Código R para PEC1 - ADO

Inés Elena Fernández Benet

2024-11-06

Documento RMarkdown con el código en R

Comenzamos el análisis abriendo los datos. Hemos escogido el dataset sobre Caquexia Humana, del repositorio ofrecido por el profesor Alex Sanchez Pla.

```r
datos <- read.csv("human_cachexia.csv")
head(datos)
```

```
##     Patient.ID Muscle.loss X1.6.Anhydro.beta.D.glucose X1.Methylnicotinamide
## 1     PIF_178    cachexic                        40.85                 65.37
## 2     PIF_087    cachexic                        62.18                340.36
## 3     PIF_090    cachexic                       270.43                 64.72
## 4 NETL_005_V1    cachexic                       154.47                 52.98
## 5     PIF_115    cachexic                        22.20                 73.70
## 6     PIF_110    cachexic                       212.72                 31.82
##   X2.Aminobutyrate X2.Hydroxyisobutyrate X2.Oxoglutarate X3.Aminoisobutyrate
## 1            18.73                 26.05           71.52             1480.30
## 2            24.29                 41.68           67.36              116.75
## 3            12.18                 65.37           23.81               14.30
## 4           172.43                 74.44         1199.91              555.57
## 5            15.64                 83.93           33.12               29.67
## 6            18.36                 80.64           47.94               17.46
##   X3.Hydroxybutyrate X3.Hydroxyisovalerate X3.Indoxylsulfate
## 1              56.83                 10.07            566.80
## 2              43.82                 79.84            368.71
## 3               5.64                 23.34            665.14
## 4             175.91                 25.03            411.58
## 5              76.71                 69.41            165.67
## 6              31.82                 35.16            183.09
##   X4.Hydroxyphenylacetate Acetate Acetone Adipate Alanine Asparagine Betaine
## 1                  120.30  126.47    9.49   38.09  314.19     159.17  109.95
## 2                  432.68  212.72   11.82  327.01  871.31     157.59  244.69
## 3                  292.95  314.19    4.44  131.63  464.05      89.12  116.75
## 4                  214.86   37.34  206.44  144.03  589.93     273.14  278.66
## 5                   97.51  407.48   44.26   15.03 1118.79      42.52  391.51
## 6                  132.95   81.45   14.44   25.28  237.46     157.59   66.69
##   Carnitine  Citrate Creatine Creatinine Dimethylamine Ethanolamine Formate
## 1    265.07  3714.50   196.37   16481.60        632.70       645.48  441.42
## 2    120.30  2617.57   212.72   15835.35        607.89       487.85  252.14
## 3     25.03   862.64   221.41   24587.66        735.10       407.48  249.64
## 4    200.34 13629.61    85.63   20952.22       1064.22       820.57  468.72
```

```
## 5      84.77    854.06    105.64     6768.26         242.26         365.04  114.43
## 6      40.04   1958.63    200.34    15677.78         614.00         459.44  314.19
##    Fucose Fumarate Glucose Glutamine Glycine Glycolate Guanidoacetate Hippurate
## 1 336.97     7.69  395.44    871.31 2038.56    685.40         154.47   4582.50
## 2 198.34    18.92 8690.62    601.85 1107.65    651.97         109.95   1737.15
## 3 186.79     7.10 1352.89    301.87  620.17    141.17         183.09   4315.64
## 4 407.48    96.54  862.64   1685.81 5064.45     70.81         102.51    757.48
## 5  26.05    19.69 6836.29    432.68  395.44     26.58          52.98   1152.86
## 6 123.97     5.05  512.86    298.87  482.99    428.38          57.97   3568.85
##    Histidine Hypoxanthine Isoleucine Lactate Leucine Lysine Methylamine
## 1    925.19        97.51       5.58  106.70   42.10 146.94       52.46
## 2    845.56        82.27       8.17  368.71   77.48 284.29       23.57
## 3    284.29       114.43       9.30  749.95   31.50  97.51       18.73
## 4   1043.15       223.63      37.71  368.71  103.54 290.03       48.91
## 5    327.01        66.69      40.04 3640.95  101.49 122.73       27.94
## 6    459.44        62.80       8.17  113.30   28.79 120.30       36.97
##    Methylguanidine N.N.Dimethylglycine O.Acetylcarnitine Pantothenate
## 1            9.97               23.34             52.98        25.79
## 2            7.69               87.36             50.40       186.79
## 3            4.66               24.53              5.58       145.47
## 4          141.17               40.04            254.68        42.52
## 5            5.31               46.06             45.60        74.44
## 6           43.38               24.29             13.46        35.52
##    Pyroglutamate Pyruvate Quinolinate  Serine Succinate Sucrose Tartrate Taurine
## 1         437.03    21.12      165.67  284.29    154.47   45.15    97.51 1919.85
## 2         437.03    36.97       72.97  391.51    244.69  459.44    32.79 1261.43
## 3         713.37    29.37      192.48  295.89    142.59  160.77    16.28 4272.69
## 4         566.80    64.07       86.49 1248.88    144.03  111.05   837.15 1525.38
## 5         184.93    12.30       38.09  206.44     68.72   75.19     4.53  468.72
## 6         432.68    32.79      112.17  387.61     33.45  336.97    24.05 2059.05
##    Threonine Trigonelline Trimethylamine.N.oxide Tryptophan Tyrosine Uracil
## 1    184.93       943.88                2121.76     259.82   290.03 111.05
## 2    198.34       208.51                 639.06      83.10   167.34  46.99
## 3    109.95       192.48                1152.86      82.27    60.34  31.50
## 4    376.15       992.27                1450.99     235.10   323.76  30.57
## 5     64.07        86.49                 172.43     103.54   142.59  44.26
## 6    105.64       862.64                 880.07     239.85   127.74  29.67
##    Valine  Xylose cis.Aconitate myo.Inositol trans.Aconitate pi.Methylhistidine
## 1  86.49   72.24        237.46       135.64           51.94             157.59
## 2 109.95  192.48        333.62       376.15          217.02             307.97
## 3  59.15 2164.62        330.30        86.49           58.56             145.47
## 4 102.51  125.21       1863.11       247.15           75.94             249.64
## 5 160.77  186.79        101.49       749.95           98.49              84.77
## 6  36.97   89.12        287.15       129.02          121.51             399.41
##    tau.Methylhistidine
## 1              160.77
## 2              130.32
## 3               83.93
## 4              254.68
## 5               79.84
## 6               68.72
```

Ahora creamos el contenedor SummarizedExperiment para contener los datos escogidos. Utilizaremos la librería POMA, que hace el proceso de crear el objeto SummarizedExperiment mucho más fácil.

```r
#BiocManager::install("POMA")
library(POMA)
```

```
## Welcome to POMA!
## Version 1.12.0
## POMAShiny app: https://github.com/pcastellanoescuder/POMAShiny
## For more detailed package information please visit https://pcastellanoescuder.github.io/POMA/
```

```r
#primero convertimos nuestra variable Muscle.loss en factor
datos$Muscle.loss <- as.factor(datos$Muscle.loss)

#target recoge la información "descriptiva", es decir, Patient.ID y Muscle.loss
target <- data.frame(
  Patient_ID = datos$Patient.ID,
  Condition = datos$Muscle.loss)

#features recoge la información sobre los metabolitos
features <- as.data.frame(datos[, -c(1, 2)])


#rowRanges <- GRanges(
#  seqnames = Rle("metabolite"),
#  ranges = IRanges(start = 1:nrow(counts), width = 1),
#  feature_id = rownames(counts)
#)

se <- PomaSummarizedExperiment(target = target, features = features)
se
```

```
## class: SummarizedExperiment
## dim: 63 77
## metadata(0):
## assays(1): ''
## rownames(63): X1.6.Anhydro.beta.D.glucose X1.Methylnicotinamide ...
##   pi.Methylhistidine tau.Methylhistidine
## rowData names(0):
## colnames(77): PIF_178 PIF_087 ... NETL_003_V1 NETL_003_V2
## colData names(1): Condition
```

```r
#guardamos el objeto en formato binario para subirlo nuestro repositorio de GitHub
save(se, file = "human_cachexia_se.Rda")
#también aprovechamos para guardar el conjunto de datos en archivo de texto como se indica en el enunci
write.table(datos, file = "datos.txt", sep = "\t", row.names = FALSE, col.names = TRUE, quote = FALSE)
```

Ahora que tenemos el contenedor/objeto, procedemos a hacer algunos análisis sobre la información.

Comenzamos con la exploración de los datos del conjunto de datos human_cachexia.

```r
#comenzaremos estudiando si hay valores faltantes
missing_values <- sum(is.na(datos))
cat("Número de valores faltantes:", missing_values, "\n")
```

```
## Número de valores faltantes: 0
```

```
#debido a que es un conjunto de datos con poca información,
#haremos un resumen de estadística descriptiva rápido son la función summary()
summary(datos)
```

```
##   Patient.ID          Muscle.loss  X1.6.Anhydro.beta.D.glucose
## Length:77          cachexic:47   Min.   :  4.71
## Class :character   control :30   1st Qu.: 28.79
## Mode  :character                 Median : 45.60
##                                  Mean   :105.63
##                                  3rd Qu.:141.17
##                                  Max.   :685.40
## X1.Methylnicotinamide X2.Aminobutyrate X2.Hydroxyisobutyrate X2.Oxoglutarate
## Min.   :   6.42       Min.   :  1.28   Min.   : 4.85        Min.   :   5.53
## 1st Qu.:  15.80       1st Qu.:  5.26   1st Qu.:15.80        1st Qu.:  22.42
## Median :  36.60       Median : 10.49   Median :32.46        Median :  55.15
## Mean   :  71.57       Mean   : 18.16   Mean   :37.25        Mean   : 145.09
## 3rd Qu.:  73.70       3rd Qu.: 19.49   3rd Qu.:54.60        3rd Qu.:  92.76
## Max.   :1032.77       Max.   :172.43   Max.   :93.69        Max.   :2465.13
## X3.Aminoisobutyrate X3.Hydroxybutyrate X3.Hydroxyisovalerate X3.Indoxylsulfate
## Min.   :   2.61     Min.   :  1.70     Min.   :  0.92        Min.   :  27.66
## 1st Qu.:  11.70     1st Qu.:  5.99     1st Qu.:  5.26        1st Qu.:  82.27
## Median :  22.65     Median : 11.70     Median : 12.55        Median : 144.03
## Mean   :  76.76     Mean   : 21.72     Mean   : 21.65        Mean   : 218.88
## 3rd Qu.:  56.26     3rd Qu.: 29.96     3rd Qu.: 30.27        3rd Qu.: 333.62
## Max.   :1480.30     Max.   :175.91     Max.   :164.02        Max.   :1043.15
## X4.Hydroxyphenylacetate    Acetate          Acetone          Adipate
## Min.   : 15.49          Min.   :  3.49   Min.   :  2.29   Min.   :  1.55
## 1st Qu.: 41.68          1st Qu.: 16.28   1st Qu.:  4.95   1st Qu.:  6.11
## Median : 70.11          Median : 39.65   Median :  7.10   Median : 10.18
## Mean   :112.02          Mean   : 66.14   Mean   : 11.43   Mean   : 24.76
## 3rd Qu.:145.47          3rd Qu.: 86.49   3rd Qu.: 10.49   3rd Qu.: 19.11
## Max.   :796.32          Max.   :411.58   Max.   :206.44   Max.   :327.01
##    Alanine          Asparagine        Betaine          Carnitine
## Min.   :  16.78   Min.   :  6.69   Min.   :  2.29   Min.   :  2.18
## 1st Qu.:  78.26   1st Qu.: 20.49   1st Qu.: 28.79   1st Qu.: 14.44
## Median : 194.42   Median : 42.10   Median : 64.72   Median : 23.81
## Mean   : 273.56   Mean   : 62.28   Mean   : 90.32   Mean   : 52.09
## 3rd Qu.: 399.41   3rd Qu.: 89.12   3rd Qu.:127.74   3rd Qu.: 60.95
## Max.   :1312.91   Max.   :273.14   Max.   :391.51   Max.   :487.85
##    Citrate          Creatine         Creatinine      Dimethylamine
## Min.   :   59.74  Min.   :   2.75  Min.   : 1002   Min.   :  41.26
## 1st Qu.:  788.40  1st Qu.:  17.64  1st Qu.: 3498   1st Qu.: 142.59
## Median : 1790.05  Median :  44.26  Median : 7631   Median : 304.90
## Mean   : 2235.35  Mean   : 126.83  Mean   : 8734   Mean   : 358.17
## 3rd Qu.: 3071.74  3rd Qu.: 117.92  3rd Qu.:12333   3rd Qu.: 454.86
## Max.   :13629.61  Max.   :1863.11  Max.   :33860   Max.   :1556.20
##   Ethanolamine       Formate          Fucose           Fumarate
## Min.   :  16.12   Min.   :   6.42  Min.   :  5.70   Min.   : 0.79
## 1st Qu.:  86.49   1st Qu.:  53.52  1st Qu.: 29.37   1st Qu.: 2.23
## Median : 204.38   Median :  95.58  Median : 61.56   Median : 4.10
## Mean   : 276.26   Mean   : 147.40  Mean   : 88.67   Mean   : 8.44
## 3rd Qu.: 407.48   3rd Qu.: 167.34  3rd Qu.:123.97   3rd Qu.: 7.85
## Max.   :1436.55   Max.   :1480.30  Max.   :407.48   Max.   :96.54
```

```
##       Glucose          Glutamine         Glycine          Glycolate
##   Min.   :  26.84   Min.   :  23.34   Min.   :  38.09   Min.   :  5.42
##   1st Qu.:  80.64   1st Qu.: 113.30   1st Qu.: 262.43   1st Qu.: 50.91
##   Median : 210.61   Median : 225.88   Median : 528.48   Median :130.32
##   Mean   : 559.85   Mean   : 306.87   Mean   : 880.72   Mean   :187.99
##   3rd Qu.: 407.48   3rd Qu.: 445.86   3rd Qu.:1096.63   3rd Qu.:267.74
##   Max.   :8690.62   Max.   :1685.81   Max.   :5064.45   Max.   :720.54
##   Guanidoacetate      Hippurate         Histidine         Hypoxanthine
##   Min.   :  7.03   Min.   :    92.76   Min.   :  14.15   Min.   :  3.78
##   1st Qu.: 33.78   1st Qu.:   492.75   1st Qu.:  66.69   1st Qu.: 20.70
##   Median : 64.72   Median :  1224.15   Median : 174.16   Median : 40.04
##   Mean   : 86.37   Mean   :  2286.84   Mean   : 292.64   Mean   : 61.10
##   3rd Qu.:108.85   3rd Qu.:  2921.93   3rd Qu.: 419.89   3rd Qu.: 83.93
##   Max.   :561.16   Max.   : 19341.34   Max.   :1863.11   Max.   :265.07
##     Isoleucine         Lactate           Leucine           Lysine
##   Min.   : 1.790   Min.   :    7.32   Min.   :  2.51   Min.   : 10.49
##   1st Qu.: 3.900   1st Qu.:   35.52   1st Qu.:  9.12   1st Qu.: 30.27
##   Median : 7.170   Median :   81.45   Median : 19.11   Median : 69.41
##   Mean   : 8.709   Mean   :  158.46   Mean   : 24.36   Mean   :108.79
##   3rd Qu.:11.250   3rd Qu.:  139.77   3rd Qu.: 31.19   3rd Qu.:121.51
##   Max.   :40.040   Max.   : 3640.95   Max.   :103.54   Max.   :788.40
##    Methylamine      Methylguanidine   N.N.Dimethylglycine  O.Acetylcarnitine
##   Min.   : 1.51   Min.   :  1.70   Min.   :  0.79    Min.   :  1.23
##   1st Qu.: 5.26   1st Qu.:  4.26   1st Qu.:  7.03    1st Qu.:  3.94
##   Median :14.73   Median :  7.85   Median : 21.98    Median : 11.47
##   Mean   :17.38   Mean   : 15.32   Mean   : 26.35    Mean   : 19.73
##   3rd Qu.:24.05   3rd Qu.: 19.30   3rd Qu.: 40.04    3rd Qu.: 20.91
##   Max.   :52.46   Max.   :141.17   Max.   :120.30    Max.   :254.68
##    Pantothenate     Pyroglutamate       Pyruvate         Quinolinate
##   Min.   :  2.59   Min.   :  21.33   Min.   :  0.90   Min.   :  5.21
##   1st Qu.: 11.13   1st Qu.:  68.72   1st Qu.:  4.85   1st Qu.: 26.58
##   Median : 22.65   Median : 157.59   Median : 13.46   Median : 51.42
##   Mean   : 44.88   Mean   : 211.45   Mean   : 21.29   Mean   : 66.44
##   3rd Qu.: 41.26   3rd Qu.: 301.87   3rd Qu.: 29.08   3rd Qu.: 87.36
##   Max.   :692.29   Max.   :1064.22   Max.   :184.93   Max.   :259.82
##      Serine           Succinate         Sucrose           Tartrate
##   Min.   :  16.12   Min.   :  1.72   Min.   :   6.49   Min.   :  2.20
##   1st Qu.:  83.10   1st Qu.:  8.58   1st Qu.:  19.30   1st Qu.:  6.89
##   Median : 142.59   Median : 30.88   Median :  40.85   Median : 12.94
##   Mean   : 197.69   Mean   : 60.23   Mean   : 113.23   Mean   : 40.00
##   3rd Qu.: 270.43   3rd Qu.: 74.44   3rd Qu.:  94.63   3rd Qu.: 25.79
##   Max.   :1248.88   Max.   :589.93   Max.   :2079.74   Max.   :837.15
##      Taurine          Threonine        Trigonelline    Trimethylamine.N.oxide
##   Min.   :  17.81   Min.   :  8.25   Min.   :  10.07   Min.   :  55.7
##   1st Qu.:  99.48   1st Qu.: 31.82   1st Qu.:  53.52   1st Qu.: 175.9
##   Median : 249.64   Median : 64.07   Median : 114.43   Median : 383.8
##   Mean   : 525.12   Mean   : 95.36   Mean   : 270.44   Mean   : 652.2
##   3rd Qu.: 665.14   3rd Qu.:137.00   3rd Qu.: 340.36   3rd Qu.: 735.1
##   Max.   :4272.69   Max.   :450.34   Max.   :2252.96   Max.   :5486.2
##     Tryptophan        Tyrosine          Uracil            Valine
##   Min.   :  8.67   Min.   :  4.22   Min.   :  3.10   Min.   :  4.10
##   1st Qu.: 21.33   1st Qu.: 23.57   1st Qu.: 11.94   1st Qu.: 12.18
##   Median : 46.99   Median : 60.34   Median : 27.39   Median : 33.12
##   Mean   : 66.24   Mean   : 81.76   Mean   : 35.56   Mean   : 35.67
```

```
## 3rd Qu.: 96.54    3rd Qu.:113.30    3rd Qu.: 44.26    3rd Qu.: 50.40
## Max.    :259.82    Max.    :539.15    Max.    :179.47    Max.    :160.77
##       Xylose         cis.Aconitate      myo.Inositol     trans.Aconitate
## Min.    :  10.07    Min.    :  12.94    Min.    : 11.59    Min.    :  4.90
## 1st Qu.:  29.96    1st Qu.:  36.23    1st Qu.: 30.27    1st Qu.: 12.43
## Median :  50.40    Median : 129.02    Median : 78.26    Median : 26.84
## Mean    : 100.93    Mean    : 204.22    Mean    :135.40    Mean    : 40.63
## 3rd Qu.:  89.12    3rd Qu.: 254.68    3rd Qu.:167.34    3rd Qu.: 57.40
## Max.    :2164.62    Max.    :1863.11    Max.    :854.06    Max.    :217.02
## pi.Methylhistidine tau.Methylhistidine
## Min.    :  11.36    Min.    :   8.00
## 1st Qu.:  67.36    1st Qu.:  27.39
## Median : 162.39    Median :  68.72
## Mean    : 370.29    Mean    :  89.69
## 3rd Qu.: 387.61    3rd Qu.:130.32
## Max.    :2697.28    Max.    :317.35
```

Dado que contamos con 63 columnas de metabolitos, y un factor de dos niveles (Muscle.loss), saltamos directamente a los análisis avanzados.

Comenzamos con el análisis de las Componentes Principales (PCA)

```r
#para el análisis PCA, primero separamos la informacion de los metabolitos de Patient.ID y Muscle.loss
pca_datos <- datos[, -c(1, 2)]

#calculamos el PCA usando la función prcom()
pca_resultado <- prcomp(pca_datos, scale = TRUE)

#hacemos un gráfico que muestre el resultado
plot(pca_resultado$x[, 1],
pca_resultado$x[, 2],
     col = datos$Muscle.loss,
     xlab = "PC1", ylab = "PC2",
     main = "PCA de Metabolitos")
legend("topright", legend = levels(datos$Muscle.loss),
       col = 1:length(levels(datos$Muscle.loss)), pch = 1)
```

PCA de Metabolitos
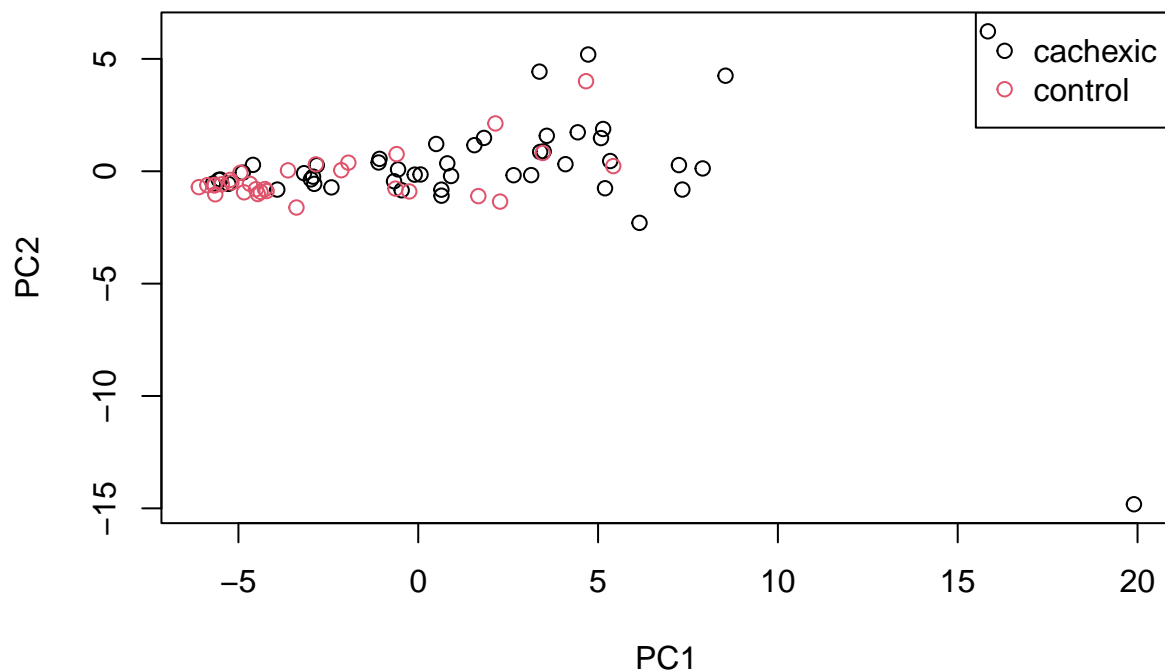
Ahora, seguimos con el análisis de varianza, ANOVA. Dado que contamos con 63 metabolitos, haremos un bucle que itere por todos los metabolitos y haga análisis de ANOVA, y nos quedaremos con aquellos que resulten significativamente diferentes.

```r
#de nuevo, separamos los metabolitos de patient.id y muscle.loss
metabolitos <- as.matrix(datos[, -c(1, 2)])
significativos <- c()

#creamos el bucle
for (metabolito in colnames(metabolitos)) {
  anova_resultado <- aov(datos[[metabolito]] ~ datos$Muscle.loss)
  p_valor <- summary(anova_resultado)[[1]][["Pr(>F)"]][1]
  if (p_valor <= 0.05) {
    significativos <- c(significativos, metabolito)
  }

}

print(significativos)
```

```
##  [1] "X2.Aminobutyrate"      "X2.Hydroxyisobutyrate" "X3.Hydroxybutyrate"
##  [4] "X3.Hydroxyisovalerate" "X3.Indoxylsulfate"     "Acetate"
##  [7] "Adipate"               "Alanine"               "Asparagine"
## [10] "Betaine"               "Citrate"               "Creatinine"
## [13] "Dimethylamine"         "Ethanolamine"          "Formate"
## [16] "Fucose"                "Glucose"               "Glutamine"
```

```
## [19] "Glycine"              "Hippurate"         "Histidine"
## [22] "Leucine"              "Methylamine"       "N.N.Dimethylglycine"
## [25] "Pyroglutamate"        "Pyruvate"          "Quinolinate"
## [28] "Serine"               "Succinate"         "Taurine"
## [31] "Threonine"            "Trigonelline"      "Trimethylamine.N.oxide"
## [34] "Tryptophan"           "Tyrosine"          "Valine"
## [37] "cis.Aconitate"        "myo.Inositol"      "trans.Aconitate"
## [40] "tau.Methylhistidine"
```

A través del análisis de PCA, podemos ver que los sujetos con conidicón control tienden a estar agrupados en la misma zona, con excepciones. Sin embargo, aquellos sujetos con condición de caquexia, tienden a estar más esparcidos, con alguna superposición a aquellos controles que no están agrupados.

Sobre el análisis de ANOVA, podemos ver que 40 de los 63 metabolitos de estudio muestran diferencias estadísticamente significativas cuando comparamos los resultados de las medias de los grupos de condiciones, control y caquexia. Estudios más específicos tendrían que hacerse para saber cómo estas diferencias se muestran en cada uno de los metabolitos.

Me he basado en varias fuentes para desarrollar el código que da respuesta a estos ejercicios:

- Sanchez, A., Carmona, F. (2024). Casos y Ejemplos de Análisis Multivariante con R. Análisis de Datos Ómicos. Universitat Oberta de Catalunya. Acceso a través del enlace: https://aspteaching.github.io/AMVCasos/

- Sanchez, A. (2024). Introduction to microarray data exploration and analysis with basic R functions. Análisis de Datos Ómicos. Universitat Oberta de Catalunya. Acceso a través del enlace: https://aspteaching.github.io/Analisis_de_datos_omicos-Ejemplo_0-Microarrays/ExploreArrays.html#2_A_first_look_at_microarray_data_The_study

- Sanchez, A. (2024). Exploración multivariante de datos ómicos: Descriptivo, PCA y Clustering. Análisis de Datos Ómicos. Universitat Oberta de Catalunya.

- Sanchez, A. (2024). MetaboData datasets [Repositorio en GitHub]. GitHub. https://github.com/nutrimetabolomics/metaboData/blob/main/Datasets/2024-Cachexia

- Bioconductor (2023). POMA Workflow. Análisis de Datos Ómicos. Acceso a través del enlace: https://web.archive.org/web/20240415023513/http://bioconductor.org/packages/release/bioc/vignettes/POMA/inst/doc/POMA-demo.html

- Morgan, M., Obenchain, V., Hester, J., Pagès, H. (2023). SummarizedExperiment for Coordinating Experimental Assays, Samples, and Regions of Interest. Acceso a través del enlace: https://bioconductor.org/packages/release/bioc/vignettes/SummarizedExperiment/inst/doc/SummarizedExperiment.html

- Morgan, M., Obenchain, V., Hester, J., Pagès, H. (2023). SummarizedExperiment for Coordinating Experimental Assays, Samples, and Regions of Interest. Acceso a través del enlace: https://bioconductor.org/packages/release/bioc/vignettes/SummarizedExperiment/inst/doc/SummarizedExperiment.html