB0002055	o-Cresol	HMDB0002055
9	HMDB0002048	m-Cresol	HMDB0002048

10	HMDB0004983	Dimethyl sulfone	HMDB0004983
11	HMDB0144632	NA	NA
12	HMDB0062140	NA	NA
13	HMDB0034203	N-(2-Methylpropyl)acetamide	HMDB0034203
14	HMDB0031651	N-(3-Methylbutyl)acetamide	HMDB0031651
15	HMDB0062041	NA The state of th	NA
16	HMDB0012296	Trimethylaminoacetone	HMDB0012296
17 18	HMDB0031404 HMDB0032416	Cyclohexylamine 2-Methylpiperidine	HMDB0031404 HMDB0032416
19	HMDB0032410	3-Methylcyclopentene	HMDB0032410
20	HMDB0062716	NA NA	NA
21	HMDB0033971	2-Diethylaminoethanol	HMDB0033971
22	HMDB0167366	NA	NA
23	HMDB0094692	NA	NA
24	HMDB0041945	NA	NA
25	HMDB0167367	NA	NA
26	HMDB0167365	NA NA	NA
27	HMDB0240305	NA .	NA HMDD0021654
28 29	HMDB0031654	3-Aminobutanoic acid NA	HMDB0031654 NA
30	HMDB0094693 HMDB0002166	(S)-b-aminoisobutyric acid	HMDB0002166
31	HMDB0002100	L-Alpha-aminobutyric acid	HMDB0002100
32	HMDB0002299	(R)-b-aminoisobutyric acid	HMDB0002299
33	HMDB0001906	2-Áminoisobutyric acid	HMDB0001906
34	HMDB0003911	3-Aminoisobutanoic acid	HMDB0003911
35	HMDB0000112	Gamma-Aminobutyric acid	HMDB0000112
36	HMDB0038394	NA	NA
37	HMDB0031329	Butyl nitrite	HMDB0031329
38	HMDB0000092	Dimethylglycine	HMDB0000092
39	HMDB0000650 HMDB0061050	D-Alpha-aminobutyric acid NA	HMDB0000650 NA
$\frac{40}{41}$	HMDB0167139	NA NA	NA NA
42	HMDB0167138	NA NA	NA
43	HMDB0000549	Gamma-Butyrolactone	HMDB0000549
44	HMDB0002523	Oxolan-3-one	HMDB0002523
45	HMDB0003407	Diacetyl	HMDB0003407
46	HMDB0031209	Ethenyl acetate	HMDB0031209
47	HMDB0034439	Isocrotonic acid	HMDB0034439
48	HMDB0033977	Methyl acrylate	HMDB0033977
49	HMDB0174868	NA NA	NA
50	HMDB0010720	But-2-enoic acid	HMDB0010720
$\frac{51}{52}$	HMDB0240288 HMDB0161316	NA NA	NA NA
53	HMDB0002994	Erythritol	HMDB0002994
54	HMDB0002334	D-Threitol	HMDB0002334 HMDB0004136
55	HMDB0094689	NA NA	NA
56	HMDB0165469	NA	NA
57	HMDB0165470	NA	NA
58	HMDB0062640	NA	NA
59	HMDB0126088	NA	NA
60	HMDB0000710	4-Hydroxybutyric acid	HMDB0000710
61	HMDB0000442	(S)-3-Hydroxybutyric acid	HMDB0000442
$\frac{62}{63}$	HMDB0000357 HMDB0000336	3-Hydroxybutyric acid (R)-3-Hydroxyisobutyric acid	HMDB0000357 HMDB0000336
64	HMDB0000330	(R)-3-Hydroxybutyric acid	HMDB0000330
65	HMDB0000011	(S)-3-Hydroxyisobutyric acid	HMDB0000011
66	HMDB0000729	Alpha-Hydroxyisobutyric acid	HMDB0000729
67	HMDB0031212	Ethoxyacetic acid	HMDB0031212
68	HMDB0059748	NA	NA
69	HMDB0000008	2-Hydroxybutyric acid	HMDB0000008
70	HMDB0015507	Gamma Hydroxybutyric Acid	HMDB0015507
71	HMDB0000630	Cytosine	HMDB0000630
$\frac{72}{73}$	HMDB0031335 HMDB0163354	2-Chloro-1-propanol NA	HMDB0031335 NA
$\frac{73}{74}$	HMDB0163354 HMDB0163353	NA NA	NA NA
75	HMDB0163351	NA NA	NA
76	HMDB0163350	NA NA	NA
77	HMDB0163352	NA	NA
78	HMDB0163702	NA	NA
79	HMDB0179351	NA	NA
80	HMDB0179346	NA	NA
81	HMDB0179345	NA.	NA
82	HMDB0179344	NA NA	NA NA
83 84	HMDB0179343	NA NA	NA NA
84 85	HMDB0179342 HMDB0179341	NA NA	NA NA
86	HMDB0179341 HMDB0169695	NA NA	NA NA
87	HMDB0169664	NA NA	NA NA
88	HMDB0165583	NA NA	NA
89	HMDB0165582	NA	NA
90	${\rm HMDB0165581}$	NA	NA
91	${\rm HMDB0165584}$	NA	NA
92	HMDB0163703	NA Distriction of the second o	NA
93	HMDB0000453	Delta-Hexanolactone	HMDB0000453
94	HMDB0060476 HMDB0032490	epsilon-Caprolactone Prenyl formate	HMDB0060476 HMDB0032490
95 96	HMDB0032490 HMDB0039581	NA	NA

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HMDB0031158
                                                                                                                   HMDB0031158
 97
                      2-Methyl-4-pentenoic acid
 98
      HMDB0031562
                      2-Methyl-3-pentenoic acid
                                                                                                                   HMDB0031562
 99
      HMDB0031559
                      4-Methyl-2,3-pentanedione
                                                                                                                   HMDB0031559
100
      {\rm HMDB0031491}
                      2,3-Hexanedione
                                                                                                                   {\rm HMDB0031491}
101
      {\rm HMDB0031560}
                      \hbox{2-Methyl-2-pentenoic acid}
                                                                                                                   HMDB0031560
      HMDB0031501
102
                      3-Hexenoic acid
                                                                                                                   HMDB0031501
      HMDB0029487
                                                                                                                   HMDB0029487
103
                      Allyl propionate
104
      HMDB0033568
                                                                                                                   HMDB0033568
                      5-Oxohexanal
      HMDB0040328
105
                                                                                                                   NA
      HMDB0031492
                      3,4-Hexanedione
                                                                                                                   HMDB0031492
106
107
      {\rm HMDB0031561}
                      4-Methyl-2-pentenoic acid
                                                                                                                   {\rm HMDB0031561}
108
     HMDB0010719
HMDB0003843
                      trans-Hex-2-enoic acid
                                                                                                                   HMDB0010719
                                                                                                                   HMDB0003843
109
                      Gamma-Caprolactone
      HMDB0240384
110
                      NA
                                                                                                                   NA
111
      HMDB0061929
                      NA
                                                                                                                   NA
      {\rm HMDB0061965}
                      NA
                                                                                                                   NA
112
      HMDB0062135
                      NA
                                                                                                                   NA
113
114
      {\rm HMDB0161115}
                      NΑ
                                                                                                                   NA
      HMDB0161116
                      NΑ
115
                                                                                                                   NA
      HMDB0163679
                      NA
116
                                                                                                                   NA
      HMDB0061652
                                                                                                                   HMDB0061652
117
                      3-hydroxyhexanoic acid
118
      HMDB0171222
                      ΝA
119
      {\rm HMDB0165042}
                      NA
                                                                                                                   NA
120
      HMDB0165043
                      NΑ
                                                                                                                   NA
      HMDB0165041
121
                      NA
                                                                                                                   NA
      HMDB0163682
                      NA
                                                                                                                   NA
122
      HMDB0163680
123
                      NA
                                                                                                                   NA
      HMDB0163681
                                                                                                                   NA
124
125
      HMDB0000317
                      2-Hydroxy-3-methylpentanoic acid
                                                                                                                   HMDB0000317
126
      {\rm HMDB0000409}
                      (5R)-5-Hydroxyhexanoic acid
                                                                                                                   {\rm HMDB0000409}
      HMDB0032158
127
                       +/-)-1-Acetoxy-1-ethoxyethane
                                                                                                                   HMDB0032158
      HMDB0000624
                                                                                                                   HMDB0000624
                      D-Leucic acid
128
      HMDB0000665
                                                                                                                   HMDB0000665
                      Leucinic acid
129
      HMDB0000746
                      Hydroxyisocaproic acid
                                                                                                                   HMDB0000746
130
      HMDB0000525
                      5-Hydroxyhexanoic acid
                                                                                                                   HMDB0000525
132
      HMDB0001624
                      2-Hydroxycaproic acid
                                                                                                                   {\rm HMDB0001624}
133
      HMDB0001975
                      2-Ethyl-2-Hydroxybutyric acid
                                                                                                                   HMDB0001975
      HMDB0010718
                                                                                                                   HMDB0010718
134
                      (R)-3-Hydroxyhexanoic acid
      HMDB0012843
                                                                                                                   HMDB0012843
                      6-Hydroxyhexanoic acid
135
      HMDB0033851
                      4,4-Dimethoxy-2-butanone
136
                                                                                                                   HMDB0033851
      HMDB0032456
                                                                                                                   {\rm HMDB0032456}
137
                      Paraldehyde
138
      {\rm HMDB0040409}
                      NA
                                                                                                                   NA
139
      HMDB0165040
                      NΑ
                                                                                                                   NA
      HMDB0059770
140
                      NA
                                                                                                                   NA
      HMDB0041844
                      NA
                                                                                                                   NA
141
142
      HMDB0029166
                      2-Methyl-3-hydroxyvaleric acid
                                                                                                                   HMDB0029166
      HMDB0061950
143
                                                                                                                   NA
                                                                                                                   HMDB0000532
144
      HMDB0000532
                      Acetylglycine
145
      {\rm HMDB0006454}
                      L-2-Amino-3-oxobutanoic acid
                                                                                                                   {\rm HMDB0006454}
      HMDB0012249
146
                      L-Aspartate-semialdehyde
                                                                                                                   HMDB0012249
      HMDB0161181
147
                      NA
                                                                                                                   NA
      {\rm HMDB0187639}
                                                                                                                   NA
148
                      NA
      HMDB0032523
                      Succinic anhydride
                                                                                                                   HMDB0032523
      HMDB0029389
                      (+)-threo-2-Amino-3,4-dihydroxybutanoic acid
                                                                                                                   HMDB0029389
150
151
      HMDB0000034
                      Àdenine
                                                                                                                   HMDB0000034
                      3-Methylcytosine
      HMDB0011601
152
                                                                                                                   HMDB0011601
      HMDB0004339
                                                                                                                   HMDB0004339
                      2-O-Methylcytosine
153
      HMDB0002894
                                                                                                                   HMDB0002894
                      5-Methylcytosine
154
155
      HMDB0128943
                      NA
                                                                                                                   NA
156
      HMDB0132477
                      NA
                                                                                                                   NA
157
      HMDB0129097
                      NA
                                                                                                                   NA
158
      HMDB0168839
                      NΑ
                                                                                                                   NA
      HMDB0128916
159
                      NA
                                                                                                                   NA
      HMDB0012233
                                                                                                                   HMDB0012233
                      Glutarate semialdehyde
160
      HMDB0029172
                      3-keto-2-Methylbutyrate
                                                                                                                   HMDB0029172
161
      HMDB0001865
                      2-Oxovaleric acid
                                                                                                                   HMDB0001865
162
163
      HMDB0000310
                      Methylacetoacetic acid
                                                                                                                   HMDB0000310
164
      HMDB0031643
                      Ethyl pyruvate
                                                                                                                   HMDB0031643
      HMDB000019
                      Alpha-ketoisovaleric acid
                                                                                                                   HMDB000019
165
      HMDB0003771
                      2-Methylacetoacetic acid
                                                                                                                   HMDB0003771
166
      HMDB0000720
167
                      Levulinic acid
                                                                                                                   {\rm HMDB0000720}
      HMDB0034466
                                                                                                                   HMDB0034466
168
                      Acetoxyacetone
      HMDB0128917
                      NA
                                                                                                                   NA
169
170
      {\rm HMDB}0129096
                      NA
                                                                                                                   NA
171
      HMDB0129098
                      NA
                                                                                                                   NA
      HMDB0168838
                      NA
172
                                                                                                                   NA
173
      HMDB0177210
                      NA
                                                                                                                   NA
174
      HMDB0169666
                      NA
                                                                                                                   ΝA
      HMDB0177209
175
                      NA
                                                                                                                   NA
176
      {\rm HMDB}0171727
                      NΑ
                                                                                                                   NA
                                                                                                                   HMDB0032356
177
      HMDB0032356
                      N-Lactoyl ethanolamine
      HMDB0039499
178
                      NA
      HMDB0031658
                                                                                                                   HMDB0031658
179
                      L-2-Amino-5-hydroxypentanoic acid
      HMDB0039790
180
                      NΑ
                                                                                                                   NA
181
      HMDB0038974
                      NA
                                                                                                                   NA
182
      HMDB0039789
                      NA
                                                                                                                   HMDB0000786
183
      HMDB0000786
                      Oxypurinol
```

184	HMDB0000292	Xanthine	HMDB0000292
185	HMDB0001182	6,8-Dihydroxypurine	HMDB0001182
186	HMDB0000744	Malic acid	HMDB0000744
187	HMDB0031518	D-Malic acid	HMDB0031518
188	HMDB0000156	L-Malic acid	HMDB0000156
189	HMDB0032872	Velcorin	HMDB0032872
190	HMDB0061971	NA NA	NA
$\frac{191}{192}$	HMDB0041477	NA Dibutyl sulfide	NA
192	HMDB0031660 HMDB0240251	NA	HMDB0031660 NA
194	HMDB0240231	NA NA	NA
195	HMDB0059659	Trans-3-hydroxy-L-proline	HMDB0059659
196	HMDB0002113	3-Hydroxy-L-proline	HMDB0002113
197	HMDB0000783	Propionylglycine	HMDB0000783
198	HMDB0000766	N-Acetyl-L-alanine	HMDB0000766
199	HMDB0000725	4-Hydroxyproline	HMDB0000725
200	HMDB0036576	NA	NA
201	HMDB0001149	5-Aminolevulinic acid	HMDB0001149
202	HMDB0002104	L-Glutamic gamma-semialdehyde	HMDB0002104
203	HMDB0006055	4-Hydroxy-L-proline	HMDB0006055
204	HMDB0060460	cis-4-Hydroxy-D-proline	HMDB0060460 HMDB0006272
$\frac{205}{206}$	HMDB0006272 HMDB0177404	5-Amino-2-oxopentanoic acid NA	NA
207	HMDB0014389	Mesalazine	HMDB0014389
208	HMDB0014903	NA NA	NA
209	HMDB0059749	NA	NA
210	HMDB0001972	3-Aminosalicylic acid	HMDB0001972
211	HMDB0014378	Aminosalicylic Acid	HMDB0014378
212	HMDB0001476	3-Hydroxyanthranilic acid	HMDB0001476
213	HMDB0059811	NA	NA
214	HMDB0012289	Tetrahydrodipicolinate	HMDB0012289
215	HMDB0014447	Tranexamic Acid	HMDB0014447
$\frac{216}{217}$	HMDB0033433	(S)-Homostachydrine	HMDB0033433
217	HMDB0039651 HMDB0039680	NA NA	NA NA
219	HMDB0039080	NA NA	NA NA
220	HMDB0037625	NA NA	NA
221	HMDB0040526	NA	NA
222	HMDB0037196	NA	NA
223	HMDB0037167	NA	NA
224	HMDB0039652	NA	NA
225	HMDB0060682	NA	NA
226	HMDB0032311	2,4-Hexadienyl acetate	HMDB0032311
227	HMDB0039673	NA	NA
228	HMDB0040463	NA NA	NA
229	HMDB0039681	NA	NA HMDD0022054
$\frac{230}{231}$	HMDB0033054 HMDB0033053	Ethyl isopropyl disulfide Ethyl propyl disulfide	HMDB0033054 HMDB0033053
$\frac{231}{232}$	HMDB0033033	1-Pentanesulfenothioic acid	HMDB0033033
233	HMDB0000157	Hypoxanthine	HMDB0000157
234	HMDB0014581	Allopurinol	HMDB0014581
235	HMDB0000943	Threonic acid	HMDB0000943
236	HMDB0062620	NA	NA
237	HMDB0000613	Erythronic acid	HMDB0000613
238	HMDB0137818	NA	NA
239	HMDB0183470	NA .	NA
240	HMDB0060348	Maleylacetic acid	HMDB0060348
$\frac{241}{242}$	HMDB0031210	Zymonic acid NA	HMDB0031210
$\frac{242}{243}$	HMDB0037759 HMDB0014273	NA NA	NA NA
$\frac{243}{244}$	HMDB000044	Ascorbic acid	HMDB0000044
245	HMDB0031193	1.2.3-Propanetricarboxylic acid	HMDB0031193
246	HMDB0006355	D-Glucurono-6,3-lactone	HMDB0006355
247	HMDB0001280	2-Aminomuconic acid semialdehyde	HMDB0001280
248	HMDB0031670	1-(Hydroxymethyl)-5,5-dimethyl-2,4-imidazolidinedione	HMDB0031670
249	HMDB0028696	Alanyl-Serine	HMDB0028696
250	HMDB0029032	Serylalanine	HMDB0029032
251	HMDB0145395	NA	NA
252	HMDB0029061	Threoninyl-Glycine	HMDB0029061
253	HMDB0028851	Glycyl-Threonine	HMDB0028851
$\frac{254}{255}$	HMDB0169117	NA NA	NA NA
$\frac{255}{256}$	HMDB0125105 HMDB0038987	NA NA	NA NA
$\frac{250}{257}$	HMDB0032029	2-Isopropylphenol	HMDB0032029
258	HMDB0032149	1-Methoxy-2,4-dimethylbenzene	HMDB0032149
259	HMDB0032625	4-Propylphenol	HMDB0032625
260	HMDB0029667	2,3,6-Trimethylphenol	HMDB0029667
261	HMDB0039782	NA	NA
262	HMDB0038986	NA	NA
263	HMDB0032624	2-Propylphenol	HMDB0032624
264	HMDB0038988	NA	NA
265	HMDB0032621	(2-Methoxyethyl)benzene	HMDB0032621
266	HMDB0038985	NA Popul ethyl ethor	NA HMDD0021212
$\frac{267}{268}$	HMDB0031312 HMDB0033962	Benzyl ethyl ether 3-Phenyl-1-propanol	HMDB0031312 HMDB0033962
269	HMDB0033962 HMDB0031627	1-Phenyl-1-propanol	HMDB0033627
270	HMDB0034378	(Âs)-1-(4-Methylphenyl)ethanol	HMDB0034378
	_ = = = = = = = = = = = = = = = = = = =	() () · · · · · · · · · · · · · · · ·	

271	HMDB0031628	2-Phenyl-1-propanol	HMDB0031628
272	HMDB0038984	NA	NA
273	HMDB0032544	2,4,6-Trimethylphenol	HMDB0032544
274	HMDB0031446	p-Isopropylphenol	HMDB0031446
275	HMDB0032441	Nona-2,4,6-trienal	HMDB0032441
276	HMDB0059896	NA	NA
277	HMDB0169118	NA	NA
278	HMDB0014362	Bethanidine	HMDB0014362
279	HMDB0160667	NA	NA
280	HMDB0160666	NA	NA
281	HMDB0160406	NA	NA
282	HMDB0160407	NA	NA
283	HMDB0000694	L-2-Hydroxyglutaric acid	HMDB0000694
$\frac{283}{284}$	HMDB0000428	2-Hydroxyglutaric acid	HMDB0000034
285	HMDB0000426	Citramalic acid	HMDB0000426
286	HMDB0000420	D-2-Hydroxyglutaric acid	HMDB0000606
287	HMDB0059655	2-Hydroxyglutarate	HMDB0059655
288	HMDB0039033	Ribonolactone	HMDB0009000
289	HMDB0161319	NA NA	NA
290	HMDB0101319	D-Xylono-1,5-lactone	HMDB0011676
290		NA	NA
291	HMDB0061190	NA NA	NA NA
292	HMDB0062739		NA NA
$\frac{293}{294}$	HMDB0160668 HMDB0041392	NA NA	NA NA
$\frac{294}{295}$			HMDB0033912
	HMDB0033912	2-Propenyl propyl disulfide	
296	HMDB0038890 HMDB0001566	NA 2 Mathalauanina	NA
297		3-Methylguanine	HMDB0001566
298	HMDB0000897	7-Methylguanine	HMDB0000897
299	HMDB0006040	N2-Methylguanine	HMDB0006040
300	HMDB0003282	1-Methylguanine	HMDB0003282
301	HMDB0011657	2,6-Diamino-4-hydroxy-5-N-methylformamidopyrimidine	HMDB0011657
302	HMDB0000232	Quinolinic acid	HMDB0000232
303	HMDB0033161	2,6-Pyridinedicarboxylic acid	HMDB0033161
304	HMDB0185628	NA	NA
305	HMDB0001330	2-Amino-3-carboxymuconic acid semialdehyde	HMDB0001330
306	HMDB0062578	NA	NA
307	HMDB0060260	NA	NA
308	HMDB0001552	2-Keto-glutaramic acid	HMDB0001552
309	HMDB0061157	NA	NA
310	HMDB0168723	NA	NA
311	HMDB0168724	NA	NA
312	HMDB0029449	(2R,3R,4R)-2-Amino-4-hydroxy-3-methylpentanoic acid	HMDB0029449
313	HMDB0142963	NA	NA
314	HMDB0033453	Fagomine	HMDB0033453
315	HMDB0182861	NĀ	NA
316	HMDB0137457	NA	NA
317	HMDB0012308	Vanillin	HMDB0012308
318	HMDB0166107	NA	NA
319	HMDB0150437	NA	NA
320	HMDB0125528	NA	NA
321	HMDB0146889	NA	NA
322	HMDB0166109	NA	NA
323	HMDB0183904	NA	NA
324	HMDB0183905	NA	NA
325	HMDB0146870	NA	NA
326	HMDB0166106	NA	NA
327	HMDB0171094	NA	NA
328	HMDB0029659	2',4'-Dihydroxyacetophenone	HMDB0029659
329	HMDB0041283	NA NA	NA
330	HMDB0029657	2.4'-Dihydroxyacetophenone	HMDB0029657
331	HMDB0032606	3-Methoxybenzoic acid	HMDB0032606
332	HMDB0034172	Methyl 2-hydroxybenzoate	HMDB0034172
333	HMDB0032604	2-Methoxybenzoic acid	HMDB0032604
334	HMDB0029661	3,4'-Dihydroxyacetophenone	HMDB0029661
335	HMDB0029662	3,5'-Dihydroxyacetophenone	HMDB0029662
336	HMDB0023002	Methylparaben	HMDB0032572
337	HMDB0032629	2.5'-Dihydroxyacetophenone	HMDB0032629
338	HMDB0032023	2,0-5mythxylaceophelione 1-(5-Methyl-2-furanyl)-1,2-propanedione	HMDB0033003
339	HMDB0033003	Ethyl 2-furanyl diketone	HMDB0033003
340	HMDB0032919 HMDB0036907	NA	NA
341	HMDB0000703	Mandelic acid	HMDB0000703
342	HMDB0001101	p-Anisic acid	HMDB0001101
343	HMDB00001101	p-Hydroxyphenylacetic acid	HMDB0000101
$\frac{343}{344}$	HMDB0000440	3-Hydroxyphenylacetic acid	HMDB0000020
$\frac{344}{345}$	HMDB0000440 HMDB0000669	Ortho-Hydroxyphenylacetic acid	HMDB0000440 HMDB0000669
$\frac{345}{346}$	HMDB0000009 HMDB0002390	3-Cresotinic acid	HMDB0000009 HMDB0002390
$\frac{340}{347}$			HMDB0002390 HMDB0003791
	HMDB0003791	3,4-Dihydroxyphenylacetaldehyde 4-Hydroxy-3-methylbenzoic acid	
348	HMDB0004815		HMDB0004815
349	HMDB0032594	2-(Hydroxymethyl)benzoic acid	HMDB0032594
350	HMDB0031609	Phenoxyacetic acid	HMDB0031609
351	HMDB0168664	NA NA	NA NA
352	HMDB0172092	NA NA	NA
353	HMDB0166108	NA	NA
354	HMDB0029658	2',3'-Dihydroxyacetophenone	HMDB0029658
355	HMDB0029660	2',6'-Dihydroxyacetophenone	HMDB0029660
356	HMDB0172091	NA	NA
357	HMDB0032399	Methyl furfuracrylate	HMDB0032399

```
HMDB0062635
358
                      NA
                                                                                                                  NA
      HMDB0060390
                      NA
                                                                                                                  NA
359
      HMDB0062005
360
                      NA
                                                                                                                  NA
361
      {\rm HMDB0124926}
                      NA
                                                                                                                  NA
362
      {\rm HMDB0037685}
                      NA
                                                                                                                  NA
      HMDB0000239
                      Pyridoxine
                                                                                                                  HMDB0000239
363
      HMDB0155164
364
                      NA
                                                                                                                  NA
365
      HMDB0035178
                      6-Acetyl-2,3-dihydro-2-(hydroxymethyl)-4(1H)-pyridinone
                                                                                                                  HMDB0035178
      HMDB0004817
366
                      5-Hydroxydopamine
                                                                                                                  HMDB0004817
367
      HMDB0001537
                      6-Hydroxydopamine
                                                                                                                  HMDB0001537
368
      {\rm HMDB0000216}
                      Norepinephrine
                                                                                                                  {\rm HMDB0000216}
369
      HMDB0012150
                      2-Keto-6-acetamidocaproate
                                                                                                                  HMDB0012150
      HMDB0162021
                      NΑ
370
                                                                                                                  NΑ
371
      HMDB0040972
                      NΑ
                                                                                                                  NA
372
      HMDB0038628
                      NA
                                                                                                                  NA
      HMDB0004073
                      5-Hydroxyindoleacetaldehyde
                                                                                                                  HMDB0004073
373
374
      HMDB0000197
                      Indoleacetic acid
                                                                                                                  {\rm HMDB0000197}
375
      HMDB0166095
                      NA
                                                                                                                  NA
376
      HMDB0060758
                      NΑ
                                                                                                                  NA
      HMDB0240317
377
                      NA
                                                                                                                  NA
378
      HMDB0162022
                      NA
                                                                                                                  NA
379
      HMDB0162020
                      NA
                                                                                                                  NA
380
      {\rm HMDB0162023}
                      NA
                                                                                                                  NA
                                                                                                                  HMDB0013292
381
      HMDB0013292
                      p-Methylhippuric acid
      HMDB0000821
                                                                                                                  HMDB0000821
382
                      Phenylacetylglycine
      HMDB0000859
                                                                                                                  HMDB0000859
                      Methyl hippurate
383
      HMDB0011723
                                                                                                                  {\rm HMDB0011723}
384
                      2-Methylhippuric acid
      HMDB0060366
                                                                                                                  HMDB0060366
385
                      3-Carbamoyl-2-phenylpropionaldehyde
386
      HMDB0060389
                      4-Hydroxy-5-phenyltetrahydro-1,3-oxazin-2-one
                                                                                                                  HMDB0060389
387
      {\rm HMDB0034250}
                      Betamipron
                                                                                                                  {\rm HMDB0034250}
                      Methyl\ n-acetylanthranilate
388
      HMDB0032388
                                                                                                                  HMDB0032388
      HMDB0013245
                                                                                                                  HMDB0013245
                      m-Methylhippuric acid
389
      HMDB0012309
390
                      Vanillylamine
                                                                                                                  {\rm HMDB0012309}
      HMDB0004825
                                                                                                                  HMDB0004825
391
                      p-Octopamine
      HMDB0156498
                      ÑΑ
392
                                                                                                                  NA
                                                                                                                  HMDB0000073
393
      {\rm HMDB0000073}
                      Dopamine
394
      HMDB0060277
                      NA
                                                                                                                  NA
      HMDB0037786
395
                      NA
                                                                                                                  NA
      HMDB0172919
396
                      NA
                                                                                                                  NA
      HMDB0028850
                                                                                                                  HMDB0028850
397
                      Glycyl-Serine
      HMDB0029424
                      L-4-Hydroxyglutamine
                                                                                                                  HMDB0029424
398
399
      {\rm HMDB0029039}
                      Serylglycine
                                                                                                                  HMDB0029039
     HMDB0177509
HMDB0133596
400
                      NΑ
                                                                                                                  NA
401
                      NA
                                                                                                                  NA
      HMDB0157134
402
                      NA
                                                                                                                  NA
403
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                      NA
                                                                                                                  NA
      HMDB0133747
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404
                                                                                                                  NA
405
      {\rm HMDB0133748}
                      NA
                                                                                                                  NA
406
      {\rm HMDB0133597}
                      NA
                                                                                                                  NA
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407
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                                                                                                                  NA
      HMDB0133599
408
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                                                                                                                  NA
      HMDB0133594
409
                      NA
                                                                                                                  NA
410
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                      NA
                                                                                                                  NA
411
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                      NA
                                                                                                                  NA
412
      {\rm HMDB0133504}
                      NA
                                                                                                                  NA
      HMDB0141158
413
                      NA
                                                                                                                  NA
      HMDB0133755
414
                      NA
                                                                                                                  NA
      HMDB0133751
                      NA
                                                                                                                  NA
415
      HMDB0133750
                      NA
416
                                                                                                                  NA
417
      HMDB0133595
                      NA
418
      HMDB0033833
                      Methyl cinnamate
                                                                                                                  HMDB0033833
419
      HMDB0060335
                      1,2-Dihydronaphthalene-1,2-diol
                                                                                                                  HMDB0060335
      HMDB0135643
                                                                                                                  ^{\rm NA}_{\rm HMDB0032611}
420
                      NA
      HMDB0032611
421
                      3-(4-Methoxyphenyl)-2-propenal
      HMDB0033830
                                                                                                                  HMDB0033830
422
                      Cassiastearoptene
      HMDB0040577
423
424
      {\rm HMDB0029714}
                      4,5-Dihydro-1-benzoxepin-3(2H)-one
                                                                                                                  HMDB0029714
425
      HMDB0033591
                      {\bf Safrole}
                                                                                                                  HMDB0033591
      HMDB0038893
426
                      NA
                                                                                                                  NA
      HMDB0146627
427
                      NA
                                                                                                                  NA
      {\rm HMDB0141046}
428
                      NA
                                                                                                                  NA
429
      HMDB0040592
                                                                                                                  NA
      HMDB0041931
                      NA
                                                                                                                  NA
430
431
      HMDB0029223
                      alpha-Methylphenylalanine
                                                                                                                  HMDB0029223
432
      HMDB0029224
                      N-methylphenylalanine
                                                                                                                  HMDB0029224
      HMDB0042012
433
                      NΑ
                                                                                                                  NA
434
      HMDB0039655
                      NA
                                                                                                                  NA
435
      HMDB0033763
                      Ethyl N-methylanthranilate
                                                                                                                  HMDB0033763
436
      HMDB0040021
                                                                                                                  HMDB0030372
437
      HMDB0030372
                      Maltoxazine
                      3,5-Dimethylphenyl methylcarbamate
                                                                                                                  HMDB0031811
438
      HMDB0031811
      HMDB0005199
                                                                                                                  HMDB0005199
439
                      (R.)-Salsolinol
      HMDB0001189
                      2(N)-Methyl-norsalsolinol
                                                                                                                  HMDB0001189
440
      HMDB0129369
441
                      ΝÀ
                                                                                                                  NA
442
      HMDB0135530
                      NA
                                                                                                                  NA
443
      HMDB0135531
                      NA
                                                                                                                  NA
444
      HMDB0135533
                      NA
                                                                                                                  NA
```

445	${\rm HMDB0128615}$	NA	NA
446	HMDB0135532	NA	NA
447	HMDB0033813	3-(3,4-Methylenedioxyphenyl)propenal	HMDB0033813
$\frac{448}{449}$	HMDB0032883	1,4,5-Naphthalenetriol	HMDB0032883 HMDB0032990
449	HMDB0032990 HMDB0163660	7-Hydroxy-6-methyl-2H-1-benzopyran-2-one NA	NA
451	HMDB0103000	Herniarin	HMDB0029758
452	HMDB0059622	NA NA	NA
453	HMDB0031054	10-Hydroxy-2,8-decadiene-4,6-diynoic acid	HMDB0031054
454	HMDB0060747	NA	NA
455	HMDB0001434	3-Methoxytyrosine	HMDB0001434
456	HMDB0011754	Methyldopa	HMDB0011754
457	HMDB0040003	NA	NA
458	HMDB0172928	NA NA	NA
459	HMDB0172925	NA	NA
$\frac{460}{461}$	HMDB0151309	NA NA	NA NA
462	HMDB0037153 HMDB0151285	NA NA	NA NA
463	HMDB0151284	NA	NA
464	HMDB0062564	NA	NA
465	HMDB0163545	NA	NA
466	HMDB0031437	(-)-Bornesitol	HMDB0031437
467	HMDB0029965	Methyl beta-D-glucopyranoside	HMDB0029965
468	HMDB0031449	Sequoyitol	HMDB0031449
469	HMDB0029915	D-4-O-Methyl-myo-inositol	HMDB0029915
$470 \\ 471$	HMDB0029916	4-O-Methyl-myo-inositol Mytilitol	HMDB0029916
$471 \\ 472$	HMDB0033816 HMDB0034219	D-Pinitol	HMDB0033816 HMDB0034219
473	HMDB0034222	L-Pinitol	HMDB0034213
474	HMDB0034221	L-Quebrachitol	HMDB0034222
475	HMDB0033750	D-Glycero-D-galacto-heptitol	HMDB0033750
476	${\rm HMDB0037295}$	NA	NA
477	HMDB0014962	Enprofylline	HMDB0014962
478	HMDB0001847	Caffeine	HMDB0001847
479	HMDB0039467	NA .	NA
480	HMDB0031699	S-(3-Methyl-2-butenyl) 2-methylpropanethioate	HMDB0031699
$\frac{481}{482}$	HMDB0033843 HMDB0028843	Polyvidone Glycyl-Histidine	HMDB0033843 HMDB0028843
483	HMDB0028845	Histidinyl-Glycine	HMDB0028845
484	HMDB0014814	Benzyl Benzoate	HMDB0028888
485	HMDB0032039	Benzoin	HMDB0032039
486	HMDB0014018	4-Hydroxypropofol	HMDB0014018
487	HMDB0037389	NA	NA
488	HMDB0038292	NA	NA
489	HMDB0040439	NA	NA
490	HMDB0039685	NA	NA
$\frac{491}{492}$	HMDB0041497 HMDB0031840	NA (S,Z)-Lyratol acetate	NA HMDB0031840
492	HMDB0035801	(S,L)-Lyrator acetate $(2S,4R)$ -p-Mentha- $1(7)$,5-dien-2-ol acetate	HMDB0035801
494	HMDB0035375	Ethyl (2E,4E,7Z)-Decatrienoate	HMDB0035375
495	HMDB0035376	Ethyl (2E,4Z,7Z)-Decatrienoate	HMDB0035376
496	HMDB0132986	NA	NA
497	HMDB0034450	Neocnidilide	HMDB0034450
498	HMDB0032567	Hexylresorcinol	HMDB0032567
499	HMDB0035126	(Åś)-Myrtenyl acetate	HMDB0035126
500	HMDB0041610	NA	NA
501	HMDB0038046	NA	NA
502	HMDB0037018	NA NA	NA NA
$\frac{503}{504}$	HMDB0037231 HMDB0035085	Vulgarole	HMDB0035085
505	HMDB0033033	vagarote NA	NA
506	HMDB0029388	Cucurbic acid	HMDB0029388
507	${\rm HMDB0037326}$	NA	NA
508	HMDB0033601	Dihydrojasmonic acid	HMDB0033601
509	HMDB0040195	NA .	NA
510	HMDB0035723	(1R,2S,3S,4R)-p-Menthane-2,3-diol	HMDB0035723
511	HMDB0034457 HMDB0061987	Propyl heptanoate NA	HMDB0034457 NA
$\frac{512}{513}$	HMDB0062146	NA NA	NA NA
514	HMDB0038038	NA NA	NA
515	HMDB0036228	2-Methylpropyl hexanoate	HMDB0036228
516	HMDB0040167	NA	NA
517	HMDB0036136	NA	NA
518	HMDB0187563	NA	NA
519	HMDB0037387	NA	NA
520	HMDB0000511	Capric acid	HMDB0000511
$\frac{521}{522}$	HMDB0031264	Methyl nonanoate 1-Methylethyl heptanoic acid	HMDB0031264 HMDB0094654
$\frac{522}{523}$	HMDB0094654 HMDB0171179	NA	NA
$\frac{525}{524}$	HMDB0171179 HMDB0171178	NA NA	NA NA
525	HMDB0171177	NA NA	NA
526	HMDB0171176	NA	NA
527	HMDB0179213	NA	NA
528	HMDB0179212	NA	NA
529	HMDB0179927	NA NA	NA
530 531	HMDB0180500	NA NA	NA NA
531	HMDB0180498	NA	11/A

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HMDB0180499
532
                       NA
                                                                                                                      NA
533
      HMDB0180497
                       NA
                                                                                                                      NA
      HMDB0180502
534
                       NA
      {\rm HMDB0180501}
                       NA
                                                                                                                      NA
535
536
      {\rm HMDB0180503}
                       NA
                                                                                                                      NA
537
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                       NA
                                                                                                                      NA
      HMDB0171175
538
                       NA
                                                                                                                      NA
539
      HMDB0061805
                       NA
                                                                                                                      NA
                                                                                                                      NA
      HMDB0180097
                       NA
540
      HMDB0032302
                       Heptanal propyleneglycol acetal
                                                                                                                      HMDB0032302
541
542
      {\rm HMDB0032155}
                       Acetaldehyde 1,3-octanediol acetal
                                                                                                                      {\rm HMDB0032155}
543
      {\rm HMDB0032264}
                       Ethyl 2-ethylhexanoate
                                                                                                                      HMDB0032264
      HMDB0032315
                       Hexanal butane-2,3-diol acetal
                                                                                                                      HMDB0032315
544
      HMDB0032045
                       Pentyl 3-methylbutanoate
                                                                                                                      HMDB0032045
545
546
      HMDB0041216
                                                                                                                      NA
      HMDB0034849
                                                                                                                      HMDB0034849
547
                       4-Methylnonanoic acid
      HMDB0037849
                       Hexyl 2-methylpropanoate
                                                                                                                      {\rm HMDB0037849}
548
549
      HMDB0040157
                       NΑ
                                                                                                                      NA
                                                                                                                      HMDB0033620
      HMDB0033620
                       Hexyl butyrate
550
      HMDB0035595
                                                                                                                      HMDB0035595
551
                      trans-p-Menthane-1,8-diol 1,1-Diethoxy-2-hexene
552
      HMDB0029760
                                                                                                                      HMDB0029760
553
      HMDB0032070
                       Isooctyl acetate
                                                                                                                      HMDB0032070
554
      {\rm HMDB0040211}
                       NA
                                                                                                                      NA
555
      HMDB0040529
                       NΑ
                                                                                                                      NA
      HMDB0038783
556
                       NA
                                                                                                                      NA
      HMDB0036145
                       NA
                                                                                                                      NA
557
      HMDB0039218
558
                                                                                                                      NA
                       NA
      HMDB0038602
                                                                                                                      HMDB0038602
559
                       Octyl acetate
                       Isopentyl isopentanoate
560
      HMDB0030029
                                                                                                                      HMDB0030029
561
      {\rm HMDB0031739}
                       7-Hydroxy-3,7-dimethyloctanal
                                                                                                                      HMDB0031739
562
      HMDB0035360
                       N-Methyl-1-deoxynojirimycin
                                                                                                                      HMDB0035360
      HMDB0013988
                       N-Deschlorobenzovl indomethacin
                                                                                                                      HMDB0013988
563
      HMDB0038339
564
                       NA
                                                                                                                      NA
      HMDB0033436
                       Nigellimine N-oxide
                                                                                                                      HMDB0033436
565
      HMDB0038338
566
                       NA
                                                                                                                      NA
567
      HMDB0139875
                       NA
                                                                                                                      NA
                                                                                                                      HMDB0029034
568
      HMDB0029034
                       Serylasparagine
      HMDB0028740
                                                                                                                      HMDB0028740
569
                       Asparaginyl-Serine
      HMDB0032401
                       (+/-)-3-[(2-methyl-3-furyl)thio]-2-butanone
                                                                                                                      HMDB0032401
570
571
      HMDB0059660
                                                                                                                      NA
      HMDB0000114
                                                                                                                      HMDB0000114
572
                       Glycerylphosphorylethanolamine
573
      {\rm HMDB0033349}
                       Casimiroin
                                                                                                                      HMDB0033349
574
      HMDB0013859
                       2-Dechloroethylifosfamide
                                                                                                                      HMDB0013859
575
      HMDB0013858
                       3-Dechloroethylifosfamide
                                                                                                                      HMDB0013858
576
      HMDB0060881
                                                                                                                      NA
577
      HMDB0028776
                       Cysteinyl-Hydroxyproline
                                                                                                                      HMDB0028776
      HMDB0028860
                                                                                                                      HMDB0028860
578
                       Hydroxyprolyl-Cysteine
579
      {\rm HMDB0032660}
                       (2Z,4'Z)-2-(5-Methylthio-4-penten-2-ynylidene)-1,6-dioxaspiro[4.4]non-3-ene
                                                                                                                      HMDB0032660
580
      {\rm HMDB0004821}
                       Bisnorbiotin
                                                                                                                      HMDB0004821
      HMDB0060618
581
                       NA
                                                                                                                      NA
      HMDB0059798
582
                       NA
                                                                                                                      NA
      {\rm HMDB0059799}
                       NA
                                                                                                                      NA
583
584
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                                                                                                                      NA
      HMDB0059797
                       NA
                                                                                                                      NA
585
586
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                       NA
                                                                                                                      NA
                                                                                                                      HMDB0014673
587
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                       Mephenytoin
      HMDB0014932
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588
                       Primidone
      HMDB0001238
                       N-Acetylserotonin
                                                                                                                      HMDB0001238
589
590
      HMDB0240319
                                                                                                                      NA
591
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                       Alanyl-Phenylalanine
                                                                                                                      HMDB0028694
592
      HMDB0028988
                       Phenylalanyl-Alanine
                                                                                                                      HMDB0028988
593
      HMDB0062497
                       NΑ
                                                                                                                      NA
      HMDB0060855
594
                       NA
                                                                                                                      NA
      HMDB0139921
                       NA
595
                                                                                                                      NA
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596
                       Hexobarbital
      HMDB0038163
597
                       NA
                                                                                                                      NA
598
      {\rm HMDB0038162}
                                                                                                                      NA
                       NA
                                                                                                                      HMDB0032564
599
      HMDB0032564
                       1,3-Diphenylpropane
      HMDB0240493
                                                                                                                      \begin{array}{c} {\rm NA} \\ {\rm HMDB0029741} \end{array}
600
                      NΑ
      HMDB0029741
                       \hbox{2-Isopropyl-3,5-dimethoxy-6-methylpyrazine}
601
602
      HMDB0040551
                                                                                                                      NA
      HMDB0000210
                       Pantothenic acid
                                                                                                                      HMDB0000210
603
      HMDB0062717
                       NA
604
                                                                                                                      NA
                                                                                                                      HMDB0033092
605
      HMDB0033092
                       3-(1-Hydroxymethyl-1-propenyl)pentanedioic acid
606
      HMDB0032306
                       4-Heptenal diethyl acetal
                                                                                                                      HMDB0032306
      HMDB0062766
                       4-ethylamino-6-isopropylamino-1,3,5-triazin-2-ol
                                                                                                                      HMDB0062766
607
608
      HMDB0035175
                       \hbox{2-Amino-1,6-dimethylfuro} [3,2\hbox{-e}] \hbox{imidazo} [4,5\hbox{-b}] \hbox{pyridine}
                                                                                                                      HMDB0035175
609
      HMDB0012204
                       Cis-zeatin
                                                                                                                      HMDB0012204
610
      HMDB0040032
                       NA
611
      {\rm HMDB0040111}
                       NΑ
                                                                                                                      NA
612
      HMDB0040090
                      NA
                                                                                                                      NA
      HMDB0040112
613
                       NA
                                                                                                                      NA
      HMDB0040091
                       NA
                                                                                                                      NA
614
      HMDB0032865
                                                                                                                      HMDB0032865
615
                       N-Phenyl-2-naphthylamine
616
      HMDB0042002
617
      HMDB0181581
                                                                                                                      HMDB0028797
618
      HMDB0028797
                       Glutaminylglycine
```

```
HMDB0028682
619
                                                                                                                     HMDB0028682
                       Alanyl-Asparagine
620
      HMDB0028724
                       Asparaginyl-Alanine
                                                                                                                     HMDB0028724
      HMDB0028855
                                                                                                                     HMDB0028855
621
                       Glycyl-Gamma-glutamate
622
      {\rm HMDB0028839}
                       Glycyl-Glutamine
                                                                                                                     {\rm HMDB0028839}
623
      {\rm HMDB0033191}
                       2,2,4,4,-Tetramethyl-6-(1-\text{oxopropyl})-1,3,5-\text{cyclohexanetrione}
                                                                                                                     HMDB0033191
      HMDR0150426
624
                                                                                                                     HMDB0034046
      HMDB0034046
                      1.2.3.4-Tetramethoxy-5-(2-propenyl)benzene
625
626
      HMDB0037492
                      NA
                                                                                                                     NA
      HMDB0040424
627
                      NA
                                                                                                                     NA
628
      HMDB0061823
                       NA
                                                                                                                     NA
629
      {\rm HMDB0061942}
                      NA
                                                                                                                     NA
                                                                                                                     HMDB0032589
630
      HMDB0032589
                       1\hbox{-}(5\hbox{-}Acetyl\hbox{-}2\hbox{-}hydroxyphenyl)\hbox{-}3\hbox{-}methyl\hbox{-}1\hbox{-}butan one
      HMDB0132937
                      ΝÀ
631
                                                                                                                     NΑ
632
      HMDB0132935
                      NΑ
                                                                                                                     NΑ
633
      HMDB0132936
                      NA
                                                                                                                     NA
                                                                                                                     NA
      HMDB0132939
                      NA
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4 Pathway Analysis

In this step, users are asked to select a pathway library, as well as specify the algorithms for pathway enrichment analysis and pathway topology analysis.

4.1 Pathway Library

There are 15 pathway libraries currently supported, with a total of 1173 pathways:

- Homo sapiens (human) [80]
- Mus musculus (mouse) [82]
- Rattus norvegicus (rat) [81]
- Bos taurus (cow) [81]
- Danio rerio (zebrafish) [81]
- Drosophila melanogaster (fruit fly) [79]
- Caenorhabditis elegans (nematode) [78]
- Saccharomyces cerevisiae (yeast) [65]
- Oryza sativa japonica (Japanese rice) [83]
- Arabidopsis thaliana (thale cress) [87]
- Escherichia coli K-12 MG1655 [87]
- Bacillus subtilis [80]
- Pseudomonas putida KT2440 [89]
- Staphylococcus aureus N315 (MRSA/VSSA)[73]
- Thermotoga maritima [57]

Your selected pathway library code is **hsa** (KEGG organisms abbreviation).

4.2 Over Representation Analysis

Over-representation analysis tests if a particular group of compounds is represented more than expected by chance within the user uploaded compound list. In the context of pathway analysis, we are testing if compounds involved in a particular pathway are enriched compared to random hits. MetPA offers two of the most commonly used methods for over-representation analysis:

- Fishers'Exact test
- Hypergeometric Test

Please note, MetPA uses one-tailed Fisher's exact test which will give essentially the same result as the result calculated by the hypergeometric test.

The selected over-representation analysis method is **Hypergeometric test**.

4.3 Pathway Topology Analysis

The structure of biological pathways represent our knowledge about the complex relationships among molecules within a cell or a living organism. However, most pathway analysis algorithms fail to take structural information into consideration when estimating which pathways are significantly changed under conditions of study. It is well-known that changes in more important positions of a network will trigger a more severe impact on the pathway than changes occurred in marginal or relatively isolated positions.

The pathway topology analysis uses two well-established node centrality measures to estimate node importance - degree centrality and betweenness centrality. Degree centrality is defined as the number of links occurred upon a node. For a directed graph there are two types of degree: in-degree for links come from other nodes, and out-degree for links initiated from the current node. Metabolic networks are directed graph. Here we only consider the out-degree for node importance measure. It is assumed that nodes upstream will have regulatory roles for the downstream nodes, not vice versa. The betweenness centrality measures the number of shortest paths going through the node. Since the metabolic network is directed, we use the relative betweenness centrality for a metabolite as the importance measure. The degree centrality measure focuses more on local connectivities, while the betweenness centrality measure focuses more on global network topology. For more detailed discussions on various graph-based methods for analyzing biological networks, please refer to the article by Tero Aittokallio, T. et al. ¹

Please note, for comparison among different pathways, the node importance values calculated from centrality measures are further normalized by the sum of the importance of the pathway. Therefore, the total/maximum importance of each pathway is 1; the importance measure of each metabolite node is actually the percentage w.r.t the total pathway importance, and the pathway impact value is the cumulative percentage from the matched metabolite nodes.

Your selected node importance measure for topological analysis is relative betweenness centrality.

5 Pathway Analysis Result

The results from pathway analysis are presented graphically as well as in a detailed table.

A Google-map style interactive visualization system was implemented to facilitate data exploration. The graphical output contains three levels of view: **metabolome view**, **pathway view**, and **compound view**. Only the metabolome view is shown below. Pathway views and compound views are generated dynamically based on your interactions with the visualization system. They are available in your downloaded files.

¹Tero Aittokallio and Benno Schwikowski. *Graph-based methods for analyzing networks in cell biology*, Briefings in Bioinformatics 2006 7(3):243-255

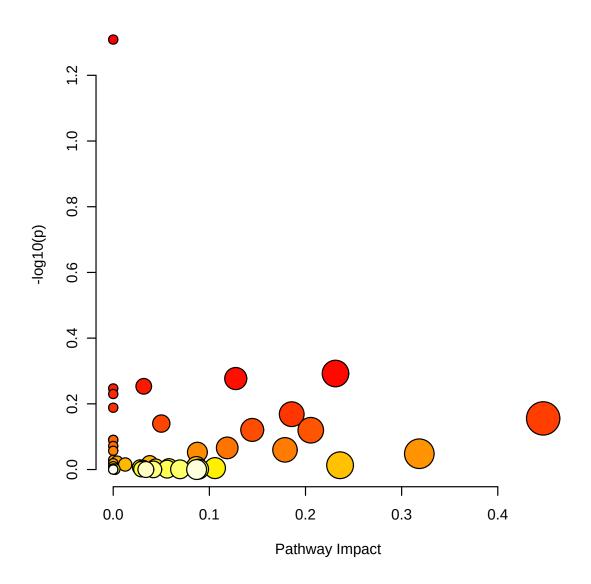


Figure 1: Summary of Pathway Analysis

The table below shows the detailed results from the pathway analysis. Since we are testing many pathways at the same time, the statistical ${\bf p}$ values from enrichment analysis are further adjusted for multiple testings. In particular, the **Total** is the total number of compounds in the pathway; the **Hits** is the actually matched number from the user uploaded data; the **Raw p** is the original ${\bf p}$ value calculated from the enrichment analysis; the **Holm p** is the ${\bf p}$ value adjusted by Holm-Bonferroni method; the **FDR p** is the ${\bf p}$ value adjusted using False Discovery Rate; the **Impact** is the pathway impact value calculated from pathway topology analysis.

Table 2: Result from Pathway Analysis

	Total	Expected	Hits	Raw p	-log10(p)	Holm adjust	FDR	Impact
Linoleic acid metabolism	5	0.94	3	4.91E-02	1.31E+00	1.00E+00	1.00E+00	0.00
Primary bile acid biosynthesis	46	8.67	9	5.10E-01	2.92E-01	1.00E+00	1.00E+00	0.23
Vitamin B6 metabolism	9	1.70	2	5.28E-01	2.77E-01	1.00E+00	1.00E+00	0.13
Butanoate metabolism	15	2.83	3	5.58E-01	2.53E-01	1.00E+00	1.00E+00	0.03
D-Arginine and D-ornithine metabolism	4	0.75	1	5.66E-01	2.47E-01	1.00E+00	1.00E+00	0.00
Phenylalanine metabolism	10	1.88	2	5.89E-01	2.30E-01	1.00E+00	1.00E+00	0.00
Synthesis and degradation of ketone bod-	5	0.94	1	6.48E-01	1.88E-01	1.00E+00	1.00E+00	0.00
ies								
Tryptophan metabolism	41	7.72	7	6.78E-01	1.69E-01	1.00E+00	1.00E+00	0.19
Glycerophospholipid metabolism	36	6.78	6	6.99E-01	1.56E-01	1.00E+00	1.00E+00	0.45
Pantothenate and CoA biosynthesis	19	3.58	3	7.25E-01	1.40E-01	1.00E+00	1.00E+00	0.05
Ether lipid metabolism	20	3.77	3	7.58E-01	1.21E-01	1.00E+00	1.00E+00	0.14
Steroid hormone biosynthesis	85	16.01	14	7.59E-01	1.20E-01	1.00E+00	1.00E+00	0.21
Ascorbate and aldarate metabolism	8	1.51	1	8.13E-01	9.02E-02	1.00E+00	1.00E+00	0.00
Valine, leucine and isoleucine biosynthe-	8	1.51	1	8.13E-01	9.02E-02	1.00E+00	1.00E+00	0.00
sis								
Ubiquinone and other terpenoid-quinone	9	1.70	1	8.48E-01	7.16E-02	1.00E+00	1.00E+00	0.00
biosynthesis								
Retinol metabolism	17	3.20	2	8.59E-01	6.59E-02	1.00E+00	1.00E+00	0.12
Arginine and proline metabolism	38	7.16	5	8.71E-01	5.99E-02	1.00E+00	1.00E+00	0.18
Caffeine metabolism	10	1.88	1	8.77E-01	5.71E-02	1.00E+00	1.00E+00	0.00
Pyrimidine metabolism	39	7.35	5	8.86E-01	5.28E-02	1.00E+00	1.00E+00	0.09
Glycine, serine and threonine metabolism	33	6.22	4	8.95E-01	4.81E-02	1.00E+00	1.00E+00	0.32
alpha-Linolenic acid metabolism	13	2.45	1	9.34E-01	2.94E-02	1.00E+00	1.00E+00	0.00
Glycosylphosphatidylinositol (GPI)-	14	2.64	1	9.47E-01	2.37E-02	1.00E+00	1.00E+00	0.00
anchor biosynthesis								
Nicotinate and nicotinamide metabolism	15	2.83	1	9.57E-01	1.91E-02	1.00E+00	1.00E+00	0.00
Valine, leucine and isoleucine degrada-	40	7.54	4	9.60E-01	1.76E-02	1.00E+00	1.00E+00	0.04
tion								
Glycerolipid metabolism	16	3.01	1	9.65E-01	1.54E-02	1.00E+00	1.00E+00	0.01
Tyrosine metabolism	42	7.91	4	9.70E-01	1.31E-02	1.00E+00	1.00E+00	0.24
Pentose and glucuronate interconversions	18	3.39	1	9.77E-01	1.00E-02	1.00E+00	1.00E+00	0.00
Alanine, aspartate and glutamate	28	5.27	2	9.79E-01	9.17E-03	1.00E+00	1.00E+00	0.09
metabolism	00	0.77	1	0.050.01	0.545.00	1.000 + 00	1.000.00	0.04
Citrate cycle (TCA cycle)	20 30	3.77	1	9.85E-01	6.54E-03	1.00E+00	1.00E+00	0.04
Porphyrin and chlorophyll metabolism		5.65	2	9.85E-01	6.35E-03	1.00E+00	1.00E+00	0.03
Drug metabolism - cytochrome P450 Glyoxylate and dicarboxylate	55 32	10.36 6.03	5 2	9.87E-01 9.90E-01	5.83E-03 4.38E-03	1.00E+00 1.00E+00	1.00E+00 1.00E+00	$0.06 \\ 0.11$
metabolism and dicarboxylate	32	0.03	4	9.90E-01	4.36E-03	1.00E+00	1.00E+00	0.11
Pyruvate metabolism	22	4.14	1	9.90E-01	4.27E-03	1.00E+00	1.00E+00	0.03
Propanoate metabolism	23	4.14	1	9.90E-01 9.92E-01	3.45E-03	1.00E+00 1.00E+00	1.00E+00 1.00E+00	0.03
Phosphatidylinositol signaling system	28	5.27	1	9.92E-01 9.97E-01	1.19E-03	1.00E+00 1.00E+00	1.00E+00 1.00E+00	0.00
Glutathione metabolism	28	5.27	1	9.97E-01 9.97E-01	1.19E-03 1.19E-03	1.00E+00 1.00E+00	1.00E+00 1.00E+00	0.00
Fatty acid degradation	39	7.35	2	9.97E-01 9.97E-01	1.17E-03	1.00E+00 1.00E+00	1.00E+00 1.00E+00	0.03
Fatty acid degradation Fatty acid elongation	39	7.35	2	9.97E-01 9.97E-01	1.17E-03 1.17E-03	1.00E+00 1.00E+00	1.00E+00 1.00E+00	0.03
Steroid biosynthesis	42	7.91	2	9.97E-01 9.98E-01	6.58E-04	1.00E+00 1.00E+00	1.00E+00 1.00E+00	0.00
Cysteine and methionine metabolism	33	6.22	1	9.98E-01 9.99E-01	4.09E-04	1.00E+00 1.00E+00	1.00E+00 1.00E+00	0.04
Fatty acid biosynthesis	47	8.85	2	9.99E-01 9.99E-01	2.49E-04	1.00E+00 1.00E+00	1.00E+00 1.00E+00	0.04
Arachidonic acid metabolism	36	6.78	1	1.00E+00	2.49E-04 2.15E-04	1.00E+00 1.00E+00	1.00E+00 1.00E+00	0.00
Purine metabolism	65	12.24	3	1.00E+00 1.00E+00	5.68E-05	1.00E+00 1.00E+00	1.00E+00 1.00E+00	0.00
Metabolism of xenobiotics by cytochrome	68	12.24	3	1.00E+00 1.00E+00	3.22E-05	1.00E+00 1.00E+00	1.00E+00 1.00E+00	0.03
P450	00	12.01	'	1.00±+00	J.22E-03	1.00D+00	1.005+00	0.03
Aminoacyl-tRNA biosynthesis	48	9.04	1	1.00E+00	1.63E-05	1.00E+00	1.00E+00	0.00
71111110GCy1-01(1711 DIOSy11011CSIS	10	J 0.04	1	1.001 00	1.0011-00	1.001100	1.001 00	0.00

6 Appendix: R Command History

```
[1] "mSet<-InitDataObjects(\"conc\", \"pathora\", FALSE)"
[2] "cmpd.vec<-c(\"HMDBO000123\",\"HMDB0014691\",\"HMDB0031239\",\"HMDB0161401\",\"HMDB0001858\",\"]
[3] "mSet<-Setup.MapData(mSet, cmpd.vec);"
[4] "mSet<-CrossReferencing(mSet, \"hmdb\");"
[5] "mSet<-CreateMappingResultTable(mSet)"
[6] "mSet<-SetKEGG.PathLib(mSet, \"hsa\", \"current\")"
[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] "mSet<-PreparePDFReport(mSet, \"guest9635927675918439296\")\n"</pre>
```

The report was generated on Mon May 24 15:22:15 2021 with R version 4.0.2 (2020-06-22).