Sensory Study of Cold Brew Arabica Coffee Based on Brewing Time and Water Temperature

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Stat 224 - Design of Experiments

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Abstract

Cold brew coffee is an alternative method of brewing coffee as the younger generation is more inclined on this coffee drink. This paper studies a pilot study looking for an optimal method of cold brewing Arabica French press coffee comparing different brewing techniques on water temperature and brewing time. Sensory analysis results showed that regardless of the cold brewing technique, based on coffee tasting experience, the coffee was generally favorable. Cold brew coffee profile can be extracted as early as 4 hours but even the 8-hour brewing time lacked the distinct coffee aroma profile. In a home setting, there is no optimal method for cold brewing coffee as this varies based on the coffee drinker's preference.

Keywords: cold brew coffee, brewing time, water temperature, sensory analysis

Sensory Study of Cold Brew Arabica Coffee Based on Brewing Time and Water Temperature

In the Philippines, especially during the warmer months of the year, more coffee drinkers prefer drinking cold beverages. A popular international coffee chain marketed their summer-inspired beverages indicating more consumers are drinking cold beverages (Interaksyon, 2024). Also, according to the USA National Coffee Association, cold brew coffee has been increasing in popularity (French, 2023). In Poland, almost 13% of the population prefers cold brew coffee (Czarniecka, 2021); this is in line with at least more than 10% of the population in the USA that prefers cold brew coffee, too.

A survey study was conducted in Thailand, which is also a tropical country, exploring preferences on coffee drinking and it found out that 73% of the respondents prefer iced coffee and 6% would mostly order a cold brew coffee (Satjawitwisarn, 2019). Although iced coffee is different from cold brew coffee, as the former can be prepared using hot brew method, the temperature of the cold brew coffee makes it practical for the coffee drinker to enjoy the beverage cold.

In contrast with the hot brew method, the cold brew has a more floral taste and less bitter, sour, and rubbery taste profile (Batali, 2022) which can be associated with the younger population being attracted to its taste when marketed on TikTok (Angell, 2021).

Materials and Method

The experiment

A 2 x 2 factorial experimental design was conducted testing the method of cold brewing using purified water in fridge temperature and room temperature in air-tight glass jars replicating a home setting. Another factor considered was testing the brewing time between 4 and 8 hours. An overall summation score of sensory variables was constructed to

assess if the respondent would prefer which brewing methods they would seem palatable to their preferences.

Assessments and measures

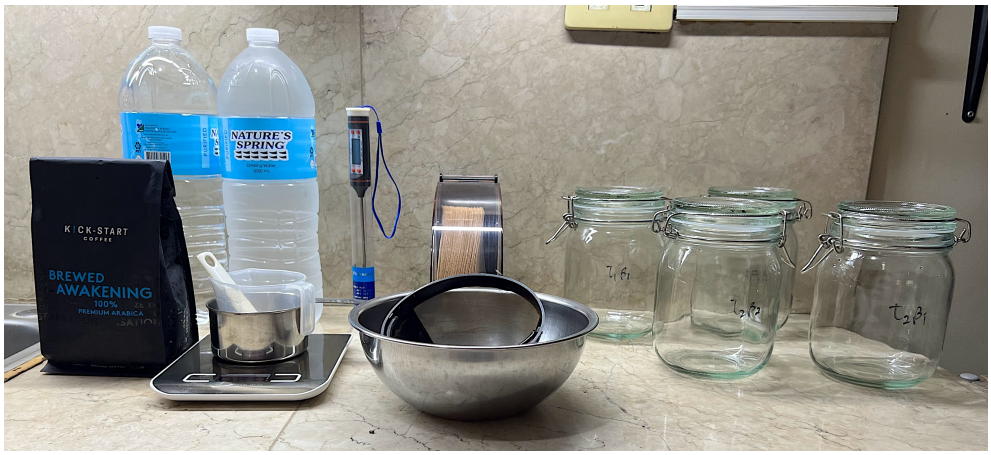
Coffee grounds. As shown in Figure 1, a supermarket-bought Kickstart Coffee Premium Arabica French press ground coffee was selected. This was a medium-dark roast choice as this produced a fuller and deeper flavor than the light and medium roast, according to the Agtron Scale (Pérez, 2016). Although the coffee grind particle size influences the taste of the coffee when brewed at different brewing methods, only the coarse (French press) grind size was selected (Fuller, 2017).

Coffee to water ratio remained constant at 75 g/liter (60 grams of coffee ground to 800 ml of purified water) as this was within the coffee to water ratio range recommendation by International Organization for Standardization, 2008 for sensory study (Claassen, 2021). This was measured using a digital weighing scale, excluding the weight of the measurement cup. The 800 ml purified water was measured using a plastic 250 ml measuring cup in batches.

After measurement, the coffee grounds were mixed inside the water jars and shaken vigorously by hand ensuring proper mixture. To replicate a home-made cold brew preparation, all jars were left undisturbed except when taking temperature measurement.

Figure 1

Materials Used in the Experiment



Water temperature. Two levels of water temperatures were considered as the first treatment of the experiment: ($\boldsymbol{\tau}_1$) fridge temperature which was approximately < 8°C and ($\boldsymbol{\tau}_2$) room temperature in the Philippines. These were the starting water temperatures at the time of water immersion of the ground coffee beans and will be stored in 1 liter air-tight glass jars to reduce the contamination of bacteria as shown in Figure 2. As the average temperature fluctuated all throughout the brewing time even in a household refrigerator or stored in the shaded and dark place in the experimenter's location, it was considered as an uncontrollable factor. A cooking digital thermometer was used to measure the hourly temperature while cold brewing, measured after 30 seconds after dipping the thermometer conductor into the water; this was used to assess and minimize variation on the brewing temperature.

Figure 2

Starting Room Temperature

Brewing time. According to the experiment performed by Claassen et al., the flavor profile of a cold brew coffee can be extracted as early as 2 to 3 hours in a warm environment. Due to the experimenter's location in a tropical country, this was accounted so the selection of brewing time treatment levels were set at (β_1) 4 hours and (β_2) 8 hours, taking consideration that the conclusion of the study from Claassen et al., resulted that the coffee extraction did not require to be more than 7 hours to release the coffee profile (Claassen, 2021). These brewing times were within 10% of the survey respondents who cold brewed their coffees between 2 to 8 hours, almost 25% who cold brewed within 8 to 14 hours (Claassen, 2021).

Brewing was scheduled a day before the respondents tasted the cold brew coffee. After cold brewing, the coffee grounds were filtered using a double-filtration of fine wire mesh and paper filter into separate glass containers, as shown on Figure 3. After all the coffee liquid has been filtered, the coffees were put back in clean air-tight glass jars and stored in the

fridge to avoid rancidity and retain freshness. The jars were placed in an ice box filled with ice to retain the cold temperature before respondent tasting.

Figure 3

Double Filtration Method

Sensory score. Five sensory profiles were scored according to the respondent's preference which were the simplified version based on ISO 2008 for coffee preparation sensory analysis. These profiles were scored by the respondent from 1 to 5 where 1 was the lowest and 5 being the highest. These were (1) aroma - pleasant smell from the coffee, (2) flavor - notes of bitterness, sweetness, floral and fruitiness, (3) acidity - sharpness or numbing sensation in the tongue, (4) body - perception of how heavy or strong the coffee was in the mouth and lastly, (5) aftertaste - the flavor that lingered after drinking the coffee. The row sums of these profiles were the dependent variable (Caballero, 2015).

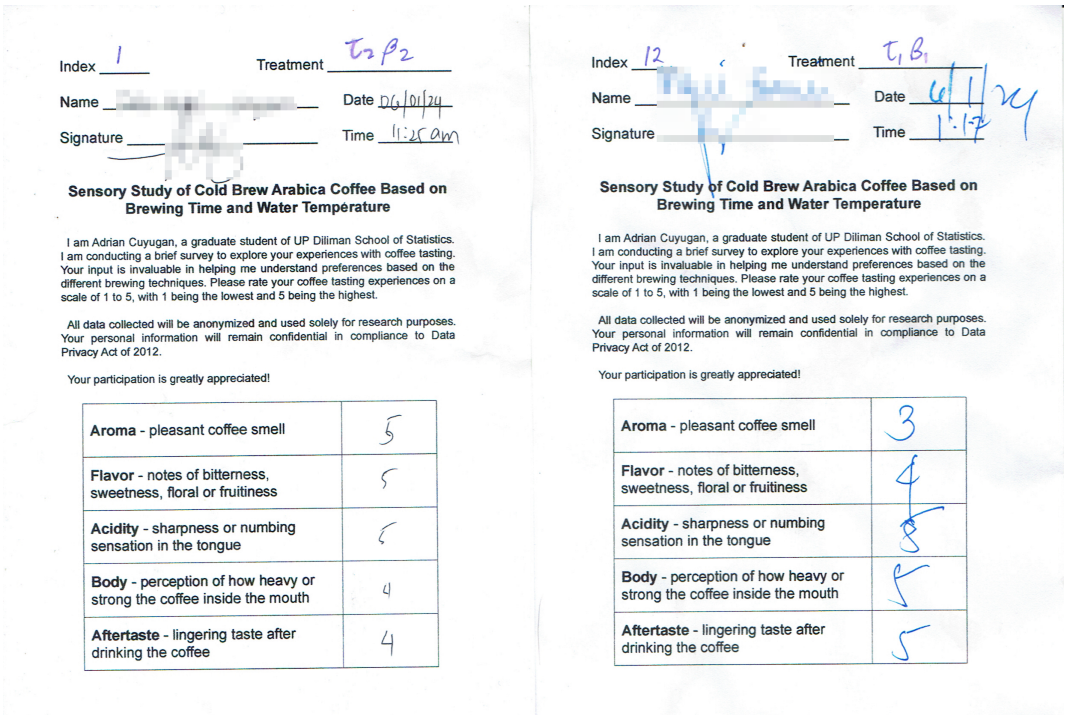
The sum of each sensory attribute was chosen to be the dependent variable, referenced from the unstructured hedonic scale (International Organization for Standardization, 2003).

Respondents. As shown in Figure 4, twelve respondents were selected among the experimenter's group of friends which produced 3 replicates per combination of treatment levels. Each respondent was assigned a unique index number on the survey form. Randomization of the combination of treatments of cold brew coffee was done using the standard normal distribution arranged in ascending order assigned for each index. A cup of cold brew coffee from the randomized coffee treatment was served to each respondent but was not required to finish the whole serving.

Another uncontrollable factor considered was the respondent's preference of adding fats such as milk or non-dairy creamer, and sweetener such as sugar. To minimize this, the respondents were asked only to score the sensory attributes based on black cold brew coffee. The respondents were only allowed to taste the chosen brewing treatment and were asked to complete the survey form after tasting. The respondents were also asked not to share their scores.

Figure 4

Anonymized Survey Form



Index 1 Treatment T_2B_2

Name [redacted] Date 06/01/24

Signature [redacted] Time 11:25 am

Sensory Study of Cold Brew Arabica Coffee Based on Brewing Time and Water Temperature

I am Adrian Cuyugan, a graduate student of UP Diliman School of Statistics. I am conducting a brief survey to explore your experiences with coffee tasting. Your input is invaluable in helping me understand preferences based on the different brewing techniques. Please rate your coffee tasting experiences on a scale of 1 to 5, with 1 being the lowest and 5 being the highest.

All data collected will be anonymized and used solely for research purposes. Your personal information will remain confidential in compliance to Data Privacy Act of 2012.

Your participation is greatly appreciated!

Aroma - pleasant coffee smell	5
Flavor - notes of bitterness, sweetness, floral or fruitiness	5
Acidity - sharpness or numbing sensation in the tongue	5
Body - perception of how heavy or strong the coffee inside the mouth	4
Aftertaste - lingering taste after drinking the coffee	4

Index 12 Treatment T_1B_1

Name [redacted] Date 6/1/24

Signature [redacted] Time 1:17

Sensory Study of Cold Brew Arabica Coffee Based on Brewing Time and Water Temperature

I am Adrian Cuyugan, a graduate student of UP Diliman School of Statistics. I am conducting a brief survey to explore your experiences with coffee tasting. Your input is invaluable in helping me understand preferences based on the different brewing techniques. Please rate your coffee tasting experiences on a scale of 1 to 5, with 1 being the lowest and 5 being the highest.

All data collected will be anonymized and used solely for research purposes. Your personal information will remain confidential in compliance to Data Privacy Act of 2012.

Your participation is greatly appreciated!

Aroma - pleasant coffee smell	3
Flavor - notes of bitterness, sweetness, floral or fruitiness	4
Acidity - sharpness or numbing sensation in the tongue	5
Body - perception of how heavy or strong the coffee inside the mouth	5
Aftertaste - lingering taste after drinking the coffee	5

Data analysis. Analysis of variance was used to identify the relationship between the treatment factors and the sensory score. ANOVA calculation was done using the ANOVA estimation using R (R Core Team, n.d.) and the codes are available in the Appendix for reproducibility. Residual analysis was also done to ensure that the model was valid. Also, several statistical tests of normality were computed on the residuals.

The two factor interactions among the samples were also attributed as the focus of study using a fixed effects model. Post-hoc tests were also done on the interactions.

Supplemental Spearman correlation analysis was performed on each sensory profile score to ensure that these individual attributes did not exhibit high multicollinearity. Descriptive plots and summary statistics were prepared on the sensory scores, brewing hourly temperatures and treatment effects.

Results

Sensory score

In Figure 5, coffee that was cold brewed inside the fridge scored higher ($\boldsymbol{\mu}$ = 21.5, $\boldsymbol{\sigma}$ = 2.8) than cold brewed in room temperature ($\boldsymbol{\mu}$ = 18.8, $\boldsymbol{\sigma}$ = 5). While the 4-hour brewing time treatment scored higher ($\boldsymbol{\mu}$ = 21.2, $\boldsymbol{\sigma}$ = 3.5) than 8-hour brewing time treatment ($\boldsymbol{\mu}$ = 19.2, $\boldsymbol{\sigma}$ = 4.7); the differences in their means were not tested statistically. From a possible total score of 25 points, the results were generally favorable regardless of the brewing technique.

The largest variation in each sensory attribute after combining the brewing techniques, was the treatment when cold brewed at room temperature of 8 hours. Also, it is noticeable that when cold brewed, the coffee lacked the distinct coffee aroma as shown in Figure 6.

The acidity profile is highly correlated with the aftertaste profile (r=0.93) as shown in Figure 7.

Figure 5

Distribution Plots of Sensory Score

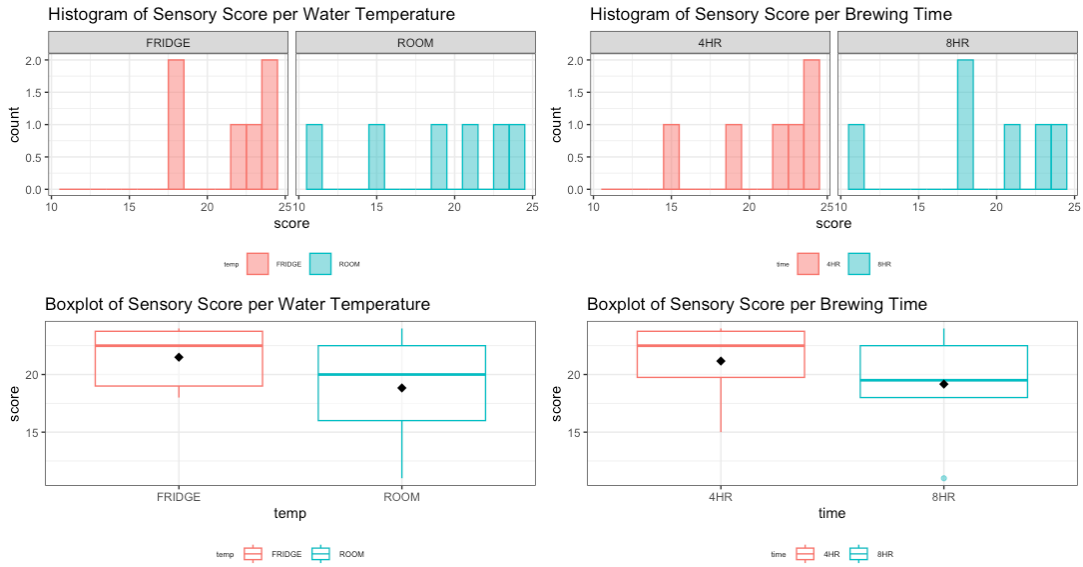


Figure 6

Distribution of Sensory Attributes per Treatment

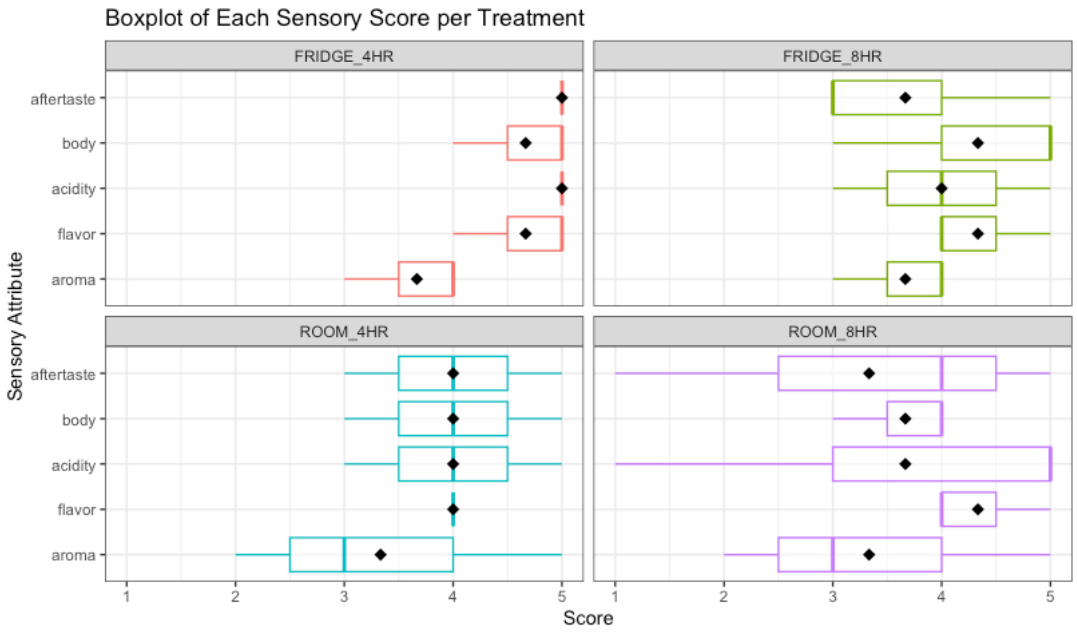
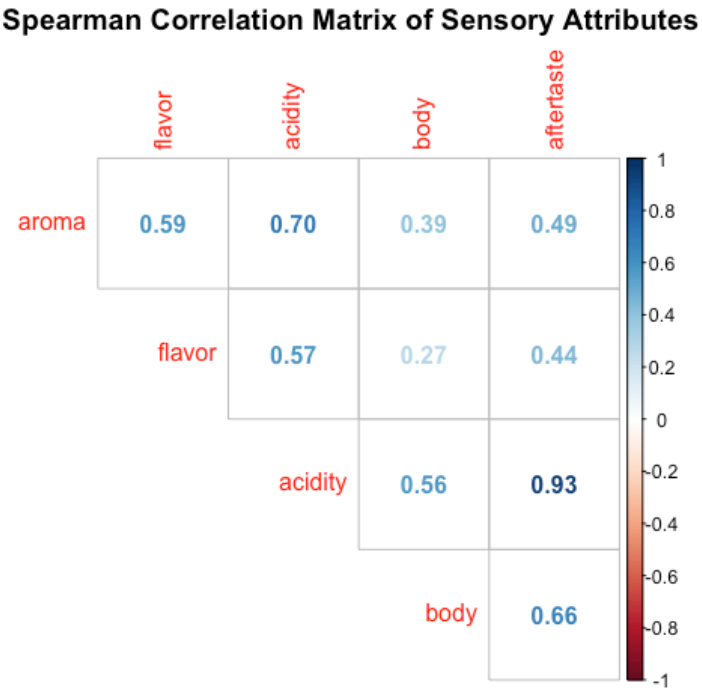


Figure 7

Correlation Matrix of Sensory Attributes



Results of sensory score on cold brewing technique

Table 7 shows that there were no significant variables on both the main effects (F_{fridge} = 1.143, p-value = 0.316 and F_{time} = 0.643, p-value = 0.446) and the interaction treatment effects ($F_{temp:time}$ = 0.161, p-value = 0.699). Although the coffee that was brewed inside the fridge for 4 hours had the highest mean sensory score and smallest standard deviation, as shown in Figure 8, the differences in the means of other cold brewing techniques were not significantly different from each other as shown in Figure 9; these were tested using Scheffe's test (min $\boldsymbol{\mu}$ = 48.35), Tukey HSD test (min $\boldsymbol{\mu}$ = 44.33), Duncan's new multiple range test (min $\boldsymbol{\mu}$ = 31.93 at critical range 2) and Fisher's LSD test (min $\boldsymbol{\mu}$ = 31.93).

The residuals were approximately normal. Although there were some outliers that could have affected the model fit, as there were only 3 replicates from the 2 x 2 design as shown in Figure 10.

The following normality tests were also calculated and were found that the residuals were approximately normally distributed using Shapiro-Wilk normality test (W = 0.94, p-value = 0.6257), Exact one-sample Komolgorov-Smirnov test on normal distribution (D = 1.727, p-value < 0.01) and Anderson-Darling normality test (A = 0.2352, p-value = 0.733).

Table 2

ANOVA table

	Sum Sq	df	F	p-value
(Intercept)	1587.00	1	85.0179	< 0.01
temp	20.17	1	1.0804	0.3290
time	13.50	1	0.7232	0.4198
temp:time	3.00	1	0.1607	0.6990
Residuals	149.33	8		

Figure 8

Interaction plot

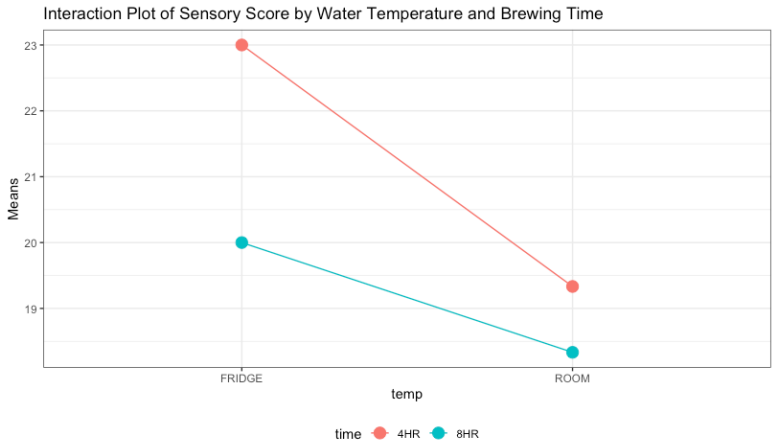


Figure 9

Post-hoc tests

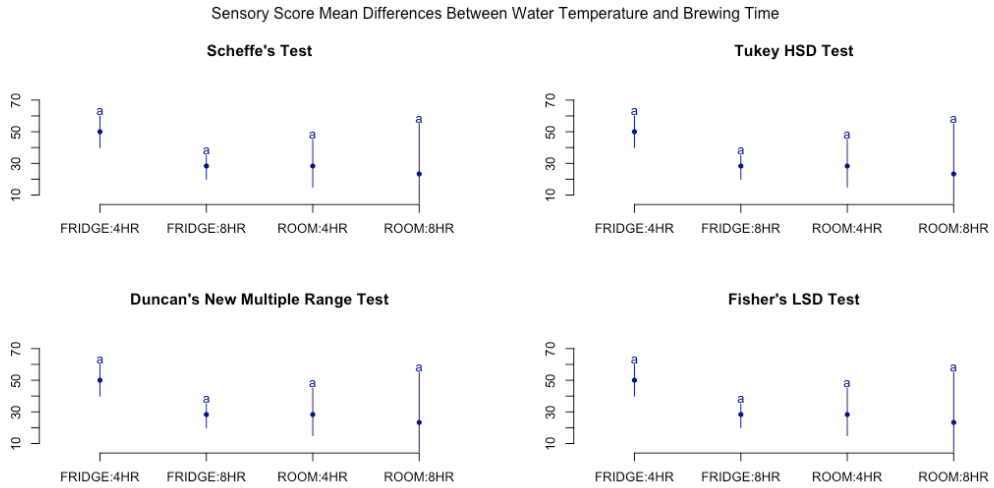
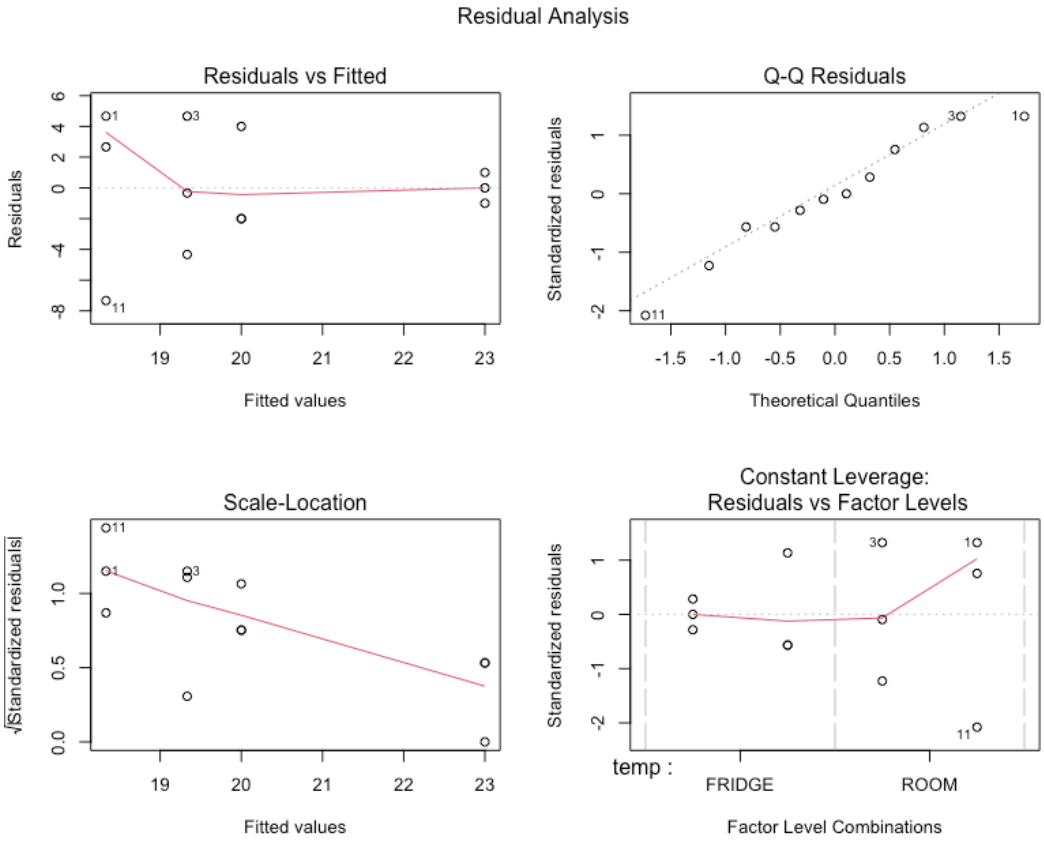


Figure 10

Residual analysis plots



Discussion

In this experiment, it has been found that regardless of the cold brewing technique of Arabica French ground coffee, whether it was brewed in a room temperature or inside the fridge, or brewed for 4 hours and 8 hours, the sensory analysis based on the coffee tasting experience were found to be not significant or has no effect in a home setting, that no such thing as optimal cold brewing method as this varies according to an individual's preference. This is beneficial that coffee can be cold brewed as early as 4 hours if a coffee drinker prefers to get a dose of caffeine in mid-afternoon after it has started brewing in the morning.

As coffee drinkers tend to look for the distinct coffee aroma which lacked in cold brew method, it is not recommended to choose this method but if a coffee drinker prefers a less acidic and bolder taste, the results showed that this method is effective. Also, the double filtration adds to the more pleasant coffee experience as there were very little fine powder sediments of coffee grounds.

As the ground coffee could potentially have been exposed to other microbial hazards during roasting and grinding, the cold brew method should be performed in a sanitary manner, using air-tight glass containers is one of those.

It would be interesting to extend this experiment to other coffee variety such as Robusta or mixed. Also, a different experiment can be conducted comparing the hot brew vs cold brew method as more coffee drinkers are typically familiar with the former and recently, the younger generation is more inclined to enjoy the latter.

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Appendix

Introduction

A summary of R codes used to do statistical analysis on an experimental design case study. This is a supplemental document to be included in the research paper.

```
#### Library management ####
## Install necessary libraries
install.packages(c('car','psych','nortest','ggplot2','dplyr', 'corrplot',
                   'data.table', 'gridExtra', 'agricolae', 'car'),
                 repos = "http://cran.us.r-project.org")

## Load libraries
library(car)          # Regression analysis
library(psych)        # Descriptive stats
library(nortest)      # Anderson-Darling test for normality
library(ggplot2)      # Graphics
library(dplyr)        # Data preparation
library(data.table)   # Data preparation
library(gridExtra)    # Side by side plots
library(agricolae)    # Post-hoc tests
library(corrplot)     # Correlation plot
```

Dataset preparation

Randomize experimental units

Randomization of 12 experimental units using standard normal distribution to form a 2 x 2 factorial experiment.

Treatment levels

1. Water temperature
   - Room
   - Fridge
2. Brewing time
   - 4 hours
   - 12 hours

```
# Set random seed for reproducibility
set.seed(100)

## Create dataset of treatment levels
# Create standard normal random numbers
# Create 3 replicates of water temperature x brewing time
df <- data.frame(random = rnorm(n = 12, mean = 0, sd = 1),
                 temp = as.factor(c(rep('ROOM', each = 3),
                                    rep('FRIDGE', each = 3),
                                    rep('ROOM', each = 3),
                                    rep('FRIDGE', each = 3))),
```

```
                  time = as.factor(c(rep('4HR', each = 6),
                                     rep('8HR', each = 6))))

# Arrange random numbers in ascending order for randomization of responden
ts
df <- df %>% arrange(random)

# Remove randomization column
df <- df[,-1]

# Create respondent index after randomization
df <- data.frame(df, index = as.double(1:12))
```

Sensory scores

Five sensory attributes were collected during coffee tasting experience scored on an unlabeled 5-point scale. These are:

1. Aroma
2. Flavor
3. Acidity
4. Body
5. Aftertaste

The sensory score is the sum of all sensory attributes.

```
## Sensory score dataset based on respondents' answers ##
sensory <- data.frame(index = as.double(1:12),
                      aroma = as.numeric(c(5,3,5,4,3,3,4,4,2,4,2,3)),
                      flavor = as.numeric(c(5,4,4,4,4,4,5,5,4,5,4,4)),
                      acidity = as.numeric(c(5,5,5,4,4,3,5,5,3,5,1,5)),
                      body = as.numeric(c(4,4,5,3,4,5,5,4,3,5,3,5)),
                      aftertaste = as.numeric(c(4,5,5,3,4,3,5,5,3,5,1,5)))

# Row sums of Sensory Score
sensory$score <- rowSums(sensory[,2:6])

# Merge datasets
df <- merge(x = df, y = sensory, by.x = 'index')
```

Water temperature while brewing

The water temperature of each treatment were monitored hourly to assess variation.

```
## Temperature Monitoring per Treatment
# Create dataset
monitor_df <- setNames(data.frame(t(data.frame(
  c('2024-05-31 16:15:00', 'Fridge', '4Hr', 13.1),
  c('2024-05-31 16:17:00', 'Fridge', '8Hr', 13),
  c('2024-05-31 16:20:00', 'Room', '4Hr', 29.7),
  c('2024-05-31 16:24:00', 'Room', '8Hr', 29.6),
  c('2024-05-31 17:25:00', 'Fridge', '4Hr', 14.3),
```

```
  c('2024-05-31 17:25:00', 'Fridge', '8Hr', 14.8),
  c('2024-05-31 17:27:00', 'Room', '4Hr', 31.1),
  c('2024-05-31 17:28:00', 'Room', '8Hr', 31.1),
  c('2024-05-31 18:34:00', 'Fridge', '4Hr', 11.3),
  c('2024-05-31 18:35:00', 'Fridge', '8Hr', 11.3),
  c('2024-05-31 18:31:00', 'Room', '4Hr', 31.6),
  c('2024-05-31 18:32:00', 'Room', '8Hr', 31.5),
  c('2024-05-31 19:37:00', 'Fridge', '4Hr', 8.1),
  c('2024-05-31 19:38:00', 'Fridge', '8Hr', 8.3),
  c('2024-05-31 19:39:00', 'Room', '4Hr', 31.9),
  c('2024-05-31 19:40:00', 'Room', '8Hr', 32),
  c('2024-05-31 20:34:00', 'Fridge', '4Hr', 6),
  c('2024-05-31 20:34:00', 'Fridge', '8Hr', 5.8),
  c('2024-05-31 20:30:00', 'Room', '4Hr', 32.1),
  c('2024-05-31 20:31:00', 'Room', '8Hr', 32.1),
  c('2024-05-31 21:25:00', 'Fridge', '8Hr', 5.3),
  c('2024-05-31 21:26:00', 'Room', '8Hr', 32.1),
  c('2024-05-31 22:32:00', 'Fridge', '8Hr', 5.7),
  c('2024-05-31 22:31:00', 'Room', '8Hr', 32.1),
  c('2024-05-31 23:28:00', 'Fridge', '8Hr', 4.9),
  c('2024-05-31 23:27:00', 'Room', '8Hr', 32),
  c('2024-06-01 00:18:00', 'Fridge', '8Hr', 6.2),
  c('2024-06-01 00:28:00', 'Room', '8Hr', 31.9)
  )), row.names = NULL),
  c('datetimestamp', 'temp', 'time', 'celcius'))

# Adjust datatype per column in monitor_df
monitor_df$datetimestamp <- as.POSIXct(monitor_df$datetimestamp, tz = 'Asi
a/Manila')
monitor_df$temp <- as.factor(monitor_df$temp)
monitor_df$time <- as.factor(monitor_df$time)
monitor_df$celcius <- as.double(monitor_df$celcius)
```

Exploratory data analysis

Summary statistics and descriptive plots.

Summary statistics

```
# Score by water temperature and brewing time
describeBy(x = df, group = df$temp, digits = 2)
describeBy(x = df, group = df$time, digits = 2)
```

Descriptive plots

Water temperature and brewing time

Histogram and boxplot

```
## Descriptive plots
temp_hist <- ggplot(data = df, aes(x = score, col = temp, fill = temp)) +
  geom_histogram(binwidth = 1, alpha = 0.5) +
  ggtitle('Histogram of Sensory Score per Water Temperature') +
```

```
  facet_wrap(~ temp) +
  theme_bw() +
  theme(legend.position = "bottom",
        legend.title = element_text(size = 5),
        legend.text = element_text(size = 5))

time_hist <- ggplot(data = df, aes(x = score, col = time, fill = time)) +
  geom_histogram(binwidth = 1, alpha = 0.5) +
  ggtitle('Histogram of Sensory Score per Brewing Time') +
  facet_wrap(~ time) +
  theme_bw() +
  theme(legend.position = "bottom",
        legend.title = element_text(size = 5),
        legend.text = element_text(size = 5))

temp_box <- ggplot(data =  df, aes(x = temp, y = score)) +
  geom_boxplot(aes(col = temp), alpha = 0.5) +
  stat_summary(fun = mean, colour = 'black', geom = "point",
               shape = 18, size = 3, show.legend = F) +
  ggtitle('Boxplot of Sensory Score per Water Temperature') +
  theme_bw() +
  theme(legend.position = "bottom",
        legend.title = element_text(size = 6),
        legend.text = element_text(size = 6))

time_box <- ggplot(data =  df, aes(x = time, y = score)) +
  geom_boxplot(aes(col = time), alpha = 0.5) +
  stat_summary(fun = mean, colour = 'black', geom = "point",
               shape = 18, size = 3, show.legend = F) +
  ggtitle('Boxplot of Sensory Score per Brewing Time') +
  theme_bw() +
  theme(legend.position = "bottom",
        legend.title = element_text(size = 6),
        legend.text = element_text(size = 6))

# Arrange the histogram and boxplots into one plot
grid.arrange(temp_hist, time_hist,
             temp_box, time_box, nrow = 2, ncol = 2)
```

Sensory scores

Boxplot of each sensory score per treatment.

```
## Distribution of Sensory Scores
# Create dataset from final to remove index and overall score
drop_cols <- c('index', 'score')
sensory_df <- df[, !(names(df) %in% drop_cols)]

# Combine treatment levels into one column
sensory_df$treatment <- as.factor(paste(sensory_df$temp, sensory_df$time,
sep = '_'))

# Remove Water Temperature and Brewing Time columns
```

```
sensory_df <- sensory_df[, -1:-2]

# Transform sensory_df from wide to long format
sensory_df_tall <- melt(setDT(sensory_df), id.vars = 'treatment')

# Boxplot of sensory scores faceted by brewing time
ggplot(data = sensory_df_tall, aes(x = value, y = variable)) +
  geom_boxplot(aes(col = treatment), alpha = 0.5) +
  stat_summary(fun = mean, col = 'black', geom = "point",
               shape = 18, size = 3, show.legend = F) +
  facet_wrap(~ treatment) +
  xlab('Score') + ylab('Sensory Attribute') +
  ggtitle('Boxplot of Each Sensory Score per Treatment') +
  theme_bw() +
  theme(legend.position = 'none')
```

Correlation

Spearman correlation matrix plot of sensory attributes.

```
# Compute correlation matrix
sensory_corr <- cor(sensory_df[,1:5], method = 'spearman')
corrplot(sensory_corr, method="number", mar=c(0,0,2,0), diag = F, type = '
upper',
         title = 'Spearman Correlation Matrix of Sensory Attributes')
```

Lineplot of temperature monitoring

Lineplot of temperature monitoring per treatment.

```
## Line plot of Temperature Monitoring per Treatment
ggplot(monitor_df, aes(x = datetimestamp, y = celcius)) +
  geom_line(aes(col = time:temp)) +
  facet_wrap(~time) +
  ylim(0, 35) +
  ggtitle('Temperature Monitoring per Treatment') +
  xlab('Timestamp') + ylab('Celcius') +
  theme_bw() +
  theme(legend.position = 'bottom')
```

Model

ANOVA

```
## ANOVA
model <- aov(score ~ temp*time, data = df)
Anova(model, type = "III")
```

Residual analysis

1. Residuals vs fitted values / homogeneity of variance
2. Normal probability plot of residuals / normality of residuals

3. Standardized residuals vs Fitted values
4. Spread level plot

```
par(mfrow = c(1,2))
par(mar = c(5,4,4,2))
plot(model, which=c(1,2))
mtext("Residual Analysis", side = 3, line = -1, outer = T)
par(mfrow = c(1,1))

# Normality tests on residuals
shapiro.test(model$residuals)
ks.test(x = model$residuals, y = 'rnorm')
ad.test(model$residuals)

# Test of constancy of variance on residuals
leveneTest(score ~ temp*time, data = df)
```

Interaction effect

```
# Calculate means for each treatment combination
score_means <- df %>%
  group_by(temp, time) %>%
  summarise(Means = mean(score),
            SD = sd(score))
print(score_means)

# Interaction plot
ggplot(data = score_means, aes(x = temp, y = Means, col = time, group = ti
me)) +
  geom_point(size = 4) + geom_line() +
  ggtitle('Interaction Plot of Sensory Score by Water Temperature and Brew
ing Temperature') +
  theme_bw()
```

Post-hoc tests

1. Scheffe's Test
2. Tukey HSD Test
3. Duncan's New Multiple Range Test
4. Fisher's LSD Test

```
# Scheffe's test
scheffe <- scheffe.test(model_aov, trt = c('temp', 'time'), console = T)
print(scheffe)

# Tukey HSD
tukey <- HSD.test(model_aov, trt = c('temp', 'time'), console = T)
print(tukey)

# Duncan's new multiple range test
duncan <- duncan.test(model_aov, trt = c('temp', 'time'), console = T)
print(duncan)

# Least Significant difference
```

```
lsd <- LSD.test(model_aov, trt = c('temp', 'time'), console = T)
print(lsd)

# Plot post-hoc tests groups
par(mfrow = c(2,2))
par(mar = c(3,5,6,1))

plot(scheffe, main = "Scheffe's Test")
plot(tukey, main = 'Tukey HSD Test')
plot(duncan, main = "Duncan's New Multiple Range Test")
plot(lsd, main = "Fisher's LSD Test")
mtext("Sensory Score Mean Differences Between Water Temperature and Brewin
g Time",
      side = 3, line = -1.2, outer = T)

par(mfrow = c(1,1))
```