TMIC
The Metabolomics Innovation Center

# High Performance Chemical Isotope Labeling LC-MS Metabolomics Analysis Report

## Prepared by TMIC Li-Node

| | |
|---|---|
| Project Name | Comprehensive GLOBAL Metabolomics of XXX Samples |
| Project Number | TMICXXX |
| Client | XXX |
| Document Type | Metabolomic Profiling Analysis Report |
| Document Name | Analysis Report of 4-Channel Analysis |
| Document Number | XXX |

| Sample Received | Analysis Started | Report |
|---|---|---|
| January 01, 2025 | January 07, 2025 | January 17, 2025 |

## Table of Contents

# 1 Overview

This document reports the results for "Metabolomics of …" (4-Channel Analysis). Data was collected using Dansyl-labeling Kit or DmPA-labeling Kit. Analysis was performed using IsoMS Pro 1.4.0 (NovaMT Inc.) and NovaMT Metabolite Database v3.0.

# 2 Materials and Methods

## 2.1 General Information

| | |
|---|---|
| **Sample Type:** | xxx |
| **Sample Group:** | A total of 34 samples with 12 in the "Group A" group, 11 in the "Group B" group, and 11 in the "Group C" group. |
| **Replicates:** | Single replicate |
| **Analysis Method:** | 4-channel analysis |
| **Number of Kits Used:** | 2 labelling kit(s) per channel |

## 2.2 Sample Preparation

### 2.2.1 Sample Randomization

Samples were randomized before any procedures to eliminate potential technical variations from sample preparation and instrument drift. The randomized samples were used for the following preparations and analyses.

### 2.2.2 Aliquoting and Generation of the Pooled Sample

Each individual sample was vortexed then centrifuged at 15,000 g for 1 min. Supernatant was taken and split into aliquots for different labeling methods, backup and preparation of pooled sample. For the one aliquot for preparing of pooled sample, 50 µL was taken from each individual sample, and then combined and mixed thoroughly to prepare the pooled sample, which was used as the reference.

### 2.2.3 Protein precipitation (for serum/plasma/saliva)

Each individual sample was spun down. Then, 90 µL of LC-MS grade methanol was added to perform protein precipitation. The methanol extract was completely dried after incubation at -20 °C for 0.5 hour, then temporally stored in -80 °C freezer until labeling.

### 2.2.4 Chemical Isotope Labeling

### 2.2.5 Mixing

The $^{12}C_2$-labeled individual sample was mixed with $^{13}C_2$-labeled reference sample in equal volume. The mixture was ready to be analyzed by LC-MS. Prior to LC-MS analysis of the entire sample set, quality control (QC) sample was prepared by equal volume mix of a $^{12}C$-labeled and a $^{13}C$-labeled pooled sample.

### 2.3 LC-MS Analysis Condition

The LC-MS analysis was strictly followed the SOP. QC samples were injected every 20 sample runs to monitor instrument performance.

| | |
|---|---|
| **Instrument:** | Thermo Scientific Vanquish LC linked to Bruker Impact II QTOF Mass Spectrometer |
| **Column:** | Agilent eclipse plus reversed phase C18 column (150 x 2.1 mm, 1.8 µm particle size) |
| **MPA:** | 0.1% (v/v) formic acid in water |
| **MPB:** | 0.1% (v/v) formic acid in acetonitrile |
| **Gradient:** | t = 0 min, 25% B; t = 10 min, 99% B; t = 15 min, 99% B; t = 15.1 min, 25% B; t=18 min, 25% B |
| **Flow Rate:** | 400 µL/min |
| **Column Oven Temperature:** | 40 °C |
| **Mass Range:** | m/z 220-1000 |
| **Acquisition Rate:** | 1 Hz |

### 2.4 Data Processing

A total of 148 LC-MS data from 4-channel analysis (37 LC-MS data, including 3 QC, in each channel) were first exported to .csv file with ProteoWizard MS convert 3.0 software. The exported data were uploaded to IsoMS Pro 1.4.0. After Data Quality Check, Data Processing was performed. Parameters used for data processing are below.

| | |
|---|---|
| **Minimum m/z:** | 220 |
| **Maximum m/z:** | 1000 |
| **Saturation Intensity:** | 20000000 |
| **Retention Time Tolerance** | 9 seconds |
| **Mass Tolerance:** | 10 ppm |

### 2.5 Data Cleansing

Four groups were assigned to 37 LC-MS data in each channel: 12 data files labeled as 'Group A' group, 11 data files labeled as 'Group B' group, 11 data files labeled as 'Group C' group and 3 data files labeled as 'QC' group. Peak pairs without data present in at least 80.0% of samples in any group were filtered out (see section 3.2). Data were normalized by Ratio of Total Useful Signal.

### 2.6 Metabolite Identification

The parameters used for metabolite identification are below.

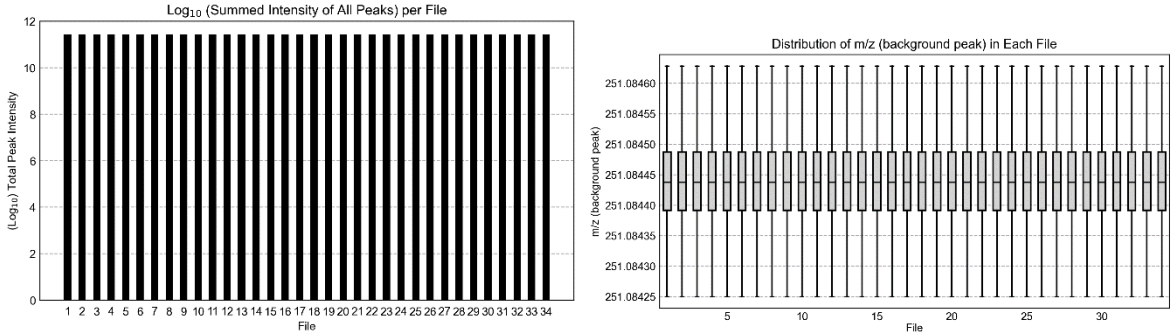
| | |
|---|---|
| **Retention Time Tolerance for CIL Library ID** | 10 seconds |
| **Retention Time Tolerance for LI Library ID** | 75 seconds |
| **Mass Tolerance for CIL Library ID** | 10 ppm |
| **Mass Tolerance for LI Library ID** | 10 ppm |
| **Mass Tolerance for Mass-Based Database ID** | 10 ppm |

# 3 Results

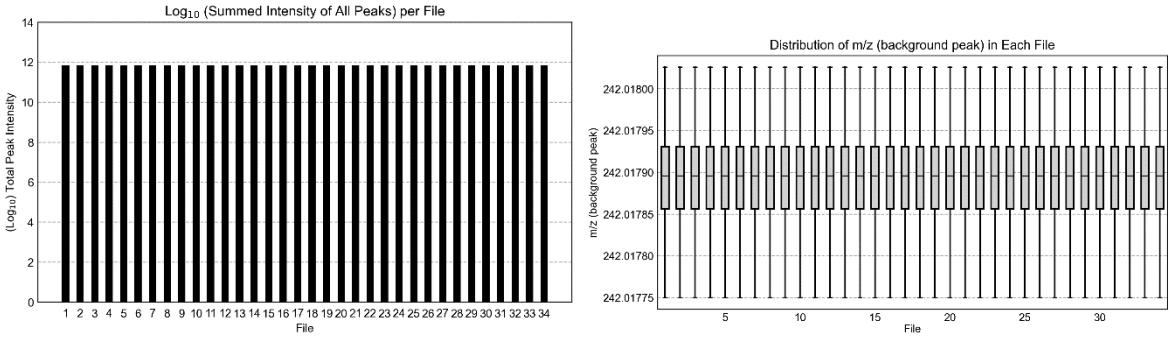
## 3.1 Data Quality Check

### 3.1.1 Mass Accuracy Check

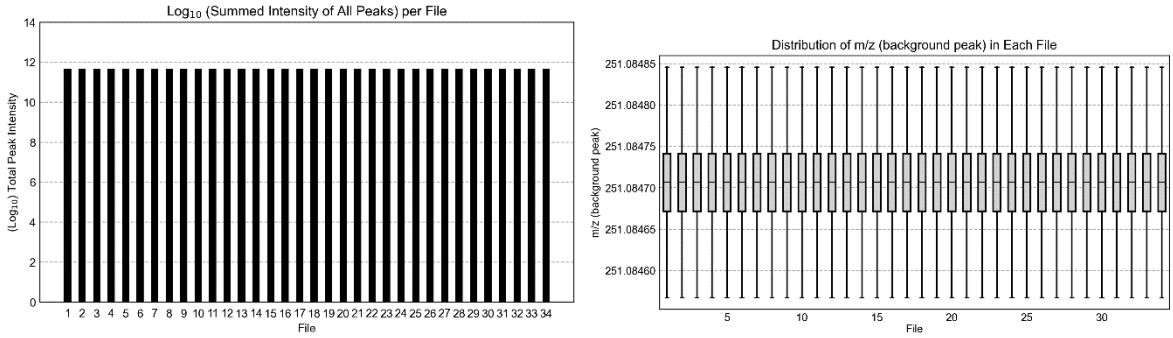
m/z 251.0849 was selected as background peak to check the mass accuracy for 34 samples in amine/phenol channel analysis. The summed intensity of all peaks was consistent during all runs. The mass of the background peak was consistent during all runs and all are within the expected range, showing good stability and mass accuracy for data acquisition.



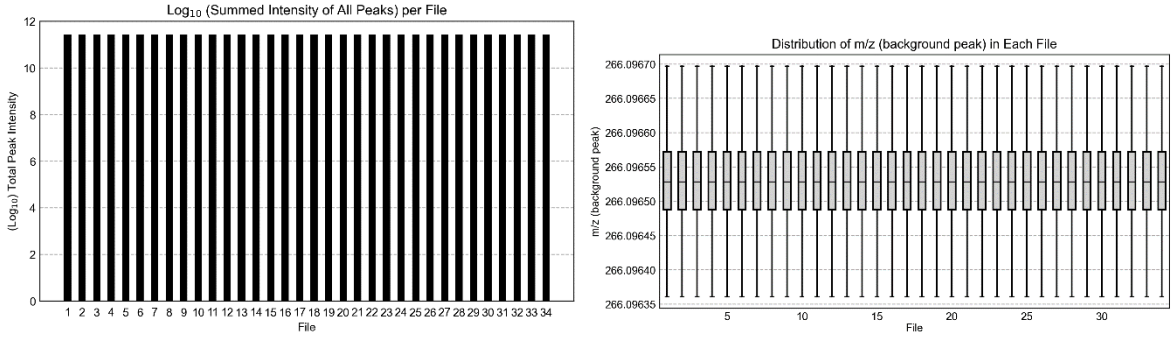

m/z 242.0175 was selected as background peak to check the mass accuracy for 34 samples in carboxyl channel analysis. The summed intensity of all peaks was consistent during all runs. The mass of the background peak was consistent during all runs and all are within the expected range, showing good stability and mass accuracy for data acquisition.



m/z 251.0849 was selected as background peak to check the mass accuracy for 34 samples in hydroxyl channel analysis. The summed intensity of all peaks was consistent during all runs. The mass of the background peak was consistent during all runs and all are within the expected range, showing good stability and mass accuracy for data acquisition.

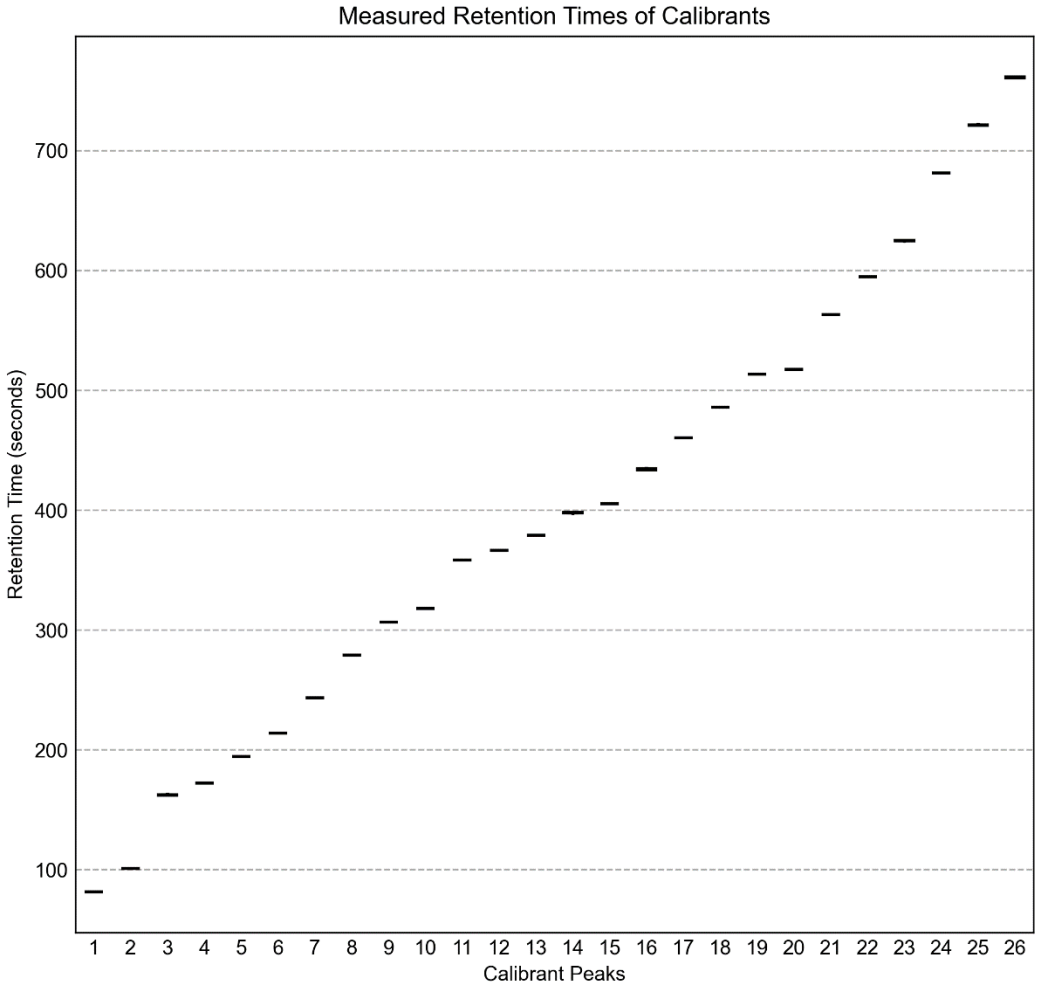



m/z 266.0958 was selected as background peak to check the mass accuracy for 34 samples in carbonyl channel analysis. The summed intensity of all peaks was consistent during all runs. The mass of the background peak was consistent during all runs and all are within the expected range, showing good stability and mass accuracy for data acquisition.



### 3.1.2 Retention Time Check

Four calibration data were used to check the retention time in each channel. All calibrant peaks were well aligned. The retention times of calibrants were consistent for all calibration data, showing good RT stability for data acquisition.



### 3.2 Data Processing and Cleansing

A total of 37 LC-MS data were processed for each channel. 4-channel LC-MS data of one sample were combined after data processing. Less commonly detected peak pairs were filtered out to ensure data quality. After filtering, 5707 ± 30 peak pairs per sample were retained (from Supplemental Table 1). The table below (Table 1) shows the peak pair numbers detected in each sample. One supplemental table showing the list of peak pairs was generated with this report (Supplemental Table 1), which is the final metabolite-intensity table from the CIL LC-MS measurement of the samples.

In the Supplemental Table 1, peak pairs without data present in at least 80.0% of samples in any group were filtered out. Applying this 80%-rule ensures that only the commonly detectable peak pairs are retained for further analysis, without the use of excessive missing-value imputation. This 80% rule states that, if all the analyzed samples belong to one group, the retained peak pairs are those detectable in >= 80% of the samples. If the analyzed samples belong to two or more groups, the retained peak pairs are those detectable in >= 80% of the samples in any one of the groups. For example, in a study comparing group A (100 samples) and group B (100 samples), a peak pair will be retained if it is detectable in >=80% of the samples in group A, even though this peak pair may be detectable in none or a few of the group B samples. However, if a peak pair is detectable in <80% of the group A samples and <80% of the group B samples, this peak pair will be filtered out, as this peak pair is considered to be less commonly detected.

After filtering, all data were normalized by the ratio of total useful signals. The missing values of peak pairs in some samples due to low signal intensity (i.e., below the detection limit) was replaced with a rationally determined ratio by a unique zero-imputation program. This table can be used for statistical analysis without the need of applying any missing value imputation method given in a statistical tool.

Table 1. Number of Metabolites Detected in Each Sample

| Sample Name | Group | Number of Peak Pairs |
|---|---|---|
| sample 1 | A | 5693 |
| sample 2 | A | 5709 |
| sample 3 | A | 5700 |
| sample 4 | A | 5697 |
| sample 5 | A | 5713 |
| sample 6 | A | 5719 |
| sample 7 | A | 5686 |
| sample 8 | A | 5658 |
| sample 9 | A | 5723 |
| sample 10 | A | 5693 |
| sample 11 | A | 5709 |
| sample 12 | A | 5686 |
| sample 13 | B | 5757 |
| sample 14 | B | 5692 |
| sample 15 | B | 5708 |
| sample 16 | B | 5701 |
| sample 17 | B | 5698 |
| sample 18 | B | 5712 |
| sample 19 | B | 5720 |
| sample 20 | B | 5687 |
| sample 21 | B | 5659 |
| sample 22 | B | 5724 |
| sample 23 | B | 5690 |
| sample 24 | C | 5718 |
| sample 25 | C | 5680 |
| sample 26 | C | 5763 |

| Sample Name | Group | Number of Peak Pairs |
|---|---|---|
| sample 27 | C | 5690 |
| sample 28 | C | 5712 |
| sample 29 | C | 5705 |
| sample 30 | C | 5692 |
| sample 31 | C | 5710 |
| sample 32 | C | 5722 |
| sample 33 | C | 5682 |
| sample 34 | C | 5662 |
| QC 1 | QC | 5721 |
| QC 2 | QC | 5695 |
| QC 3 | QC | 5708 |

### 3.3 Metabolite Identification

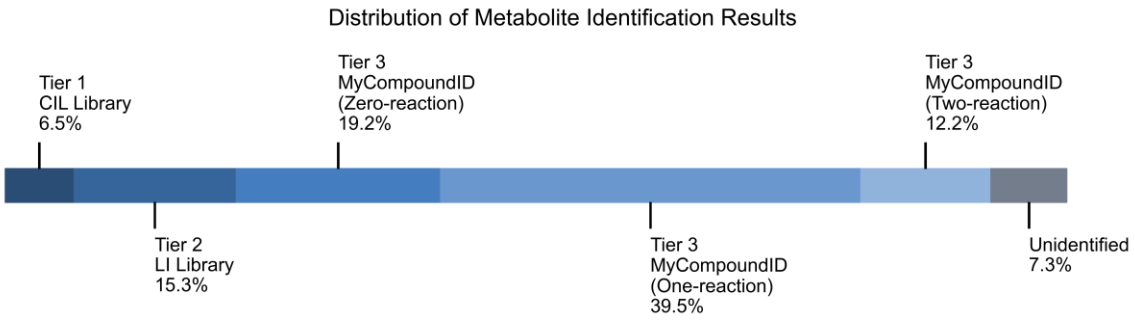
Three-tier ID approach was used to perform metabolite identification.

In tier 1, peak pairs were searched against a labeled metabolite library (CIL Library) based on accurate mass and retention time. The CIL Library contains more than 1,500 experimental entries. 378 peak pairs were positively identified in tier 1.

In tier 2, linked identity library (LI Library) was used for identification of the remaining peak pairs. LI Library includes over 9,000 pathway-related metabolites, providing high-confidence putative identification results based on accurate mass and predicted retention time matches. 893 peak pairs were putatively identified in tier 2.

In tier 3, the remaining peak pairs were searched, based on accurate mass match, against the MyCompoundID (MCID) library composed of 8,021 known human endogenous metabolites (zero-reaction library), their predicted metabolic products from one metabolic reaction (375,809 compounds) (one-reaction library) and two metabolic reactions (10,583,901 compounds) (two-reaction library). 1124, 2311 and 715 peak pairs were matched in the zero-, one- and two-reaction libraries, respectively.

Thus, out of 5845 unique peak pairs detected, 5421 (92.7%) pairs could be positively identified or putatively matched. Among them, 490 peak pairs were identified as high-confidence results (tier 1 and tier 2), which can be used for other analysis (e.g., pathway analysis).




The identification results for each peak pair are shown in Supplemental Table 1. Metabolites that were identified in tier 1 and tier 2 are listed below.

Table 2. 378 Metabolites that were positively identified in tier 1 (CIL Library)

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| AN02027002 | C08362 | (9Z)-Hexadecenoic Acid |
| BM00647000 | C01983, C01984 | (S)-Mandelic acid |
| BM00132006 | | 2,3-Butanediol |
| BM00670003 | C00196 | 2,3-Dihydroxybenzoic acid |
| BM00761001 | C02625 | 2,4-Dichlorophenol |
| AN00670004 | C00628 | 2,5-Dihydroxybenzoic acid |
| AN00189000 | C02356 | 2-Aminobutyric acid/2-Aminoisobutyric acid |
| AN00726001 | | 2-Aminooctanoic acid |
| AN00219002 | C01987 | 2-Aminophenol |
| AN00197004 | C05984 | 2-Hydroxybutyric acid |
| AN00594002 | C02630 | 2-Hydroxyglutaric Acid |
| AN00647005 | C05852 | 2-Hydroxyphenylacetic acid |
| AN00177004 | C00109 | 2-Ketobutyric acid |
| AN00396002 | C00902 | 2-Ketohexanoic acid |
| AN01210001 | | 2-Methylhippuric acid |
| AN00638001 | | 2-Phenylglycine |
| BM00626003 | | 2-Phenylpropionic acid |
| AN01076000 | C05580 | 3,4-Dihydroxymandelic acid |
| AN00856002 | C01161 | 3,4-Dihydroxyphenylacetic acid |
| AN00670001 | | 3,5-Dihydroxybenzoic acid |
| BM00823019 | C11457 | 3-(3-Hydroxyphenyl)propanoic acid |
| AN01052008 | C03672 | 3-(4-Hydroxyphenyl)lactic acid |
| AN00189001 | C05145 | 3-Aminoisobutyric acid |
| BM00216000 | C01467 | 3-Cresol |
| AN00167001 | | 3-Hexanone |
| BM00311000 | C03067 | 3-Hydroxybenzaldehyde |
| AN00477007 | C00587 | 3-Hydroxybenzoic Acid |
| BM00326002 | C03351 | 3-Hydroxybenzyl alcohol |
| AN00197001 | | 3-Hydroxybutanoic acid |
| AN00197000 | C06001 | 3-Hydroxyisobutyric Acid |
| AN00283004 | C20827 | 3-Hydroxyisovaleric Acid |
| AN00769001 | C03761 | 3-Hydroxymethylglutaric acid |
| AN00647003 | C05593 | 3-Hydroxyphenylacetic Acid |
| AN00130007 | C01013 | 3-Hydroxypropanoic acid |
| AN01266002 | C05584 | 3-Methoxy-4-hydroxymandelic acid |
| AN00396000 | C03465 | 3-Methyl-2-oxovaleric acid |
| AN00109007 | C07329 | 3-Methylbutanal |
| BM00647013 | C14088 | 3-Methylsalicylic acid |
| AN00419002 | C02642 | 3-Ureidopropionic Acid |
| AN03968005 | | 3-keto-7alpha,12alpha-Dihydroxy-5alpha-cholanic acid |
| AN03980014 | | 3beta-Cholic acid |
| AN00793000 | C00811 | 4-Coumaric acid |
| BM00216003 | C01468 | 4-Cresol/3-Cresol |
| AN00269012 | C13637 | 4-Ethylphenol |
| BM00311001 | C00633 | 4-Hydroxybenzaldehyde/3-Hydroxybenzaldehyde |
| AN00477004 | C00156 | 4-Hydroxybenzoic acid |
| AN00197005 | C00989 | 4-Hydroxybutanoic acid |
| BM01229007 | | 4-Hydroxyhippuric acid |
| AN00647002 | C00642 | 4-Hydroxyphenylacetic acid |
| AN00396012 | C00233 | 4-Methyl-2-oxopentanoic acid |
| BM00487001 | C00870 | 4-Nitrophenol |
| AN00406002 | C00430 | 5-Aminolevulinic acid |
| AN00277004 | C00431 | 5-Aminopentanoic acid |
| AN01274001 | | 5-Dodecenoic acid |
| AN00774001 | C16741 | 5-Hydroxylysine |
| AN02059000 | | 5-Methylcytidine |
| AN03836002 | | 5beta-Cholanic acid-12alpha-ol-3-one |
| BM00410006 | C02378 | 6-Aminohexanoic acid |
| AN00487003 | C01020 | 6-Hydroxynicotinic acid |
| AN00743002 | | 7-Hydroxyoctanoic acid |
| AN03968004 | C04643 | 7-Ketodeoxycholic Acid |
| AN03836005 | | 7-Ketolithocholic acid |
| AN03836001 | | 7alpha-Hydroxy-3-oxo-5b-cholanoic acid |
| AN00014000 | C00084 | Acetaldehyde |
| AN00177002 | C00164 | Acetoacetic Acid |
| AN00026002 | C00207 | Acetone - isomer 1/Propanal |

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| AN00060002 | C00511 | Acrylic Acid |
| AN00452000 | C00147 | Adenine |
| BM00573004 | C06104 | Adipic Acid |
| AN00124000 | C00041 | Alanine |
| AN00738000 | | Alanyl-Alanine |
| AN01346002 | | Alanyl-Aspartic Acid |
| AN01544002 | | Alanyl-Glutamic acid |
| AN01530001 | | Alanyl-Glutamine |
| AN00574007 | | Alanyl-Glycine |
| AN01660001 | | Alanyl-Histidine |
| AN01324000 | | Alanyl-Isoleucine |
| AN01534000 | | Alanyl-Lysine |
| AN01782000 | | Alanyl-Phenylalanine |
| AN01133002 | | Alanyl-Valine |
| AN01608003 | C00542 | Allocystathionine |
| AN00754003 | C00956 | Aminoadipic acid |
| AN00468006 | C00108 | Anthranilic acid |
| AN00945000 | C00062 | Arginine |
| AN00958000 | | Argininic acid |
| AN03117000 | | Arginyl-Arginine |
| AN01721000 | | Arginyl-Glycine |
| AN02122000 | | Arginyl-Serine |
| AN00419000 | C00152 | Asparagine |
| AN01902001 | | Asparaginyl-Asparagine |
| AN01922000 | | Asparaginyl-Aspartic acid |
| AN01146000 | | Asparaginyl-Glycine |
| AN02236000 | | Asparaginyl-Histidine |
| AN01563000 | | Asparaginyl-Serine |
| AN01742000 | | Asparaginyl-Threonine |
| AN00428000 | C00049 | Aspartic acid |
| AN01922001 | | Aspartyl-Asparagine |
| AN01933001 | | Aspartyl-Aspartic acid |
| AN01163001 | | Aspartyl-Glycine |
| AN02254000 | | Aspartyl-Histidine |
| AN01906003 | | Aspartyl-Isoleucine |
| AN02121002 | | Aspartyl-Lysine |
| AN01708000 | | Aspartyl-Proline |
| AN01757004 | | Aspartyl-Threonine |
| EF02406002 | | Aspartyphenylalanine |
| AN01132000 | C08261 | Azelaic acid |
| BM00208000 | C00261 | Benzaldehyde |
| AN00124003 | C00099 | Beta-Alanine |
| AN00410004 | C02486 | Beta-Leucine |
| AN01790000 | C06313 | Biopterin |
| AN00061006 | C01412 | Butanal |
| AN03850013 | C02528 | Chenodeoxycholic Acid |
| AN00594011 | C02614, C02612 | Citramalic acid |
| AN01194001 | C00158 | Citric acid/Isocitric acid |
| AN00958001 | C00327 | Citrulline |
| AN03543000 | C00735 | Cortisol |
| BP00108001 | C01771 | Crotonic Acid |
| AN02362001 | | Cysteinyl-Arginine |
| AN01965001 | | Cysteinyl-Glutamic acid |
| AN02070000 | | Cysteinyl-Histidine |
| AN01405000 | | Cysteinyl-Serine |
| AN02456000 | | Cysteinyl-Tyrosine |
| AN01818000 | C00491 | Cystine |
| AN01857000 | C00475 | Cytidine |
| AN00233000 | C00380 | Cytosine |
| AN01024016 | C01487 | D-Allose |
| AN02087000 | C00352 | D-Glucosamine 6-phosphate |
| AN01024001 | C00031 | D-Glucose |
| AN00207000 | C00258 | D-Glyceric acid |
| AN00315001 | C16884 | D-Threitol |
| AN00704003 | C12307 | Decanal/2-Decanone |
| AN00920000 | C01571 | Decanoic acid |
| AN01672000 | C00881 | Deoxycytidine |
| AN02208001 | C00330 | Deoxyguanosine |

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| BM00823005 | C01744 | Desaminotyrosine |
| AN00108006 | C00741 | Diacetyl |
| AN00204000 | C06772 | Diethanolamine |
| AN01713000 | C02678 | Dodecanedioic acid |
| AN01300003 | C02679 | Dodecanoic acid |
| AN00037000 | C00189 | Ethanolamine |
| AN00513001 | C00346 | Ethanolamine phosphate |
| AN00418009 | | Ethylmalonic acid |
| BP01216007 | C01494 | Ferulic acid |
| AN00796000 | C01019 | Fucose |
| AN00265000 | C00122 | Fumaric Acid |
| AN01024000 | C00984 | Galactose |
| BM00887000 | C01424 | Gallic acid |
| AN03980000 | C17649 | Gamma-Muricholic acid |
| AN00583000 | C00302 | Glutamic Acid |
| AN00574000 | C00064 | Glutamine |
| AN02742002 | | Glutaminyl-Arginine |
| AN02118003 | | Glutaminyl-Aspartic Acid |
| AN02336002 | | Glutaminyl-Glutamic acid |
| AN02092001 | | Glutaminyl-Leucine |
| AN01742001 | | Glutaminyl-Serine/Seryl-Glutamine |
| AN01544000 | | Glutamyl-Alanine |
| AN02758001 | | Glutamyl-Arginine |
| AN02118004 | | Glutamyl-Asparagine |
| AN02135002 | | Glutamyl-Aspartic acid |
| AN02350001 | | Glutamyl-Glutamic acid |
| AN02336003 | | Glutamyl-Glutamine |
| AN01346004 | | Glutamyl-Glycine |
| AN02110005 | | Glutamyl-Isoleucine |
| AN02110000 | | Glutamyl-Leucine |
| AN02376000 | | Glutamyl-Methionine |
| AN02608004 | | Glutamyl-Phenylalanine |
| AN03154000 | | Glutamyl-Tryptophan |
| AN02849001 | | Glutamyl-Tyrosine |
| AN00418002 | C00489 | Glutaric Acid |
| AN01133007 | | Gly-Norleucine |
| AN00943007 | | Gly-Norvaline |
| AN00136000 | C00116 | Glycerol |
| AN00076000 | C00037 | Glycine |
| AN00080000 | C00160 | Glycolic Acid |
| AN00574005 | | Glycyl-Alanine |
| AN01721001 | | Glycyl-Arginine |
| AN01146001 | | Glycyl-Asparagine |
| AN01163002 | | Glycyl-Aspartic acid |
| AN01346005 | | Glycyl-Glutamic acid |
| AN01460000 | | Glycyl-Histidine |
| AN01133001 | C02155 | Glycyl-Leucine |
| AN01338000 | | Glycyl-Lysine |
| AN01612000 | | Glycyl-Phenylalanine |
| AN00914000 | | Glycyl-Proline |
| AN00972001 | | Glycyl-Threonine |
| AN00419004 | C02037 | Glycyl-glycine |
| BM00326004 | C01502 | Guaiacol |
| AN00274000 | C00581 | Guanidinoacetic acid |
| AN01006000 | C01586 | Hippuric Acid |
| AN00235000 | C00388 | Histamine |
| AN00684000 | | Histidine |
| AN01660002 | | Histidinyl-Alanine |
| AN02070001 | | Histidinyl-Cysteine |
| AN02459001 | | Histidinyl-Glutamic acid |
| AN01135000 | C01924 | Homoarginine |
| AN01150000 | C02427 | Homocitrulline |
| AN01061000 | C16511 | Homocysteic acid |
| AN00856000 | C00544 | Homogentisic acid |
| AN00291001 | C00263 | Homoserine |
| AN01052009 | C05582 | Homovanillic acid |
| AN00626000 | C05629 | Hydrocinnamic acid/3-Methylphenylacetic acid |
| AN00227003 | C00530 | Hydroquinone |

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| AN00406000 | C01157 | Hydroxyproline |
| AN00218000 | C00519 | Hypotaurine |
| AN00459000 | C00262 | Hypoxanthine |
| AN00345002 | C02835 | Imidazole-4-acetic acid |
| AN00956003 | C00954 | Indole-3-acetic acid |
| BM00559000 | C08493 | Indole-3-carboxaldehyde |
| BM01147000 | C22236 | Indole-3-propionic acid |
| BM01113000 | | Indoleacrylic acid |
| AN00410002 | C00407 | Isoleucine |
| AN01324002 | | Isoleucyl-Alanine |
| AN01906006 | | Isoleucyl-Aspartic acid |
| AN01714000 | | Isoleucyl-Valine |
| AN00856010 | | Isovanillic acid |
| BM00392004 | C00490 | Itaconic acid |
| AN01408003 | C01718 | Kynurenine |
| AN00284000 | C03283 | L-2,4-Diaminobutanoic acid |
| AN01608000 | C02291 | L-Cystathionine /Allocystathionine |
| AN00277001 | C01799 | L-Norvaline |
| AN01024019 | C00247 | L-Sorbose |
| BM01168000 | C00666 | LL-2,6-Diaminoheptanedioic acid |
| AN00130001 | C00186 | Lactic Acid |
| AN03286003 | C00243 | Lactose |
| AN00410000 | C00123 | Leucine |
| AN01906007 | | Leucyl-Aspartic acid |
| AN02095001 | | Leucyl-Lysine |
| AN02941001 | | Leucyl-Tryptophan |
| AN01714001 | | Leucyl-Valine |
| AN00769003 | | Levoglucosan |
| AN00266005 | | Levulinic acid |
| AN02413000 | C01595 | Linoleic acid |
| AN00578000 | C00047 | Lysine |
| AN01534001 | | Lysyl-Alanine |
| AN02121003 | | Lysyl-Aspartic acid |
| AN02339002 | | Lysyl-Glutamic acid |
| AN02095003 | | Lysyl-Leucine /Leucyl-Lysine |
| AN02593000 | | Lysyl-Methionine sulfoxide |
| AN01861000 | | Lysyl-Proline |
| AN02840000 | | Lysyl-Tyrosine |
| AN01892000 | | Lysyl-Valine |
| AN00265001 | C01384 | Maleic acid |
| AN00435000 | C00711 | Malic Acid |
| AN00193001 | C00383 | Malonic Acid |
| AN00392001 | C01732 | Mesaconic Acid |
| AN00608000 | C00073 | Methionine |
| AN00810000 | C02989 | Methionine Sulfoxide |
| AN01586003 | | Methionyl-Alanine |
| AN02142003 | | Methionyl-Leucine |
| AN00102001 | | Methyl propenyl ketone |
| AN00060000 | C00546 | Methylglyoxal |
| AN00066000 | C02294 | Methylguanidine |
| AN00281003 | C02170 | Methylmalonic acid |
| AN00418007 | C08645 | Methylsuccinic acid |
| BM03850008 | C15515 | Murideoxycholic acid |
| AN01024005 | C00137 | Myoinositol |
| TA00952000 | C01042 | N-Acetyl-Aspartic acid |
| AN01597000 | C01132 | N-Acetyl-D-galactosamine |
| AN01597004 | C00140 | N-Acetyl-D-glucosamine |
| AN01597003 | C00645 | N-Acetyl-D-mannosamine |
| AN00583008 | | N-Acetyl-DL-serine |
| AN00273000 | | N-Acetyl-Glycine |
| TA00406009 | | N-Acetyl-alanine |
| AN02835000 | C00270 | N-Acetylneuraminic acid |
| AN01729001 | | N-Formyltryptophan |
| AN00583007 | | N-Methyl-D-aspartic acid |
| AN00124004 | C00213 | N-Methyl-Glycine |
| TA00943000 | C00437 | N-acetyl-Ornithine |
| AN01133000 | C02727 | N6-Acetyl-Lysine |
| AN02004003 | C05926 | Neopterin |

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| AN00410003 | C01933 | Norleucine |
| AN01069002 | C05589 | Normetanephrine |
| AN03717001 | | Norursodeoxycholic Acid |
| AN00583002 | C00979 | O-Acetyl-L-serine |
| AN02466002 | C01530 | Octadecanoic acid |
| AN00376001 | C01545 | Octanal |
| AN02437000 | C00712 | Oleic Acid/Vaccenic Acid |
| BM03980010 | C17727 | Omega-Muricholic acid |
| AN00423000 | C00077 | Ornithine |
| BM00826012 | C11924 | Perillic acid |
| AN00307000 | C05332 | Phenethylamine |
| AN00145000 | C00146 | Phenol |
| AN00299005 | C00601 | Phenylacetaldehyde |
| AN00460002 | C07086 | Phenylacetic Acid |
| AN01210009 | C05598 | Phenylacetylglycine |
| AN00814000 | C00079 | Phenylalanine |
| AN02385000 | | Phenylalanyl-Leucine |
| AN02141000 | | Phenylalanyl-Proline |
| AN01996001 | | Phenylalanyl-Serine |
| AN00823016 | C05607 | Phenyllactic acid |
| BM00344002 | C02183 | Phloroglucinol |
| AN00318000 | C10164 | Picolinic Acid |
| AN00736000 | C02656 | Pimelic acid /3-Methyladipic Acid |
| AN00385000 | C00408 | Pipecolic acid |
| AN00259000 | C00148 | Proline |
| AN01106001 | | Prolyl-Alanine |
| AN02275001 | | Prolyl-Arginine/Arginyl-Proline |
| AN01708001 | | Prolyl-Aspartic acid |
| AN01874002 | | Prolyl-Glutamic acid |
| AN00914001 | | Prolyl-Glycine |
| AN01998001 | | Prolyl-Histidine |
| AN01688003 | | Prolyl-Leucine |
| AN01861001 | | Prolyl-Lysine |
| AN01904001 | | Prolyl-Methionine |
| AN01516001 | | Prolyl-Threonine |
| AN02725000 | | Prolyl-Tryptophan |
| AN02380001 | | Prolyl-Tyrosine |
| AN01489000 | | Prolyl-Valine |
| AN00026003 | C00479 | Propanal |
| AN00842000 | C00250 | Pyridoxal |
| BM00344003 | C01108 | Pyrogallol |
| AN00380000 | C01879 | Pyroglutamic acid |
| AN00117000 | C00022 | Pyruvic acid |
| AN02714000 | C00777 | Retinoic acid |
| AN02071002 | | Ribothymidine |
| AN00477006 | C00805 | Salicylic acid |
| BM01229005 | C07588 | Salicyluric acid |
| AN01323000 | C08277 | Sebacic Acid |
| AN01790003 | C00835 | Sepiapterin |
| AN00202000 | C00065 | Serine |
| AN00975002 | C00780 | Serotonin |
| AN01583002 | | Seryl-Aspartic acid |
| AN01405001 | | Seryl-Cysteine |
| AN01757006 | | Seryl-Glutamic acid |
| AN00770001 | | Seryl-Glycine |
| AN01852001 | | Seryl-Histidine |
| AN01744001 | | Seryl-Lysine |
| AN01779001 | | Seryl-Methionine |
| AN00565000 | C00315 | Spermidine |
| AN02696001 | C00319 | Sphingosine |
| AN00281002 | C00042 | Succinic Acid |
| AN00177003 | C00232 | Succinic semialdehyde |
| BM01266000 | C10833 | Syringic acid |
| AN00329000 | C00245 | Taurine |
| AN01690004 | C06424 | Tetradecanoic acid |
| AN00291000 | C00188 | Threonine |
| AN01608002 | | Threoninyl-Cysteine |
| AN01936001 | | Threoninyl-Glutamic acid |

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| AN01735004 | | Threoninyl-Leucine |
| AN01927001 | | Threoninyl-Lysine |
| AN01516002 | | Threoninyl-Proline |
| AN00345001 | C00178 | Thymine |
| AN02296000 | | Thyroine |
| AN01687000 | C16308 | Traumatic Acid |
| BP01491000 | C17076 | Tridecylic Acid |
| AN01348000 | C00078 | Tryptophan |
| AN03834000 | | Tryptophyl-Tryptophan |
| AN01037004 | C00082 | Tyrosine |
| AN01801001 | | Tyrosyl-Glycine |
| AN03081001 | | Tyrosyl-Phenylalanine |
| AN01109004 | C17715 | Undecanoic acid |
| AN00240000 | C00106 | Uracil |
| AN00855000 | C00366 | Uric acid |
| AN01868000 | C00299 | Uridine |
| BM03850002 | C07880 | Ursodiol |
| AN00277003 | C00183 | Valine |
| AN01133006 | | Valyl-Alanine |
| AN01890005 | | Valyl-Glutamine |
| AN00943003 | | Valyl-Glycine |
| AN02180002 | | Valyl-Phenylalanine |
| AN01349002 | | Valyl-Serine |
| AN01548005 | | Valyl-Threonine |
| AN01522000 | | Valyl-Valine |
| BM00856008 | C06672 | Vanillic acid |
| AN00646000 | C00385 | Xanthine |
| AN00266001 | C00141 | a-Ketoisovaleric acid |
| AN00971000 | C02504 | alpha-Isopropylmalic acid |
| AN02387003 | C06427 | alpha-Linolenic acid |
| AN01024021 | C02336 | beta-D-Fructose |
| AN00406012 | C03440 | cis-4-Hydroxy-D-proline |
| AN00934000 | C00417 | cis-Aconitic acid |
| AN02350000 | C05282 | gamma-Glutamylglutamic acid |
| BM00216002 | C01542 | o-Cresol/4-Cresol |
| AN01037003 | | o-Tyrosine |
| AN00662000 | C04227 | p-Octopamine |
| AN01464000 | | prolyl-proline |
| BM00793002 | C12621 | trans-3-Hydroxycinnamic acid |
| BM00934003 | C02341 | trans-Aconitic acid |

Table 3. 893 Metabolites that were high-confidence putative matched in tier 2 (LI Library)

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| AN01640006 | C16318 | (+)-7-Isomethyljasmonic acid |
| BM01755001 | C16600 | (-)-threo-Iso(homo)3-citric acid |
| AN02071000 | C05131 | (1-Ribosylimidazole)-4-acetic acid |
| BM00866018 | C19083 | (1R,4S)-1-Hydroxy-2-oxolimonene |
| AN00513000 | C05678 | (2-Amino-1-hydroxyethyl)phosphonate |
| BM02325001 | C20278 | (2R,3R)-3-Methylornithinyl-N6-lysine |
| AN00971001 | C04411 | (2R,3S)-3-Isopropylmalic acid |
| AN00423002 | C03943 | (2R,4S)-2,4-Diaminopentanoic acid |
| AN00578003 | C05161 | (2R,5S)-2,5-Diaminohexanoic acid |
| AN01371003 | C04593 | (2S,3R)-3-Hydroxybutane-1,2,3-tricarboxylic acid |
| BM01111001 | C20258 | (2S,4S)-4-Hydroxy-2,3,4,5-tetrahydrodipicolinic acid |
| BM00926005 | C17366 | (2S,5S)-trans-Carboxymethylproline |
| BM01083005 | C11405 | (3R)-3-Isopropenyl-6-oxoheptanoic acid |
| AN00578004 | C01142 | (3S)-3,6-Diaminohexanoic acid |
| AN00578005 | C01186 | (3S,5S)-3,5-Diaminohexanoic acid |
| AN05016000 | C05786 | (3Z)-Phycocyanobilin |
| AN01194003 | C04575 | (4R,5S)-4,5,6-Trihydroxy-2,3-dioxohexanoic acid |
| AN03088000 | C06429 | (4Z,7Z,10Z,13Z,16Z,19Z)-Docosahexaenoic acid |
| BM01706000 | C20817 | (5S)-3-(2-Aminoethylsulfanyl)-7-oxo-1-azabicyclo[3.2.0]heptane-2-carboxylic acid |
| AN02882006 | C07354 | (7S,8S)-DiHODE |
| AN03120001 | C16513 | (7Z,10Z,13Z,16Z,19Z)-Docosapentaenoic acid |
| AN02804003 | C03242 | (8Z,11Z,14Z)-Icosatrienoic acid |
| BM00638000 | C04350 | (E)-4-Hydroxyphenylacetaldehyde oxime |
| AN00956001 | C03230 | (Indol-3-yl)glycolaldehyde |
| AN00077000 | C03194 | (R)-1-Aminopropan-2-ol |
| AN00441003 | C04272 | (R)-2,3-Dihydroxy-3-methylbutanoic acid |
| AN00598000 | C06007 | (R)-2,3-Dihydroxy-3-methylpentanoic acid |
| AN00769008 | C02488 | (R)-2-Ethylmalic acid |
| AN01371001 | C01251 | (R)-2-Hydroxybutane-1,2,4-tricarboxylic acid |
| AN00769012 | C01088 | (R)-3,3-Dimethylmalic acid |
| AN00573009 | C14463 | (R)-3-Hydroxy-3-methyl-2-oxopentanoic acid |
| AN00422002 | | (R)-3-Hydroxyhexanoic acid |
| AN00573011 | C01053 | (R)-4-Dehydropantoic acid |
| AN00598002 | C00418 | (R)-Mevalonic acid |
| AN00598001 | C00522 | (R)-Pantoic acid |
| AN00360000 | C00450 | (S)-2,3,4,5-Tetrahydropyridine-2-carboxylic acid |
| AN00769011 | C16390 | (S)-2-(Hydroxymethyl)glutaric acid |
| AN00573008 | C06006 | (S)-2-Aceto-2-hydroxybutanoic acid |
| BM00606000 | C03742 | (S)-4-Hydroxymandelonitrile |
| AN00561008 | C03656 | (S)-5-Amino-3-oxohexanoic acid |
| AN00429000 | C02091 | (S)-Ureidoglycine |
| AN00184002 | C20249 | (Z)-3-Peroxyaminoacrylic acid |
| AN00981001 | | 1,2-Dehydrosalsolinol |
| AN00767000 | C15606 | 1,2-Dihydroxy-5-(methylthio)pent-1-en-3-one |
| BM01817000 | C16196 | 1,2-Dihydroxynaphthalene-6-sulfonic acid |
| AN04326000 | C04823 | 1-(5'-Phosphoribosyl)-5-amino-4-(N-succinocarboxamide)-imidazole |
| AN03221000 | C04677 | 1-(5'-Phosphoribosyl)-5-amino-4-imidazolecarboxamide |
| BM01009002 | C01214 | 1-Amino-1-deoxy-scyllo-inositol |
| AN00171002 | C01234 | 1-Aminocyclopropane-1-carboxylic acid |
| AN01481002 | C11437 | 1-Deoxy-D-xylulose 5-phosphate |
| AN02657000 | C04545 | 1-Methylguanosine |
| AN00247003 | C03564 | 1-Pyrroline-2-carboxylic acid |
| AN00380007 | C04282 | 1-Pyrroline-4-hydroxy-2-carboxylic acid |
| AN00247000 | C03912 | 1-Pyrroline-5-carboxylic acid |
| AN04478002 | C00234 | 10-Formyltetrahydrofolic acid |
| AN02975002 | C14780 | 11(R)-HETE |
| AN02975008 | C14770 | 11,12-EET |
| AN03167002 | C05949 | 12-Keto-leukotriene B4 |
| AN03968003 | | 12-Ketochenodeoxycholic acid |
| AN01465001 | C16311 | 12-Oxo-9(Z)-dodecenoic acid |
| AN02955000 | C14807 | 12-OxoETE |
| AN02857002 | C04785 | 13(S)-HPOT |
| AN02615001 | C14765 | 13-OxoODE |
| AN02931006 | C14717 | 15-Deoxy-Delta12,14-PGJ2 |

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| AN03427008 | C05960 | 15-Keto-prostaglandin F2alpha |
| AN02263001 | | 15-Methylpalmitic acid |
| AN02955002 | C04577 | 15-OxoETE |
| AN03196005 | C14781 | 15H-11,12-EETA |
| AN02975010 | C14778 | 16(R)-HETE |
| AN02744000 | C05140 | 16alpha-Hydroxyandrost-4-ene-3,17-dione |
| AN02615006 | C16346 | 17-Hydroxylinolenic acid |
| AN02975005 | C14749 | 19(S)-HETE |
| AN02615005 | C16342 | 2(R)-HOT |
| AN02857001 | C16341 | 2(R)-HPOT |
| AN00162000 | | 2,2,2-Trifluoroethanol |
| BM00903001 | C03972 | 2,3,4,5-Tetrahydrodipicolinic acid |
| AN00887001 | | 2,3,4-Trihydroxybenzoic acid |
| AN00355000 | C03458 | 2,3,6-Trihydroxypyridine |
| AN00858000 | | 2,3-Diaminosalicylic acid |
| BM01244007 | C06580 | 2,3-Dihydroxy-p-cumic acid |
| AN03057000 | C14794 | 2,3-Dinor-8-iso prostaglandin F2alpha |
| AN01906009 | C19972 | 2,4-Bis(acetamido)-2,4,6-trideoxy-beta-L-altropyranose |
| BM00663001 | C16399 | 2,4-Diamino-6-hydroxylaminotoluene |
| BM00317000 | C14401 | 2,4-Diaminotoluene |
| AN00297002 | | 2,4-Dihydroxybutanoic acid |
| AN01161001 | C06201 | 2,4-Dihydroxyhept-2-enedioic acid |
| AN00732000 | C20781 | 2,4-Diketo-3-deoxy-L-fuconic acid |
| PR01750000 | | 2,5-Dihydroxybenzoate 2-O-sulfate |
| PR03108001 | | 2,5-Dihydroxybenzoate 5-O-glucuronide |
| PR01750001 | | 2,5-Dihydroxybenzoate 5-O-sulfate |
| AN00392002 | C00433 | 2,5-Dioxopentanoic acid |
| AN01068000 | C04744 | 2,6-Diamino-4-hydroxy-5-N-methylformamidopyrimidine |
| BM00843001 | C16397 | 2,6-Diamino-4-nitrotoluene |
| AN00679002 | C15523 | 2,6-Dihydroxynicotinic acid |
| AN00856004 | C06207 | 2,6-Dihydroxyphenylacetic acid |
| AN02050000 | C04441 | 2-(3-Carboxy-3-aminopropyl)-L-histidine |
| AN03566000 | | 2-(acetylamino)-1,5-anhydro-2-deoxy-3-O-b-D-galactopyranosyl-D-arabino-Hex-1-enitol |
| AN00418000 | C00900 | 2-Acetolactic acid/(S)-2-Acetolactic acid |
| AN01184000 | C16850 | 2-Amino-3,7-dideoxy-D-threo-hept-6-ulosonic acid |
| ED00601000 | C04075 | 2-Amino-4-chloro-4-pentenoic acid |
| BM01184001 | C21247 | 2-Amino-5-epi-valiolone |
| AN00561006 | C05825 | 2-Amino-5-oxohexanoic acid |
| AN00514000 | C03824 | 2-Aminomuconate semialdehyde |
| AN01633000 | C20653 | 2-Benzylmalic acid |
| AN01509000 | C11434 | 2-C-Methyl-D-erythritol 4-phosphate |
| AN01229000 | C05604 | 2-Carboxy-2,3-dihydro-5,6-dihydroxyindole |
| AN01214000 | C06473 | 2-Dehydro gluconic acid |
| AN00594003 | C03826 | 2-Dehydro-3-deoxy-D-xylonic acid |
| AN00769000 | C03827 | 2-Dehydro-3-deoxy-L-fuconic acid |
| AN00993001 | C01216 | 2-Dehydro-3-deoxy-galactonic acid |
| AN00993010 | C06892 | 2-Deoxy-5-keto-D-gluconic acid |
| AN00796005 | C02781 | 2-Deoxygalactopyranose |
| AN01385001 | C05835 | 2-Formaminobenzoylacetic acid |
| BM00322000 | C07103 | 2-Hydroxy-1,4-benzoquinone |
| BM00252002 | C00596 | 2-Hydroxy-2,4-pentadienoic acid |
| PR02098001 | | 2-Hydroxy-3-(4-hydroxyphenyl)propenoate O-sulfate |
| AN01019002 | C05350 | 2-Hydroxy-3-(4-hydroxyphenyl)propenoic acid |
| AN00966006 | C03217 | 2-Hydroxy-3-oxoadipic acid |
| AN00592000 | C03459 | 2-Hydroxy-3-oxosuccinic acid |
| AN00793003 | C02763 | 2-Hydroxy-3-phenylpropenoic acid |
| AN01288001 | C04642 | 2-Hydroxy-5-carboxymethylmuconate semialdehyde |
| BM00909003 | C07478 | 2-Hydroxy-5-methyl-cis,cis-muconic acid |
| AN01455000 | C12624 | 2-Hydroxy-6-ketononatrienedioic acid |
| BM01987000 | C06587 | 2-Hydroxy-6-oxo-6-(4'-chlorophenyl)-hexa-2,4-dienoic acid |
| AN01483000 | C04479 | 2-Hydroxy-6-oxonona-2,4-diene-1,9-dioic acid |
| BM01606001 | C14106 | 2-Hydroxy-7-hydroxymethylchromene-2-carboxylic acid |
| BM00371001 | C11354 | 2-Hydroxy-cis-hex-2,4-dienoic acid |
| BM00254008 | C01147 | 2-Hydroxycyclohexan-1-one |
| AN01137002 | | 2-Hydroxydecanoic acid |

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| AN00414001 | C03981 | 2-Hydroxyethylenedicarboxylic acid |
| AN00909000 | C05600 | 2-Hydroxyhepta-2,4-dienedioic acid |
| BM00525004 | C00682 | 2-Hydroxymuconate semialdehyde |
| BM00711002 | C02501 | 2-Hydroxymuconic acid |
| PR01724005 | | 2-Hydroxyphenylacetic acid O-sulfate |
| AN00751001 | | 2-Indolecarboxylic acid |
| AN00715001 | C02631 | 2-Isopropylmaleic acid |
| BM00711000 | C02222 | 2-Maleylacetic acid |
| AN00626002 | C17883 | 2-Methoxy-4-vinylphenol |
| AN01032000 | C06050 | 2-Methyl-3-hydroxy-5-formylpyridine-4-carboxylic acid |
| AN00532000 | | 2-Methyl-4-heptanone |
| AN00725002 | | 2-Methylbutyrylglycine |
| AN01371002 | C02225 | 2-Methylcitric acid |
| BM00699000 | C14099 | 2-Naphthaldehyde |
| BM00525005 | C03586 | 2-Oxo-2,3-dihydrofuran-5-acetic acid |
| AN00583003 | C05941 | 2-Oxo-4-hydroxy-5-aminovaleric acid |
| AN00995003 | C20327 | 2-Oxo-4-phenylbutyric acid |
| AN00927000 | C03771 | 2-Oxoarginine |
| AN00557000 | C00940 | 2-Oxoglutaramic acid |
| AN00909001 | C03063 | 2-Oxohept-3-enedioic acid |
| AN00971002 | C05994 | 2-Propylmalic acid |
| AN00023000 | C05985 | 2-Propynal |
| AN03075000 | C16519 | 2-Succinyl-5-enolpyruvyl-6-hydroxy-3-cyclohexene-1-carboxylic acid |
| BM01757002 | C22073 | 2-[(2-Aminoethylcarbamoyl)methyl]-2-hydroxybutanedioic acid |
| BM01198003 | C17691 | 2-epi-5-epi-Valiolone |
| AN01592008 | C03461 | 2-trans,6-trans-Farnesal |
| AN03326000 | C00942 | 3',5'-Cyclic GMP |
| PR03664000 | | 3,4-Dihydroxy-L-phenylalanine 3-O-glucuronide |
| AN00856003 | C05577 | 3,4-Dihydroxymandelaldehyde |
| PR03312004 | | 3,4-Dihydroxymandelaldehyde 3-O-glucuronide |
| PR01931004 | | 3,4-Dihydroxymandelaldehyde 3-O-sulfate /3,4-Dihydroxymandelaldehyde 4-O-sulfate |
| PR01931005 | | 3,4-Dihydroxymandelaldehyde 4-O-sulfate |
| PR03520002 | | 3,4-Dihydroxymandelate 4-O-glucuronide |
| AN00647004 | C04043 | 3,4-Dihydroxyphenylacetaldehyde |
| PR03312003 | | 3,4-Dihydroxyphenylacetate 4-O-glucuronide |
| PR01931002 | | 3,4-Dihydroxyphenylacetic acid 3-O-sulfate |
| AN00674004 | | 3,4-Dihydroxyphenylethanol |
| AN01052011 | C10447 | 3,4-Dihydroxyphenylpropanoic acid |
| AN01040000 | | 3,4-Dimethoxyphenylethylamine |
| AN00823015 | C01198 | 3-(2-Hydroxyphenyl)propanoic acid |
| AN01266003 | C01207 | 3-(3,4-Dihydroxyphenyl)lactic acid |
| AN01241000 | C04045 | 3-(3,4-Dihydroxyphenyl)pyruvic acid |
| PR03466000 | | 3-(4-Hydroxyphenyl)pyruvate O-glucuronide |
| AN01019001 | C01179 | 3-(4-Hydroxyphenyl)pyruvic acid |
| AN00255000 | | 3-Amino-2-piperidone |
| AN01037005 | C04368 | 3-Amino-3-(4-hydroxyphenyl)propanoic acid |
| BM01665000 | C12469 | 3-Amino-4,7-dihydroxy-8-chlorocoumarin |
| BM00657002 | C12115 | 3-Amino-4-hydroxybenzoic acid |
| AN00065001 | C05665 | 3-Aminopropanal |
| AN01633001 | C20654 | 3-Benzylmalic acid |
| AN00047000 | C06145 | 3-Butynal |
| BM00253000 | C02512 | 3-Cyano-L-alanine |
| AN01214006 | C00618 | 3-Dehydro-L-gulonic acid |
| AN00435002 | C03064 | 3-Dehydro-L-threonic acid |
| AN01161002 | C00944 | 3-Dehydroquinic acid |
| AN00909002 | C02637 | 3-Dehydroshikimic acid |
| AN02696000 | C02934 | 3-Dehydrosphinganine |
| BM01169004 | C12459 | 3-Dimethylallyl-4-hydroxybenzaldehyde |
| BM01379000 | C12458 | 3-Dimethylallyl-4-hydroxybenzoic acid |
| BM01781000 | C12457 | 3-Dimethylallyl-4-hydroxymandelic acid |
| AN00769009 | C01989 | 3-Ethylmalic acid |
| AN00157000 | C16310 | 3-Hexenal |
| AN00283003 | | 3-Hydroxy-2-methyl-[S-(R,R)]-butanoic acid |
| AN00418003 | C04181 | 3-Hydroxy-3-methyl-2-oxobutanoic acid |
| BM00573003 | C16272 | 3-Hydroxy-5-oxohexanoic acid |

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| AN01634002 | C03227 | 3-Hydroxy-L-kynurenine |
| AN00406001 | | 3-Hydroxy-L-proline |
| AN01353000 | C01259 | 3-Hydroxy-N6,N6,N6-trimethyl-L-lysine |
| BM00711001 | C03676 | 3-Hydroxy-cis,cis-muconic acid |
| PR03918001 | | 3-Hydroxy-kynurenine O-glucuronide |
| BM00333002 | C14602 | 3-Hydroxyaminophenol |
| PR01738000 | | 3-Hydroxyanthranilate O-sulfate |
| BM01229006 | | 3-Hydroxyhippuric acid |
| AN01029004 | C05636 | 3-Hydroxykynurenamine |
| PR03469001 | | 3-Hydroxykynurenamine O-glucuronide |
| AN01019004 | | 3-Hydroxyphenylpyruvic acid |
| AN00487000 | C18620 | 3-Hydroxypicolinic acid |
| AN00070002 | C00969 | 3-Hydroxypropanal |
| AN01831000 | | 3-Mercaptolactate-cysteine disulfide |
| AN00823014 | C05581 | 3-Methoxy-4-hydroxyphenylacetaldehyde |
| PR03283000 | | 3-Methoxy-4-hydroxyphenylacetaldehyde O-glucuronide |
| AN01079002 | C05594 | 3-Methoxy-4-hydroxyphenylethyleneglycol |
| AN01052010 | C05583 | 3-Methoxy-4-hydroxyphenylglycolaldehyde |
| BM00299001 | C07209 | 3-Methylbenzaldehyde |
| BM00594000 | C06029 | 3-Methylmalic acid/D-erythro-3-Methylmalic acid |
| BM00873002 | C12477 | 3-Methylpyrrole-2,4-dicarboxylic acid |
| BM00460007 | C14087 | 3-Methylsalicylaldehyde |
| BM00487002 | C14418 | 3-Nitrophenol |
| AN01655000 | | 3-Nitrotyrosine |
| AN01108002 | | 3-Oxodecanoic acid |
| AN00396004 | C02122 | 3-Oxohexanoic acid |
| AN00718001 | | 3-Oxooctanoic acid |
| AN00117001 | C00222 | 3-Oxopropanoic acid |
| BM01392003 | | 3-Phenylpropionylglycine |
| AN00971003 | C02123 | 3-Propylmalic acid |
| AN00814002 | | 3-Pyridinebutanoic acid |
| AN00655000 | C00606 | 3-Sulfino-L-alanine |
| BM01157000 | C06336 | 3-Sulfocatechol |
| AN02127003 | | 3-hydroxy-3-(3-hydroxyphenyl)propanoic acid-O-sulphate |
| AN04196001 | C04554 | 3alpha,7alpha-Dihydroxy-5beta-cholestanic acid |
| AN04056003 | C17333 | 3beta-Hydroxy-5-cholestenoic acid |
| AN03682004 | | 3beta-Hydroxy-delta5-cholenic acid |
| AN00751003 | C05639 | 4,6-Dihydroxyquinoline |
| AN00751004 | C05637 | 4,8-Dihydroxyquinoline |
| AN01620000 | C05652 | 4-(2-Amino-5-hydroxyphenyl)-2,4-dioxobutanoic acid |
| AN01385000 | C01252 | 4-(2-Aminophenyl)-2,4-dioxobutanoic acid |
| AN03414000 | C06118 | 4-(4-Deoxy-alpha-D-gluc-4-enuronosyl)-D-galacturonic acid |
| AN01694002 | C04796 | 4-(L-Alanin-3-yl)-2-hydroxy-cis,cis-muconate 6-semialdehyde |
| AN02791000 | C21107 | 4-(beta-D-Ribofuranosyl)phenol 5'-phosphate |
| AN01643000 | C11355 | 4-Amino-4-deoxychorismic acid |
| AN00493001 | C01279 | 4-Amino-5-hydroxymethyl-2-methylpyrimidine |
| AN00115001 | C00555 | 4-Aminobutyraldehyde |
| BM00333000 | C18351 | 4-Aminocatechol |
| AN01217000 | | 4-Aminohippuric acid |
| BM01100002 | C04484 | 4-Carboxy-2-hydroxymuconate semialdehyde |
| BM01026000 | C22137 | 4-Chloro-L-lysine |
| BM00354000 | C14450 | 4-Chloroaniline |
| BM00365000 | C02124 | 4-Chlorophenol |
| AN00884000 | C03077 | 4-Chlorophenylacetic acid |
| BM00368000 | C16473 | 4-Fluorocatechol |
| AN00386000 | C02647 | 4-Guanidinobutanal |
| AN00551000 | C03078 | 4-Guanidinobutanamide |
| AN00256001 | | 4-Heptanone |
| BM00418004 | C03589 | 4-Hydroxy-2-oxopentanoic acid |
| PR03076004 | | 4-Hydroxy-3-methoxy-benzaldehyde O-glucuronide |
| BM00979000 | C06034 | 4-Hydroxy-4-methylglutamic acid |
| AN03933001 | | 4-Hydroxy-5-(3',5'-dihydroxyphenyl)-valeric acid-O-glucuronide |
| AN01189000 | | 4-Hydroxydebrisoquine |
| AN00703006 | | 4-Hydroxynonenal |

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| AN00460001 | C03765 | 4-Hydroxyphenylacetaldehyde |
| PR02872001 | | 4-Hydroxyphenylacetaldehyde O-glucuronide |
| AN00481000 | C06044 | 4-Hydroxyphenylethanol |
| BM00818005 | C03590 | 4-Hydroxyphenylglyoxylic acid |
| AN01288000 | C01036 | 4-Maleylacetoacetic acid /4-Fumarylacetoacetic acid |
| BM00754000 | C06234 | 4-Methyl-L-glutamic acid |
| BM00711003 | C06035 | 4-Methylene-2-oxoglutaric acid |
| BM00722001 | C00651 | 4-Methylene-L-glutamic acid |
| BM00716001 | C01109 | 4-Methylene-L-glutamine |
| AN00593000 | C01180 | 4-Methylthio-2-oxobutanoic acid |
| AN01076002 | | 4-O-Methylgallic acid |
| AN00785001 | C19567 | 4-Oxo-1-(3-pyridyl)-1-butanone |
| AN00380006 | C01877 | 4-Oxoproline |
| AN02714004 | C16683 | 4-Oxoretinol |
| AN00808002 | C00971 | 4-Pyridoxolactone |
| BM01157001 | C06674 | 4-Sulfocatechol |
| BM03412000 | C18349 | 4-[2-(5-Carboxy-2-hydroxy-3-methoxyphenyl)-2-oxoethylidene]-2-hydroxy-2-pentenedioic acid |
| AN00505003 | C20522 | 4-imidazolylpropanoic acid |
| AN01981001 | C05198 | 5'-Deoxyadenosine |
| AN02975012 | C04805 | 5(S)-HETE |
| AN00606002 | C05578 | 5,6-Dihydroxyindole |
| AN02975006 | C14768 | 5,6-EET |
| AN03167000 | C14815 | 5,6-Epoxytetraene |
| AN01177000 | C17938 | 5,6-Indolequinone-2-carboxylic acid |
| AN01668003 | C05655 | 5-(2'-Carboxyethyl)-4,6-dihydroxypicolinic acid |
| AN02003000 | C05641 | 5-(3'-Carboxy-3'-oxopropenyl)-4,6-dihydroxypicolinic acid |
| AN02031000 | C05656 | 5-(3'-Carboxy-3'-oxopropyl)-4,6-dihydroxypicolinic acid |
| AN00725008 | C03087 | 5-Acetamidopentanoic acid |
| AN00406003 | C01110 | 5-Amino-2-oxopentanoic acid |
| AN00174001 | C12455 | 5-Aminopentanal |
| AN00270000 | C00990 | 5-Aminopentanamide |
| BM01455001 | C18338 | 5-Carboxyvanillic acid |
| AN00966000 | C04053 | 5-Dehydro-4-deoxy-D-glucuronic acid |
| AN01214010 | C21644 | 5-Dehydro-L-gluconic acid |
| AN00993009 | C16737 | 5-Deoxy-D-glucuronic acid |
| AN01314000 | C12248 | 5-Hydroxy-2-oxo-4-ureido-2,5-dihydro-1H-imidazole-5-carboxylic acid |
| AN01992000 | C05648 | 5-Hydroxy-N-formylkynurenine |
| AN00956002 | C05634 | 5-Hydroxyindoleacetaldehyde |
| AN01180000 | C05635 | 5-Hydroxyindoleacetic acid |
| AN01559000 | C05646 | 5-Hydroxyindolepyruvic acid |
| AN01029003 | C05638 | 5-Hydroxykynurenamine |
| PR03469000 | | 5-Hydroxykynurenamine O-glucuronide |
| PR02102000 | | 5-Hydroxykynurenamine O-sulfate |
| AN01634001 | C05651 | 5-Hydroxykynurenine |
| PR03918000 | | 5-Hydroxykynurenine O-glucuronide |
| AN02012000 | C05844 | 5-L-Glutamyl-taurine |
| AN01360003 | C05660 | 5-Methoxyindoleacetic acid |
| AN01186000 | | 5-Methoxytryptophol |
| AN02955001 | C14732 | 5-OxoETE |
| AN00266002 | C03273 | 5-Oxopentanoic acid |
| AN01846000 | C03366 | 5-Phosphooxy-L-lysine |
| AN01692000 | C03090 | 5-Phosphoribosylamine |
| EF01663003 | | 5-Tetradecenoic acid |
| AN03819001 | | 5beta-Cholanic acid-3, 7-dione |
| AN01232000 | C01300 | 6-(Hydroxymethyl)-7,8-dihydropterin |
| AN01114000 | C05548 | 6-Acetamido-2-oxohexanoic acid |
| AN00561007 | C03239 | 6-Amino-2-oxohexanoic acid |
| BM00422001 | C06103 | 6-Hydroxyhexanoic acid |
| AN01356000 | C05663 | 6-Hydroxykynurenic acid |
| PR04107000 | | 6-Hydroxymelatonin O-glucuronide |
| AN03615002 | C05962 | 6-Keto-prostaglandin E1 |
| AN03641001 | C05961 | 6-Keto-prostaglandin F1alpha |
| AN00514001 | C04226 | 6-Oxo-1,4,5,6-tetrahydronicotinic acid |
| AN01790002 | C03684 | 6-Pyruvoyltetrahydropterin |
| AN01811004 | C02953 | 7,8-Dihydrobiopterin |

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| AN02034000 | C04874 | 7,8-Dihydroneopterin |
| AN01035001 | C21065 | 7,8-Dihydroxanthopterin |
| AN01011000 | C16675 | 7-Aminomethyl-7-carbaguanine |
| AN00954000 | C15996 | 7-Cyano-7-carbaguanine |
| BM00550002 | C16590 | 7-Oxoheptanoic acid |
| AN04160000 | C17337 | 7alpha-Hydroxy-3-oxo-4-cholestenoic acid |
| PR04523004 | | 7alpha-Hydroxydehydroepiandrosterone 3-O-glucuronide |
| AN02975001 | C14776 | 8(S)-HETE |
| AN02975007 | C14769 | 8,9-EET |
| AN00898021 | C18202 | 8-Methyl-6-nonenoic acid |
| AN02615003 | C04780 | 8-[(1R,2R)-3-Oxo-2-{(Z)-pent-2-enyl}cyclopentyl]octanoic acid |
| AN02650001 | C14825 | 9(10)-EpOME |
| AN03819002 | | 9(11), (5beta)-Cholenic acid-3alpha-ol-12-one |
| AN02650000 | C14767 | 9(S)-HODE |
| AN02615002 | C16326 | 9(S)-HOT |
| AN02912002 | C14828 | 9,10-DHOME |
| AN02615000 | C14766 | 9-OxoODE |
| AN00918000 | C16322 | 9-Oxononanoic acid |
| AN02413001 | C04056 | 9-cis,11-trans-Octadecadienoic acid |
| AN02464003 | C16681 | 9-cis-Retinal |
| AN02714005 | C15493 | 9-cis-Retinoic acid |
| AN00119000 | C01769 | Acetoin |
| BM00107001 | C02659 | Acetone cyanohydrin |
| AN03822000 | C05993 | Acetyl adenylic acid |
| BM00396001 | C06102 | Adipate semialdehyde |
| AN03151000 | C16527 | Adrenic acid |
| AN01036000 | | Adrenochrome o-semiquinone |
| AN04929000 | C05554 | Aerobactin |
| AN01320000 | | Alanyl-Hydroxyproline |
| AN02337000 | C00806 | Alanyl-Tryptophan/Tryptophyl-Alanine |
| AN00718002 | | Alpha-Ketooctanoic acid |
| AN00028000 | C06735 | Aminoacetaldehyde |
| AN00065000 | C01888 | Aminoacetone |
| AN00113000 | C20253 | Aminoacrylic acid |
| BM00333001 | C14604 | Aminohydroquinone |
| AN00287000 | C00872 | Aminomalonic acid |
| AN02776000 | C00219 | Arachidonic acid |
| AN02758000 | | Arginyl-Glutamic acid |
| AN02745000 | | Arginyl-Lysine |
| AN00966003 | C00072 | Ascorbic acid |
| AN02109000 | | Asparaginyl-Glutamine |
| AN01887000 | | Asparaginyl-Hydroxyproline |
| AN01720000 | | Asparaginyl-Valine |
| AN01708005 | | Aspartyl-L-proline |
| AN03174000 | C04540 | Aspartylglycosamine |
| BM02257001 | C20942 | Bacilysin |
| BM00344000 | C02814 | Benzene-1,2,4-triol |
| AN00818000 | | Benzoquinoneacetic acid |
| AN02899000 | | Beta-D-Glucopyranuronic acid |
| AN05473000 | C16564 | Bis(glutathionyl)spermine disulfide |
| AN04623000 | C03646 | Bis-gamma-glutamylcystine |
| AN00061003 | C02845 | Butanone |
| AN04155000 | C05673 | CMP-2-aminoethylphosphonate |
| AN05180000 | C03691 | CMP-N-glycoloylneuraminic acid |
| AN04469000 | C05674 | CMP-N-trimethyl-2-aminoethylphosphonate |
| AN05743000 | C00323 | Caffeoyl-CoA |
| AN00036000 | C01563 | Carbamic acid |
| BM01872001 | C20818 | Carbapenem biosynthesis intermediate 2 |
| BM00842003 | C20821 | Carbapenem biosynthesis intermediate 6 |
| AN01660003 | C00386 | Carnosine |
| BM00227000 | C00090 | Catechol |
| BM00903000 | C21249 | Cetoniacytone B |
| BM00086000 | C06754 | Chloroacetaldehyde |
| AN01654001 | C00251 | Chorismic acid |
| BM00898014 | C16462 | Citronellic acid |
| BM05307000 | C12032 | Clorobiocin |
| AN02387002 | C07289 | Crepenynic acid |

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| AN00013000 | C01417 | Cyanic acid |
| BM00108000 | C16267 | Cyclopropanecarboxylic acid |
| AN01797000 | | Cystathionine sulfoxide |
| AN00304000 | C00097 | Cysteine |
| AN01608001 | | Cysteinyl-Threonine |
| PR03873000 | | Cysteinyldopa 3-O-sulfate |
| PR03873001 | | Cysteinyldopa 4-O-sulfate |
| AN00681001 | C04122 | D-1-Aminopropan-2-ol O-phosphate |
| AN01194002 | | D-Glucaro-1,4-lactone |
| AN02250000 | C01726 | D-Lombricine |
| AN01548006 | C04020 | D-Lysopine |
| AN01908000 | C04137 | D-Octopine |
| AN00594008 | C06032 | D-erythro-3-Methylmalic acid |
| BM01057002 | C14113 | Decahydro-2-naphthoic acid |
| AN00113001 | C02218 | Dehydroalanine |
| AN05236000 | | Dehydroisocoproporphyrinogen |
| AN03167003 | C05958 | Delta-12-Prostaglandin J2 |
| AN00360001 | C04092 | Delta1-Piperideine-2-carboxylic acid |
| AN02287001 | C18133 | Deoxyshikonin |
| BM02863000 | C05143 | Dhurrin |
| BM00371002 | C06719 | Dihydrophloroglucinol |
| PR03639001 | | Dihydrotestosterone 17-O-sulfate |
| AN00592001 | C00975 | Dihydroxyfumaric acid |
| AN02485001 | | Diphenol glucuronide |
| AN03523001 | | Dityrosine |
| AN01229001 | C00822 | Dopaquinone |
| AN00528000 | C06231 | Ectoine |
| AN01696000 | | Endalin |
| AN02339000 | | Epsilon-(gamma-Glutamyl)-Lysine |
| AN02585003 | C16319 | Etherolenic acid |
| AN00256002 | | Ethyl isobutyl ketone |
| AN01784000 | C16502 | Farnesoic acid |
| AN01408002 | C05647 | Formyl-5-hydroxykynurenamine |
| PR03769000 | | Formyl-5-hydroxykynurenamine O-glucuronide |
| PR02520000 | | Formyl-5-hydroxykynurenamine O-sulfate |
| AN00808001 | C05653 | Formylanthranilic acid |
| AN00938000 | C16674 | Formylisoglutamine |
| AN02121000 | | Gamma-glutamyl-ornithine |
| AN00477005 | C05585 | Gentisate aldehyde |
| PR02900001 | | Gentisate aldehyde 2-O-glucuronide |
| PR02900002 | | Gentisate aldehyde 5-O-glucuronide |
| BM00866012 | C16461 | Geranic acid |
| AN02089000 | | Glutaminyl-Hydroxyproline |
| AN03144000 | | Glutaminyl-Tryptophan |
| AN01874000 | | Glutamyl-Proline |
| AN01144001 | | Glutaryl-Glycine |
| AN02808000 | C00051 | Glutathione |
| AN05115000 | C00127 | Glutathione disulfide |
| AN04193000 | C05730 | Glutathionylspermidine |
| AN01334004 | | Glycyl-Gamma-glutamic acid |
| AN02477000 | | Glycyl-Prolyl-Hydroxyproline |
| AN00029000 | C17349 | Guanidine |
| AN01242000 | C00800, C00257 | Gulonic acid |
| AN05127000 | | Harderoporphyrinogen |
| AN03196003 | C14808 | Hepoxilin A3 |
| AN01945000 | C16343 | Heptadecatrienal |
| AN02184003 | C16344 | Heptadecatrienoic acid |
| AN01828000 | C00517 | Hexadecanal |
| AN02496000 | C19615 | Hexadecanedioic acid |
| AN02055000 | C00249 | Hexadecanoic acid |
| AN02050001 | | Histidinyl-Threonine |
| AN03270000 | | Histidinyl-Tryptophan |
| AN02951002 | | Histidinyl-Tyrosine |
| AN01826000 | C00884 | Homocarnosine |
| PR03312000 | | Homogentisic acid 2-O-glucuronide |
| PR03312001 | | Homogentisic acid 5-O-glucuronide |
| PR03489000 | | Homovanillate O-glucuronide |
| BM00219001 | C02720 | Hydroxylaminobenzene |

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| AN00743001 | | Hydroxyoctanoic acid |
| AN01887001 | | Hydroxyprolyl-Asparagine |
| AN02089002 | | Hydroxyprolyl-Gamma-glutamic acid |
| AN02089001 | | Hydroxyprolyl-Glutamine |
| AN02226000 | | Hydroxyprolyl-Histidine |
| AN01684001 | | Hydroxyprolyl-Proline |
| AN01544003 | | Hydroxyprolyl-Serine |
| AN02608001 | | Hydroxyprolyl-Tyrosine |
| AN01711000 | | Hydroxyprolyl-Valine |
| AN00193002 | C00168 | Hydroxypyruvic acid |
| AN02004001 | | Hydroxysepiapterin |
| AN02827002 | C16525 | Icosadienoic acid |
| AN02804004 | C16522 | Icosatrienoic acid |
| AN00698000 | C05568 | Imidazole lactic acid |
| AN00671001 | C03277 | Imidazole pyruvic acid |
| AN00403001 | C05840 | Iminoaspartic acid |
| AN00064000 | C15809 | Iminoglycine |
| AN00582000 | C05579 | Indole-5,6-quinone |
| AN01360002 | C02043 | Indolelactic acid |
| AN01332000 | C00331 | Indolepyruvic acid |
| AN00431003 | C05658 | Indoxyl |
| AN01844001 | C04299 | Inositol cyclic phosphate |
| AN00561001 | | Isobutyrylglycine |
| AN01194007 | C00311 | Isocitric acid |
| AN01052002 | | Isohomovanillic acid |
| AN01876002 | | Isoleucyl-Hydroxyproline |
| AN01548000 | | Isoleucyl-Serine |
| AN01735001 | | Isoleucyl-Threonine |
| AN01640006 | C16318 | Isomer 1 of (+)-7-Isomethyljasmonic acid |
| BM01755001 | C16600 | Isomer 1 of (-)-threo-Iso(homo)3-citric acid |
| AN02027002 | C08362 | Isomer 1 of (9Z)-Hexadecenoic acid |
| AN00441003 | C04272 | Isomer 1 of (R)-2,3-Dihydroxy-3-methylbutanoic acid |
| AN00767000 | C15606 | Isomer 1 of 1,2-Dihydroxy-5-(methylthio)pent-1-en-3-one |
| BM01817000 | C16196 | Isomer 1 of 1,2-Dihydroxynaphthalene-6-sulfonic acid |
| BM01009002 | C01214 | Isomer 1 of 1-Amino-1-deoxy-scyllo-inositol |
| AN00171002 | C01234 | Isomer 1 of 1-Aminocyclopropane-1-carboxylic acid |
| AN02615001 | C14765 | Isomer 1 of 13-OxoODE |
| AN03427008 | C05960 | Isomer 1 of 15-Keto-prostaglandin F2alpha |
| AN00355000 | C03458 | Isomer 1 of 2,3,6-Trihydroxypyridine |
| BM01184001 | C21247 | Isomer 1 of 2-Amino-5-epi-valiolone |
| AN00726001 | | Isomer 1 of 2-Aminooctanoic acid |
| AN00796005 | C02781 | Isomer 1 of 2-Deoxygalactopyranose |
| BM01987000 | C06587 | Isomer 1 of 2-Hydroxy-6-oxo-6-(4'-chlorophenyl)-hexa-2,4-dienoic acid |
| AN00197004 | C05984 | Isomer 1 of 2-Hydroxybutyric acid |
| AN01137002 | | Isomer 1 of 2-Hydroxydecanoic acid |
| AN00177004 | C00109 | Isomer 1 of 2-Ketobutyric acid |
| AN00396002 | C00902 | Isomer 1 of 2-Ketohexanoic acid |
| AN00995003 | C20327 | Isomer 1 of 2-Oxo-4-phenylbutyric acid |
| AN00255000 | | Isomer 1 of 3-Amino-2-piperidone |
| AN00283003 | | Isomer 1 of 3-Hydroxy-2-methyl-[S-(R,R)]-butanoic acid |
| BM00460007 | C14087 | Isomer 1 of 3-Methylsalicylaldehyde |
| AN01108002 | | Isomer 1 of 3-Oxodecanoic acid |
| AN00718001 | | Isomer 1 of 3-Oxooctanoic acid |
| AN02127003 | | Isomer 1 of 3-hydroxy-3-(3-hydroxyphenyl)propanoic acid-O-sulphate |
| AN00751004 | C05637 | Isomer 1 of 4,8-Dihydroxyquinoline |
| BM01026000 | C22137 | Isomer 1 of 4-Chloro-L-lysine |
| AN00793000 | C00811 | Isomer 1 of 4-Coumaric acid |
| AN00785001 | C19567 | Isomer 1 of 4-Oxo-1-(3-pyridyl)-1-butanone |
| AN00380006 | C01877 | Isomer 1 of 4-Oxoproline |
| AN00808002 | C00971 | Isomer 1 of 4-Pyridoxolactone |
| AN00277004 | C00431 | Isomer 1 of 5-Aminopentanoic acid |
| AN01274001 | | Isomer 1 of 5-Dodecenoic acid |
| AN01180000 | C05635 | Isomer 1 of 5-Hydroxyindoleacetic acid |
| AN00774001 | C16741 | Isomer 1 of 5-Hydroxylysine |
| AN03836002 | | Isomer 1 of 5beta-Cholanic acid-12alpha-ol-3-one |
| BM00550002 | C16590 | Isomer 1 of 7-Oxoheptanoic acid |

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| AN00918000 | C16322 | Isomer 1 of 9-Oxononanoic acid |
| AN00014000 | C00084 | Isomer 1 of Acetaldehyde |
| AN00119000 | C01769 | Isomer 1 of Acetoin |
| AN00026002 | C00207 | Isomer 1 of Acetone - isomer 1/Propanal |
| AN01036000 | | Isomer 1 of Adrenochrome o-semiquinone |
| AN01544002 | | Isomer 1 of Alanyl-Glutamic acid |
| AN00718002 | | Isomer 1 of Alpha-Ketooctanoic acid |
| AN00754003 | C00956 | Isomer 1 of Aminoadipic acid |
| AN02776000 | C00219 | Isomer 1 of Arachidonic acid |
| AN03174000 | C04540 | Isomer 1 of Aspartylglycosamine |
| AN01548006 | C04020 | Isomer 1 of D-Lysopine |
| AN00704003 | C12307 | Isomer 1 of Decanal/2-Decanone |
| AN05236000 | | Isomer 1 of Dehydroisocoproporphyrinogen |
| AN02287001 | C18133 | Isomer 1 of Deoxyshikonin |
| BM00371002 | C06719 | Isomer 1 of Dihydrophloroglucinol |
| PR03639001 | | Isomer 1 of Dihydrotestosterone 17-O-sulfate |
| AN02485001 | | Isomer 1 of Diphenol glucuronide |
| AN00418009 | | Isomer 1 of Ethylmalonic acid |
| AN01408002 | C05647 | Isomer 1 of Formyl-5-hydroxykynurenamine |
| AN02849001 | | Isomer 1 of Glutamyl-Tyrosine |
| AN01828000 | C00517 | Isomer 1 of Hexadecanal |
| AN02055000 | C00249 | Isomer 1 of Hexadecanoic acid |
| AN00684000 | | Isomer 1 of Histidine |
| AN01061000 | C16511 | Isomer 1 of Homocysteic acid |
| AN00291001 | C00263 | Isomer 1 of Homoserine |
| AN02004001 | | Isomer 1 of Hydroxysepiapterin |
| AN01360002 | C02043 | Isomer 1 of Indolelactic acid |
| AN00574004 | C16673 | Isomer 1 of Isoglutamine |
| AN01876002 | | Isomer 1 of Isoleucyl-Hydroxyproline |
| BM00392004 | C00490 | Isomer 1 of Itaconic acid |
| AN00291005 | C05519 | Isomer 1 of L-Allothreonine |
| AN00410000 | C00123 | Isomer 1 of Leucine |
| AN00578000 | C00047 | Isomer 1 of Lysine |
| AN02121003 | | Isomer 1 of Lysyl-Aspartic acid |
| BM00344001 | C11918 | Isomer 1 of Maltol |
| AN00608000 | C00073 | Isomer 1 of Methionine |
| AN00102001 | | Isomer 1 of Methyl propenyl ketone |
| AN00281003 | C02170 | Isomer 1 of Methylmalonic acid |
| PR00561005 | | Isomer 1 of N-Acetyl-(S)-2-Aminobutanoic acid |
| AN00583008 | | Isomer 1 of N-Acetyl-DL-serine |
| PR00189009 | | Isomer 1 of N-Acetyl-Ethanolamine |
| AN00938001 | C00439 | Isomer 1 of N-Formimino-L-glutamic acid |
| AN01778000 | C02700 | Isomer 1 of N-formylkynurenine |
| PR00943004 | | Isomer 1 of N5-Acetyl-L-Ornithine |
| AN00410003 | C01933 | Isomer 1 of Norleucine |
| AN00385000 | C00408 | Isomer 1 of Pipecolic acid |
| AN00259000 | C00148 | Isomer 1 of Proline |
| BM00344003 | C01108 | Isomer 1 of Pyrogallol |
| AN00596001 | C17268 | Isomer 1 of Pyruvophenone |
| AN00281002 | C00042 | Isomer 1 of Succinic acid |
| BM01168004 | C20914 | Isomer 1 of Tabtoxin biosynthesis intermediate 4 |
| AN01711001 | | Isomer 1 of Valyl-Hydroxyproline |
| AN01892001 | | Isomer 1 of Valyl-Lysine |
| AN00934000 | C00417 | Isomer 1 of cis-Aconitic acid |
| AN01640006 | C16318 | Isomer 2 of (+)-7-Isomethyljasmonic acid |
| BM01755001 | C16600 | Isomer 2 of (-)-threo-Iso(homo)3-citric acid |
| BM01817000 | C16196 | Isomer 2 of 1,2-Dihydroxynaphthalene-6-sulfonic acid |
| BM00460007 | C14087 | Isomer 2 of 3-Methylsalicylaldehyde |
| AN00751004 | C05637 | Isomer 2 of 4,8-Dihydroxyquinoline |
| BM01026000 | C22137 | Isomer 2 of 4-Chloro-L-lysine |
| AN00277004 | C00431 | Isomer 2 of 5-Aminopentanoic acid |
| BM00550002 | C16590 | Isomer 2 of 7-Oxoheptanoic acid |
| AN00918000 | C16322 | Isomer 2 of 9-Oxononanoic acid |
| AN00014000 | C00084 | Isomer 2 of Acetaldehyde |
| AN01548006 | C04020 | Isomer 2 of D-Lysopine |
| AN01828000 | C00517 | Isomer 2 of Hexadecanal |
| AN00608000 | C00073 | Isomer 2 of Methionine |
| AN00281003 | C02170 | Isomer 2 of Methylmalonic acid |

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| PR00943004 | | Isomer 2 of N5-Acetyl-L-Ornithine |
| AN00281002 | C00042 | Isomer 2 of Succinic acid |
| BM01168004 | C20914 | Isomer 2 of Tabtoxin biosynthesis intermediate 4 |
| AN01548006 | C04020 | Isomer 3 of D-Lysopine |
| BM04636001 | C00927 | Isonocardicin A |
| AN00033000 | C01845 | Isopropanol |
| AN00929002 | | Isovalerylalanine |
| AN01440000 | C08491 | Jasmonic acid |
| AN00380005 | C04281 | L-1-Pyrroline-3-hydroxy-5-carboxylic acid |
| AN00273001 | C03508 | L-2-Amino-3-oxobutanoic acid |
| BM01144000 | C03871 | L-2-Amino-6-oxoheptanedioic acid |
| AN00583004 | C05938 | L-4-Hydroxyglutamate semialdehyde |
| BM00842002 | C12323 | L-4-Hydroxyphenylglycine |
| AN00291005 | C05519 | L-Allothreonine |
| AN00561000 | C04076 | L-Allysine |
| AN01671000 | C00826 | L-Arogenic acid |
| AN00273002 | C00441 | L-Aspartate 4-semialdehyde |
| AN00868000 | C00506 | L-Cysteic acid |
| AN01024003 | C01720 | L-Fuconic acid |
| AN01667000 | C03287 | L-Glutamyl 5-phosphate |
| AN00493000 | C01929 | L-Histidinal |
| AN01012005 | C17235 | L-Homophenylalanine |
| AN01260000 | C05588 | L-Metanephrine |
| AN00876002 | C00547 | L-Noradrenaline |
| PR01947000 | | L-Noradrenaline 3-O-sulfate |
| EF02022001 | | L-Pyridosine |
| BM02037000 | C16138 | L-Pyrrolysine |
| AN01024020 | C01934 | L-Rhamnonic acid |
| AN00769005 | C02991 | L-Rhamnono-1,4-lactone |
| AN02113000 | | L-Tyrosine O-sulfate |
| AN01900001 | | L-alpha-Aspartyl-L-hydroxyproline |
| AN02107001 | | L-alpha-glutamyl-L-hydroxyproline |
| BM00380002 | C22141 | L-beta-Ethynylserine |
| AN01933000 | | L-beta-aspartyl-L-aspartic acid |
| AN01163000 | | L-beta-aspartyl-L-glycine |
| AN01583001 | | L-beta-aspartyl-L-serine |
| AN01757003 | | L-beta-aspartyl-L-threonine |
| AN00782000 | C05947 | L-erythro-4-Hydroxyglutamic acid |
| ED02071001 | C22140 | L-gamma-Glutamyl-(3R)-L-beta-ethynylserine |
| AN01130001 | | L-glycyl-L-hydroxyproline |
| AN02380000 | | L-phenylalanyl-L-hydroxyproline |
| AN00583005 | C03618 | L-threo-3-Methylaspartic acid |
| AN01876003 | | Leucyl-Hydroxyproline |
| AN01688001 | | Leucyl-Proline |
| AN03196007 | C02165 | Leukotriene B4 |
| AN05162000 | C02166 | Leukotriene C4 |
| BM00344001 | C11918 | Maltol |
| AN04939000 | | Mesoporphyrin IX |
| PR03666000 | | Metanephrine O-glucuronide |
| PR03975000 | | Metatonin N-glucuronide |
| AN00009000 | C00132 | Methanol |
| AN01971000 | | Methionyl-Threonine |
| AN01939000 | | Methionyl-Valine |
| AN00130004 | | Methoxyacetic acid |
| AN00396003 | | Mevalonolactone |
| AN00951000 | C01041 | Monodehydroascorbic acid |
| BM03948000 | C12221 | Myxochelin B |
| AN00744000 | C02728 | N(6)-Methyllysine |
| AN00738001 | C06442 | N(gamma)-Acetyldiaminobutyric acid |
| AN01171000 | C05933 | N(omega)-Hydroxyarginine |
| BM01257001 | C19715 | N,N-Dihydroxy-L-phenylalanine |
| BM00609000 | C20314 | N,N-Dihydroxy-L-valine |
| AN02555000 | C03406 | N-(L-Arginino)succinic acid |
| PR00561005 | | N-Acetyl-(S)-2-Aminobutanoic acid |
| PR01065002 | | N-Acetyl-2-Aminomuconate semialdehyde |
| PR01789001 | | N-Acetyl-2-Carboxy-2,3-dihydro-5,6-dihydroxyindole |
| PR01144002 | | N-Acetyl-2-Oxo-4-hydroxy-5-aminovaleric acid |
| PR01809000 | | N-Acetyl-3,4-Dihydroxy-L-phenylalanine |

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| PR01229010 | | N-Acetyl-3-Hydroxyanthranilic acid |
| PR02188000 | | N-Acetyl-4-(2-Amino-3-hydroxyphenyl)-2,4-dioxobutanoic acid |
| PR01949000 | | N-Acetyl-4-(2-Aminophenyl)-2,4-dioxobutanoic acid |
| TA02137001 | | N-Acetyl-5-Hydroxy-L-tryptophan |
| PR02604000 | | N-Acetyl-5-Hydroxy-N-formylkynurenine |
| PR02417003 | | N-Acetyl-6-(1'-Hydroxy-2'-oxopropyl)-tetrahydropterin |
| PR02417000 | | N-Acetyl-6-Lactoyl-5,6,7,8-tetrahydropterin |
| PR02392000 | | N-Acetyl-6-Pyruvoyltetrahydropterin |
| AN03398000 | C04016 | N-Acetyl-7-O-acetylneuraminic acid |
| AN03398001 | | N-Acetyl-9-O-acetylneuraminic acid |
| PR01006005 | | N-Acetyl-Anthranilic acid |
| PR00381000 | | N-Acetyl-Dehydroalanine |
| AN01234000 | | N-Acetyl-Dopamine |
| PR01789000 | | N-Acetyl-Dopaquinone |
| PR00189009 | | N-Acetyl-Ethanolamine |
| PR01970000 | | N-Acetyl-Formyl-5-hydroxykynurenamine |
| PR05241000 | | N-Acetyl-Glutathione disulfide |
| TA00926001 | | N-Acetyl-Hydroxyproline |
| PR01130004 | | N-Acetyl-Isoglutamine |
| PR00722000 | | N-Acetyl-L-2-Amino-3-oxobutanoic acid |
| PR01144003 | | N-Acetyl-L-4-Hydroxyglutamate semialdehyde |
| PR01646001 | | N-Acetyl-L-Adrenaline |
| TA02422000 | | N-Acetyl-L-Cystine |
| PR01766000 | | N-Acetyl-L-Dopachrome |
| PR00977002 | | N-Acetyl-L-Homocysteine |
| PR01449002 | | N-Acetyl-L-Noradrenaline |
| TA00708002 | | N-Acetyl-L-Proline |
| TA01623001 | | N-Acetyl-L-Tyrosine |
| TA01144004 | C00624 | N-Acetyl-L-glutamic acid |
| TA01130000 | | N-Acetyl-L-glutamine |
| PR01733000 | | N-Acetyl-N(omega)-Hydroxyarginine |
| PR01734001 | | N-Acetyl-N-Methylserotonin |
| PR00406011 | | N-Acetyl-Sarcosine |
| PR02392001 | | N-Acetyl-Sepiapterin |
| AN01013000 | | N-Acetyl-Tyramine |
| TA00938003 | | N-Acetyl-asparagine |
| AN00406005 | C01073 | N-Acetyl-beta-alanine |
| TA01392000 | C03519 | N-Acetyl-phenylalanine |
| PR02058000 | | N-Acetyl-sn-Glycero-3-phosphoethanolamine |
| PR00926003 | | N-Acetyl-trans-3-Hydroxy-L-proline |
| AN03567000 | C17951 | N-Acetylbialaphos |
| AN00956000 | C02298 | N-Acetylindoxyl |
| AN02590000 | C02713 | N-Acetylmuramic acid |
| AN00400000 | C02714 | N-Acetylputrescine |
| AN01546000 | C00978 | N-Acetylserotonin |
| PR03861000 | | N-Acetylserotonin O-glucuronide |
| AN00380003 | | N-Acryloylglycine |
| AN00561002 | | N-Butyrylglycine |
| AN00419003 | C01043 | N-Carbamoylsarcosine |
| AN00189006 | C11735 | N-Ethylglycine |
| AN00734001 | C03409 | N-Formimino-L-aspartic acid |
| AN00938001 | C00439 | N-Formimino-L-glutamic acid |
| AN00824000 | C19872 | N-Formyl-4-amino-5-aminomethyl-2-methylpyrimidine |
| AN00952001 | C01045 | N-Formyl-L-glutamic acid |
| AN00978002 | C03145 | N-Formylmethionine |
| BM00587000 | C20310 | N-Hydroxy-L-isoleucine |
| BM01037000 | C19712 | N-Hydroxy-L-phenylalanine |
| BM01257000 | C03004 | N-Hydroxy-L-tyrosine |
| BM00433000 | C20313 | N-Hydroxy-L-valine |
| AN00725003 | | N-Isovaleroylglycine |
| TM00754001 | C01046 | N-Methyl-L-glutamic acid |
| AN00277000 | | N-Methyl-a-aminoisobutyric acid |
| AN00681000 | C01210 | N-Methylethanolamine phosphate |
| AN00337000 | C05127 | N-Methylhistamine |
| PR03583000 | | N-Methylserotonin O-glucuronide |
| AN02508000 | | N-Ribosylhistidine |
| TA01903000 | | N-acetyl-Tryptophan |

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| AN01778000 | C02700 | N-formylkynurenine |
| AN02336005 | | N-gamma-Glutamyl-Glutamine |
| PR02197000 | | N2'-Acetyl-5'-Hydroxykynurenine |
| PR04468000 | | N2'-Acetyl-CMP-2-aminoethylphosphonate |
| PR02454001 | | N2-Acetyl-5-Phosphooxy-L-lysine |
| PR04468001 | | N2-Acetyl-CMP-2-aminoethylphosphonate |
| PR03487001 | | N2-Acetyl-Cysteinyldopa |
| AN02172003 | | N2-Acetyl-L-Cystathionine |
| PR01349003 | | N2-Acetyl-L-Hydroxylysine |
| AN03710000 | C20333 | N2-Citryl-N6-acetyl-N6-hydroxy-L-lysine |
| PR01612003 | | N3-Acetyl-5'-Hydroxykynurenamine |
| PR04121001 | | N3-Acetyl-S-Adenosyl-L-homocysteine |
| PR03877001 | | N3-Acetyl-S-Adenosylmethioninamine |
| PR00943004 | | N5-Acetyl-L-Ornithine |
| PR04121000 | | N6'-Acetyl-S-Adenosyl-L-homocysteine |
| PR03877000 | | N6'-Acetyl-S-Adenosylmethioninamine |
| AN01138000 | C03793 | N6,N6,N6-Trimethyl-L-lysine |
| AN00774000 | C01028 | N6-Hydroxy-L-lysine |
| AN02416001 | | N6-Methyladenosine/N-Acetyl-6-(1'-Hydroxy-2'-oxopropyl)-tetrahydropterin |
| AN02121001 | | N6-beta-Aspartyl-Lysine |
| PR03487000 | | N7'-Acetyl-Cysteinyldopa |
| AN01117001 | C01029 | N8-Acetyl-spermidine |
| AN02207000 | C06469 | Neuraminic acid |
| AN00318001 | C00253 | Nicotinic acid |
| BM03780000 | C17355 | Nocardicin G |
| AN02772000 | C01682 | Nopaline |
| AN03865000 | | Norcholic acid |
| ED02962000 | | Norfloxacin |
| AN02336000 | | Norophthalmic acid |
| AN00814003 | | Norsalsolinol |
| BM05032000 | C12473 | Novclobiocin 104 |
| AN00754002 | C01077 | O-Acetyl-L-homoserine |
| AN00433003 | | O-Methyl-L-threonine |
| AN01087000 | C01005 | O-Phospho-L-serine |
| AN01560000 | C01118 | O-Succinyl-L-homoserine |
| AN02912000 | | Octadecanedioic acid |
| AN02541000 | C21016 | Ophthalmic acid |
| AN00414000 | C00036 | Oxaloacetic acid |
| AN01159000 | C05379 | Oxalosuccinic acid |
| AN01565000 | C00864 | Pantothenic acid |
| BM00966008 | C06033 | Parapyruvic acid |
| AN02406001 | | Phenylalanyl-Aspartic acid |
| AN02644001 | | Phenylalanyl-Methionine |
| AN02198001 | | Phenylalanyl-Threonine |
| AN00619001 | C02137 | Phenylglyoxylic acid |
| AN00793004 | C00166 | Phenylpyruvic acid |
| AN02760000 | | Pimelylcarnitine |
| AN03880000 | C18044 | Pregnenolone sulfate |
| AN01654002 | C00254 | Prephenic acid |
| AN01860002 | | Prolyl-Gamma-glutamic acid |
| AN01860001 | | Prolyl-Glutamine |
| AN01684000 | | Prolyl-Hydroxyproline |
| AN01688002 | | Prolyl-Isoleucine |
| AN00406010 | | Propionylglycine |
| AN03167006 | C05954 | Prostaglandin B2 |
| AN03196010 | | Prostaglandin C1(1-) |
| AN03167005 | C05955 | Prostaglandin C2 |
| AN03427007 | C00696 | Prostaglandin D2 |
| AN03427004 | C00584 | Prostaglandin E2 |
| BM02625000 | C00844 | Prunasin |
| AN03162000 | C20082 | Pseudaminic acid |
| AN00745000 | | Putreanine |
| AN00122000 | C00134 | Putrescine |
| AN00863000 | C00534 | Pyridoxamine |
| AN01932000 | C00647 | Pyridoxamine phosphate |
| PR01947002 | | Pyridoxine O-sulfate |
| AN01948000 | C00627 | Pyridoxine phosphate |

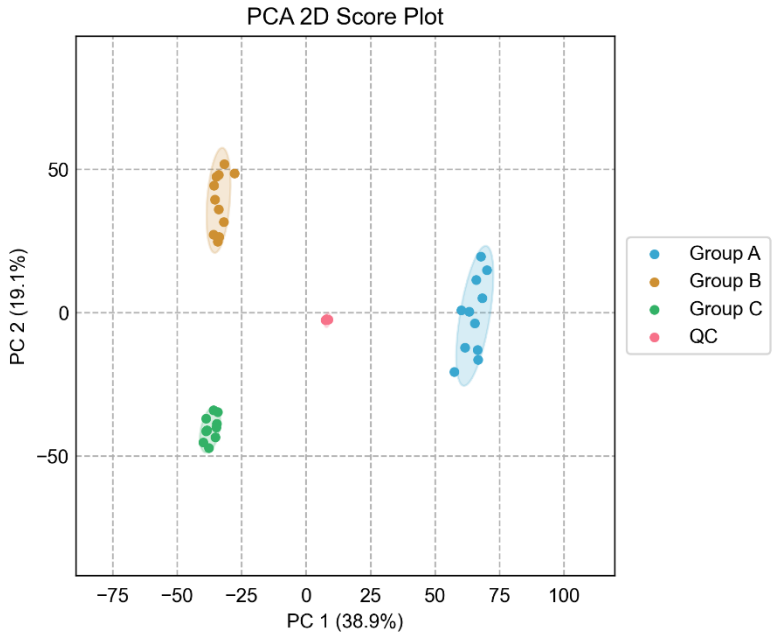
| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| AN01599000 | C02587 | Pyrimidodiazepine |
| AN01157002 | | Pyrocatechol sulfate |
| AN02734000 | | Pyrogallol-2-O-glucuronide |
| BM00058000 | | Pyrrolidine |
| AN00596001 | C17268 | Pyruvophenone |
| BM00227001 | C01751 | Resorcinol |
| AN03521010 | C01850 | Rosmarinic acid |
| AN03771000 | C00021 | S-Adenosyl-L-homocysteine |
| AN03901000 | C00019 | S-Adenosyl-L-methionine |
| AN03446000 | C01137 | S-Adenosylmethioninamine |
| AN01786000 | | S-Cysteinosuccinic acid |
| AN04120000 | C05526 | S-Glutathionyl-L-cysteine |
| AN02206000 | C03539 | S-Ribosyl-L-homocysteine |
| AN01301000 | C05824 | S-Sulfo-L-cysteine |
| AN02354000 | C00449 | Saccharopine |
| BM00311002 | C06202 | Salicylaldehyde |
| AN02707000 | C06046 | Salidroside |
| AN01792000 | | Salsoline-1-carboxylic acid |
| AN01623000 | | Salsolinol 1-carboxylic acid |
| AN01544004 | | Serinyl-Hydroxyproline |
| PR03420000 | | Serotonin O-glucuronide |
| AN01563001 | | Seryl-Asparagine |
| AN01378000 | | Seryl-Threonine |
| AN02223000 | | Seryl-Tyrosine |
| AN01735000 | | Spermic acid 2 |
| AN02358000 | C16300 | Stearidonic acid |
| AN03276000 | | Stearoylglycine |
| BM03284000 | C01121 | Streptidine 6-phosphate |
| AN01326001 | | Symmetric dimethylarginine |
| AN04966000 | C09332 | THF-L-glutamic acid |
| BM01757000 | C20913 | Tabtoxin biosynthesis intermediate 3 |
| BM01168004 | C20914 | Tabtoxin biosynthesis intermediate 4 |
| BM02567000 | C20915 | Tabtoxin biosynthesis intermediate 5 |
| BM01130002 | C20918 | Tabtoxinine-beta-lactam |
| BM01130003 | C20920 | Tabtoxinine-delta-lactam |
| BM00818004 | C06337 | Terephthalic acid |
| AN03582000 | | Tetrahydropentoxyline |
| AN01924001 | | Threoninyl-Glutamine |
| AN02050002 | | Threoninyl-Histidine |
| AN02198002 | | Threoninyl-Phenylalanine |
| AN01378001 | | Threoninyl-Serine |
| AN01589001 | | Threoninyl-Threonine |
| AN03641000 | C05963 | Thromboxane B2 |
| AN01849000 | C00214 | Thymidine |
| AN00708001 | | Tiglylglycine |
| AN01465000 | C16309 | Traumatin |
| AN02725001 | | Tryptophyl-Proline |
| AN02887000 | C03033 | Tyramine O-glucuronide |
| AN01996003 | | Tyrosyl-Alanine |
| AN03079000 | | Tyrosyl-Methionine sulfoxide |
| AN02223001 | | Tyrosyl-Serine |
| AN02430001 | | Tyrosyl-Threonine |
| AN05145000 | C20359 | UDP-2-acetamido-3-amino-2,3-dideoxy-alpha-D-glucuronic acid |
| AN04992000 | C00167 | UDP-glucuronic acid |
| AN01730004 | | Valyl-Aspartic acid |
| AN01711001 | | Valyl-Hydroxyproline |
| AN01714002 | | Valyl-Isoleucine |
| AN01892001 | | Valyl-Lysine |
| AN01432001 | | Vanilpyruvic acid |
| AN00536000 | | Vinylacetylglycine |
| BM03980004 | C17650 | Vulpecholic acid |
| AN02931009 | C16679 | all-trans-18-Hydroxyretinoic acid |
| BM00055001 | C05714 | alpha-Aminopropiononitrile |
| BM04110000 | C17651 | alpha-Phocaecholic acid |
| AN01534003 | C05341 | beta-Alanyl-Lysine |
| AN01173000 | | beta-Damascenone |
| BM00525003 | C06603 | cis,cis-4-Hydroxymuconic semialdehyde |

| NovaMT Library No. | External Identifier | Compound |
|---|---|---|
| BM01315000 | C20581 | cis-(Homo)2-aconitic acid |
| BM01375004 | C14092 | cis-1,2-Dihydroxy-1,2-dihydro-8-carboxynaphthalene |
| BM00892002 | C06729 | cis-1,2-Dihydroxy-4-methylcyclohexa-3,5-diene-1-carboxylic acid |
| BM01105002 | C14112 | cis-2-Carboxycyclohexyl-acetic acid |
| AN01052012 | C12622 | cis-3-(3-Carboxyethenyl)-3,5-cyclohexadiene-1,2-diol |
| AN01079003 | C11588 | cis-3-(Carboxy-ethyl)-3,5-cyclo-hexadiene-1,2-diol |
| BM00499000 | C04431 | cis-4-Carboxymethylenebut-2-en-4-olide |
| EF00898003 | | cis-4-Decenoic acid |
| BM00252000 | C07091 | cis-Acetylacrylic acid |
| AN01019008 | | cis-Caffeic acid |
| AN04001000 | C00206 | dADP |
| BM00373003 | C05715 | gamma-Amino-gamma-cyanobutanoic acid |
| AN00189003 | C00334 | gamma-Aminobutyric acid |
| AN02758002 | | gamma-Glutamyl-Arginine |
| AN01346001 | | gamma-Glutamyl-Glycine |
| AN02608000 | | gamma-Glutamyl-Phenylalanine |
| AN01757008 | | gamma-Glutamyl-Serine |
| AN01936002 | | gamma-Glutamyl-Threonine |
| BM01281000 | C06114 | gamma-Glutamyl-beta-aminopropiononitrile |
| BM01857001 | C05711 | gamma-Glutamyl-beta-cyanoalanine |
| AN01516000 | C15700 | gamma-Glutamyl-gamma-aminobutyraldehyde |
| AN02339003 | | gamma-Glutamyllysine |
| BM02198000 | C20926 | gamma-Glutamyltyramine |
| BM00460000 | C07211 | m-Methylbenzoic acid |
| BM00630000 | C06576 | p-Cumic alcohol |
| AN01417001 | C05596 | p-Hydroxyphenylacetylglycine |
| AN00847001 | C04548 | p-Synephrine |
| BM00299003 | C06758 | p-Tolualdehyde |
| AN01496000 | C01233 | sn-Glycero-3-phosphoethanolamine |
| AN01019003 | C12623 | trans-2,3-Dihydroxycinnamic acid |
| AN00414002 | C03548 | trans-2,3-Epoxysuccinic acid |
| BM00652032 | C11942 | trans-2-Methyl-5-isopropylhexa-2,5-dienal |

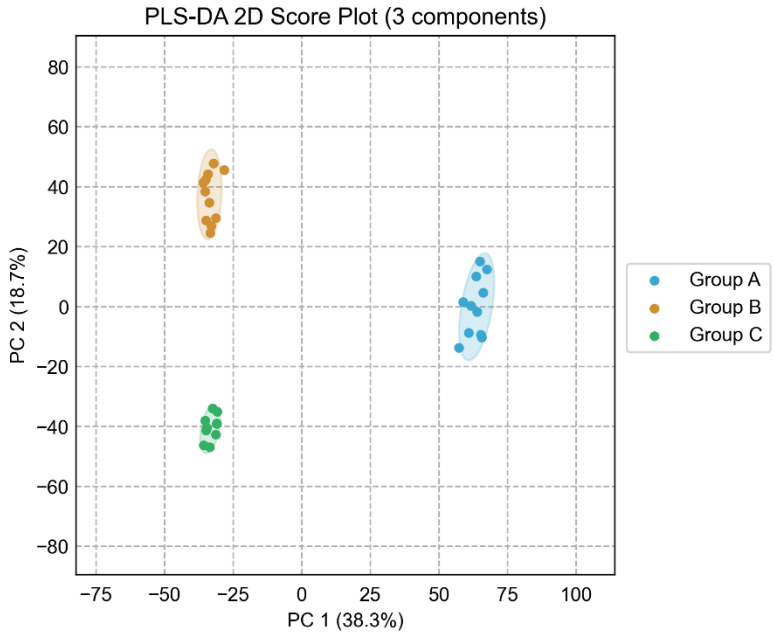
### 3.4 Multivariate Analysis

#### 3.4.1 Comparison between 'Group A', 'Group B', and 'Group C' groups

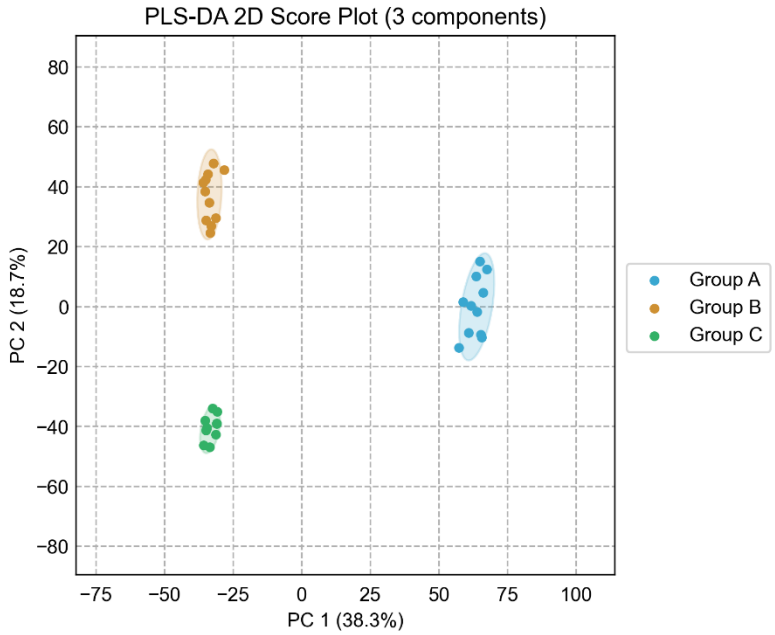
Principle component analysis (PCA) 2D scores plot (with QC) is shown below. .



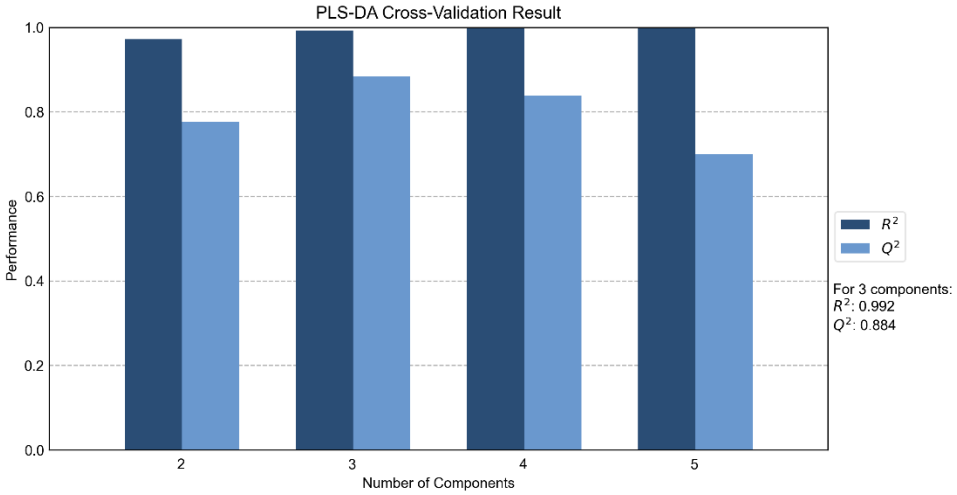

Principle component analysis (PCA) 2D scores plot (without QC) is shown below.



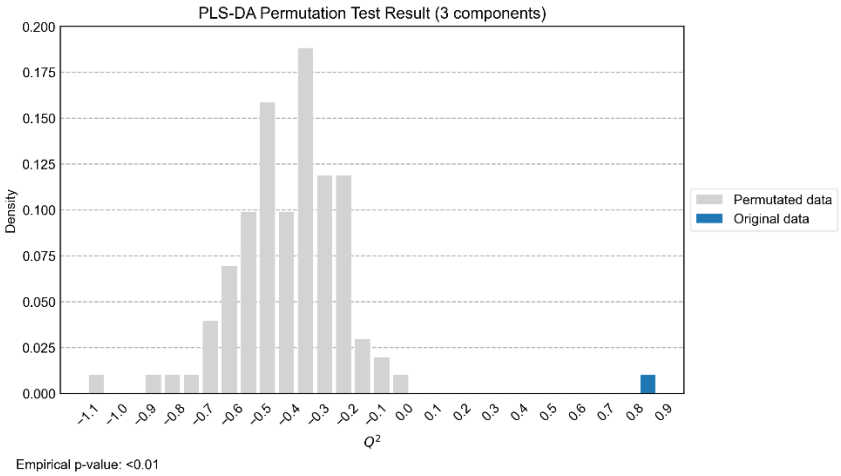
Partial least squares discriminant analysis (PLS-DA) scores plot (without QC) is below.



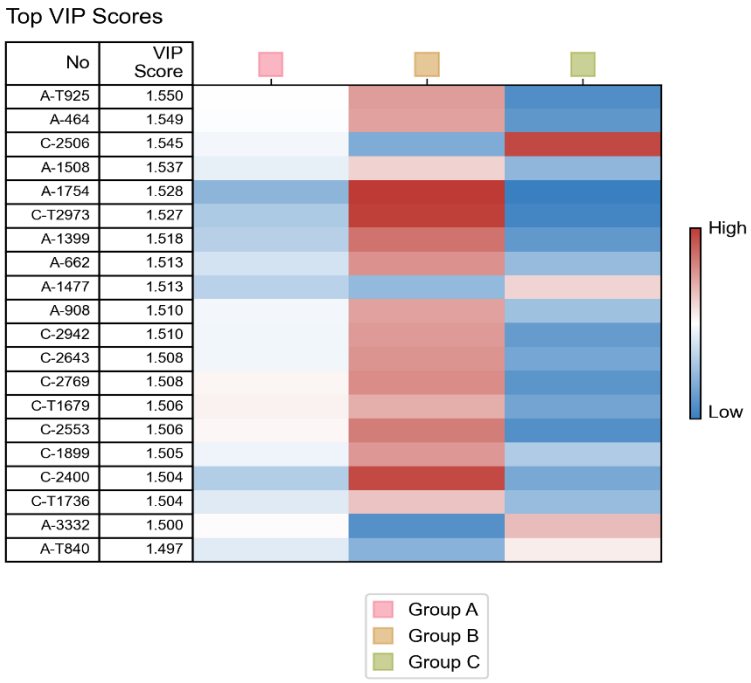

PLS-DA cross validation results are shown below ($R^2$=1.000, $Q^2$=0.294).



PLS-DA permutation test results are shown below. Empirical p-value: <0.01

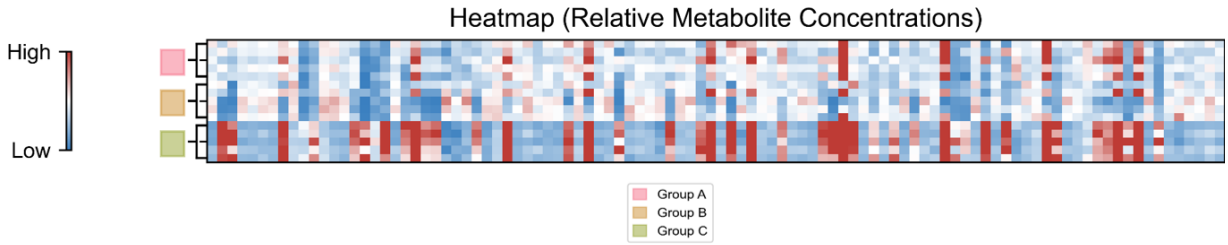



PLS-DA VIP Scores Heatmap is shown below.

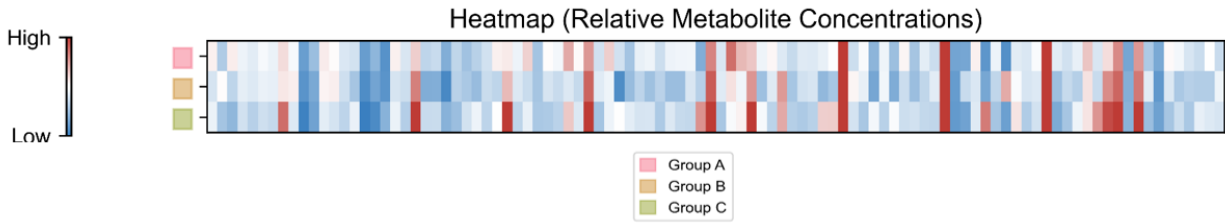



| No | VIP Score |
|---|---|
| A-T925 | 1.550 |
| A-464 | 1.549 |
| C-2506 | 1.545 |
| A-1508 | 1.537 |
| A-1754 | 1.528 |
| C-T2973 | 1.527 |
| A-1399 | 1.518 |
| A-662 | 1.513 |
| A-1477 | 1.513 |
| A-908 | 1.510 |
| C-2942 | 1.510 |
| C-2643 | 1.508 |
| C-2769 | 1.508 |
| C-T1679 | 1.506 |
| C-2553 | 1.506 |
| C-1899 | 1.505 |
| C-2400 | 1.504 |
| C-T1736 | 1.504 |
| A-3332 | 1.500 |
| A-T840 | 1.497 |

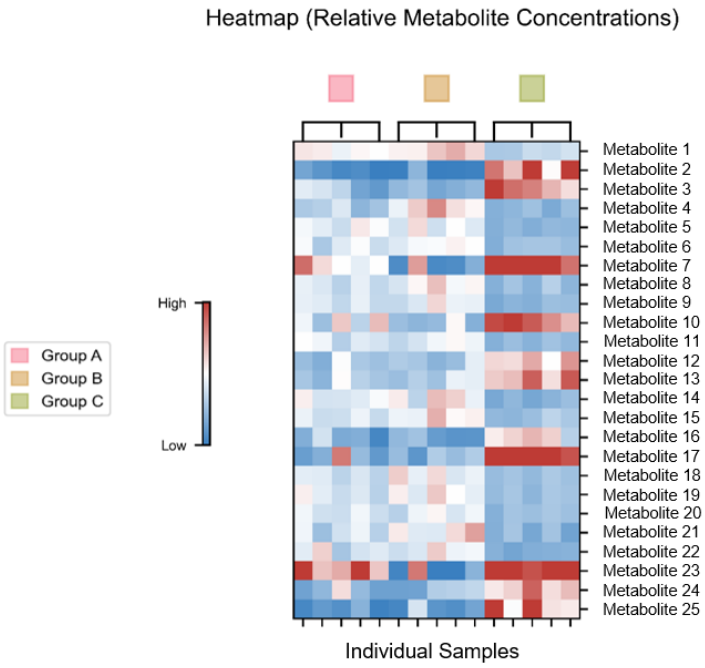
Heatmap (without QC) is shown below. Data for every sample is displayed, showing the top 100 high-confidence identified metabolites ranked by p-value.



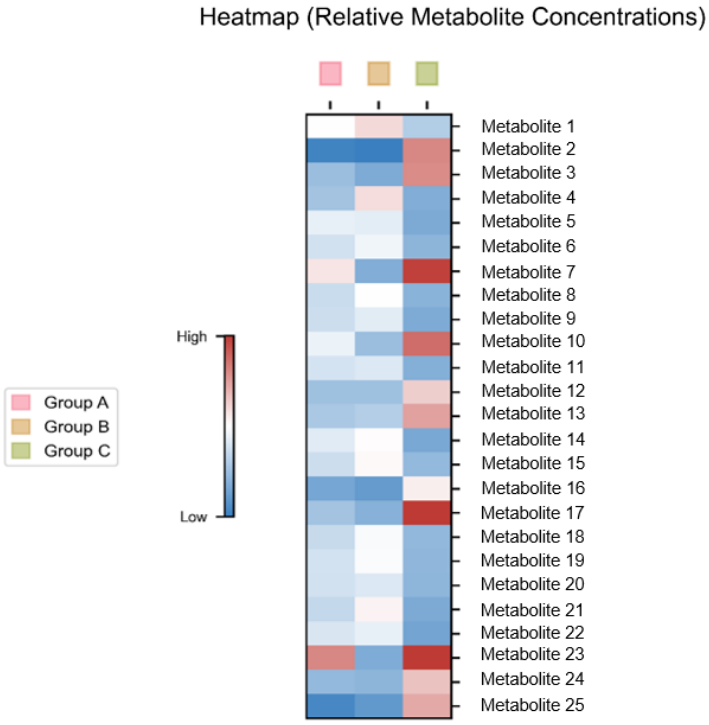

Heatmap (without QC) is shown below. Data for the average of each group is displayed, showing the top 100 high-confidence identified metabolites ranked by p-value.



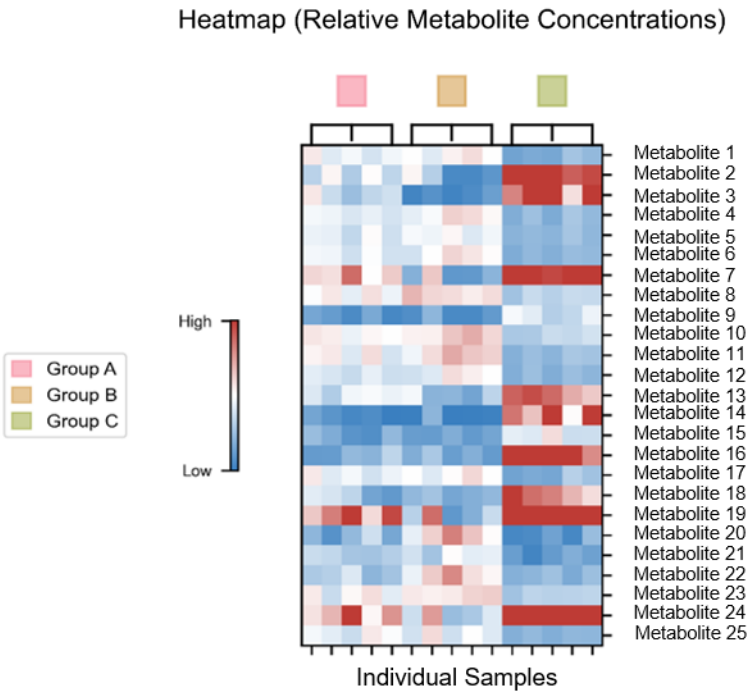
Heatmap (without QC) is show below. Data for every sample is displayed, showing the top 25 Tier 1 and Tier 2 identified metabolites ranked by p-value.



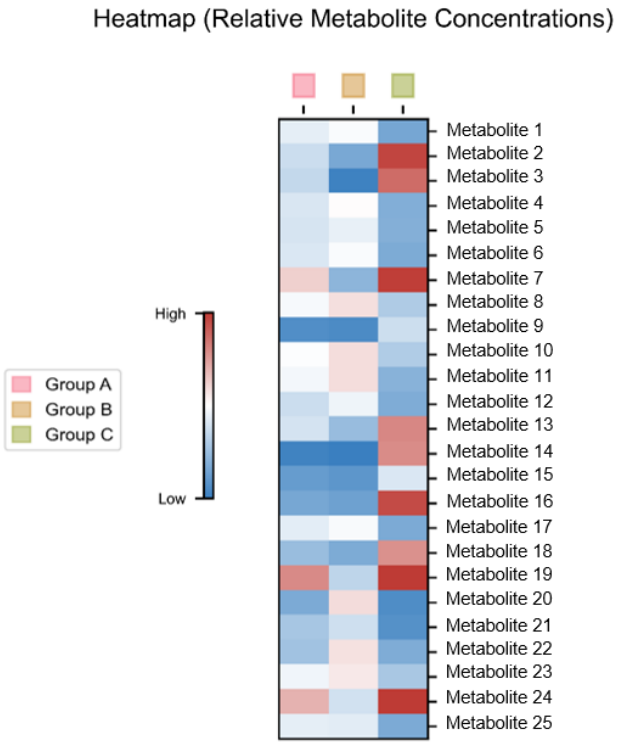

Heatmap (without QC) is shown below. Data for the average of each group is displayed, showing the top 25 Tier 1 and Tier 2 identified metabolites ranked by p-value.



Heatmap (without QC) is show below. Data for every sample is displayed, showing the top 25 Tier 1, Tier 2, and Tier 3 identified metabolites ranked by p-value.




Heatmap (without QC) is shown below. Data for the average of each group is displayed, showing the top 25 Tier 1, Tier 2, and Tier 3 identified metabolites ranked by p-value.



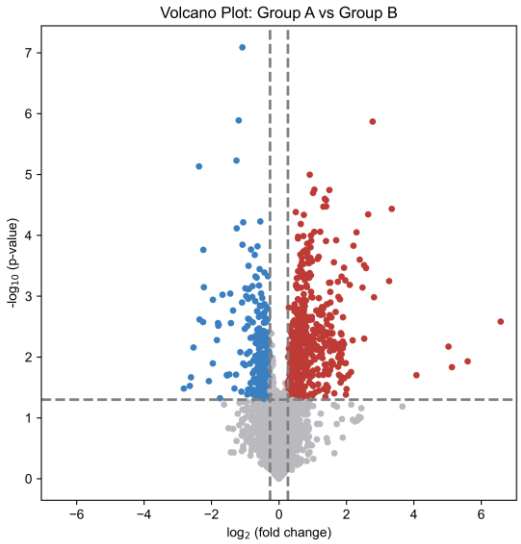
## 3.5 Univariate Analysis

### 3.5.1 Comparison between 'Group A' group and 'Group B' group

Volcano plot was constructed by plotting the fold change (FC) of each metabolite against p-value. The fold change was calculated as Mean(Group A) / Mean(Group B). The results of pathway/panel-related metabolites identified in tier 1 and tier 2 were shown in Supplemental Table 2.

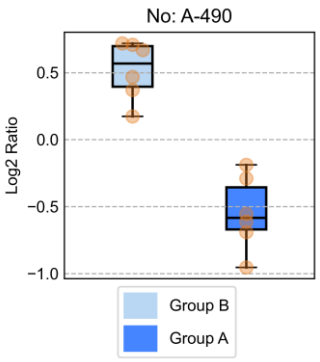
When using FC > 1.2 or < 0.83, p-value < 0.05, and q-value (or FDR-adjusted p-value) < 0.25 as criteria, the analysis showed that 1346 peak pairs with FC > 1.2, q-value < 0.25 and 1302 peak pairs with FC < 0.83, q-value < 0.25 (corresponding q-value threshold is 0.22).

Without considering FDR adjustment and using FC > 1.2 or < 0.83 and p-value < 0.05 as criteria, the analysis showed that 520 peak pairs with FC > 1.2, p-value < 0.05 (in red) and 333 peak pairs with FC < 0.83, p-value < 0.05 (in blue) (corresponding Storey's q-value threshold is 0.22). Among them, 67 peak pairs can be positively identified in tier 1 using CIL Library, 116 peak pairs can be high-confidence putative identified in tier 2 using LI Library and 600 peak pairs can be putatively identified in tier 3 using MCID library (Supplemental Table 3a).

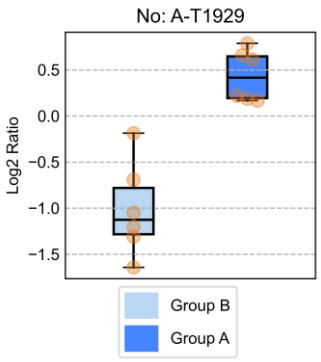



Shown below are the box plots of two identified significantly changed metabolites in tier 1, working as examples of metabolite concentration changes.

**Ribothymidine**
Fold Change = 0.48, p-value = 6.1e-05



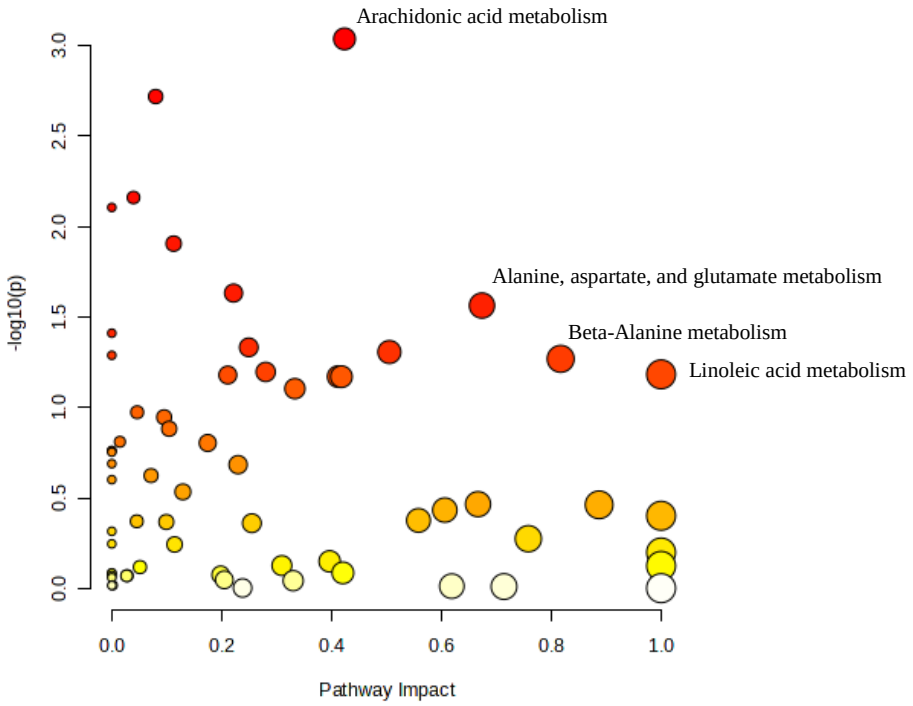

**Asparaginyl-Histidine**
Fold Change = 2.633, p-value = 0.00012



## 3.6 Pathway Analysis

### 3.6.1 Comparison between 'Group A' group and 'Group B' group (in Homo sapiens (KEGG) library)

Metabolites that were identified in tier 1 and tier 2 as high-confidence results were used for pathway analysis. The pathway analysis was performed using Global Test as enrichment analysis and Relative-betweeness Centrality as topology analysis in MetaboAnalyst (www.metaboanalyst.ca). The figure below shows the scatter plot of pathway analysis.




The table below shows the detailed information for each pathway.

| Pathway Name | Total Cmpd | Hits | Raw p-value | Holm adjust p-value | FDR adjusted p-value | Impact |
|---|---|---|---|---|---|---|
| Arachidonic acid metabolism | 44 | 15 | 0.000916 | 0.058622 | 0.058622 | 0.42364 |
| Glycerophospholipid metabolism | 36 | 4 | 0.001908 | 0.1202 | 0.061052 | 0.07982 |
| Glycosylphosphatidylinositol (GPI)-anchor biosynthesis | 32 | 2 | 0.006901 | 0.42788 | 0.12533 | 0.03947 |
| Ether lipid metabolism | 20 | 1 | 0.007833 | 0.47783 | 0.12533 | 0 |
| Glycolysis or Gluconeogenesis | 26 | 4 | 0.012414 | 0.74487 | 0.1589 | 0.11262 |
| Retinol metabolism | 17 | 4 | 0.023302 | 1 | 0.24855 | 0.22164 |
| Alanine, aspartate and glutamate metabolism | 28 | 17 | 0.027319 | 1 | 0.24978 | 0.67388 |
| Biosynthesis of unsaturated fatty acids | 36 | 8 | 0.038829 | 1 | 0.25436 | 0 |
| Pyruvate metabolism | 23 | 7 | 0.04651 | 1 | 0.25436 | 0.24932 |
| Arginine biosynthesis | 14 | 9 | 0.049356 | 1 | 0.25436 | 0.50532 |
| Nicotinate and nicotinamide metabolism | 15 | 3 | 0.051462 | 1 | 0.25436 | 0 |
| beta-Alanine metabolism | 21 | 10 | 0.053847 | 1 | 0.25436 | 0.81717 |
| Lysine degradation | 30 | 10 | 0.063605 | 1 | 0.25436 | 0.28015 |
| Linoleic acid metabolism | 5 | 2 | 0.065575 | 1 | 0.25436 | 1 |
| Pyrimidine metabolism | 39 | 9 | 0.066143 | 1 | 0.25436 | 0.21118 |
| Citrate cycle (TCA cycle) | 20 | 8 | 0.067479 | 1 | 0.25436 | 0.41209 |
| Histidine metabolism | 16 | 6 | 0.067564 | 1 | 0.25436 | 0.41802 |
| alpha-Linolenic acid metabolism | 13 | 2 | 0.078695 | 1 | 0.2798 | 0.33333 |
| Propanoate metabolism | 22 | 6 | 0.10626 | 1 | 0.35792 | 0.04616 |
| Pantothenate and CoA biosynthesis | 20 | 9 | 0.11316 | 1 | 0.36211 | 0.09524 |
| Sphingolipid metabolism | 32 | 4 | 0.13111 | 1 | 0.39957 | 0.10444 |

| Pathway Name | Total Cmpd | Hits | Raw p-value | Holm adjust p-value | FDR adjusted p-value | Impact |
|---|---|---|---|---|---|---|
| Fatty acid biosynthesis | 47 | 5 | 0.15477 | 1 | 0.43462 | 0.01473 |
| Butanoate metabolism | 15 | 5 | 0.15714 | 1 | 0.43462 | 0.17461 |
| Fatty acid elongation | 39 | 1 | 0.17316 | 1 | 0.43462 | 0 |
| Fatty acid degradation | 39 | 1 | 0.17316 | 1 | 0.43462 | 0 |
| Biotin metabolism | 10 | 1 | 0.17656 | 1 | 0.43462 | 0 |
| Nitrogen metabolism | 6 | 1 | 0.20463 | 1 | 0.47348 | 0 |
| Purine metabolism | 70 | 12 | 0.20715 | 1 | 0.47348 | 0.2299 |
| Valine, leucine and isoleucine degradation | 40 | 8 | 0.23803 | 1 | 0.5253 | 0.07143 |
| D-Amino acid metabolism | 15 | 7 | 0.25069 | 1 | 0.5348 | 0 |
| Inositol phosphate metabolism | 30 | 2 | 0.29289 | 1 | 0.60468 | 0.12939 |
| Vitamin B6 metabolism | 9 | 4 | 0.34249 | 1 | 0.66971 | 0.66667 |
| Arginine and proline metabolism | 36 | 21 | 0.34532 | 1 | 0.66971 | 0.8872 |
| Tryptophan metabolism | 41 | 21 | 0.36934 | 1 | 0.69523 | 0.60628 |
| Taurine and hypotaurine metabolism | 8 | 6 | 0.39703 | 1 | 0.71616 | 1 |
| Glyoxylate and dicarboxylate metabolism | 32 | 11 | 0.42121 | 1 | 0.71616 | 0.55834 |
| Ubiquinone and other terpenoid-quinone biosynthesis | 19 | 4 | 0.42597 | 1 | 0.71616 | 0.04545 |
| Folate biosynthesis | 27 | 4 | 0.42964 | 1 | 0.71616 | 0.09924 |
| Amino sugar and nucleotide sugar metabolism | 42 | 9 | 0.43641 | 1 | 0.71616 | 0.25496 |
| Selenocompound metabolism | 20 | 1 | 0.48384 | 1 | 0.77415 | 0 |
| Cysteine and methionine metabolism | 33 | 18 | 0.53181 | 1 | 0.83015 | 0.75832 |
| Drug metabolism - cytochrome P450 | 55 | 1 | 0.56781 | 1 | 0.85149 | 0 |
| Terpenoid backbone biosynthesis | 18 | 2 | 0.57209 | 1 | 0.85149 | 0.11429 |
| Phosphonate and phosphinate metabolism | 6 | 2 | 0.63356 | 1 | 0.92155 | 1 |
| Glutathione metabolism | 28 | 8 | 0.70944 | 1 | 0.99228 | 0.39657 |
| One carbon pool by folate | 26 | 9 | 0.74843 | 1 | 0.99228 | 0.3096 |
| Phenylalanine metabolism | 8 | 8 | 0.75152 | 1 | 0.99228 | 1 |
| Primary bile acid biosynthesis | 46 | 6 | 0.76316 | 1 | 0.99228 | 0.05127 |
| Starch and sucrose metabolism | 18 | 1 | 0.82148 | 1 | 0.99228 | 0.4207 |
| Neomycin, kanamycin and gentamicin biosynthesis | 2 | 1 | 0.82148 | 1 | 0.99228 | 0 |
| Pentose phosphate pathway | 23 | 1 | 0.82462 | 1 | 0.99228 | 0 |
| Galactose metabolism | 27 | 5 | 0.84195 | 1 | 0.99228 | 0.19819 |
| Thiamine metabolism | 7 | 1 | 0.8513 | 1 | 0.99228 | 0 |
| Porphyrin metabolism | 31 | 2 | 0.85146 | 1 | 0.99228 | 0.02795 |
| Steroid hormone biosynthesis | 87 | 3 | 0.85274 | 1 | 0.99228 | 0.02707 |
| Fructose and mannose metabolism | 20 | 3 | 0.87421 | 1 | 0.99831 | 0 |
| Pentose and glucuronate interconversions | 19 | 3 | 0.89773 | 1 | 0.99831 | 0.20482 |
| Glycerolipid metabolism | 16 | 2 | 0.9076 | 1 | 0.99831 | 0.33022 |
| Lipoic acid metabolism | 28 | 2 | 0.96193 | 1 | 0.99831 | 0.0017 |
| Valine, leucine and isoleucine biosynthesis | 8 | 7 | 0.96384 | 1 | 0.99831 | 0 |
| Tyrosine metabolism | 42 | 29 | 0.97261 | 1 | 0.99831 | 0.61893 |
| Glycine, serine and threonine metabolism | 33 | 16 | 0.97758 | 1 | 0.99831 | 0.71399 |
| Ascorbate and aldarate metabolism | 9 | 3 | 0.99562 | 1 | 0.99831 | 0.2381 |
| Phenylalanine, tyrosine and tryptophan biosynthesis | 4 | 4 | 0.99831 | 1 | 0.99831 | 1 |

The profile suggested a perturbation in several pathways such as amino acid metabolism, and other pathways as summarized in the above table. The importance and biological functions of common metabolic pathways are listed in the references shown in the Appendix A in this report. The table that can be directly used in the Pathway Analysis Module in MetaboAnalyst (www.metaboanalyst.ca) was included with this report.

## 4 Conclusions

1) LC-MS data from 34 samples were processed. All data passed quality checks.
2) An average of 5707 ± 30 peak pairs per sample were detected.
3) Three-tier ID approach was used to perform metabolite identification. 5421 peak pairs were positively identified or putatively matched. Among them, 378 peak pairs were positively identified in tier 1 (CIL Library); 893 peak pairs were putatively identified with high-confidence in tier 2 (LI Library); 1124, 2311, and 715 peak pairs were matched in the zero-, one-, and two-reaction libraries, respectively.
4) Principal component analysis and partial least squares discriminant analysis as multivariate analysis tool, and volcano plot as univariate analysis tool, were used to analyze and view the data set.
5) Pathway analysis was performed to investigate the pathway perturbations.

# 5 Appendix A. Biological Functions of Common Metabolic Pathways

| Pathway Name | Biological Roles | References |
|---|---|---|
| Glycolysis and Gluconeogenesis | Anaerobic component of cellular respiration that occurs in the cytosol of cells. Highly regulated pathway that catabolizes glucose and other hexoses to produce energy directly as ATP, and indirectly as pyruvate and NADH. Gluconeogenesis allows non-carbohydrate metabolites to replenish glucose [1]<br>• In the "Warburg effect," glycolysis is dysregulated in tumor cells despite aerobic conditions, displacing glucose from healthy cells [2] | [1] Wünschiers et al. 2012<br><br>[2] Ganapathy-Kanniappan 2018 |
| Tricarboxylic acid cycle (Krebs cycle, citrate cycle) | Aerobic component of cellular respiration that in eukaryotes, occurs in the mitochondrial matrices of cells. Plays a central catabolic role by oxidizing acetyl-CoA derived from carbohydrate, fatty acid, and amino acid sources to produce energy directly as ATP and indirectly as oxidative phosphorylation substrates NADH and $FADH_2$ [1]<br>• In immune cells, functions in anti-inflammatory signalling via itaconate production from cis-aconitate [3] | [1] Wünschiers et al. 2012<br><br>[3] Williams and O'Neill 2018 |
| Pentose phosphate pathway | Pathway branching from glycolysis that in the oxidative phase, produces NADPH, an anabolic cofactor that functions in fatty acid, steroid, and nucleotide biosynthesis, and the light reactions in plants [4]. The non-oxidative phase notably produces ribose-5-phosphate, the precursor to nucleic acids [1, 4]<br>• 5-30% Of glucose is directed here, with higher rates occurring in erythrocytes and lipid-producing tissues [5]<br>• Ameliorates oxidative stress via NADPH, which reduces glutathione into its antioxidant form [1] | [1] Wünschiers et al. 2012<br><br>[4] Ge et al. 2020<br><br>[5] Riganti et al. 2012 |
| Pentose and glucuronate interconversions | • Helps form the extracellular matrix via production of glucuronate, a component of proteoglycans [1]<br>• In plants, helps form cell walls via production of pentoses D-xylose and L-arabinose [1] | [1] Wünschiers et al. 2012 |
| Fructose and mannose metabolism | • Provides substrates for energy production in glycolysis via conversions to glyceraldehyde-3-phosphate [1]<br>• Unregulated fructose metabolism in the liver expends ATP and increases the by-product uric acid as hepatofructokinase produces fructose-1-phosphate [6]<br>• Produces GDP mannose, a precursor to the N-glycans that facilitate protein folding [7] | [1] Wünschiers et al. 2012<br><br>[6] Helsley et al. 2020<br><br>[7] Sharma et al. 2014 |
| Galactose metabolism | • Provides substrate for energy production in glycolysis via conversion to glucose-6-phosphate [1]<br>• Inhibit glycolysis if galactose-1-phosphate accumulates [8] | [1] Wünschiers et al. 2012<br><br>[8] Liu et al. 2000 |
| Ascorbate and aldarate metabolism | • In plants and some other organisms, allows for the biosynthesis of ascorbate (vitamin C), a potent antioxidant [1] | [1] Wünschiers 2012 |
| Fatty acid biosynthesis | Use of acetyl-CoA as a principal substrate for the synthesis of fatty acids eventually involved in cell structure, energy storage, and signalling [1, 9]<br>• Fatty acids form cell membranes as they are incorporated into the structures of phospholipids, sphingolipids, phosphosphingolipids, and gangliosides [9]<br>• Fatty acids are energy storage molecules that after being converted to fatty acyl-CoA, undergo beta-oxidation to yield aerobic respiration substrates $FADH_2$, NADH, and acetyl-CoA [1, 9]<br>• Fatty acids function as signal transduction molecules that help regulate metabolism [10] | [1] Wünschiers 2012<br><br>[9] de Carvalho and Caramujo 2018<br><br>[10] Papackova and Cahova 2015 |
| Fatty acid elongation | Elongation of fatty acid acyl chains two carbons at a time, conferring new functional properties [9, 11]<br>• Can produce myristic acid (1-tetradecanoic acid), an intracellular signalling molecule, from shorter fatty acids [12]<br>• Can produce long-chain fatty acids that in plants, are used to synthesize protective structures [15] | [9] de Carvalho and Caramujo 2018<br><br>[11] Jump 2009<br><br>[12] Farazi et al. 2001<br><br>[15] Mazurek et al. 2017 |
| Fatty acid degradation | Involves beta-oxidation. Shortening of fatty acid acyl chains two carbons at a time, producing the aerobic respiration substrates $FADH_2$, NADH, and acetyl-CoA [1, 9]<br>• Helps meet the energy demands of cardiac and skeletal muscle, which require the high ATP yield of aerobic respiration [1, 13] | [1] Wünschiers 2012<br><br>[9] de Carvalho and Caramujo 2018 |

| Pathway Name | Biological Roles | References |
|---|---|---|
| | • Imbalance with fatty acid uptake by muscles results in the accumulation of intramuscular lipids, which can cause localized insulin resistance [13] | [13] Zhang et al. 2010 |
| Synthesis and degradation of ketone bodies | Pathway branching from fatty acid degradation that occurs mainly in hepatocytes during prolonged periods of fasting. Ketone bodies acetoacetate, beta-hydroxybutyrate, and acetone are water-soluble compounds that provide energy to the brain and other organs by converting to aerobic respiration substrate acetyl-CoA [1, 14]<br>• Meets energy demands when carbohydrates are not available as energy sources via glycolysis. Instead, adipocytes provide fatty acids that are catabolized to form ketone bodies [1, 14]<br>• Beta-hydroxybutyrate acts as a signalling molecule that can promote gene expression by inhibiting class I HDACs [14] | [1] Wünschiers 2012<br>[14] Newman and Verdin 2014 |
| Cutin, suberine and wax biosynthesis | Biosynthesis of fatty acid polymers integral to the structure of specialized tissues in plants and other organisms that function in protection from the environment [15, 16, 17]<br>• Cutin aids in protection as it forms the cell wall structures in the plant epidermis that create an extracellular cuticle layer [15]<br>• Suberin aids in stem protection and wound sealing as it forms the cell wall structures of the periderm [16]<br>• Wax esters have diverse functions such as water retention and buoyancy in plants and arthropods [17] | [15] Mazurek et al. 2017<br>[16] Graça 2015<br>[17] Patel et al. 2001 |
| Steroid Biosynthesis | Biosynthesis of steroids from the terpenoid precursor squalene [1]. Produces cholesterol, which mediates membrane fluidity and permeability, and is a substrate for bile acid and steroid hormone biosynthesis [1, 18]<br>• In the alternative pathway of plants, squalene converts to cycloartenol, which gives rise to the brassinosteroid phytohormones involved in growth, development, and abiotic stress responses [19] | [1] Wünschiers 2012<br>[18] Yang et al. 2016<br>[19] Li et al. 2021 |
| Primary bile acid biosynthesis | Cholesterol-derived biosynthesis of bile acids, the major component of liver bile that aids in the digestion of lipids via emulsification. The classic (neutral) pathway occurs in hepatocytes while the alternative (acidic) pathway occurs in all tissues [1]<br>• Bile acids function in toxin secretion, cholesterol homeostasis, and metabolic signalling [1, 20] | [1] Wünschiers 2012<br>[20] Vaz and Ferdinandusse 2017 |
| Ubiquinone and other terpenoid-quinone biosynthesis | Biosynthesis of quinone cofactors involved in energy production, or injury prevention and repair [1, 21]<br>• Ubiquinone facilitates ATP production as an electron carrier in the electron transport chain of aerobic respiration [1]<br>• Menaquinone increases bone density by inhibiting osteoclast activity [21]<br>• Phylloquinone (vitamin $K_1$) is a cofactor involved in blood coagulation [1] | [1] Wünschiers 2012<br>[21] Yamaguchi et al. 2003 |
| Steroid hormone biosynthesis | Cholesterol-derived biosynthesis of corticosteroids (glucocorticoids and mineralocorticoids) and sex steroids (androgens, estrogens, and progestogens) involved in homeostasis and sexual development [1, 22]<br>• Glucocorticoids such as cortisol diversely affect metabolism by increasing blood glucose, hepatic protein synthesis, and fatty acid catabolism, often in response to stress. They also suppress the immune system and inflammation [1, 22]<br>• Mineralocorticoids such as aldosterone function to regulate salt and water balance by promoting sodium reabsorption at the kidneys. This causes water reabsorption, and thus an increase in blood volume and pressure [22]<br>• Androgens such as testosterone develop male secondary sexual characteristics and masculinizing features in general [22]<br>• Estrogens such as estradiol develop female primary and secondary sexual characteristics, and promote fat anabolism [1, 22]<br>• Progestogens prepare the body for pregnancy by thickening the uterine lining and developing the breasts for lactation [22] | [1] Wünschiers 2012<br>[22] Holst et al. 2004 |
| Purine metabolism | Biosynthesis, degradation, and interconversions of purines essential to the structure of DNA and RNA, the production of energy, and metabolism as a whole [1, 23] | [1] Wünschiers 2012<br>[23] Yin et al. 2018 |

| Pathway Name | Biological Roles | References |
|---|---|---|
| | • Production of purine derivatives adenine and guanine, nucleobases used in DNA and RNA [1]<br>• Production of the adenosine and guanosine phosphates, which act as crucial metabolic cofactors and signalling molecules [1]<br>• Aberrations in purine metabolism are linked to cancers, with heightened inosine to adenosine ratios observed in tumor cells [23] | |
| Caffeine metabolism | Metabolism of the central nervous system stimulant caffeine, mainly in hepatocytes [24]<br>• Stimulant effects of caffeine diminish as it is metabolized into paraxanthine, its major product [1, 24]<br>• Two of the direct metabolic products of caffeine, theobromine and theophylline, are stimulants that are further metabolized [1, 24]<br>• Anti-inflammatory and lipolytic effects as caffeine and its related metabolites elevate cAMP levels [25] | [1] Wünschiers 2012<br>[24] Cornelis et al. 2016<br>[25] Barcelos et al. 2020 |
| Pyrimidine metabolism | Biosynthesis, degradation, and interconversions of pyrimidines essential to the structure of DNA, RNA, and nucleotide sugars involved in metabolism as a whole [1, 26]<br>• Production of pyrimidine derivatives cytosine, thymine, and uracil, nucleobases used in DNA and RNA [1]<br>• Production of glycosylating nucleotide sugars that facilitate protein and lipid modification, biosynthesis, and detoxifications [26] | [1] Wünschiers 2012<br>[26] Löffler et al. 2005 |
| Glutathione metabolism | • Production and replenishment of reduced-form glutathione, an antioxidant and cytoprotective metabolite [1]<br>• Hemolytic anemia may result from a surplus of oxidized-form glutathione in erythrocytes, due to inadequate NADPH [1] | [1] Wünschiers 2012 |
| Arginine biosynthesis | Biosynthesis of the proteinogenic amino acid arginine, mainly via the intestinal-renal axis [1]<br>• Involves the urea cycle, which eliminates toxic ammonia liberated from amino acid catabolism by converting it to urea for excretion in urine [1]<br>• Arginine is a conditionally essential amino acid as biosynthesis may be inadequate in those with cancer or other pathologies [27] | [1] Wünschiers 2012<br>[27] Rodriguez et al. 2017 |
| Alanine, aspartate and glutamate metabolism | • The alanine cycle allows for the elimination of toxic ammonia and the replenishment of glucose in muscles through alanine interconversion with pyruvate, and transport between skeletal muscle and the liver [1, 28]<br>• Aspartate can be metabolized into signalling molecules such as N-acetyl-aspartate and beta-alanine [1]<br>• Glutamate and its decarboxylation product gamma-aminobutyric acid (GABA) are excitatory and inhibitory neurotransmitters, respectively, that modulate the central nervous system [1]<br>• Aspartate and glutamate metabolism promote cell proliferation by contributing to the production of purines and pyrimidines needed to make DNA and RNA [1, 29, 30]<br>• Aspartate metabolizes into the proteinogenic amino acids glycine, serine, threonine, lysine, and cysteine. Glutamate, as a productive nitrogen donor, also aids in the biosynthesis of proteinogenic amino acids [1, 29, 30] | [1] Wünschiers 2012<br>[28] Felig 1973<br>[29] Alkan et al. 2018<br>[30] Walker and Donk 2015 |
| Glycine, serine and threonine metabolism | • Drives the folate cycle, which promotes DNA and RNA biosynthesis, through the conversion of serine and glycine. Along with the methionine cycle, which promotes purine and polyamine biosynthesis, and methylation reactions, forms “one-carbon metabolism” needed for cell proliferation [1, 32, 34]<br>• Essential to membrane synthesis as serine is a precursor to ceramides, glycerophospholipids, and sphingosines [1]<br>• Helps maintain blood-glucose levels as serine is mainly catabolized to pyruvate, the principal substrate for gluconeogenesis [1]<br>• Promotes muscle performance as glycine aids in the biosynthesis of creatine and thus phosphocreatine, which regenerates muscle ATP [1, 31] | [1] Wünschiers 2012<br>[31] Razak et al. 2017<br>[32] Wang et al. 2013 |

| Pathway Name | Biological Roles | References |
|---|---|---|
| | • Exhibits anti-inflammatory and cytoprotective effects by contributing to glutathione production and decreasing pro-apoptotic events [31, 32] | |
| Cysteine and methionine metabolism | • Links with the folate cycle, which promotes RNA and DNA biosynthesis, to form "one-carbon metabolism" needed for cell proliferation [1, 33, 34]<br>• Methionine converts to *S*-Adenosyl methionine (SAM), a methylating cofactor involved in polyamine biosynthesis and methylation reactions. The methionine cycle and methionine salvage regenerate methionine from SAM reactions [1, 33, 34]<br>• Improves the digestion of lipids as cysteine is a substrate for the biosynthesis of taurine, a bile acid conjugation partner [1]<br>• Helps maintain blood-glucose levels as cysteine catabolizes to pyruvate and favours its entry to gluconeogenesis over the TCA cycle or fatty acid synthesis [1, 35]<br>• Reduces inflammation as cysteine is a substrate for glutathione biosynthesis [1, 35] | [1] Wünschiers 2012<br>[33] Affronti et al. 2020<br>[34] Sanderson et al. 2019<br>[35] Serpa 2020 |
| Valine, leucine and isoleucine degradation | • Regulates leucine and isoleucine levels, which are positively correlated with insulin resistance [36]<br>• Improves muscle performance and hypertrophy by stimulating protein synthesis through cell signalling (primarily by leucine), and inhibiting proteolysis (primarily by branched-chained keto acids and beta-hydroxy-beta-methylbutyrate) [37]<br>• Contributes to energy production and lipid biosynthesis, as valine, leucine, and isoleucine catabolize into CoA substrates [1, 37]<br>• Leucine contributes to energy production in a fasted state by catabolizing to aerobic respiration substrate acetyl-CoA [1] | [1] Wünschiers 2012<br>[36] Zhang et al. 2017<br>[37] Holeček 2018 |
| Valine, leucine and isoleucine biosynthesis | Non-mammalian biosynthesis of the branched-chain proteinogenic amino acids from pyruvate and threonine [1] | [1] Wünschiers 2012 |
| Lysine biosynthesis | Non-mammalian biosynthesis of the proteinogenic amino acid lysine via two mutually exclusive pathways [1, 38]<br>• In plants, bacteria, and lower fungi, the diaminopimelate (DAP) pathway occurs, whereby aspartate is a precursor to lysine and DAP. In bacteria, these are incorporated into cell walls [1, 38]<br>• In higher fungi and euglenoids, the alpha-aminoadipate (AAA) pathway occurs, whereby 2-oxoglutarate is the precursor to lysine [1, 32] | [1] Wünschiers 2012<br>[38] Xu et al. 2006 |
| Lysine degradation | • Aids in fatty acid metabolism by producing carnitine, which shuttles fatty acids to the mitochondria for beta-oxidation [1]<br>• Contributes to energy production in a fasted state by producing aerobic respiration substrate acetyl-CoA [1] | [1] Wünschiers 2012 |
| Arginine and proline metabolism | • Production of nitric oxide (NO), a signalling molecule, from arginine. NO promotes vasodilation, cardiac muscle relaxation, and phagocytic immunity [1, 39, 40]<br>• Production of urea cycle substrates ornithine and citrulline, which enable the conversion of toxic ammonia to urea for excretion in urine [1]<br>• Promotes muscle performance as arginine aids in the biosynthesis of creatine and thus phosphocreatine, which regenerates muscle ATP [1, 41]<br>• Enables cell proliferation via production of the polyamines spermidine and spermine, growth factors that stabilize DNA [1]<br>• Proline cycling increases levels of reactive oxygen species, oxidative phosphorylation, and biomass precursors, implicating it in tumorigenesis and metastasis [42] | [1] Wünschiers 2012<br>[39] Ziolo et al. 2008<br>[40] Gogoi et al. 2016<br>[41] Paddon-Jones et al. 2004<br>[42] Tanner et al. 2019 |
| Histidine metabolism | • Mainly results in the production of glutamate, which promotes neural functioning, cell proliferation, and the production of other amino acids [1, 43]<br>• Production of histamine in mast and tissue cells in response to allergens, causing vasodilation and bronchoconstriction. Histamine also functions as a homeostatic neurotransmitter and aids in digestion by stimulating gastric HCl secretion [1, 43]<br>• Exhibits anti-inflammatory and cytoprotective effects via production of carnosine, which scavenges free radicals and decreases protein glycation. This occurs mostly in skeletal muscle [1, 44] | [1] Wünschiers 2012<br>[43] Holeček 2020<br>[44] Mendelson 2008<br>[45] Brosnan 2020 |

| Pathway Name | Biological Roles | References |
|---|---|---|
| | • Ameliorates DNA damage caused by UV radiation via production of urocanate in the skin [45] | |
| Tyrosine metabolism | • Production of the catecholamines and thyroid hormones that are crucial for stress responses and overall homeostasis [1]<br>• In melanocytes, produces eumelanins responsible for skin pigmentation [1]<br>• Exhibits anti-inflammatory effects through the production of antioxidants such as tocopherols and other anti-inflammatory compounds [46]<br>• Contributes to energy production by forming the 4-hydroxybenzoate structure of coenzyme Q10 [47]<br>• In plants, branches to phenolic secondary metabolic pathways involved in defense and pigmentation [46] | [1] Wünschiers 2012<br>[46] Schenck and Maeda 2018<br>[47] Turunen et al. 2004 |
| Phenylalanine metabolism | • Mainly results in the production of tyrosine and its metabolic products [1]<br>• Aberrant phenylalanine metabolism due to phenylketonuria, a hereditary disorder, can cause a buildup of phenylpyruvate and phenyllactate if dietary phenylalanine is too high. This impairs neuronal development [1]<br>• In plants, branches to phenolic secondary metabolic pathways involved in defense and pigmentation [48] | [1] Wünschiers 2012<br>[48] Tohge et al. 2013 |
| Tryptophan metabolism | • Production of serotonin, a neurotransmitter that functions in the regulation of mood, blood clotting, and smooth muscle in the circulatory and digestive systems [1, 49]<br>• Production of melatonin, a hormone that functions in the regulation of the sleep-wake cycle, blood pressure, the immune system, and other physiological functions [1, 50]<br>• Neurological effects via the kynurenine pathway, which yields compounds that affect glutamatergic neurotransmission [51]<br>• In plants, produces the phytohormone indole acetate (auxin), which promotes growth [1] | [1] Wünschiers 2012<br>[49] Jonnakuty and Gragnoli 2008<br>[50] Pandi-Perumal et al. 2006<br>[51] Kadriu et al. 2020 |
| Phenylalanine, tyrosine and tryptophan biosynthesis | Non-mammalian biosynthesis of the aromatic proteinogenic amino acids via the shikimate pathway. Mammalian tyrosine biosynthesis is derived from ingested phenylalanine [1]<br>• In plants, the shikimate pathway branches to secondary metabolic pathways that produce folates (B vitamins), pigments, and defense compounds [1, 52] | [1] Wünschiers 2012<br>[52] Parthasarathy et al. 2018 |
| beta-Alanine metabolism | • Exhibits anti-inflammatory and cytoprotective effects via production of carnosine, which scavenges free radicals and decreases protein glycation. This occurs mostly in skeletal muscle, where beta-Alanine is the rate-limiting precursor [1, 44]<br>• Contributes to energy production and lipid biosynthesis via production of CoA substrates [1]<br>• In plants, involved in defense against environmental stressors [53] | [1] Wünschiers 2012<br>[44] Mendelson 2008<br>[53] Parthasarathy et al. 2019 |
| Taurine and hypotaurine metabolism | • Aids in the digestion of lipids as taurine conjugates with bile acids to form bile salts, which emulsify lipids [1]<br>• Ameliorates oxidative stress as taurine decreases the mitochondrial production of superoxide radicals at the respiratory chain [54] | [1] Wünschiers 2012<br>[54] Jong et al. 2011 |
| D-Glutamine and D-glutamate metabolism | • Can increase oxidative stress, as D-glutamate inhibits the production of potent antioxidant glutathione [1, 55]<br>• In bacteria, helps form the peptidoglycan cell wall [56] | [1] Wünschiers 2012<br>[55] Ariyoshi et al. 2017<br>[56] Aliashkevich et al. 2018 |
| D-Arginine and D-ornithine metabolism | • In bacteria, helps form the peptidoglycan cell wall [56] | [56] Aliashkevich et al. 2018 |
| D-Alanine metabolism | • Neurological effects as D-alanine binds to NMDA receptors [57]<br>• In bacteria, helps form the peptidoglycan cell wall [56] | [57] Kiriyama and Nochi 2016 |
| Geraniol degradation | • Reduces cholesterol and isoprenoid biosynthesis by inhibiting the production of precursor mevalonate. This slows proliferation by decreasing the isoprenoid post-translational modifications of proteins utilized for cell growth [58] | [58] Polo and De Bravo 2006<br>[59] Babukumar et al. 2017 |

| Pathway Name | Biological Roles | References |
|---|---|---|
| | • Geraniol supports glucose homeostasis by altering glycolytic and gluconeogenic enzyme activity in cases of insulin hypoactivity [59] | |
| Monobactam biosynthesis | Bacterial biosynthesis of monocyclic beta-lactam antibiotics [60]<br>• Antibiotic activities of monobactams are weak against gram-positive bacteria [60]<br>• Monobactams are not cleaved by metallo-beta-lactamases, bacterial enzymes that confer broad-spectrum antibiotic resistance [61] | [60] Sykes and Bonner 1985<br>[61] Li et al. 2017 |
| Carbapenem biosynthesis | Bacterial biosynthesis of carbapenem beta-lactam antibiotics [62]<br>• Carbapenems are not cleaved by extended spectrum beta-lactamases, bacterial enzymes that confer antibiotic resistance to penicillins and celphalosporins [62]<br>• Carbapenem thienamycin is unstable and quickly metabolized by the dihydropeptidase enzyme in humans [62] | [62] Coulthurst et al. 2005 |
| Starch and sucrose metabolism | • Dietary starch and sucrose are catabolized into simpler carbohydrates for energy production via glycolysis [1]<br>• In plants, starch is synthesized from glucose polymers amylopectin and amylose for energy storage. Metabolism is tightly regulated to provide timely energy for development, nocturnal growth, and stress responses [63]<br>• In plants, sucrose is a transport sugar that is synthesized at photosynthetic organs and translocated to non-photosynthetic organs for energy storage, conversion to starch, and/or metabolism [1, 64]<br>• In plants, produces cellulose which is essential to cell wall integrity [1] | [1] Wünschiers 2012<br>[63] Skryhan et al. 2018<br>[64] Lemoine 2000 |
| Amino sugar and nucleotide sugar metabolism | Biosynthesis, interconversions, and polymerizations of sugar derivatives that confer function to macromolecules, and play a role in carbohydrate and glycoconjugate formation [1, 65, 66]<br>• Yields UDP-N-acetylglucosamine and UDP-N-acetylgalactosamine, glycosyl donors that help produce glycoproteins and glycolipids imperative to molecule activation, cell-cell interactions, and membrane functionality [1, 66]<br>• Invertebrates, fungi, and algae polymerize N-acetylglucosamine to form chitin, which composes the structure of exoskeletons and cell walls [1, 66] | [1] Wünschiers 2012<br>[65] Mikkola 2020<br>[66] Skarbek and Milewska 2016 |
| Glycerolipid metabolism | • Production, mainly by adipocytes, of energy-storing triacylglycerols from products of sugar metabolism. Triacylglycerols form intracellular lipid-regulating droplets and are the main component of adipose tissue [1]<br>• Helps regulate glucose levels via metabolic flux between gluconeogenesis and triacylglycerol production. Adipose tissue liberates glycerol and fatty acids to muscle and liver tissue for glucose or energy production via beta-oxidation [1] | [1] Wünschiers 2012 |
| Glycerophospholipid metabolism | • Production of various glycerophospholipids, the main structural component of cell membranes [1]<br>• Glycerophospholipid properties such as head group, tail length, and tail saturation affect the topography and fluidity of cell membranes they form. This influences protein integration, transport, fusion, and other membrane activities [67]<br>• Helps facilitate cellular responses by yielding diacylglycerol and inositol phosphates, second messengers involved in signal transduction, from phosphatidylinositol [1, 67] | [1] Wünschiers 2012<br>[67] Farooqui et al. 2007 |
| Inositol phosphate metabolism | • Inositol phosphates are second messengers that facilitate signal transduction by regulating the intracellular release of calcium [1]<br>• Deficiencies in myo-inositol are linked to diabetes complications in nerve, kidney, and eye tissues [68] | [1] Wünschiers 2012<br>[68] Croze and Soulage 2013 |
| Arachidonic acid metabolism | • Production of prostaglandins and other eicosanoids that function in circulatory, respiratory, and digestive system regulation, immune cell activation, and neural transmission [69] | [69] Turman and Marnett 2010<br>[70] Duroudier et al. 2009<br>[71] Chandrasekharan and Sharma-Walia 2015 |

| Pathway Name | Biological Roles | References |
|---|---|---|
| | • Mediates inflammation via production of leukotrienes and lipoxins. Leukotrienes promote and maintain inflammation, while lipoxins reduce inflammation by stimulating anti-inflammatory, and inhibiting pro-inflammatory, signalling pathways [70, 71] | |
| Linoleic acid metabolism | • Supports neuronal cell integrity via production of dihomo-gamma-linolenic acid, a membrane phospholipid component [72]<br>• Production of signalling molecules such as 13(S)-HODE that activate receptors involved in lipid metabolism and other physiological functions [73, 74] | [72] Brownlee et al. 2016<br>[73] Whelan 2013<br>[74] Nagy et al. 1998 |
| alpha-Linolenic acid metabolism | • In plants, produces jasmonic acids, a class of phytohormones involved in growth regulation and defense against biotic and abiotic environmental stressors [75] | [75] Pirbalouti et al. 2014 |
| Sphingolipid metabolism | Biosynthesis, degradation, and interconversions of sphingolipids, a class of lipids with sphingosine backbones that contribute to membrane structure and cell signalling [76, 77]<br>• Membrane component sphingomyelin is necessary for the survival of mammalian cells [76]<br>• Accumulation of proapoptotic ceramides due to sphingomyelinase overactivity contributes to the pathogenesis of type 2 diabetes mellitus and Alzheimer's disease by decreasing insulin sensitivity and promoting neuronal death, respectively [77]<br>• Mitigates or enhances tumorigenesis depending on the metabolic flux between ceramides (anti-proliferative metabolites) and sphingomyelin, glucosylceramide, and sphingosine-1-phosphate (pro-proliferative metabolites) [78] | [76] Gault et al. 2010<br>[77] Rao et al. 2013<br>[78] Ogretmen 2018 |
| Pyruvate metabolism | Biosynthesis of pyruvate and its oxidative decarboxylation to the central metabolic substrate acetyl-CoA under aerobic conditions, and reduction to fermentation products under anaerobic conditions [1]<br>• Links carbohydrate, lipid, and amino acid metabolism by providing substrates for the biosynthesis of glucose, fatty acids, ketone bodies, and amino acids [1]<br>• Meets energy demands under aerobic conditions via production of tricarboxylic acid cycle substrates acetyl-CoA and oxaloacetate [1]<br>• Meets energy demands under anaerobic conditions via the fermentation pathways, which replenish glycolysis cofactor NAD+ [1] | [1] Wünschiers 2012 |
| Glyoxylate and dicarboxylate metabolism | Pathway in plants, bacteria, insects, and vertebrates that resembles the tricarboxylic acid cycle. In the glyoxylate cycle, fatty acid-derived acetyl-CoA combines with oxaloacetate to generate succinate for entry into gluconeogenesis, and malate for replenishment of oxaloacetate to restart the cycle [1]<br>• In photosynthetic plants, supports glucose biosynthesis through energy-costly photorespiration. This replenishes Calvin cycle intermediate 3-phospho-D-glycerate from the phosphoglycolate by-product [1]<br>• In bacteria, functions in acetate consumption as acetate is converted to acetyl-CoA [1] | [1] Wünschiers 2012 |

## REFERENCES

1. Wünschiers R, Jahn M, Jahn D, Schomburg I, Peifer S, Heinzle E, Burtscher H, Garbe J, Steen A, Schobert M, et al. 2012. Metabolism. In: Michal G, Schomburg D, editors. Biochemical pathways: an atlas of biochemistry and molecular biology. 2nd ed. Hoboken (NJ): John Wiley & Sons, Inc. p. 37-209. doi:10.1002/9781118657072.
2. Ganapathy-Kanniappan S. 2018. Molecular intricacies of aerobic glycolysis in cancer: current insights into the classic metabolic phenotype. Critical Reviews in Biochemistry and Molecular Biology. 53(6):667-682. doi:10.1080/10409238.2018.1556578.
3. Williams NC, O'Neill LA. 2018. A role for the Krebs cycle intermediate citrate in metabolic reprogramming in innate immunity and inflammation. Frontiers in Immunology. 9:141. doi:10.3389/fimmu.2018.00141.
4. Ge T, Yang J, Zhou S, Wang Y, Li Y, Tong X. 2020. The role of the pentose phosphate pathway in diabetes and cancer. Frontiers in Endocrinology. 11:365. doi:10.3389/fendo.2020.00365.
5. Riganti C, Gazzano E, Polimeni M, Aldieri E, Ghigo D. 2012. The pentose phosphate pathway: an antioxidant defense and a crossroad in tumor cell fate. Free Radical Biology and Medicine. 53(3):421-436. doi:10.1016/j.freeradbiomed.2012.05.006.
6. Helsley RN, Moreau F, Gupta MK, Radulescu A, DeBosch B, Softic S. 2020. Tissue-specific fructose metabolism in obesity and diabetes. Current Diabetes Reports. 20(11):64. doi:10.1007/s11892-020-01342-8.

7. Sharma V, Ichikawa M, Freeze HH. 2014. Mannose metabolism: more than meets the eye. Biochemical and Biophysical Research Communications. 453(2):220-228. doi:10.1016/j.bbrc.2014.06.021.
8. Liu G, Hale GE, Hughes CL. 2000. Galactose metabolism and ovarian toxicity. Reproductive Toxicology. 14(5):377-384. doi:10.1016/S0890-6238(00)00096-4.
9. de Carvalho CCCR, Caramujo MJ. 2018. The various roles of fatty acids. Molecules. 23(10):2583. doi:10.3390/molecules23102583.
10. Papackova Z, Cahova M. 2015. Fatty acid signalling: the new function of intracellular lipases. International Journal of Molecular Sciences. 16(2):3831-3855. doi:10.3390/ijms16023831.
11. Jump DB. 2009. Mammalian fatty acid elongases. Methods in Molecular Biology. 579:375-389. doi:10.1007/978-1-60761-322-0_19.
12. Farazi TA, Waksman G, Gordon JI. 2001. The biology and enzymology of protein N-myristoylation. Journal of Biological Chemistry. 276(43):39501-39504. doi: 10.1074/jbc.R100042200.
13. Zhang L, Keung W, Samokhvalov V, Wang W, Lopaschuk GD. 2010. Role of fatty acid uptake and fatty acid β-oxidation in mediating insulin resistance in heart and skeletal muscle. Biochimica et Biophysica Acta – Molecular and Cell Biology of Lipids. 1801(1):1-22. doi:10.1016/j.bbalip.2009.09.014.
14. Newman JC, Verdin E. 2014. Ketone bodies as signaling metabolites. Trends in Endocrinology and Metabolism. 25(1):42-52. doi:10.1016/j.tem.2013.09.002.
15. Mazurek S, Garroum I, Daraspe J, Bellis DD, Olsson V, Mucciolo A, Butenko MA, Humbel BM, Nawrath C. 2017. Connecting the molecular structure of cutin to ultrastructure and physical properties of the cuticle in petals of *Arabidopsis*. Plant Physiology. 173(2):1146-1163. doi:10.1104/pp.16.01637.
16. Graça J. 2015. Suberin: the biopolyester at the frontier of plants. Frontiers in Chemistry. 3:62. doi:10.3389/fchem.2015.00062.
17. Patel S, Nelson DR, Gibbs AG. 2001. Chemical and physical analyses of wax ester properties. Journal of Insect Science. 1:4. doi:10.1673/031.001.0401.
18. Yang S, Kreutzberger AJB, Lee J, Kiessling V, Tamm LK. 2016. The role of cholesterol in membrane fusion. Chemistry and Physics of Lipids. 199:136-143. doi:10.1016/j.chemphyslip.2016.05.003.
19. Li S, Zheng H, Lin L, Wang F, Sui N. 2021. Roles of brassinosteroids in plant growth and abiotic stress response. Plant Growth Regulation. 93(1):29-38. doi:10.1007/s10725-020-00672-7.
20. Vaz FM, Ferdinandusse S. 2017. Bile acid analysis in human disorders of bile acid biosynthesis. Molecular Aspects of Medicine. 56:10-24. doi:10.1016/j.mam.2017.03.003.
21. Yamaguchi M, Uchiyama S, Tsukamoto Y. 2003. Inhibitory effect of menaquinone-7 (vitamin $K_2$) on the bone-resorbing factors-induced bone resorption in elderly female rat femoral tissues in vitro. Molecular and Cellular Biochemistry. 245:115-120. doi:10.1023/a:1022818111655.
22. Holst JP, Soldin OP, Guo T, Soldin SJ. 2004. Steroid hormones: relevance and measurement in the clinical laboratory. Clinics in Laboratory Medicine. 24(1):105-118. doi:10.1016/j.cll.2004.01.004.
23. Yin J, Ren W, Huang X, Deng J, Li T, Yin Y. 2018. Potential mechanisms connecting purine metabolism and cancer therapy. Frontiers in Immunology. 9:1697. doi:10.3389/fimmu.2018.01697.
24. Cornelis MC, Kacprowski T, Menni C, Gustafsson S, Pivin E, Adamski J, Artati A, Eap CB, Ehret G, Friedrich N, et al. 2016. Genome-wide association study of caffeine metabolites provides new insights to caffeine metabolism and dietary caffeine-consumption behavior. Human Molecular Genetics. 25(24):5472-5482. doi:10.1093/hmg/ddw334.
25. Barcelos RP, Lima FD, Carvalho NR, Bresciani G, Royes LF. 2020. Caffeine effects on systemic metabolism, oxidative-inflammatory pathways, and exercise performance. Nutrition Research. 80:1-17. doi:10.1016/j.nutres.2020.05.005.
26. Löffler M, Fairbanks LD, Zameitat E, Marinaki AM, Simmonds HA. 2005. Pyrimidine pathways in health and disease. Trends in Molecular Medicine. 11(9):430-437. doi:10.1016/j.molmed.2005.07.003.
27. Rodriguez PC, Ochoa AC, Al-Khami AA. 2017. Arginine metabolism in myeloid cells shapes innate and adaptive immunity. Frontiers in Immunology. 8:93. doi:10.3389/fimmu.2017.00093.
28. Felig P. 1973. The glucose-alanine cycle. Metabolism. 22(2):179-207. doi:10.1016/0026-0495(73)90269-2.
29. Alkan HF, Walter KE, Luengo A, Madreiter-Sokolowski CT, Stryeck S, Lau AN, Al-Zoughbi WA, Lewis CA, Thomas CJ, Hoefler G, et al. 2018. Cytosolic aspartate availability determines cell survival when glutamine is limiting. Cell Metabolism. 28(5):706-720. doi:10.1016/j.cmet.2018.07.021.
30. Walker MC, Donk WA. 2015. The many roles of glutamate in metabolism. Journal of Industrial Microbiology and Biotechnology. 43:419-430. doi:10.1007/s10295-015-1665-y.
31. Razak MA, Begum PS, Viswanath B, Rajagopal S. 2017. Multifarious beneficial effect of nonessential amino acid, glycine: a review. Oxidative Medicine and Cellular Longevity. 2017:1716701. doi:10.1155/2017/1716701.
32. Wang W, Wu Z, Dai Z, Yang Y, Wang J, Wu G. 2013. Glycine metabolism in animals and humans: implications for nutrition and health. Amino Acids. 45:463-477. doi:10.1007/s00726-013-1493-1.
33. Affronti HC, Rowsam AM, Pellerite AJ, Rosario SR, Long MD, Jacobi JJ, Bianchi-Smiraglia A, Boerlin CS, Gillard BM, Karasik E, et al. 2020. Pharmacological polyamine catabolism upregulation with methionine salvage pathway inhibition as an effective prostate cancer therapy. Nature Communications. 11:52. doi:10.1038/s41467-019-13950-4.
34. Sanderson SM, Gao X, Dai Z, Locasale JW. 2019. Methionine metabolism in health and cancer: a nexus of diet and precision medicine. Nature Reviews Cancer. 19:625-637. doi:10.1038/s41568-019-0187-8.
35. Serpa J. 2020. Cysteine as a carbon source, a hot spot in cancer cells survival. Frontiers in Oncology. 10:947. doi:10.3389/fonc.2020.00947.
36. Zhang S, Zeng X, Ten M, Mao X, Qiao S. 2017. Novel metabolic and physiological functions of branched chain amino acids: a review. Journal of Animal Science and Biotechnology. 8:10. doi:10.1186/s40104-016-0139-z.
37. Holeček M. 2018. Branched-chain amino acids in health and disease: metabolism, alterations in blood plasma, and as supplements. Nutrition and Metabolism. 15:33. doi:10.1186/s12986-018-0271-1.
38. Xu H, Andi B, Qian J, West AH, Cook PF. 2006. The α-aminoadipate pathway for lysine biosynthesis in fungi. Cell Biochemistry and Biophysics. 46(1):43-64. doi:10.1385/CBB:46:1:43.

39. Ziolo MT, Kohr MJ, Wang H. 2008. Nitric oxide signaling and the regulation of myocardial function. Journal of Molecular and Cellular Cardiology. 45(5):625-632. doi:10.1016/j.yjmcc.2008.07.015.
40. Gogoi M, Datey A, Wilson KT, Chakravortty D. 2016. Dual role of arginine metabolism in establishing pathogenesis. Current Opinion in Microbiology. 29:43-48. doi:10.1016/j.mib.2015.10.005.
41. Paddon-Jones D, Børsheim E, Wolfe RR. 2004. Potential ergogenic effects of arginine and creatine supplementation. The Journal of Nutrition. 134(10):2888-2894. doi:10.1093/jn/134.10.2888s.
42. Tanner JJ, Fendt S, Becker DF. 2019. The proline cycle as a potential cancer therapy target. Biochemistry. 57(25):3433-3444. doi:10.1021/acs.biochem.8b00215.
43. Holeček M. 2020. Histidine in health and disease: metabolism, physiological importance, and use as a supplement. Nutrients. 12(3):848. doi:10.3390/nu12030848.
44. Mendelson SD. 2008. 10 - Nutritional supplements and metabolic syndrome. In: Mendelson SD, editor. Metabolic Syndrome and Psychiatric Illness. Cambridge (MA): Academic Press. p. 141-186. doi:10.1016/B978-012374240-7.50012-7.
45. Brosnan ME, Brosnan JT. 2020. Histidine metabolism and function. The Journal of Nutrition. 150(1):2570s-2575s. doi:10.1093/jn/nxaa079.
46. Schenck CA, Maeda HA. 2018. Tyrosine biosynthesis, metabolism, and catabolism in plants. Phytochemistry. 149:82-102. doi:10.1016/j.phytochem.2018.02.003.
47. Turunen M, Olsson J, Dallner G. 2004. Metabolism and function of coenzyme Q. Biochimica et Biophysica Acta (BBA) – Biomembranes. 1660(1-2):171-199. doi:10.1016/j.bbamem.2003.11.012.
48. Tohge T, Watanabe M, Hoefgen R, Fernie AR. 2013. Shikimate and phenylalanine biosynthesis in the green lineage. Frontiers in Plant Science. 4:62. doi:10.3389/fpls.2013.00062.
49. Jonnakuty C, Gragnoli C. 2008. What do we know about serotonin? Journal of Cellular Physiology. 217(2):301-306. doi:10.1002/jcp.21533.
50. Pandi-Perumal SR, Srinivasan V, Maestroni GJM, Cardinali DP, Poeggeler B, Hardeland R. 2006. Melatonin: nature's most versatile biological signal? The Febs Journal. 273(13):2813-2838. doi:10.1111/j.1742-4658.2006.05322.x.
51. Kadriu B, Ballard ED, Henter ID, Murata S, Gerlus N, Zarate CA. 2020. Chapter seven - neurobiological biomarkers of response to ketamine. In: Duman RS, Krystal JH, editors. Advances in Pharmacology. Volume 89. Cambridge (MA): Academic Press. p. 195-235. doi:10.1016/bs.apha.2020.05.003.
52. Parthasarathy A, Cross PJ, Dobson RCJ, Adams LE, Savka MA, Hudson AO. 2018. A three-ring circus: metabolism of the three proteogenic aromatic amino acids and their role on the health of plants and animals. Frontiers in Molecular Biosciences. 5:29. doi:10.3389/fmolb.2018.00029.
53. Parthasarathy A, Savka MA, Hudson AO. 2019. The synthesis and role of β-alanine in plants. Frontiers in Plant Science. 10:921. doi:10.3389/fpls.2019.00921.
54. Jong CJ, Azuma J, Schaffer S. 2012. Mechanism underlying the antioxidant activity of taurine: prevention of mitochondrial oxidant production. Amino Acids. 42(6):2223-22232. doi:10.1007/s00726-011-0962-7.
55. Ariyoshi M, Katane M, Hamase K, Miyoshi Y, Nakane M, Hoshino A, Yoshifumi O, Mita Y, Kaimoto S, Uchihashi M. 2017. D-Glutamate is metabolized in the heart mitochondria. Scientific Reports. 7:43911. doi:10.1038/srep43911.
56. Aliashkevich A, Alvarez L, Cava F. 2018. New insights into the mechanisms and biological roles of D-amino acids in complex eco-systems. Frontiers in Microbiology. 9:683. doi:10.3389/fmicb.2018.00683.
57. Kiriyama Y, Nochi H. 2016. D-Amino acids in the nervous and endocrine systems. Scientifica. 2016:6494621. doi:10.1155/2016/6494621.
58. Polo MP, De Bravo MG. 2006. Effect of geraniol on fatty-acid and mevalonate metabolism in the human hepatoma cell line Hep G2. Biochemistry and Cell Biology. 84(1):102-111. doi:10.1139/o05-160.
59. Babukumar S, Vinothkumar V, Sankaranarayanan C, Srinivasan S. 2017. Geraniol, a natural monoterpene, ameliorates hyperglycemia by attenuating the key enzymes of carbohydrate metabolism in streptozotocin-induced diabetic rats. Pharmaceutical Biology. 55(1):1442-1449. doi:10.1080/13880209.2017.1301494.
60. Sykes RB, Bonner DP. 1985. Discovery and development of the monobactams. Reviews of Infectious Diseases. 7(4):S579-593. doi:10.1093/clinids/7.supplement_4.s579.
61. Li R, Oliver RA, Townsend CA. 2017. Identification and characterization of the sulfazecin monobactam biosynthetic gene cluster. Cell Chemical Biology. 24(1):24-34. doi:10.1016/j.chembiol.2016.11.010.
62. Coulthurst SJ, Barnard AML, Salmond GPC. 2005. Regulation and biosynthesis of carbapenem antibiotics in bacteria. Nature Reviews Microbiology. 3:295-306. doi:10.1038/nrmicro1128.
63. Skryhan K, Gurrieri L, Sparla F, Trost P, Blennow A. 2018. Redox regulation of starch metabolism. Frontiers in Plant Science. 9:1344. doi:10.3389/fpls.2018.01344.
64. Lemoine R. 2000. Sucrose transporters in plants: update on function and structure. Biochimica et Biophysica Acta (BBA) – Biomembranes. 1465(1-2):246-262. doi:10.1016/S0005-2736(00)00142-5.
65. Mikkola S. 2020. Nucleotide sugars in chemistry and biology. Molecules. 25(23):5755. doi:10.3390/molecules25235755.
66. Skarbek K, Milewska MJ. 2016. Biosynthetic and synthetic access to amino sugars. Carbohydrate Research. 434:44-71. doi:10.1016/j.carres.2016.08.005.
67. Farooqi AA, Horrocks LA, Farooqui T. 2007. Interactions between neural membrane glycerophospholipid and sphingolipid mediators: A recipe for neural cell survival or suicide. Journal of Neuroscience Research. 85(9):1834-1850. doi:10.1002/jnr.21268.
68. Croze ML, Soulage CO. 2013. Potential role and therapeutic interests of myo-inositol in metabolic diseases. Biochimie. 95(10):1811-1827. doi:10.1016/j.biochi.2013.05.011.
69. Turman MV, Marnett LJ. 2010. 1.03 - Prostaglandin endoperoxide synthases: structure, function, and synthesis of novel lipid signaling molecules. In: Liu H, Mander L, editors. Comprehensive Natural Products II. Amsterdam (NL): Elsevier. doi:10.1016/B978-008045382-8.00028-9.
70. Duroudier NP, Tulah AS, Sayers I. 2009. Leukotriene pathway genetics and pharmacogenetics in allergy. Allergy. 64(6):823-839. doi:10.1111/j.1398-9995.2009.02015.x.

71. Chandrasekharan J, Sharma-Walia N. 2015. Lipoxins: nature's way to resolve inflammation. Journal of Inflammation Research. 8:181-192. doi:10.2147/JIR.S90380.
72. Brownlee M, Aiello LP, Cooper ME, Vinik AI, Plutzky J, Boulton AJM. 2016. Chapter 33 – complications of diabetes mellitus. In: Melmed S, Polonsky KS, Larsen PR, Kronenberg HM, editors. Williams Textbook of Endocrinology. 13th ed. Amsterdam (NL): Elsevier. p. 1484-1581. doi:10.1016/B978-0-323-29738-7.00033-2.
73. Whelan J. 2013. Advances in Nutrition. 4(3):311-312. doi:10.3945/an.113.003772.
74. Nagy L, Tontonoz P, Alvarez JGA, Chen H, Evans RM. 1998. Oxidized LDL regulates macrophage gene expression through ligand activation of PPARγ. Cell. 93(2):229-240. doi:10.1016/s0092-8674(00)81574-3.
75. Pirbalouti AG, Sajjadi SE, Parang K. 2014. A review (research and patents) on jasmonic acid and its derivatives. Archiv der Pharmazie. 347(4):229-239. doi:10.1002/ardp.201300287.
76. Gault CR, Obeid LM, Hannun YA. 2010. An overview of sphingolipid metabolism: from synthesis to breakdown. In: Chalfant C, Poeta MD, editors. Sphingolipids as Signaling and Regulatory Molecules. Advances in Experimental Medicine and Biology. 668:1-23. doi:10.1007/978-1-4419-6741-1_1.
77. Rao RP, Vaidyanathan N, Rengasamy M, Oommen A, Somaiya N, Jagannath MR. 2013. Sphingolipid metabolic pathway: an overview of major roles played in human diseases. Journal of Lipids. 2013:178910. doi:10.1155/2013/178910.
78. Ogretmen B. 2017. Sphingolipid metabolism in cancer signalling and therapy. Nature Reviews Cancer. 18:33-50. doi:10.1038/nrc.2017.96.