Laboratory Standard Operating Procedure

Creation of a Color Reference Chart for RTB Foods Color Characterization

High-Throughput Phenotyping Protocols (HTPP), WP3

Montpellier, France, September 2020

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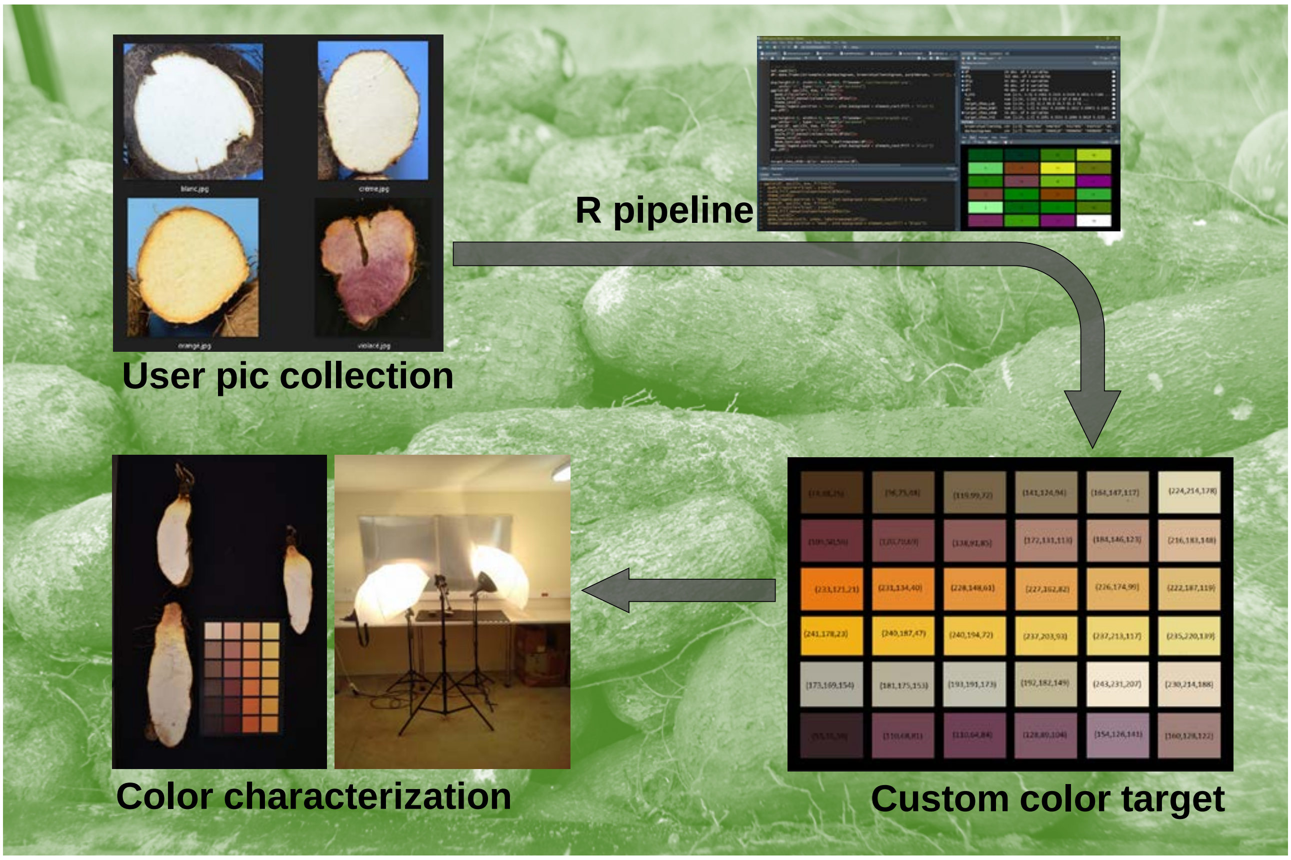

This report has been written in the framework of RTBfoods project.

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RTBfoods *WP3: High-Throughput Phenotyping Protocols (HTPP)*	

SOP: Creation of a color reference chart for RTB foods color characterization

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ABSTRACT

Either for visual evaluation or image analysis, a color selection chart allow for a more accurate and repeatable color quantification. Commercial color reference chart exist but covers a wide range of colors, making it harder to evaluate the desired object color. The present SOP describe step by step how to implement its own customized color reference chart and propose an R script automatizing the process.

The creation of a color reference chart relies first on the extraction of typical colors from a collection of available numeric images covering the range of desired product color variation. This palette of color is then characterized in different color spaces, plotted on a chart and printed. Finally, the correspondence between the desired color value and the printed chart is verified using a chromameter.

Key Words: Food quality; Colorimetry; Synthetic color chart; sRGB standard; CIELAB; R statistical computing language

1 Scope and Application

Either for visual evaluation or image analysis, a color selection chart allow for a more accurate and repeatable color quantification. Commercial color reference chart exist but it covers a wide range of colors, making it harder to evaluate the desired object color. For instance, Xrite ColorChecker offers 24 color patch covering the whole range of colors (Figure 1) while product color range (e.g. yam tuber flesh) cover hardly more than 2 or 3 color patch of the chart (e.g. white to pale yellow). To remedy this, it is possible to implement its own customized color reference chart. The present SOP detail the different steps to build it and propose an R script automatizing the process.

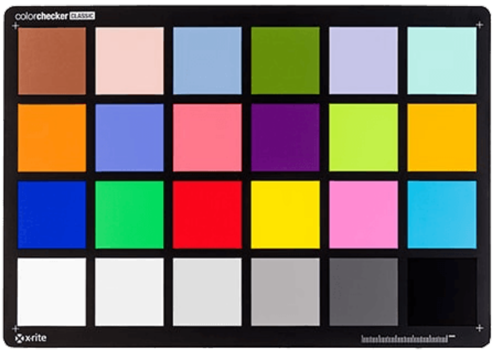

Figure 1 : Xrite ColorChecker classic chart (©PANTONE, New Jersey, USA)

The SOP RTBfoods_H2.2 and XXXX explaining how to characterize color and oxidation both rely on such custom color reference chart.

2 References

2.1 Perception of color difference

- Luo MR, Cui G, Rigg B. 2001. The development of the CIE 2000 colour-difference formula: CIEDE2000. Color Res Appl 26:340 –350.
- Mokrzycki W, Tatol M. 2011. Color difference Delta E - A survey. Machine Graphics and Vision 20(4):383-411.

2.2 Color space transformation

- Leon K, Mery D, Pedreschi F, Leon J (2006) Color measurement in L*a*b* units from RGB digital images. Food Research International 39: 1084-1091
- Rec. ITU-R BT.709-6. 2002. Parameter values for the HDTV standards for production and international programme exchange (1990, revised 2002). International Telecommunication Union, 1211 Geneva 20, Switzerland.

2.3 Color characterization

- Emmanuel ALAMU, Michael ADESOKAN (2020). SOP for Colour Measurement in Fresh Yam (Dioscorea Sp.) and Fresh Cassava (Manihot esculenta) using Chromameter. International Institute of Tropical Agriculture(IITA), Ibadan, Nigeria: RTBfoods Project Report, 10 p.
- Denis CORNET (2020). SOP for Calibrated Color Measurements of RTB Foods Using Image Analysis CIRAD UMR Agap, Montpellier, France: RTBfoods Project Report, 17 p.

3 Definitions

A **color chart** is a flat, physical object that has many different colors present. Typically, there are two different types of color charts:

- Color reference charts are intended for color comparisons and measurements. Typical tasks for such charts are checking the color reproduction of an imaging system, aiding in color management or visually determining the hue of color. Example, the ColorChecker chart.
- Color selection charts present a palette of available colors to aid the selection of spot colors, process colors, paints, pens, crayons, and so on.

A **color space** is mostly a system for describing color numerically. It relies on a "color model", i.e. an abstract mathematical model describing the way colors can be represented as tuples of numbers (e.g. triples in RGB or quadruples in CMYK).

4 Principle

The creation of a color reference chart relies first on the extraction of typical colors from a collection of available numeric images. This collection should cover the range of desired product color variation. This palette of color is then characterized in different color spaces, plotted on a chart and printed. Finally, the correspondence between the desired color value and the printed chart is verified using a chromameter.

This procedure can be done manually using available software tools (e.g. PowerPoint or Firefox color picker) or using a dedicated R script available in the Annexe or on the RTBfoods Alfresco shared website.

5 Reagents

- A collection of numeric pictures covering the color diversity of the desired object (e.g. images of yam tuber flesh, Figure 2) is necessary.

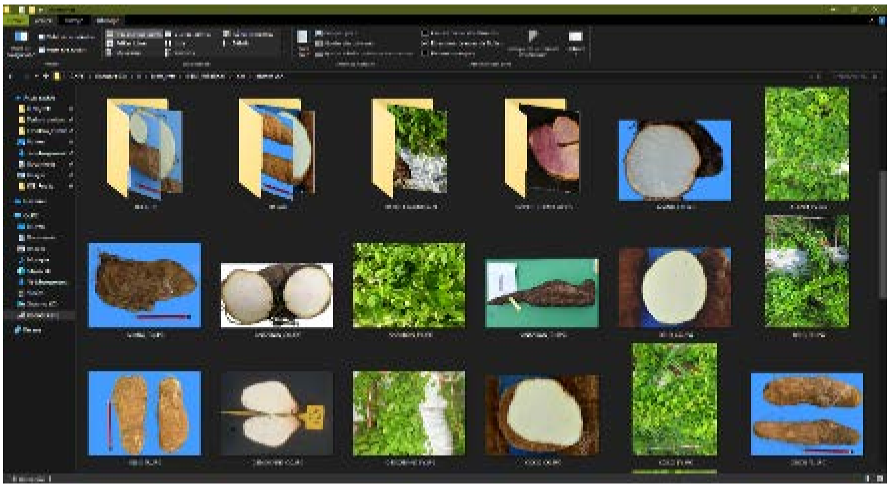

Figure 2 : Example of numeric image collection used for reference color extraction.

- Some white matte photo paper is required for printing.

6 APPARATUS

The automatized creation of a reference color chart requires a computer with R and RStudio installed.However, to ensure a consistent representation of colors, a high-quality professional printer with up to date calibration is recommended.

7 PROCEDURE

7.1 Gathering numeric images and installing software

To ease the process of color extraction, it is recommended to gather reference images into the same folder.

First software needs to be installed:

- R 3.5.3 can be downloaded here: https://cran.r-project.org/
- RStudio can be downloaded here: https://rstudio.com/products/rstudio/download/preview/

Scripts are encapsulated in a zipped RStudio project. First, the RStudio project needs to be unzipped on your computer (Figure 3). Then, the project can be loaded by clicking on the *RTBfoods_CustomColorTargetCreation.Rproj* file (Figure 4).

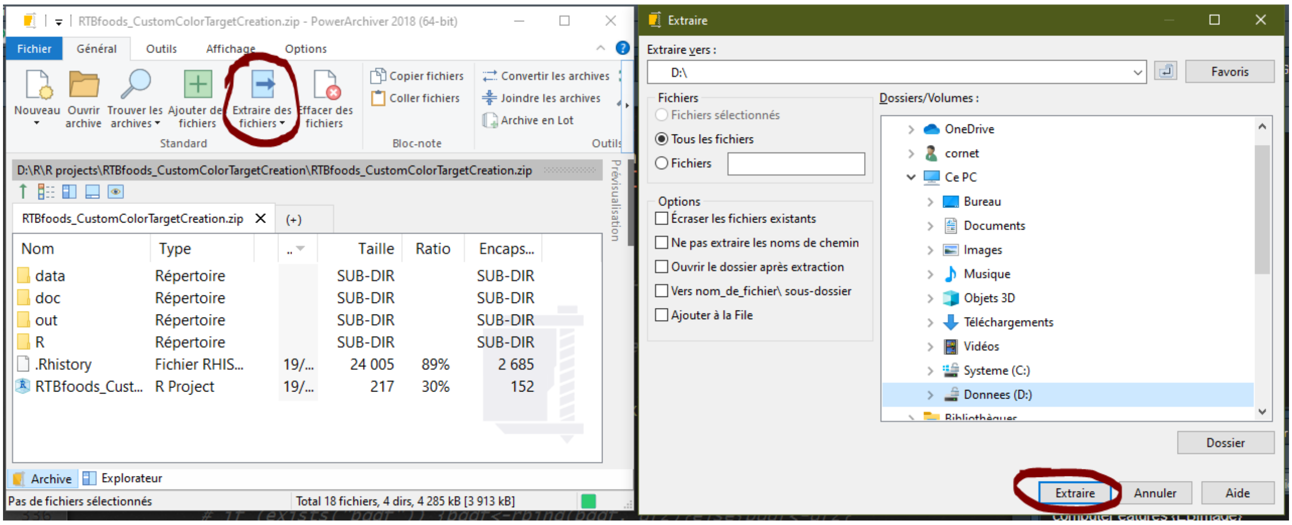

Figure 3 : Unzipping the RStudio project on the computer.

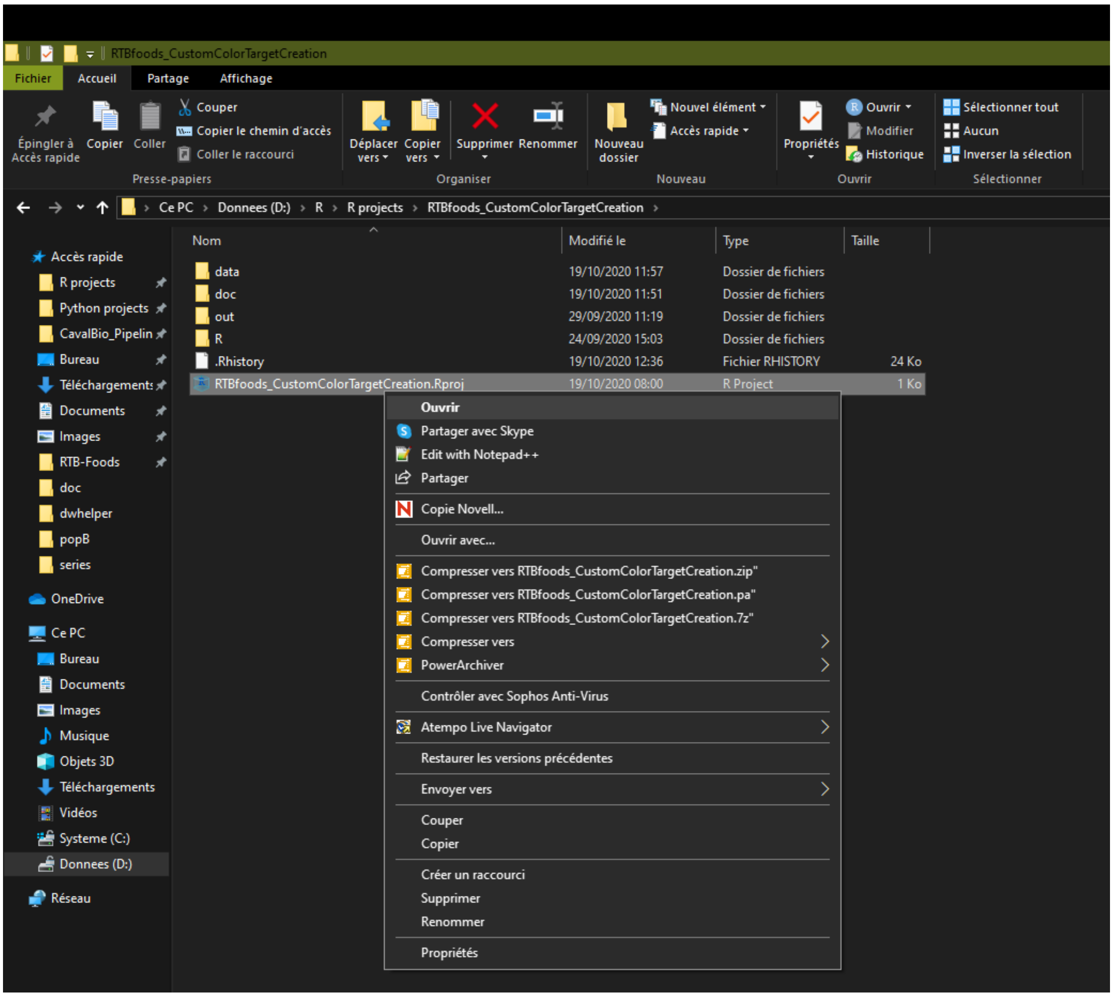

Figure 4 : Opening the RStudio project.

7.2 Creation of the reference chart

Once software are installed and the RStudio project opened, the script can be launched by clicking on the *Source* button (Figure 5).

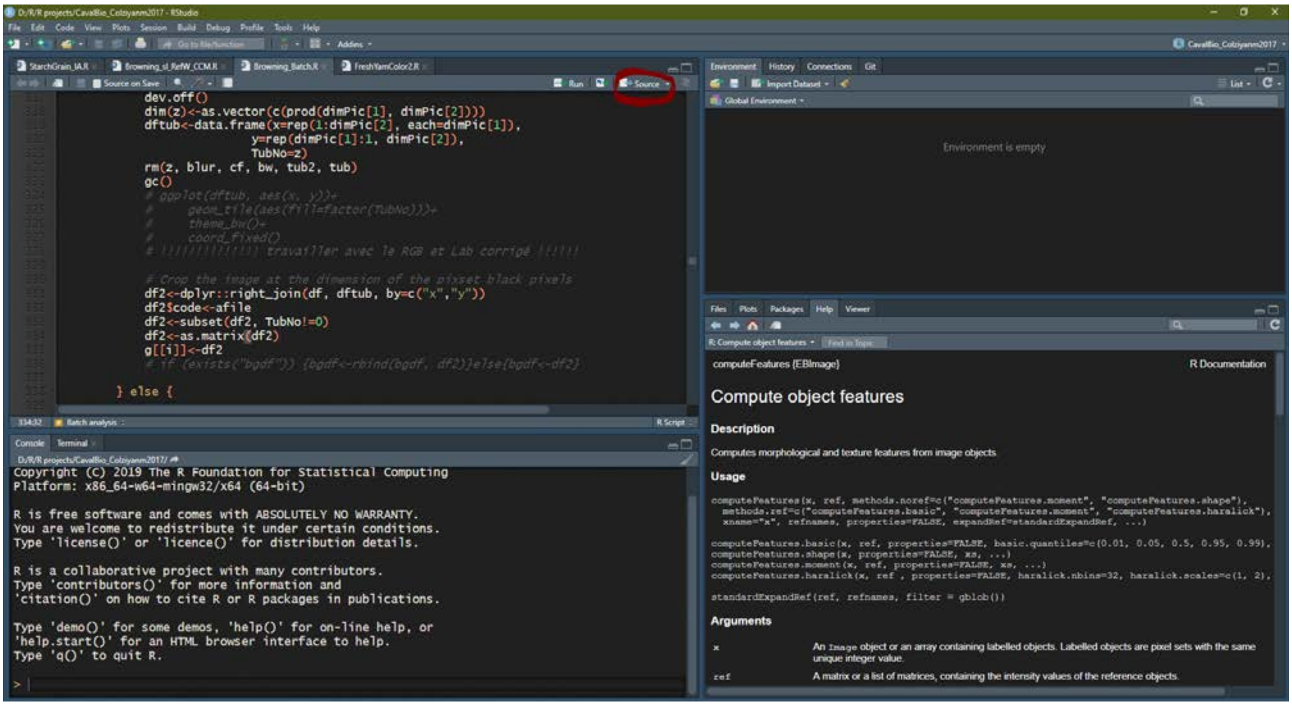

Figure 5: RStudio project window.

First, the user is asked to choose the number of colors to be included in the reference color chart and the desired design:

```
Dear user, first you'll be asked to choose the desired number of color of your custom chart. Right after you'll have to choose the number of rows and columns to fill the chart. Finally, you'll be prompt to choose images on your computer to collect color from. For each image, you'll have to choose 5 pixels corresponding to the desired color.
Enter the number of color in the desired chart:
12

Enter the number of row in the desired chart:
4

Enter the number of column in the desired chart:
4
```

Figure 7 provides an example of a custom reference chart for yam leaf color. If the number of color does not match the number of patch (i.e. number of rows X number of columns) the following error is printed on the console and the script has to be sourced again:

```
ERROR:
The number of color do not match the number of patches in the chart. Please restart the script and ensure that:
Column number * Row number = Number of color
```

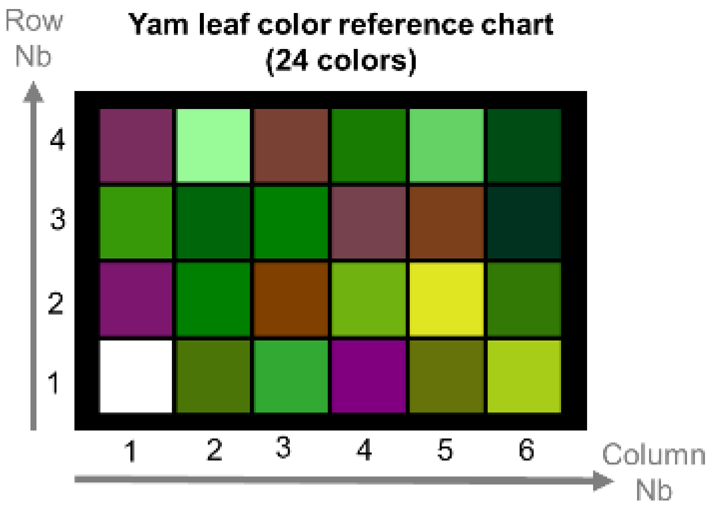

Figure 6 : Example of reference chart with 24-color patch divided into 4 rows and 6 columns.

After having defined the design of the reference chart, a pop up window will ask you to choose the location of the first image (Figure 7). The image will be loaded in the RStudio environment, and the user will have to select 5 homogenous pixels representing the first desired color:

```
Picking color N°1

Please choose an image on which you'll be asked to pick a specific color

Please click on 5 pixels corresponding to the desired color
```

The necessity to pick 5 pixels of the same color arise from the heterogeneity of the product surface and the difficulty to point to the exact desired color. For each image, the average color will be calculated between the 5 pixels and saved to build the reference chart.

This step will be repeated as many times as desired number of colors. Only the last color which will always be the reference white.

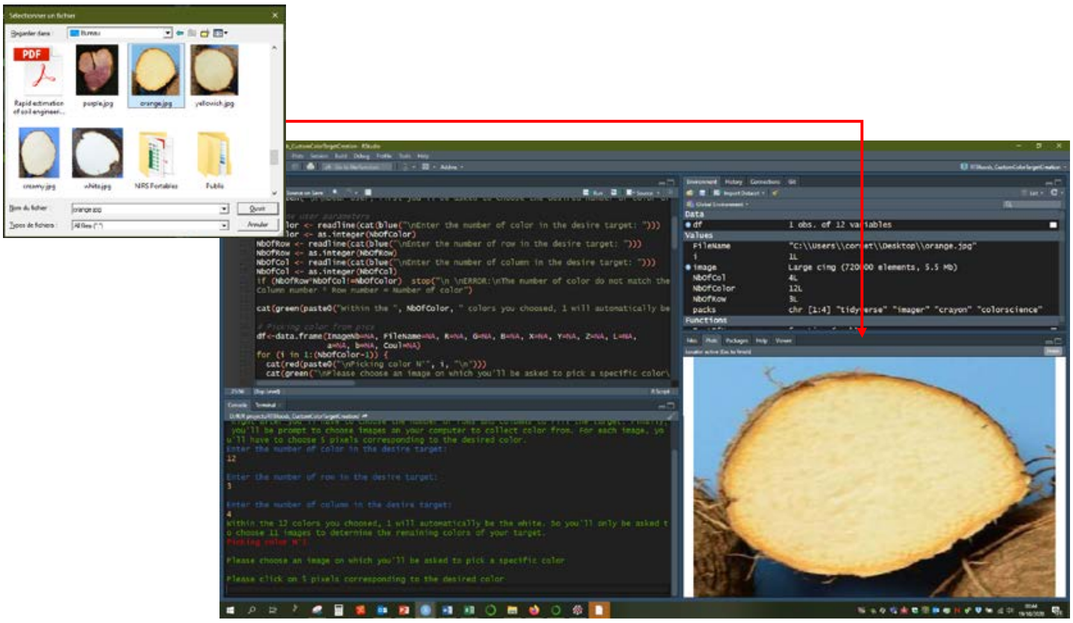

Figure 7: Pop up window allow the user to choose image location on the computer and open it in the RStudio environment.

Before building the chart, the difference between all pair of chosen color will be calculated using the CIE ΔE_{2000} (Luo et al. 2001). If some ΔE_{2000} are lower than 2, a warning is printed:

```
Warning: if deltaE2000 value is less than 2, only experienced observer can notice the difference between 2 colors. It is the case for some colors you selected. Please refer to output file ColorDifferences.csv for further detail. You may want to change some of these colors with more contrasted ones.
```

To identify which pairs of color look similar, a csv table is saved in the *out* folder of the RStudio project: *ColorDifferences.csv*. Mokrzycki & Tatol (2011) claimed that:

- $0 < \Delta E_{2000} < 1$: observer does not notice the difference,
- $1 < \Delta E_{2000} < 2$: only experienced observer can notice the difference,
- $2 < \Delta E_{2000} < 3.5$: unexperienced observer also notices the difference,
- $3.5 < \Delta E_{2000} < 5$: a clear difference in color is noticed,
- $5 < \Delta E_{2000}$: observer notices two different colors.

7.3 Printing and checking color value

8 EXPRESSION OF RESULTS

8.1 Method of calculation and formulae

8.1.1 Color spaces

Color space conversion is done starting from sRGB values of reference color as follow:

- **sRGB to XYZ**: CIE *XYZ* simulates the human perception, and which may be converted from *sRGB* as follow (Rec. ITU-R BT.709-5. 2002):

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = [M] \begin{bmatrix} sR \\ sG \\ sB \end{bmatrix}$$

with *M*, a color matrix depending on the reference white used (i.e. D50, D65):

$$M = \begin{cases} \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2126 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix} & if\ reference\ white\ is\ D65 \\ \begin{bmatrix} 0.4361 & 0.3851 & 0.1431 \\ 0.2225 & 0.7169 & 0.0606 \\ 0.0139 & 0.971 & 0.7142 \end{bmatrix} & if\ reference\ white\ is\ D50 \end{cases}$$

- **XYZ to Lab:** *CIE $L^*a^*b^*$* was designed so that the same amount of numerical change in these values corresponds to roughly the same amount of visually perceived change. It is defined as:

$$L^* = 116 f\left(\frac{Y}{Y_n}\right) - 16$$

$$a^* = 500\left[f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right)\right]$$

$$b^* = 200\left[f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right)\right]$$

with $f(q) = \begin{cases} q^{1/3} & if\ q > 0.08856 \\ 7.787q + {}^{16}/_{116} & otherwise \end{cases}$ and *Xn*, *Yn*, and *Zn* correspond to the theoretical *XYZ* values of the reference white.

8.1.2 Total Color differences

The total color difference (ΔE^*_{2000}) is calculated according to Luo et al. (2000).

8.2 Table and charts produced

Once the selection of pixels is made for all chosen images, the user can access to results in the *out* folder of the RStudio project:

- A custom reference chart *TargetB5.png* ready to print
- A custom reference chart with labelled color patch (i.e. patch number and color values) *TargetB5_RGB_Lab.png* (Figure 8)

- A summary csv table with color value and original files information *ChartColorValues.csv* (Figure 9)
- A summary csv table with ΔE_{2000} for every pair of color *ColorDifferences.csv*

Figure 8: Custom reference chart with labelled color patch (ie.e patch number and color values)

ImageNb	FileName	R	G	B	X	Y	Z	L	a	b	Coul	Row	Col
1	C:\Users\cornet\Desktop\white.jpg	234	241	240	0,8111225	0,86693896	0,94881536	94,6082437	-2,49655636	-0,32714136	#EAF1F0	1	1
2	C:\Users\cornet\Desktop\white.jpg	239	244	249	0,85042955	0,89891234	1,02474586	95,9516339	0,74661229	2,97661173	#EFF4F9	2	1
3	C:\Users\cornet\Desktop\creamy.jpg	234	233	223	0,76387962	0,81098215	0,81427014	92,1753781	-1,40248111	4,971860843	#EAE9DF	3	1
4	C:\Users\cornet\Desktop\creamy.jpg	227	224	197	0,68411314	0,73674054	0,63429074	88,7682069	-3,4958012	13,60037325	#E3E0C5	4	1
5	C:\Users\cornet\Desktop\yellowish.jpg	220	216	183	0,62617746	0,67747019	0,54568347	85,8797928	-4,06983614	16,79151913	#DCD8B7	1	2
6	C:\Users\cornet\Desktop\yellowish.jpg	216	210	169	0,58526781	0,63557616	0,46713126	83,7349076	-4,51346315	21,11450694	#D8D2A9	2	2
7	C:\Users\cornet\Desktop\orange.jpg	240	227	177	0,71340409	0,76639333	0,52621242	90,1553521	-3,16888457	26,0756209	#F0E3B1	3	2
8	C:\Users\cornet\Desktop\orange.jpg	244	201	109	0,60957941	0,62113925	0,23243446	82,9739679	4,576694463	51,11480275	#F4C96D	4	2
9	C:\Users\cornet\Desktop\purple.jpg	208	168	153	0,45765457	0,43716993	0,36158361	72,038929	12,41692924	13,29239136	#D0A899	1	3
10	C:\Users\cornet\Desktop\purple.jpg	174	110	116	0,26184799	0,21413386	0,19273674	53,3989832	26,20856248	7,357284271	#AE6E74	2	3
11	C:\Users\cornet\Desktop\purple.jpg	144	75	81	0,15503771	0,11557017	0,09197207	40,5032248	29,6446659	9,666357287	#904B51	3	3
12	Reference White	255	255	255	0,95047	1	1,08883	100	0	0	#FFFFFF	4	3

Figure 9: Summary csv table with color value and original file information.

8.3 Repeatability

Paper and printer quality (e.g. out of gamut values) may alter color during the printing process. In order to check the true color values, it is adviced to use a chromameter on the printed chart. This can be done following the SOP RTBfoods_H.2.3 (Alamu & Adesokan 2020).

Because true color values of the reference chart are known and stable, even if the light environment change (warmer light for instance) the relative evaluation is still accurate whatever we use visual evaluation or computerized image analysis.

9 Critical Points or Note on the Procedure

Because printed color is sensitive to light, it is advised to store the chart in a dark place and to print the chart on a yearly basis.

The use of a real white and matte paper is necessary to reduce color deterioration at printing.

10 APPENDICES

10.1 Appendix 1: R script

```
# Checking if library are available and (down)loading them
packs <- c("tidyverse","imager", "crayon", "colorscience")
InstIfNec<-function (pack) {
  if (!do.call(require,as.list(pack))) {
    do.call(install.packages,as.list(pack))  }
  do.call(require,as.list(pack)) }
lapply(packs, InstIfNec)
cat("\014")

cat(green("\n\nDear user, first you'll be asked to choose the desired number of color of your custom chart. Right after you'll have to choose the number of rows and columns to fill the chart. Finally, you'll be prompt to choose images on your computer to collect color from. For each image, you'll have to choose 5 pixels corresponding to the desired color."))

# Define user parameters
NbOfColor <- readline(cat(blue("\nEnter the number of color in the desired chart: ")))
NbOfColor <- as.integer(NbOfColor)
NbOfRow <- readline(cat(blue("\nEnter the number of row in the desired chart: ")))
NbOfRow <- as.integer(NbOfRow)
NbOfCol <- readline(cat(blue("\nEnter the number of column in the desired chart: ")))
NbOfCol <- as.integer(NbOfCol)
if (NbOfRow*NbOfCol!=NbOfColor)  stop("\n \nERROR:\nThe number of color do not match the number of cells in the chart. Please restart the script and ensure that:
Column number * Row number = Number of color")

cat(green(paste0("Within the ", NbOfColor, " colors you choosed, 1 will automatically be the white. So you'll only be asked to choose ", NbOfColor-1, " images to determine the remaining colors of your chart.")))

# Picking color from pics
df<-data.frame(ImageNb=NA, FileName=NA, R=NA, G=NA, B=NA, X=NA, Y=NA, Z=NA, L=NA, a=NA, b=NA, Coul=NA)
for (i in 1:(NbOfColor-1)) {
  cat(red(paste0("\nPicking color N°", i, "\n")))
  cat(green("\nPlease choose an image on which you'll be asked to pick a specific color\n"))
  FileName=file.choose(new=F)
  image<-load.image(FileName)
  image<-resize(image, 600, 400)
  cat(green("\nPlease click on 5 pixels corresponding to the desired color\n"))
  par(mar=c(0,0,0,0))
  plot(image)
  xy<-as.data.frame(lapply(locator(5), round, 0))
```

```
  RGB<-cbind(diag(image[xy$x, xy$y,1,1]),diag(image[xy$x, xy$y,1,2]), diag(image[xy$x, xy$y,1,3]))
  df[i,]<-c(i, FileName, round(mean(RGB[,1])*255,0), round(mean(RGB[,2])*255,0),
          round(mean(RGB[,3])*255,0), rep(NA, 7))
}

# Add reference white
White<-c(NbOfColor, "Reference White", 255, 255, 255, rep(NA, 7))
df<-rbind(df, White)
df[, -c(1:2)] <- sapply(df[, -c(1:2)],as.numeric)

# Get color values in other usefull colorspaces
for (i in 1:nrow(df)) {
  df[i, 6:8]<-RGB2XYZ(as.numeric(df[i, 3:5])/255)
  df[i, 9:11]<-XYZ2Lab(as.numeric(df[i, 6:8]))
  df[i, 12]<-rgb(df[i,3:5]/255)
}
df$Row<-rep(1:NbOfRow, NbOfCol)
df$Col<-rep(1:NbOfCol, each=NbOfRow)
df$PatchNb<-1:NbOfColor
df$TextColor<-ifelse((df$L/100) > 0.179, "black", "white")

# Save produced charts
png(height=9.8, width=6.9, res=300, filename="./out/TargetB5.png",
    units="in", type="cairo",family="Garamond")
g<-ggplot(df, aes(Col, Row))+
  geom_tile(color="black", size=3, fill=df$Coul)+
  theme_void()+
  theme(legend.position = "none", plot.background = element_rect(fill = "black"))
print(g)
dev.off()

png(height=9.8, width=6.9, res=300, filename="./out/TargetB5_RGB_Lab.png",
    units="in", type="cairo",family="Garamond")
g<-ggplot(df, aes(Col, Row))+
  geom_tile(color="black", size=3, fill=df$Coul)+
  theme_void()+
  geom_text(aes(x=Col, y=Row+0.3, label=PatchNb), color=df$TextColor, size=12)+
  geom_text(aes(x=Col, y=Row+0.1, label=paste0("RGB (", R, ",", G, ",", B, ")")),
          size=4, color=df$TextColor)+
  geom_text(aes(x=Col, y=Row, label=paste0("XYZ (", round(X,2), ",",
                                round(Y, 2), ",", round(Z, 2), ")")),
          size=4, color=df$TextColor)+
```

```
  geom_text(aes(x=Col, y=Row-0.1, label=paste0("Lab (", round(L,0), ",",
                                  round(a, 0), ",", round(b, 0), ")")),
          size=4, color=df$TextColor)+
  theme(legend.position = "none", plot.background = element_rect(fill = "black"))
print(g)
dev.off()

# Calculation of color differences between selected patches
cb<-combn(df$PatchNb, 2)
dE<-data.frame(PatchNb1=NA, PatchNb2=NA, dE2000=NA)
for (i in 1:ncol(cb)) {
  dE[i,]<-c(cb[,i], deltaE2000(t(df[cb[,i][1], c("R", "G", "B")])[,1],
                          t(df[cb[,i][2], c("R", "G", "B")])[,1]))
}
dE<-dE[order(dE$dE2000),]

if (min(dE$dE2000)<2) {
  cat(green("\nWarning: if deltaE2000 value is less than 2, only experienced observer can notice the difference between 2 colors. It is the case for some colors you selected. Please refer to output file ColorDifferences.csv for further detail. You may want to change some of these colors with more contrasted ones."))
}

# Saving data frames
write.csv2(df[,-c(15,16)], "./out/ChartColorValues.csv", row.names =F)
write.csv2(dE, "./out/ColorDifferences.csv", row.names =F)
```

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