Date of submission: 5/21/22

The Effect of Temperature and Tea Type on pH

Zachary Stewart, Political Science, California Polytechnic State University
Matthew Chen, Statistics, California Polytechnic State University
Myles Harp, Statistics, California Polytechnic State University

Abstract

In this study, we sought out to find if either the temperature that tea is brewed at or the type of tea being brewed have an effect on pH. To discover the answer to this question, we conducted an experiment in which we purchased three different kinds of tea (green, black, and oolong) and ran 36 separate tests in a random order. In this test we had three replicates of each different treatment combination. This experiment had a 4X3 factorial treatment structure with twelve different treatment combinations. The design structure of this study was a completely randomized design with three replicates for each treatment combination. From our experiment, we found that the model as a whole was significant on the pH level of the tea. After further analysis in the effects tests, we found that the factor of tea type has a significant effect on the pH level of the tea, while temperature does not appear to be significant. In addition to this, an interaction effect between the factors of tea type and temperature was observed. This experiment could be important to understanding the most optimal tea brewing methods.

1. Introduction

We conducted this experiment to determine if the temperature or tea type have an effect on the PH level of the tea. We tested three types of tea at four different temperatures to see if our assumptions were correct. We used a total of 36 tea bags for this experiment with three teas for every treatment combination. We are hoping that the experiment will give us insight into how tea type and temperature affect pH level of tea. We know different tea types have different ingredients, but want to see what actual differences there are in the pH level. We hope this experiment brings awareness about different aspects of the tea brewing process to the Western World that are not common knowledge for the general public.

Green, black, and oolong tea originate in East Asia and are known to be good for health and well-being. For thousands of years, East Asians have drank tea with their meals and have been used as an herbal medicine. Since most researchers in the western world conduct research of food and beverages based on their Western diet, we hope that our experiment could bring awareness to the readers about the popularity of different tea type in East Asia. Studying and analyzing the pH level of each treatment combination can bring more awareness about the potential effects of certain kinds of teas to this audience. One important aspect of this experiment to consider is that no additives such as sugar, lemon, or milk are involved in this study. Adding additives such as sugar, milk, or lemon can change the chemical structure of the tea, reducing the tea's potential health benefits. According to the article "Identification and Classification of the Tea Samples by UsingSensory Mechanism and Arduino UNO", adding milk is better when compared to sugar and lemon when it comes to the health benefits, because it does not change the pH level of the tea since it is nearly neutral. Knowing there are differences in pH levels of teas is important as well, according to the article "Identification and Classification of the Tea Samples by UsingSensory Mechanism and Arduino UNO", black tea has a PH level of around 4.9 to 5.5, green tea is around 7 to 10,and oolong tea ranges from around 5.9 to 8.2. The main difference between these types of teas is the method of cultivation which results in a difference of look, smell, and pH.

2. Materials and Methods

2.1 Treatment Structure

In this experiment, we used a 4x3 factorial treatment structure with 12 total treatment combinations. The first factor of interest we identified was the temperature of the tea being brewed. Temperature is an ordinal variable that was identified at four levels at 140℉,145℉,150℉,155℉. These specific levels were chosen, because our PH meter only worked up to temperatures of 160℉. The 2nd factor we used in this experiment was the type of tea which is nominal. In this

experiment we used three different types of tea (green, black, and oolong) to give a broad spectrum of how different teas affect pH.

2.2 Response Variable(s)

The one response variable we identified in this experiment was pH. pH is a scale from 0-14 that measures the total concentration of hydronium ions in a solution. A higher pH measurement (8-14) means a solution is basic, a lower pH measurement means a solution is more acidic (0-6), and a pH measurement of 7 means the solution is neutral. We measured the pH level of each tea by using a digital pH meter right after the hot water was poured into the cup. In this experiment, we were not aiming for higher or lower pH values, but wanted to observe the differences in each treatment combination.

2.3 Experimental Unit

The experimental unit that was used in this experiment was each cup of tea. We acquired these experimental units by purchasing the teabags from Raleys and using water from the tap. We purchased a total of 36 tea bags from the store and filled 36 cups with tap water, giving us a total of 3 replicates per treatment.

2.4 Design Structure

This experiment is a CRD with 3 replicates per treatment combination. In this experiment we used random assignment through JMP to randomize the run order.

2.5 Dealing with other sources of variation

The use of JMP to randomize treatments and run order allowed us to control some unwanted sources of variation. Some sources that we identified that could cause variation within our data was the temperature cooling down and the size of the cups that were being used. We controlled this by randomizing the runs between the three cups being used, as well as once the water was set to temperature we made sure to measure once the tea had steeped (right at two minutes).

2.6 Statistical model and data analysis

$y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$

$i=(1,2,3,4)$

i represents the number of levels of temperature.

$j=(1,2,3)$

j represents the number of levels of tea type.

$k=(1,2,3)$

k represents the number of cups of tea assigned to each treatment combination, with 3 cups of tea being assigned to each treatment.

y_{ijk} is the increase in pH level in the kth cup of tea at ith level of temperature and jth level of tea type.

μ is the overall average pH level of every cup of tea.

α_i is the effect on the ith level of temperature on the pH level of the cup of tea.

β_j is the effect on the jth level of tea type on the pH level of the cup of tea.

$(\alpha\beta)_{ij}$ is the effect of the interaction between the ith level of temperature and the jth level of tea type on the pH level of the cup of tea.

ε_{ijk} is the random error in pH level of the kth cup of tea at the ith level of temperature and the jth level of tea type.

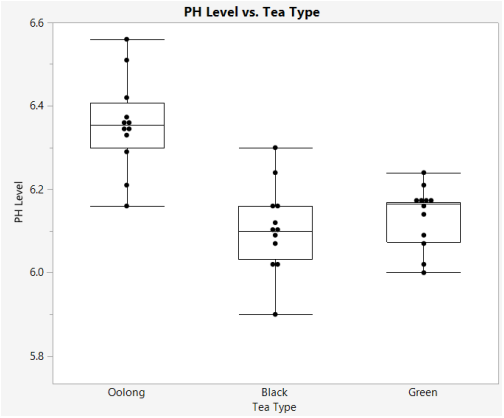
We analyzed this effects model using JMP pro version 16.0.0. In this experiment we used an ANOVA model with all fixed effects. We used a FWER of .05 for our ANOVA analysis.

3. Analysis and Results

3.1 Descriptive statistics

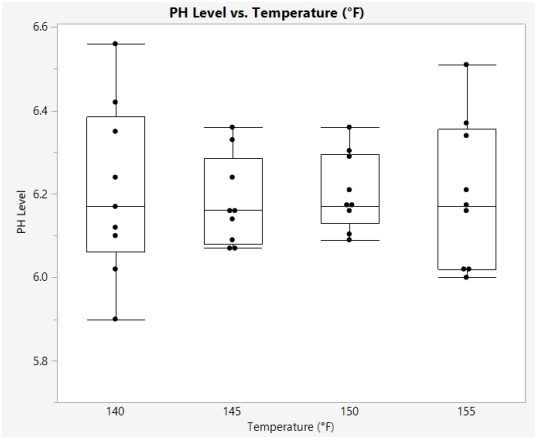
Based off of the initial box plots, it appears that tea type has an effect on pH level and temperature has no noticeable effect on pH level.

Figure 3.1: Side-by-side boxplots showing how pH level changed based on tea type



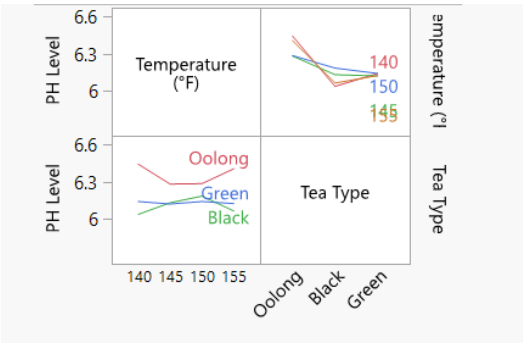
Based on figure 3.1, it appears that tea type does have an effect on the pH level of the tea. We have come to this conclusion, because in the plot, it appears that oolong tea has a much higher median (around 6.35) than either black or green tea (around 6.1-6.15). This shows that oolong yielded significantly larger pH levels than either black or green tea. We could also see that the Onlong result is statistically significant due to not having much overlap with the other two types.

Figure 3.2: Side-by-side boxplots showing how pH level changed based on temperature



Based on figure 3.2, it appears that the temperature the tea is brewed at yielded no significant effect on pH. We believe this to be true, because all of the median points of the box plots center around 6.15-6.20. There was variation in the ranges of the box plots, but not anything that would lead me to believe these findings are significant because there is way too much overlap between the box plots which is an indication of having a lot of within-group variation.

Figure 3.3: Interaction plots between temperature and tea type



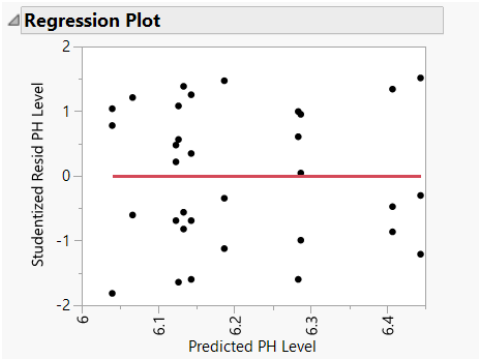
Based on figure 3.3, it does appear that there is indeed interaction between the factors of temperature and tea type. This is true, because there are intersecting lines in both of the plots so the lines are not parallel. This means that the effects of the factors have an effect on each other.

3.2 Inferential findings

ANOVA Assumptions

Equal Variance of Random Errors

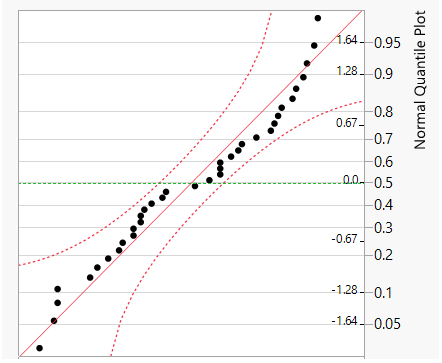
Figure 3.4: Scatter Plot of predicted values vs studentized residuals



From figure 3.4, it appears that there is no megaphone or fanning pattern in the plot of predicted pH level and residuals, so we can affirm that the equal variance of random errors assumption is satisfied.

Normality of Random Errors

Figure 3.5: Normal qqplot and Shapiro-Wilk test



	W	Prob<W
Shapiro-Wilk	**.9434**	**0.0648**

From figure 3.5, it appears that there is quite a bit of abnormality in the qqplot as many of the points are far away from the central line. Although this is true, the Shapiro-Wilk goodness-of-fit test yielded a p-value of .0648, which at an alpha level of .05 satisfies the test of normality of random errors so we do not have enough evidence to say that normality is violated. Although this assumption is confirmed, it is something to definitely keep an eye on.

Independence of Random Errors

Due to the randomization of run order using JMP done in this experiment, the independence of random errors assumption is verified.

ANOVA Analysis

Testing for the validity of the ANOVA assumptions in the previous section allows us to be confident that the conclusions provided from our data are accurate. When looking at Table 3.2, the ANOVA table for the effect tests, we see that the interaction between temperature and tea type is not significant, given by the p-value 0.1392. Seeing that there is no interaction effect

between the variables, we focus on the main effects. With a large p-value, 0.9161, temperature does not have a main effect, which is not surprising based on our original observation of Figure 3.2. However, we find that there is a main effect of tea type on pH values, confirmed by the small p-value of less than 0.0001.

Building off of that, we look to answer our secondary question, whether or not there are certain combinations of tea type and temperature that do not fall under the "average" pH level of tea type according to the *Healthline* and *Tea and Coffee* websites. In order to explore this, we will refer to Table 3.1, which looks at the mean pH and tests for significance between the treatment combinations. From looking at the table we see that Oolong tea has the overall highest pH no matter the temperature and all mean values are in between the ideal range of 5.5 to 7 . Black and green tea are mixed around between 6.04 to 6.187, a very small difference. Black tea has an average pH range of 4.9 to 5.5, so seeing no values within that range is surprising. Similarly, green tea has an average pH range between 7 and 10, yet none of the means are near reaching 7. After finding out there is a main effect for tea type, we will use Table 3.3 to observe the letters' plot and means to find that Oolong tea is statistically significantly different than green and black tea.

Table 3.1: Mean pH for Temperature* Tea type combinations

Temperature	Tea Type	Mean
140°F	Oolong	6.443
155°F	Oolong	6.407
150°F	Oolong	6.287
145°F	Oolong	6.283
150°F	Black	6.187
140°F	Green	6.143
150°F	Green	6.143
145°F	Black	6.133
155°F	Green	6.127
145°F	Green	6.123
155°F	Black	6.067
140°F	Black	6.040

Table 3.2: ANOVA table for the model and effects test for tea type, temperature, and tea type*temperature

Source	DF	Sum of Squares	Mean Squares	F-ratio	p-value
Temperature	3	0.0045	0.0015	0.169	0.9161
Tea Type	2	0.4448	0.2224	24.972	<.0001
Temperature* Tea Type	6	0.0968	0.0161	1.812	0.1392
Error	24	0.2137	0.0089		
Total	35	0.7598			

Table 3.3: Mean and letters plot for tea type

Tea Type	Letters Plot	Least Square Means
Oolong	A	6.3550
Green	B	6.1342
Black	B	6.1067

Note: Levels that share a letter have means that are not statistically significantly different.

4. Conclusion

Based on our research, we have found that oolong will always have the highest pH level no matter the temperature and the mean pH level falls into the average range that oolong tea should have based on scientific study and analysis. Therefore, we could conclude that the temperature in general does not have an effect on the pH level of oolong tea. However, we also found out that black and green tea do not produce the ideal pH level that scientific study determine. Finally, we could conclude that temperature does have an effect on black and green tea but the differences in temperature that we choose do not produce much differences in their respective pH level.

5. Next steps

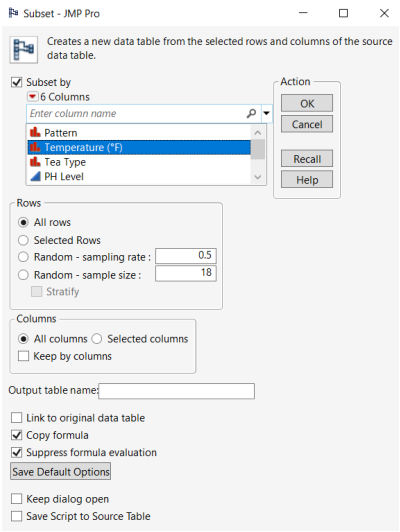
During our data collection, we explored some ideas that could help improve our study and strengthen our data. We believed that if we could have found a way to have the temperature stay at the targeted temperature consistently, it would answer our research question more truthfully. Also, we could have been slightly more consistent with how long the pH reader was in the tea, but the variation of time only changed the readings very slightly (+/- .01). The other possible variation could have come from the kettle we used, unsure if the temperature provided was consistent every time. A follow up experiment could be boiling the tea's to the three "ideal" temperatures (ex. black tea is supposed to be boiled at 212 degrees fahrenheit) and then measure the pH once the tea has cooled off to a certain temperature, this may have a greater effect on the pH.

References

- Patil, Bachute, and Kotcha (2021), "Identification and Classification of the Tea samples by Using Sensory Mechanism ", *Inventions, 6,94.*
- *"Is Tea Acidic or Alkaline - Find Out Here," Tea and Coffee*
- *"Acidity in Tea: pH levels, Effects, and more." Healthline*

Appendix

Randomization Scheme



ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	0.54609722	0.049645	5.5746
Error	24	0.21373333	0.008906	Prob > F
C. Total	35	0.75983056		0.0002*

Tukey Comps for tea type

Level			Least Sq Mean
Oolong	A		6.3550000
Green		B	6.1341667
Black		B	6.1066667

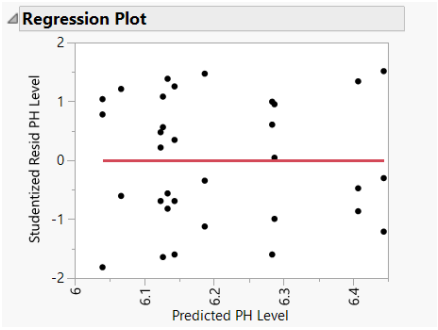
Tukey Comparisons of Temperature*Tea Type

Temperature (°F)	Tea Type				Least Squares Mean
140	Oolong	A			6.4433333
155	Oolong	A	B		6.4066667
150	Oolong	A	B	C	6.2866667
145	Oolong	A	B	C	6.2833333
150	Black	A	B	C	6.1866667
140	Green		B	C	6.1433333
150	Green		B	C	6.1433333
145	Black		B	C	6.1333333
155	Green			C	6.1266667
145	Green			C	6.1233333
155	Black			C	6.0666667
140	Black			C	6.0400000

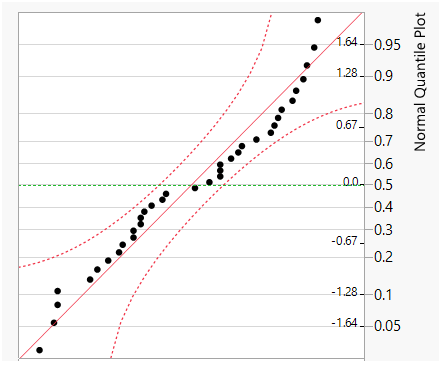
Effects Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Temperature (°F)	3	3	0.00451944	0.1692	0.9161
Tea Type	2	2	0.44477222	24.9716	<.0001*
Temperature (°F)*Tea Type	6	6	0.09680556	1.8117	0.1392

Residual Plot



QQPlot



Goodness of Fit Test

Goodness-of-Fit Test

	W	Prob<W
Shapiro-Wilk	0.9433798	0.0648