IEE 572 - DESIGN ENGINEERING EXPERIMENTS

Project Report

A test to measure acidity among different types of coffee and its brewing methods

Instructor : Dr. Douglas C. Montgomery

Table of Contents

List of Figures	2
List of Tables	3
Objective	4
Recognition and statement of the problem	4
Selection of the response variable	4
Choice of factor, levels and ranges	4
Choice of experimental design	5
Experiment data	7
Statistical analysis of the data	8
Conclusion	19
References	20

List of Figures

Fig. 1 Factorial design displayed using JMP 6

Fig. 2 Run order for the experiment 6

Fig. 3 Oneway Analysis of measured pH (Bean) 9

Fig. 4 Oneway ANOVA (Bean) 9

Fig. 5 Oneway analysis of measured pH (Roast) 10

Fig. 6 Oneway ANOVA (Roast) 10

Fig. 7 Oneway analysis of measured pH (Brewing Method) 11

Fig. 8 Oneway ANOVA (Brewing Method) 11

Fig. 9 Fit model analysis with blocking (main effects + block effect) 12

Fig. 10 Fit model analysis with blocking 13

Fig. 11 Fit model analysis without blocking and 2-factor interactions 14

Fig. 12 Fit model analysis without blocking (main effects only) 15

Fig. 13 Fit model analysis without blocking (main effects only) 16

Fig. 14 Fit model analysis without blocking with 2-factor interaction 17

Fig. 15 Residual analysis (with 2-factor interaction) 18

Fig. 16 Parameter estimates and effect tests for model with 2-factor interaction 18

Fig. 17 Prediction profiler for model with 2-factor interaction 19

List of Tables

Table 1. Description of the factors and their levels 5

Table 2. Sorted collected experimental data 7

Objective

High acidity in coffee causes increased acid reflux and corrodes enamel on teeth. We want to determine the optimum conditions required for preparing a cup of coffee which will have the best possible level of acidity, which will not cause any harm to the drinker.

Recognition and statement of the problem

There exists a lot of debate on the effect of coffee on gastrointestinal health, many experts saying that the acidic nature of coffee is harmful for people with sensitive gastrointestinal systems [1]. On the pH scale, any number less than seven means the substance is acidic. Coffee mostly ranges in between 4.85 to 5.10 on the pH scale, implying that it is indeed acidic. Even though this is less acidic than many fruits such as apples and grapes, given that Americans consume *several* cups of coffee a day, this is often the cause behind heartburns and stomach issues. In this experiment, we would like to find the optimal levels of factors that result in the lowest possible acidity of coffee, so that we can scientifically reduce our intake of acidic beverages, without sacrificing that morning cup of coffee.

Selection of the response variable

The response variable to be measured is the acidity of a brewed cup of coffee. The acidity will be measured using a pH meter, and the same pH meter will be used to test all cups of coffee throughout the experiment. The factors that will be held constant are as follows:

1. Water temperature
2. Brand of coffee
3. Brand of water
4. Water quantity
5. Coffee quantity

Choice of factor, levels and ranges

Nuisance factors - Nuisance factors are those that may affect the measured result, but are not of primary interest. The following are such factors,

1. Freshness of beans/ground - store bought coffee is ground a long time ago and then stays packaged as well. Hence we decided to consider this as a nuisance factor.
2. Coffee grind size - store bought and freshly ground at home will never have the same grind size

After analyzing the various factors which may affect the response variable which is the level of acidity in coffee, we decided that the following factors are the most important and will have a significant impact on the response variable. There are 3 major factors having two levels each. This results in the experiment having a total of 2^3 runs. We as a team of 3 people decided to perform the 8 runs of the experiment per person which will also allow us to introduce replication in our experiment. The pH meter used for measuring the acidity in this experiment will be common for all the runs to keep the results consistent.

Table 1. Description of factors and their levels

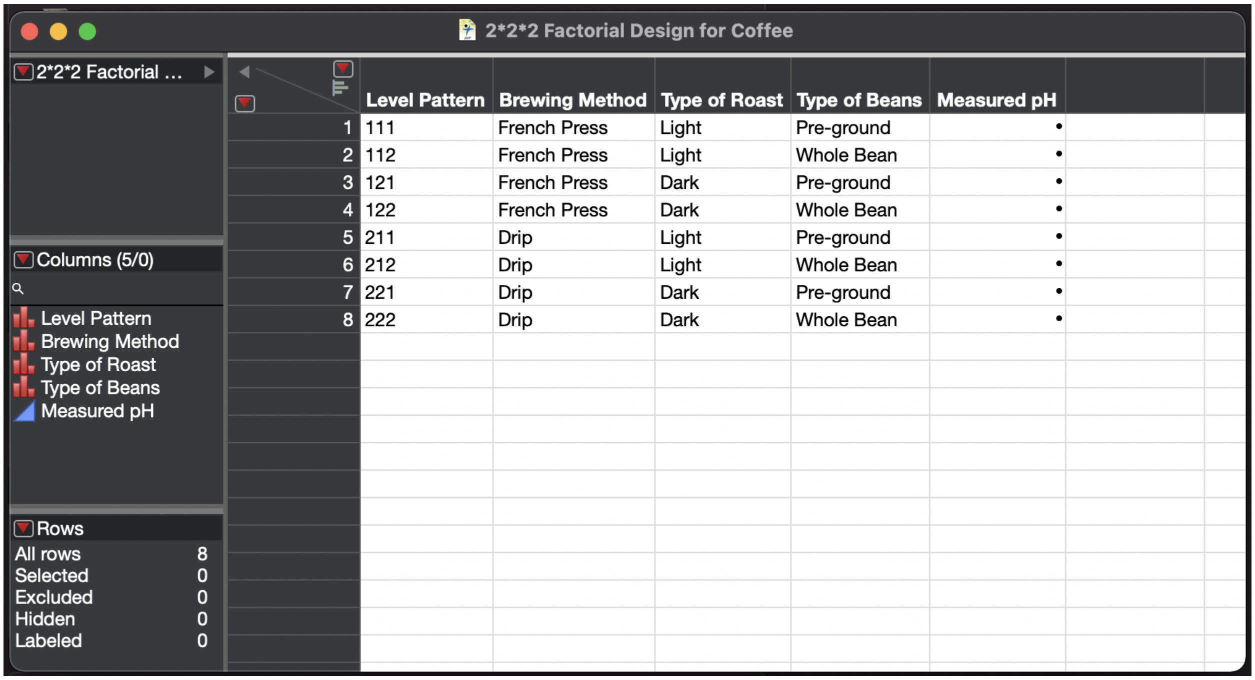
Factors	Description	Level 1	Level 2
1	Brewing method for the coffee	French press	Drip
2	Roast of the coffee beans	Light	Dark
3	Type of the coffee beans	Pre-ground (store bought)	Whole bean (freshly ground)

Choice of Experimental Design

Randomization and run order:

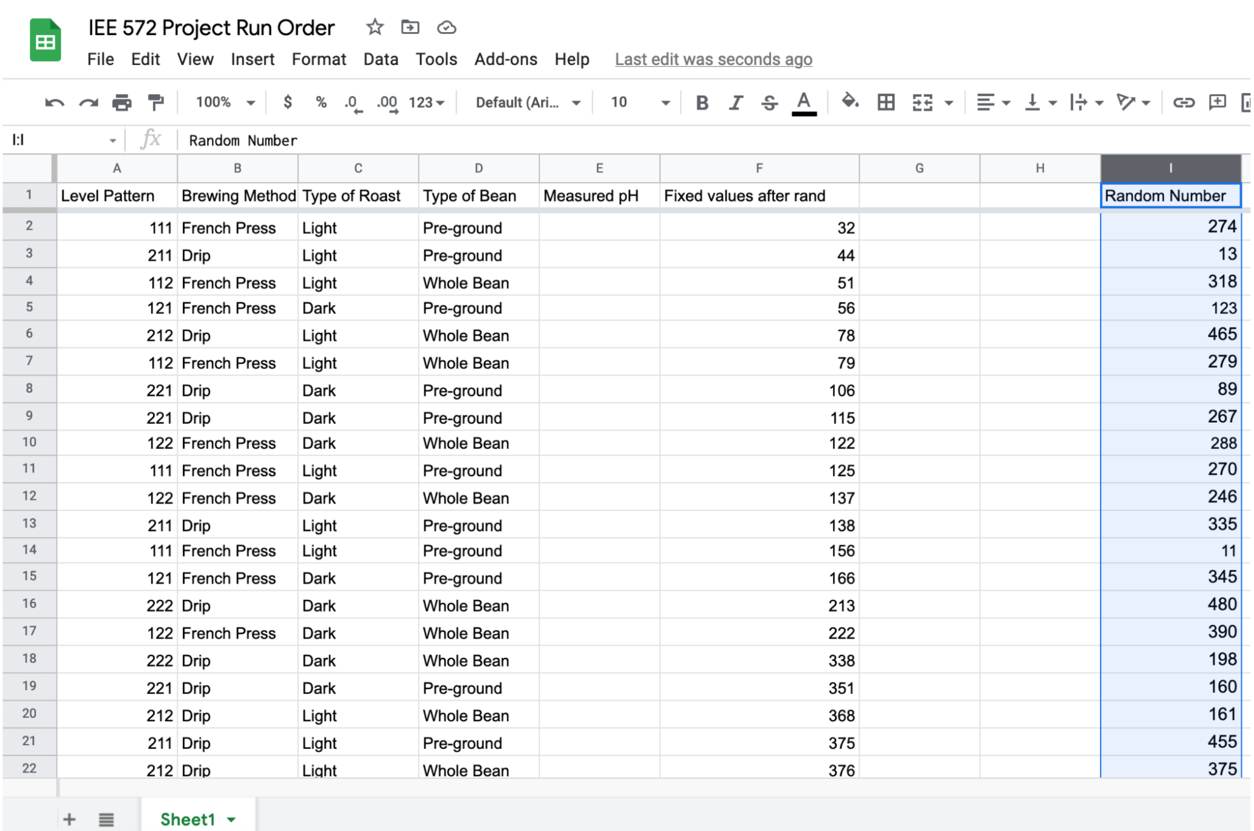
There are 3 factors and 2 levels for each factor, therefore we used 2^3 full factorial design. Each replicate consists of 8 runs to accommodate the 2^3 possible combinations of factor levels. Since there are 3 experimenters in our case, each experimenter performs one full replicate, thus resulting in a total of 24 runs. Furthermore, each experimenter i.e. each replicate, is considered as a block in this experiment.

In order to randomize the experiment, we create a table on Google Sheet with the 24 rows of runs. We add a new column that generates random numbers in between 1 and 500. We fix these numbers and then sort all the rows in ascending order of these generated random numbers. A screenshot of how we determined our run order is provided below in table 3. We will be following the JMP table as shown for each block.



	Level Pattern	Brewing Method	Type of Roast	Type of Beans	Measured pH
1	111	French Press	Light	Pre-ground	•
2	112	French Press	Light	Whole Bean	•
3	121	French Press	Dark	Pre-ground	•
4	122	French Press	Dark	Whole Bean	•
5	211	Drip	Light	Pre-ground	•
6	212	Drip	Light	Whole Bean	•
7	221	Drip	Dark	Pre-ground	•
8	222	Drip	Dark	Whole Bean	•

Fig 1. Factorial design displayed using JMP



	A	B	C	D	E	F	G	H	I
1	Level Pattern	Brewing Method	Type of Roast	Type of Bean	Measured pH	Fixed values after rand			Random Number
2	111	French Press	Light	Pre-ground		32			274
3	211	Drip	Light	Pre-ground		44			13
4	112	French Press	Light	Whole Bean		51			318
5	121	French Press	Dark	Pre-ground		56			123
6	212	Drip	Light	Whole Bean		78			465
7	112	French Press	Light	Whole Bean		79			279
8	221	Drip	Dark	Pre-ground		106			89
9	221	Drip	Dark	Pre-ground		115			267
10	122	French Press	Dark	Whole Bean		122			288
11	111	French Press	Light	Pre-ground		125			270
12	122	French Press	Dark	Whole Bean		137			246
13	211	Drip	Light	Pre-ground		138			335
14	111	French Press	Light	Pre-ground		156			11
15	121	French Press	Dark	Pre-ground		166			345
16	222	Drip	Dark	Whole Bean		213			480
17	122	French Press	Dark	Whole Bean		222			390
18	222	Drip	Dark	Whole Bean		338			198
19	221	Drip	Dark	Pre-ground		351			160
20	212	Drip	Light	Whole Bean		368			161
21	211	Drip	Light	Pre-ground		375			455
22	212	Drip	Light	Whole Bean		376			375

Fig 2. Run order for the experiment

Performing the Experiment

The experiment runs were conducted according to the aforementioned run order. While running the experiment, the temperature was held constant, this was done because the temperature for the drip machine could not be controlled, therefore the value of 205 ℉ was held constant for both the brewing methods. The temperature was measured using a cooking thermometer for every run. Once brewed, for each run the coffee was put in the same cups (thoroughly washed) and let sit for 2 minutes before a reading was measured by the pH meter. The same pH meter was used for measuring all the runs of the experiment. It was calibrated to 0.1 level of pH with an accuracy of +/-0.01pH. Care was taken to ensure that the pH meter was cleaned after every run to avoid any residue and cause for error. Furthermore, new coffee filters were used for each run for the drip coffee. The data collected is as shown below and analysed using JMP Pro statistical software.

Experiment Data

The experiment was conducted with randomization as outlined above, but for clarification the following collected data has been sorted by blocks and level pattern:

Table 2. Sorted collected experimental data

Block	Level Pattern	Brewing Method	Type of Roast	Type of Bean	Measured pH	Repeated measurement (if needed)
1	111	French Press	Light	Pre-ground	4.86	5.96
1	112	French Press	Light	Whole Bean	5.66	
1	121	French Press	Dark	Pre-ground	5.56	
1	122	French Press	Dark	Whole Bean	6.26	
1	211	Drip	Light	Pre-ground	5.56	
1	212	Drip	Light	Whole Bean	5.56	
1	221	Drip	Dark	Pre-ground	6.36	
1	222	Drip	Dark	Whole Bean	6.46	
2	111	French Press	Light	Pre-ground	5.06	
2	112	French Press	Light	Whole Bean	5.96	
2	121	French Press	Dark	Pre-ground	5.86	
2	122	French Press	Dark	Whole Bean	6.36	

2	211	Drip	Light	Pre-ground	5.66	
2	212	Drip	Light	Whole Bean	5.86	
2	221	Drip	Dark	Pre-ground	6.46	
2	222	Drip	Dark	Whole Bean	6.56	
3	111	French Press	Light	Pre-ground	5.16	
3	112	French Press	Light	Whole Bean	5.96	
3	121	French Press	Dark	Pre-ground	5.96	
3	122	French Press	Dark	Whole Bean	6.36	
3	211	Drip	Light	Pre-ground	5.86	
3	212	Drip	Light	Whole Bean	5.86	
3	221	Drip	Dark	Pre-ground	6.56	
3	222	Drip	Dark	Whole Bean	6.46	

The first measurement taken in the experiment provided a number far lower than the other measured pH levels, therefore we repeated that measurement. This reading is considered as a ‘trial’ run for the experiment to determine the adequacy of the results, avoid experimental errors and practice the experimental technique. Potential explanations for the outlier could be that the pH meter needed time to initialize or ‘calibrate’. All statistical analyses were conducted with the repeated measurement of 5.96.

Statistical Analysis of the Data

1. Effect of a single factor: Fit Y by X

First, we analyze the estimate of a single factor on the response variable. To do this, we perform a one-way analysis of variance on JMP with our experimental data.

For the Oneway ANOVA analysis, we report the Summary of Fit, the Pooled t test, the ANOVA table, and the means for the one way ANOVA.

1.1 Effect of Type of Bean on Measured pH: One-way ANOVA

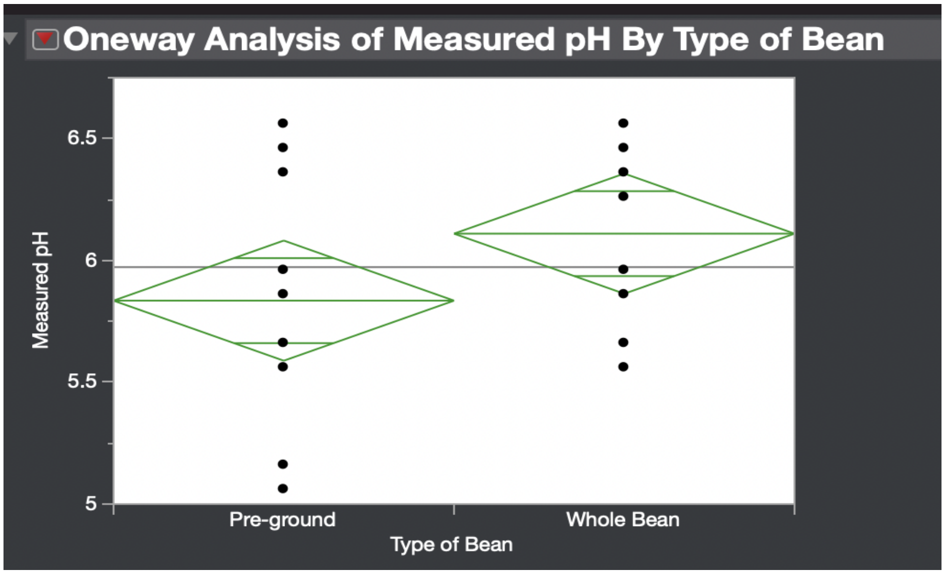


Fig 3. Oneway Analysis of measured pH (Bean)

Oneway Anova

Summary of Fit

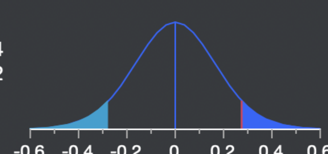
Rsquare	0.108391
Adj Rsquare	0.067863
Root Mean Square Error	0.411897
Mean of Response	5.9725
Observations (or Sum Wgts)	24

Pooled t Test

Whole Bean-Pre-ground

Assuming equal variances

Difference	0.27500	t Ratio	1.635384
Std Err Dif	0.16816	DF	22
Upper CL Dif	0.62373	Prob > |t|	0.1162
Lower CL Dif	-0.07373	Prob > t	0.0581
Confidence	0.95	Prob < t	0.9419



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Type of Bean	1	0.4537500	0.453750	2.6745	0.1162
Error	22	3.7325000	0.169659		
C. Total	23	4.1862500			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Pre-ground	12	5.83500	0.11890	5.5884	6.0816
Whole Bean	12	6.11000	0.11890	5.8634	6.3566

Std Error uses a pooled estimate of error variance

Fig. 4 Oneway ANOVA (Bean)

1.2 Effect of Type of Roast on Measured pH: One-way ANOVA

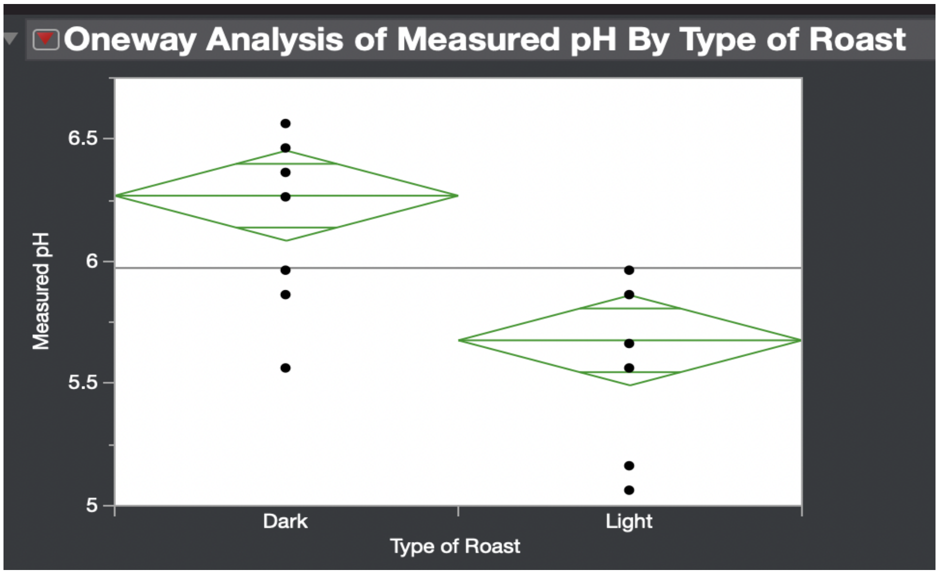


Fig. 5 Oneway analysis of measured pH (Roast)

Oneway Anova

Summary of Fit

Rsquare	0.501742
Adj Rsquare	0.479094
Root Mean Square Error	0.307913
Mean of Response	5.9725
Observations (or Sum Wgts)	24

Pooled t Test

Light-Dark
Assuming equal variances

Difference	-0.59167	t Ratio	-4.70678
Std Err Dif	0.12571	DF	22
Upper CL Dif	-0.33097	Prob > |t|	0.0001*
Lower CL Dif	-0.85236	Prob > t	0.9999
Confidence	0.95	Prob < t	<.0001*

-0.5 0 0.5

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Type of Roast	1	2.1004167	2.10042	22.1538	0.0001*
Error	22	2.0858333	0.09481		
C. Total	23	4.1862500			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Dark	12	6.26833	0.08889	6.0840	6.4527
Light	12	5.67667	0.08889	5.4923	5.8610

Std Error uses a pooled estimate of error variance

Fig. 6 Oneway ANOVA (Roast)

1.3 Effect of Brewing Method on Measured pH: One-way ANOVA

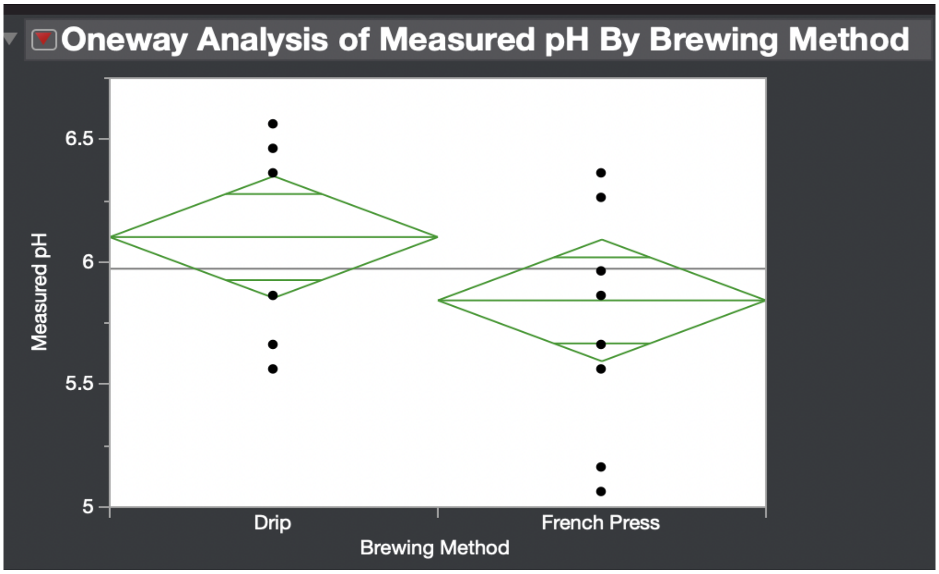
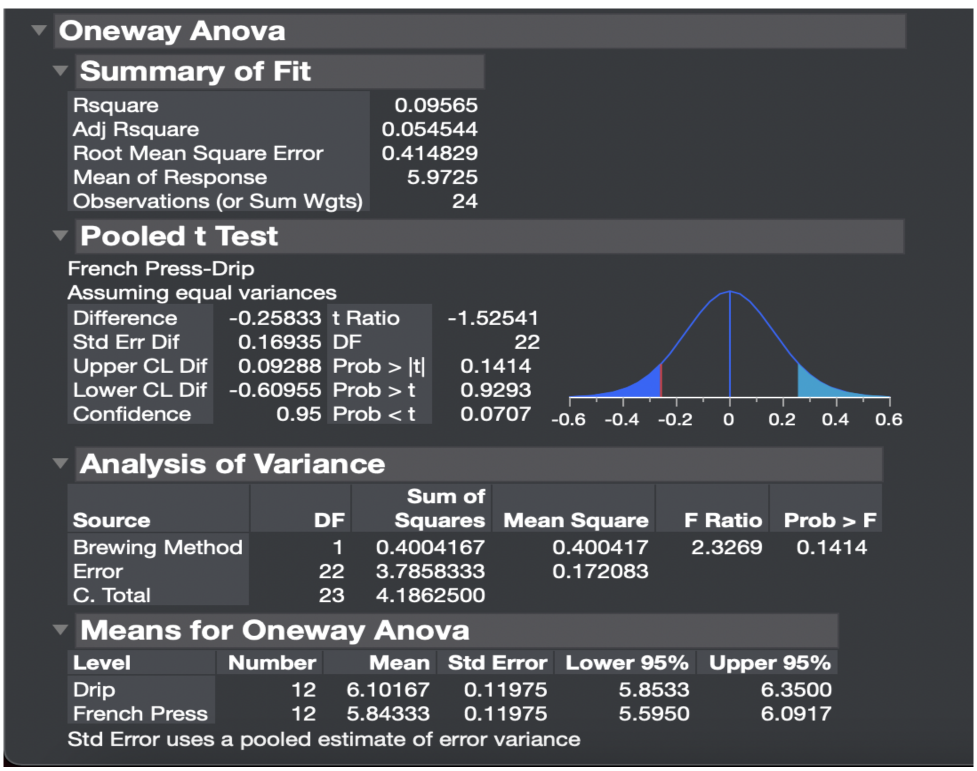


Fig. 7 Oneway analysis of measured pH (Brewing Method)



Oneway Anova

Summary of Fit

Rsquare	0.09565
Adj Rsquare	0.054544
Root Mean Square Error	0.414829
Mean of Response	5.9725
Observations (or Sum Wgts)	24

Pooled t Test

French Press-Drip

Assuming equal variances

Difference	-0.25833	t Ratio	-1.52541
Std Err Dif	0.16935	DF	22
Upper CL Dif	0.09288	Prob > |t|	0.1414
Lower CL Dif	-0.60955	Prob > t	0.9293
Confidence	0.95	Prob < t	0.0707

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Brewing Method	1	0.4004167	0.400417	2.3269	0.1414
Error	22	3.7858333	0.172083		
C. Total	23	4.1862500			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Drip	12	6.10167	0.11975	5.8533	6.3500
French Press	12	5.84333	0.11975	5.5950	6.0917

Std Error uses a pooled estimate of error variance

Fig. 8 Oneway ANOVA (Brewing Method)

2. Fitting the Model

We try two types of models: one with blocking and one without considering the blocks, and treating each block as just another replicate. For this set of analyses, we report the Actual vs Predicted plots, Effect Summary, Lack of Fit, Summary of Fit, Parameter Estimates and Effect Tests. We also show the plot of Residuals.

2.1 With Blocking:

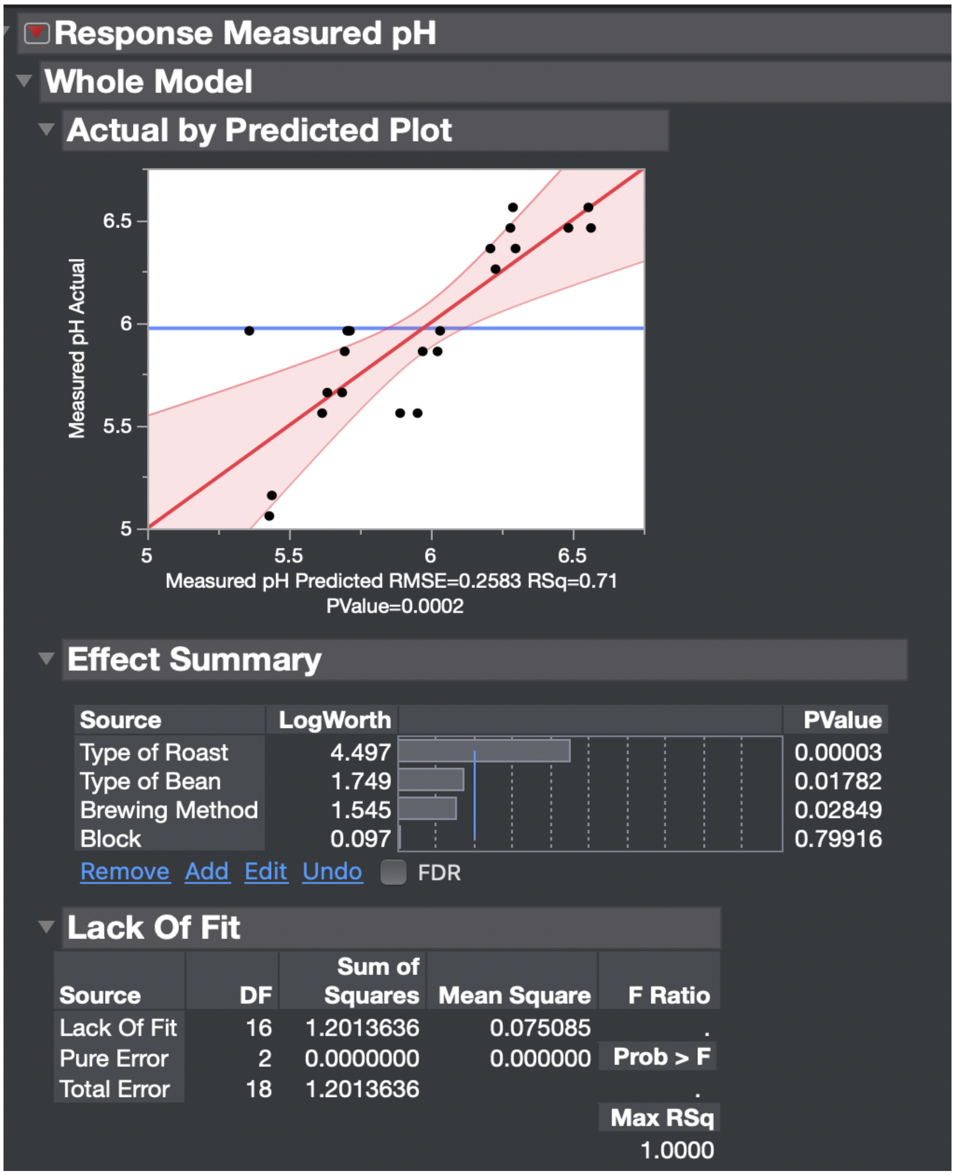
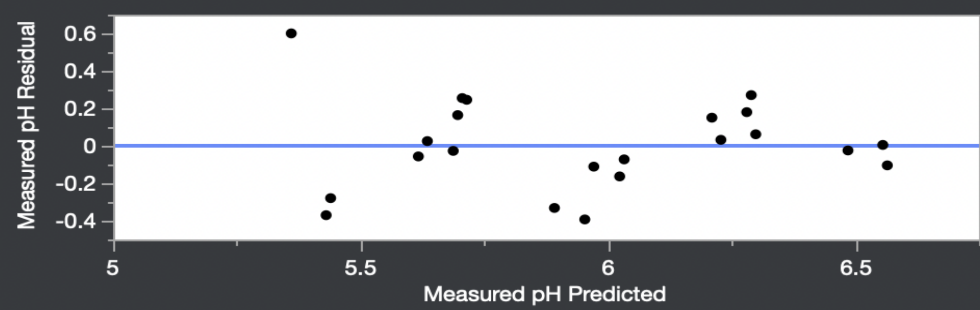


Fig. 9 Fit model analysis with blocking (main effects + block effect)

Residual by Predicted Plot



Summary of Fit

RSquare	0.713022
RSquare Adj	0.633305
Root Mean Square Error	0.258346
Mean of Response	5.9725
Observations (or Sum Wgts)	24

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	2.9848864	0.596977	8.9445
Error	18	1.2013636	0.066742	Prob > F
C. Total	23	4.1862500		0.0002*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.9725	0.052735	113.26	<.0001*
Brewing Method[Drip]	0.1284091	0.05392	2.38	0.0285*
Type of Roast[Dark]	0.2965909	0.05392	5.50	<.0001*
Type of Bean[Pre-ground]	-0.1375	0.052735	-2.61	0.0178*
Block[1]	-0.05	0.074578	-0.67	0.5111
Block[2]	0.0204545	0.077078	0.27	0.7937

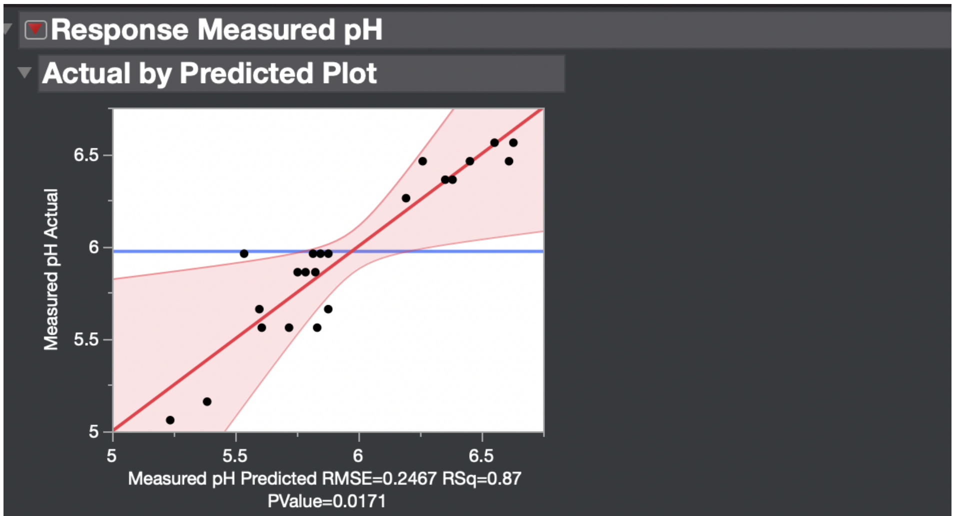
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Brewing Method	1	1	0.3785277	5.6715	0.0285*
Type of Roast	1	1	2.0193972	30.2566	<.0001*
Type of Bean	1	1	0.4537500	6.7985	0.0178*
Block	2	2	0.0303030	0.2270	0.7992

Fig. 10 Fit model analysis with blocking

From the plot of Residuals in Figure 10, we see that there are some values which are a little bit strange (for example, the first point from the left), and we also notice that the variability seems to decrease for higher values of the pH.

Now, we add 2-factor interactions into this model (along with block-factor interactions).



Effect Summary

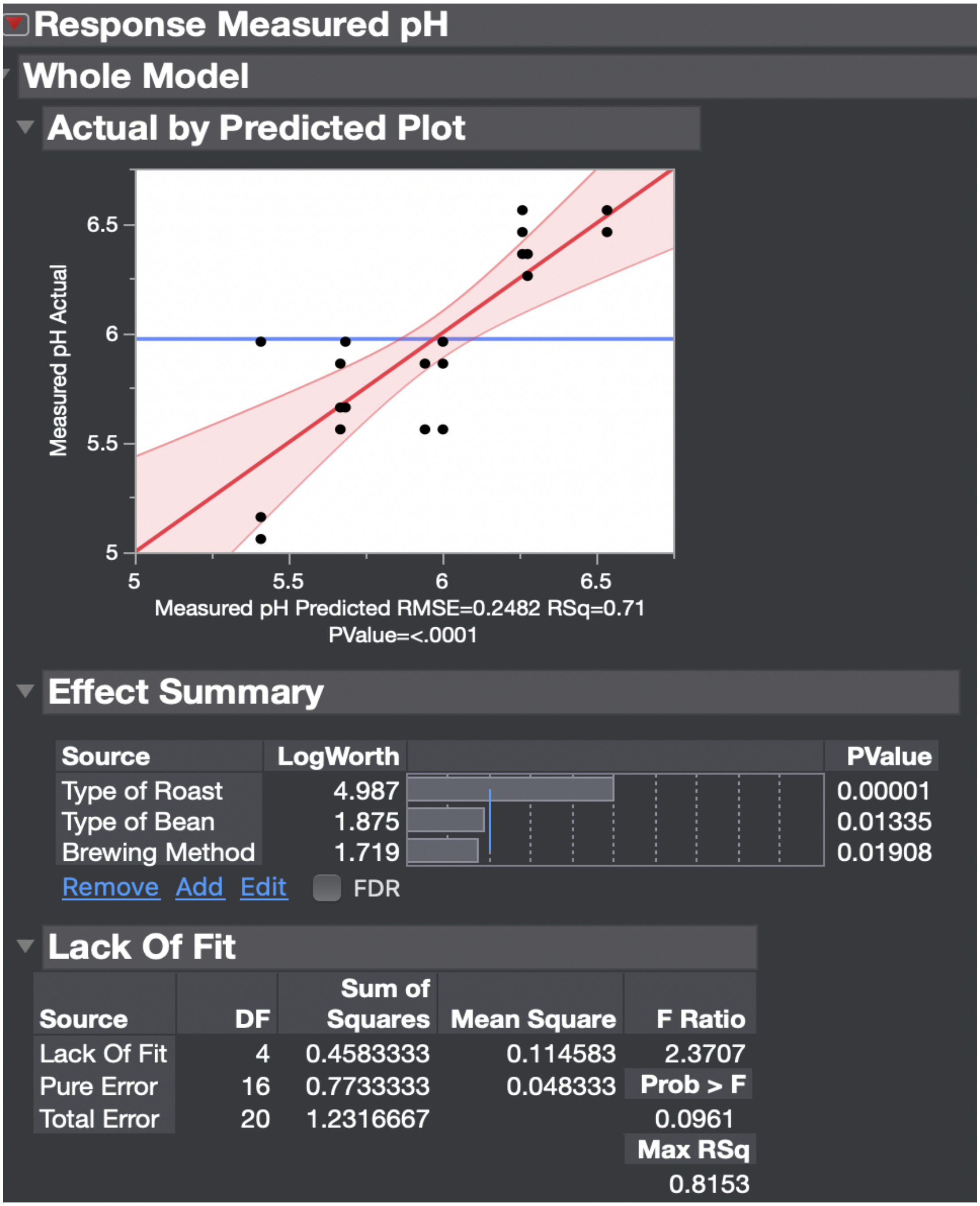
Source	LogWorth	PValue
Type of Roast	3.424	0.00038
Type of Bean	1.454	0.03516
Brewing Method	1.391	0.04066
Brewing Method*Type of Bean	1.187	0.06501
Brewing Method*Type of Roast	0.828	0.14860
Type of Bean*Block	0.220	0.60259
Brewing Method*Block	0.171	0.67483
Type of Roast*Block	0.154	0.70083
Block	0.123	0.75364 ^
Type of Roast*Type of Bean	0.031	0.93145

Remove Add Edit FDR ('^' denotes effects with containing effects above them)

Fig 11 Fit model analysis with blocking and 2-factor interactions

We see that adding the 2-factor interactions including the block interactions increases the R^2 from 0.71 to 0.87, even though the interaction effects do not seem that significant, based on the p-values.

2.2 Without Blocking:



Source	LogWorth	PValue
Type of Roast	4.987	0.00001
Type of Bean	1.875	0.01335
Brewing Method	1.719	0.01908

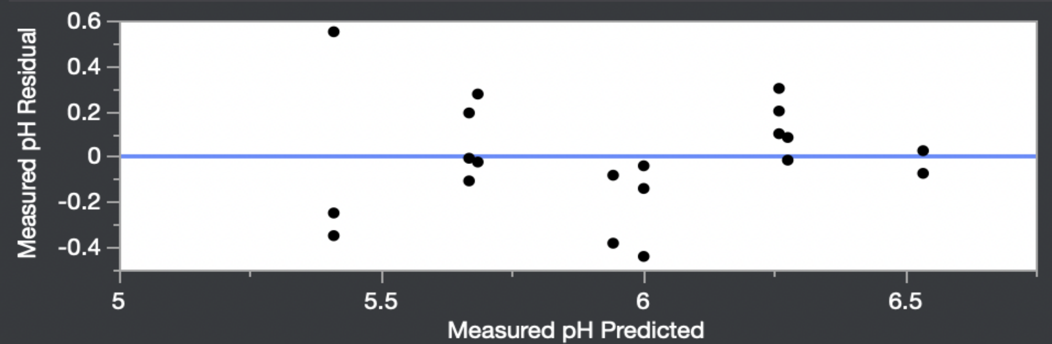
Remove Add Edit FDR

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	4	0.4583333	0.114583	2.3707
Pure Error	16	0.7733333	0.048333	Prob > F
Total Error	20	1.2316667		0.0961
				Max RSq
				0.8153

Fig. 12 Fit model analysis without blocking (main effects only)

Residual by Predicted Plot



Summary of Fit

RSquare	0.705783
RSquare Adj	0.66165
Root Mean Square Error	0.24816
Mean of Response	5.9725
Observations (or Sum Wgts)	24

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	2.9545833	0.984861	15.9923
Error	20	1.2316667	0.061583	**Prob > F**
C. Total	23	4.1862500		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.9725	0.050655	117.90	<.0001*
Brewing Method[Drip]	0.1291667	0.050655	2.55	0.0191*
Type of Roast[Dark]	0.2958333	0.050655	5.84	<.0001*
Type of Bean[Pre-ground]	-0.1375	0.050655	-2.71	0.0133*

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Brewing Method	1	1	0.4004167	6.5020	0.0191*
Type of Roast	1	1	2.1004167	34.1069	<.0001*
Type of Bean	1	1	0.4537500	7.3681	0.0133*

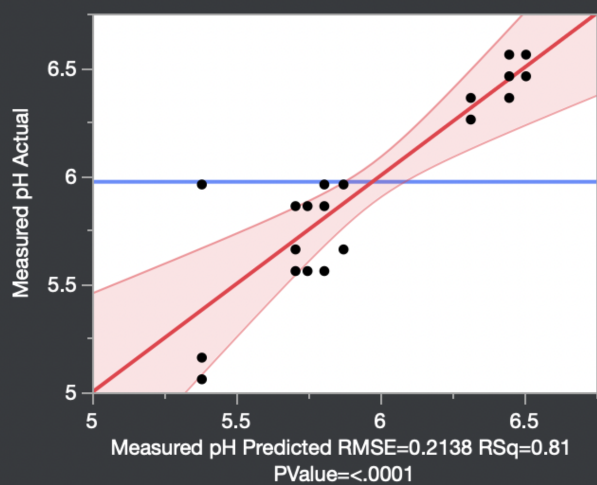
Fig. 13 Fit model analysis without blocking (main effects only)

From these statistics, we see that the R^2 is around 0.71, which shows that our model somewhat fits well to the experimental data. However, there might be other factors that would need to be considered for a better fit.

For this next section of analyses, we consider 2-factor interaction effects as well, while fitting the model.

Response Measured pH

Actual by Predicted Plot



Effect Summary

Source	LogWorth	PValue
Type of Roast	5.492	0.00000
Type of Bean	2.234	0.00583
Brewing Method	2.057	0.00878
Brewing Method*Type of Bean	1.709	0.01956
Brewing Method*Type of Roast	1.059	0.08737
Type of Roast*Type of Bean	0.034	0.92505

Remove Add Edit FDR

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	1	0.00375000	0.003750	0.0776
Pure Error	16	0.77333333	0.048333	Prob > F
Total Error	17	0.77708333		0.7842
				Max RSq
				0.8153

Fig 14 Fit model analysis without blocking, *with* 2-factor interactions

Here we see that once we add the 2-factor interaction effects to the model, we get a significant improvement in the model fit: the R^2 increases from 0.71 to 0.81.

Here we show the residual plots and the studentized residual:

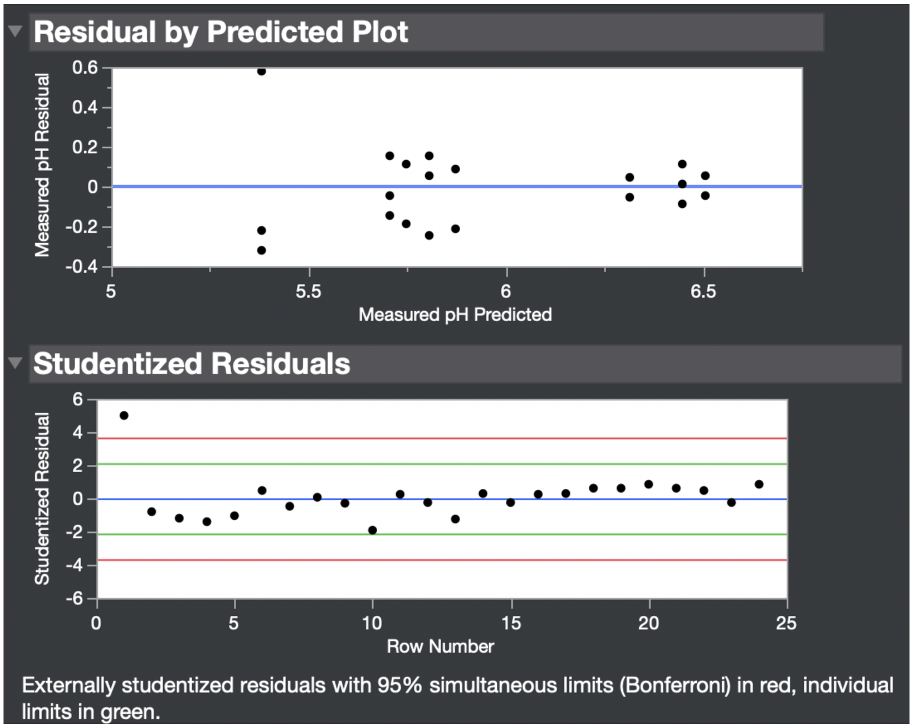


Fig 15 Residual Analysis (with 2-factor interactions)

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.9725	0.043642	136.85	<.0001*
Brewing Method[Drip]	0.1291667	0.043642	2.96	0.0088*
Type of Roast[Dark]	0.2958333	0.043642	6.78	<.0001*
Type of Bean[Pre-ground]	-0.1375	0.043642	-3.15	0.0058*
Brewing Method[Drip]*Type of Roast[Dark]	0.0791667	0.043642	1.81	0.0874
Brewing Method[Drip]*Type of Bean[Pre-ground]	0.1125	0.043642	2.58	0.0196*
Type of Roast[Dark]*Type of Bean[Pre-ground]	-0.004167	0.043642	-0.10	0.9251

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Brewing Method	1	1	0.4004167	8.7598	0.0088*
Type of Roast	1	1	2.1004167	45.9501	<.0001*
Type of Bean	1	1	0.4537500	9.9265	0.0058*
Brewing Method*Type of Roast	1	1	0.1504167	3.2906	0.0874
Brewing Method*Type of Bean	1	1	0.3037500	6.6450	0.0196*
Type of Roast*Type of Bean	1	1	0.0004167	0.0091	0.9251

Fig 16 Parameter Estimates and Effect Tests for model with 2-factor interactions

From the parameter estimates and the effect tests, we see that out of all the 2 factor interactions, *the Brewing Method-Type of Bean* seems significant.

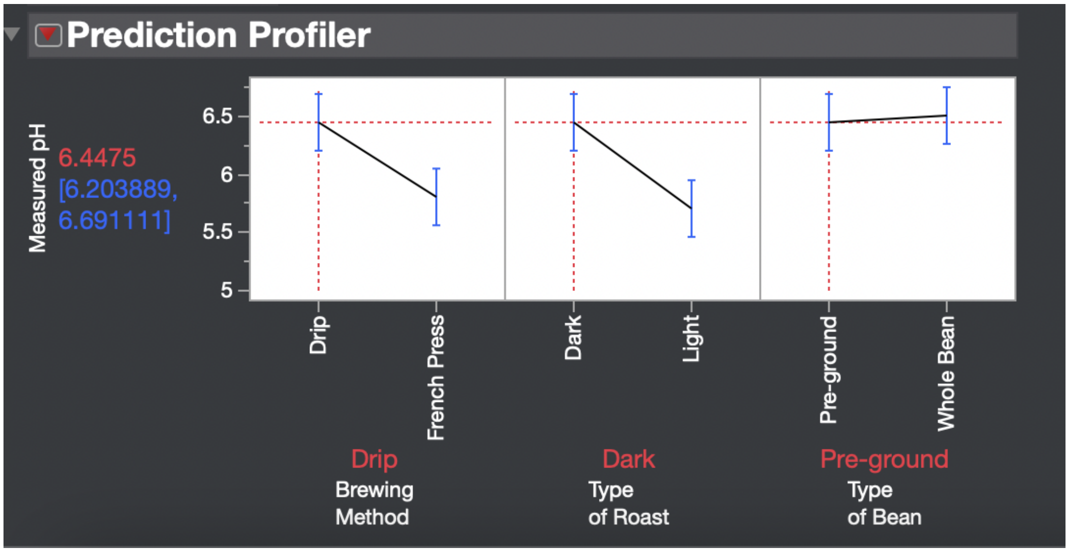


Fig 17 Prediction Profiler for Model with 2-factor interactions

Since more acidic coffee, i.e. coffee with lower values of pH is considered harmful for gastrointestinal functions, we want to look for the combination of factors that would give us the highest pH coffee that we can get. So, looking at this prediction profiler, we would go for a dark roast, drip coffee. If we had a choice between pre-ground and whole bean, we would choose the whole bean, even though it would not result in that much of a difference in the pH.

Conclusion

Based on the JMP results we can conclude that the type of roast is the most significant factor in determining the levels of acidity in this experiment with a p-value of 0.00003. After the type of roast is the type of bean with a p-value of 0.01782 followed by the brewing method with a p-value of 0.02849. From this study and analysis, we found that the dark roast coffee had a higher level of pH meaning it was less acidic compared to the light roast coffee. We determined that the optimal combination of factors to minimize the level of acidity would be dark roast, drip machine, and whole bean.

Moving forward, the next step could be to run another experiment and exclude the brew method because according to the data it has the least significance on the acidity level. We could also look into other possible factors that would potentially improve the fit of the model. Further study could be conducted with a 2k full factorial experiment with a few more factors included. Particularly, the temperature of water which was kept constant in this study. The level of pH is known to be affected with the temperature. Another potential factor which can be considered is time after which the pH reading is taken.

References

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