June 14th, 2023

Middle East Technical University

IE 368 – Quality Planning and Control

Case Study 3 – FASTPOP INC.

Spring 2023

Group Number 19

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"Academic integrity is expected of all students of METU at all times, whether in the presence or absence of members of the faculty. Understanding this, I declare that I shall not give, use, or receive unauthorized aid in this study."

Table of Contents

Introduction

FASTPOP INC., a small company operating food trucks, is seeking to improve their popcorn making process to increase the yield of their corn kernels, since these kernels have been an issue when it comes to the company's efficiency. As such, the company has decided to conduct a robust design study to enhance their popcorn production.

In this case study, the primary objective is to explore innovative approaches and solutions to minimize the number of unpopped kernels in FASTPOP INC.'s popcorn batches. The goal is to find out which parameters can be utilized in order to minimize the number of unpopped kernels and maximize overall yield.

Robust Design Study Description

The robust design study will consider making samples of popcorn using different parameters (or factors) to see which combination of factors is likely to give out the best result. Some of the factors will be control factors, i.e.: factors that can be controlled in a non-laboratory setting, and most of the other factors are noise factors that cannot be controlled or can be controlled in a laboratory setting.

In order to measure the output and determine which combination is the best, a response variable is to be determined. The response variable will be the % by mass of unpopped kernels from the total weight of the starting mass of kernels. This response variable is denoted as y. Since the response variable is a percentage-based variable by mass, it is continuous.

To measure y, a scale is used to measure the starting mass of kernels before the popping/cooking process starts, and the mass of unpopped kernels is measured after the popping process is finished for that respective sample, then:

$$y = \frac{m(unpopped\ kernels)}{m(total\ kernels)}$$

where $m(.)$ is the measured mass. It is also possible to measure the mass of the popcorn (or popped kernels) and use $y = 1 - \frac{m(popped\ kernels)}{m(total\ kernels)}$; however, measuring the popcorns' mass is more difficult than the unpopped counterpart. It is also worth noting that the mass of the kernel is not changing throughout the popping process, since there is no mass exchange or mass flowing from and to the kernel; rather, the volume – and hence, the density – of the kernel is changing.

The factors of the popping process include but are not limited to (Table 1):

Control Factor	Noise Factor
Stove Type	Worker
Amount of Oil	Setup
Pot Size	Outside Temperature
Pot Type	Humidity
Cooking Temperature	Individual Quality of Kernels
Cooking Time	Atmospheric Pressure
Number of Kernels	Moistness of the Kernels

Table 1: Possible Factors for the Kernel Popping Process.

It is worth noting that some noise factors are not even known to FASTPOP INC., which can make the robust study process more difficult.

The robust design study will consider 4 control factors and 2 noise factors, at two levels each (Table 2). The noise factors will be considered by making four replications of each combination of control factors, by using the full factorial table for the two, 2-level noise factors:

	Control Factors				Noise Factors	
Level	Pot Size	Cooking Temp.	Cooking Time	Amount of Oil	Moistness	Outside Temperature
+	Big (16.5cm diameter, 10.5cm high)	High	3.5mins	2 tsp's	Moist	Hot
-	Small (12cm diameter, 9cm tall)	Low	2.5mins	1 tsp	Dry	Cold

Table 2: Used factors in FASTPOP's robust design study, and the respective value of each level for each factor.

Note: "Moist kernels" are determined by having batches of kernels submerged in water for about 2 hours. The outside temperature is "controlled" by having a member of the case study group do the respective experiments in Algiers, Algeria and the other half are done in Ankara, Türkiye for Hot and Cold outside temperatures, respectively. Note that each member performing the experiments also has different equipment and that is also a noise factor.

The orthogonal array used is an L8 array (Table 3):

Pot Size	Cooking Temperature	Cooking Time (Mins)	Amount of Oil (Tsp)	Moist-Hot	Moist-Cold	Dry-Hot	Dry-Cold
-1	-1	-1	-1				
-1	-1	+1	+1				
-1	+1	-1	+1				
-1	+1	+1	-1				
+1	-1	-1	+1				
+1	-1	+1	-1				
+1	+1	-1	-1				
+1	+1	+1	+1				

Table 3: L8 orthogonal array.

Results Analysis

After running the experiments, the following results were obtained (Table 4):

Pot Size	Cooking Temperature	Cooking Time (Mins)	Amount of Oil (Tsp)	Moist-Hot	Moist-Cold	Dry-Hot	Dry-Cold
-1	-1	-1	-1	0.45	0.67	0	0.52
-1	-1	+1	+1	0.22	0.98	0	0.03
-1	+1	-1	+1	0.88	0.6	0	0.5
-1	+1	+1	-1	1	0.4	0	0.01
+1	-1	-1	+1	0.92	1	1	1
+1	-1	+1	-1	0.38	0.69	0	0.98
+1	+1	-1	-1	0.83	0.41	0.35	0.11
+1	+1	+1	+1	0.47	0.11	0	0.01

Table 4: Results of Experiments.

Denote the Pot Size, Cooking Temperature, Cooking Time, and Amount of Oil factors as A, B, C, and D, respectively. Since the response variable follows the the-smaller-the-better approach, the following signal-to-noise ratio is to be used:

$$SNR = -10 \log \left(\frac{1}{n} \sum_{i=1}^{n} y_i^2 \right)$$

The SNR, mean, and natural logarithm of the standard deviation is as follows (Table 5):

Moist-Hot	Moist-Cold	Dry-Hot	Dry-Cold	Mean	SNR	StDev	ln(StDev)
0.45	0.67	0	0.52	0.41	6.37	0.25	-1.39
0.22	0.98	0	0.03	0.31	5.98	0.4	-0.92
0.88	0.6	0	0.5	0.5	4.61	0.32	-1.14
1	0.4	0	0.01	0.35	5.38	0.41	-0.89
0.92	1	1	1	0.98	0.17	0.03	-3.51
0.38	0.69	0	0.98	0.51	4.03	0.36	-1.02
0.83	0.41	0.35	0.11	0.43	6.06	0.26	-1.35
0.47	0.11	0	0.01	0.15	12.35	0.19	-1.66

Table 5: Mean, SNR, StDev and ln(StDev) of the experiment results.

After using Minitab's Taguchi design analysis, using the four factors as the terms as a start, it is found that none of the factors are significant; none of the factors have a p-value of less than 0.05 (Figure 1):

Linear Model Analysis: SN ratios versus Pot Size, Cooking Temperature, Cooking Time (Mins), Amount of Oil (Tsp)

Estimated Model Coefficients for SN ratios

Term	Coef	SE Coef	T	P
Constant	5.61757	1.412	3.977	0.028
PotSize -1	-0.03344	1.412	-0.024	0.983
Cooking -1	-1.47894	1.412	-1.047	0.372
Cooking -1	-1.31519	1.412	-0.931	0.420
Amounto -1	-0.15790	1.412	-0.112	0.918

Model Summary

S	R-Sq	R-Sq(adj)
3.9950	39.72%	0.00%

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	0.0089	0.0089	0.0089	0.00	0.983
CookingTemperature	1	17.4981	17.4981	17.4981	1.10	0.372
CookingTime (Mins)	1	13.8379	13.8379	13.8379	0.87	0.420
Amountof Oil (Tsp)	1	0.1995	0.1995	0.1995	0.01	0.918
Residual Error	3	47.8812	47.8812	15.9604		
Total	7	79.4256				

Linear Model Analysis: Means versus Pot Size, Cooking Temperature, Cooking Time (Mins), Amount of Oil (Tsp)

Estimated Model Coefficients for Means

Term	Coef	SE Coef	T	P
Constant	0.45375	0.08463	5.362	0.013
PotSize -1	-0.06250	0.08463	-0.739	0.514
Cooking -1	0.09875	0.08463	1.167	0.328
Cooking -1	0.12375	0.08463	1.462	0.240
Amounto -1	-0.02875	0.08463	-0.340	0.756

Model Summary

S	R-Sq	R-Sq(adj)
0.2394	58.11%	2.25%

Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	0.031250	0.031250	0.031250	0.55	0.514
CookingTemperature	1	0.078013	0.078013	0.078013	1.36	0.328
CookingTime (Mins)	1	0.122513	0.122513	0.122513	2.14	0.240
Amountof Oil (Tsp)	1	0.006613	0.006613	0.006613	0.12	0.756
Residual Error	3	0.171875	0.171875	0.057292		
Total	7	0.410263				

Linear Model Analysis: Ln StDevs versus Pot Size, Cooking Temperature, Cooking Time (Mins), Amount of Oil (Tsp)

Estimated Model Coefficients for Ln StDevs

Term	Coef	SE Coef	T	P
Constant	-1.3227	0.2422	-5.461	0.012
PotSize -1	0.3778	0.2422	1.560	0.217
Cooking -1	-0.2043	0.2422	-0.844	0.461
Cooking -1	-0.3448	0.2422	-1.424	0.250
Amounto -1	0.3051	0.2422	1.260	0.297

Model Summary

S	R-Sq	R-Sq(adj)
0.6851	69.26%	28.27%

Analysis of Variance for Ln StDevs

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	1.1419	1.1419	1.1419	2.43	0.217
CookingTemperature	1	0.3340	0.3340	0.3340	0.71	0.461
CookingTime (Mins)	1	0.9514	0.9514	0.9514	2.03	0.250
Amountof Oil (Tsp)	1	0.7446	0.7446	0.7446	1.59	0.297
Residual Error	3	1.4080	1.4080	0.4693		
Total	7	4.5799				

Figures 1: Minitab Analysis of Base Factors.

While noting that there are omitted terms (interaction terms), it may be worthwhile to include these terms. At first, it is assumed that amount of oil has no effect on the response variable, and the Minitab analysis is made using the terms A, B, C, AB, AC, and BC, leaving one degree of freedom for the residual error (Figure 2):

Linear Model Analysis: SN ratios versus Pot Size, Cooking Temperature, Cooking Time (Mins)

Estimated Model Coefficients for SN ratios

Term	Coef	SE Coef	T	P
Constant	5.61757	0.1579	35.576	0.018
PotSize -1	-0.03344	0.1579	-0.212	0.867
Cooking -1	-1.47894	0.1579	-9.366	0.068
Cooking -1	-1.31519	0.1579	-8.329	0.076
PotSize*Cooking -1 -1	2.07126	0.1579	13.117	0.048
PotSize*Cooking -1 -1	1.22217	0.1579	7.740	0.082
Cooking*Cooking -1 -1	0.44871	0.1579	2.842	0.215

Model Summary

S	R-Sq	R-Sq(adj)
0.4466	99.75%	98.24%

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	0.0089	0.0089	0.0089	0.04	0.867
Cooking Temperature	1	17.4981	17.4981	17.4981	87.72	0.068
Cooking Time (Mins)	1	13.8379	13.8379	13.8379	69.37	0.076
PotSize*Cooking Temperature	1	34.3209	34.3209	34.3209	172.06	0.048
PotSize*Cooking Time (Mins)	1	11.9495	11.9495	11.9495	59.91	0.082
Cooking Temperature* Cooking Time (Mins)	1	1.6107	1.6107	1.6107	8.08	0.215
Residual Error	1	0.1995	0.1995	0.1995		
Total	7	79.4256				

Linear Model Analysis: Means versus Pot Size, Cooking Temperature, Cooking Time (Mins)

Estimated Model Coefficients for Means

Term	Coef	SE Coef	T	P
Constant	0.45375	0.02875	15.783	0.040
PotSize -1	-0.06250	0.02875	-2.174	0.274
Cooking -1	0.09875	0.02875	3.435	0.180
Cooking -1	0.12375	0.02875	4.304	0.145
PotSize*Cooking -1 -1	-0.13125	0.02875	-4.565	0.137
PotSize*Cooking -1 -1	-0.06250	0.02875	-2.174	0.274
Cooking*Cooking -1 -1	0.01875	0.02875	0.652	0.632

Model Summary

S	R-Sq	R-Sq(adj)
0.0813	98.39%	88.72%

Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	0.031250	0.031250	0.031250	4.73	0.274
Cooking Temperature	1	0.078013	0.078012	0.078012	11.80	0.180
Cooking Time (Mins)	1	0.122513	0.122513	0.122513	18.53	0.145
PotSize*Cooking Temperature	1	0.137813	0.137813	0.137813	20.84	0.137
PotSize*Cooking Time (Mins)	1	0.031250	0.031250	0.031250	4.73	0.274
Cooking Temperature* Cooking Time (Mins)	1	0.002813	0.002813	0.002813	0.43	0.632
Residual Error	1	0.006613	0.006613	0.006613		
Total	7	0.410263				

Linear Model Analysis: Ln StDevs versus Pot Size, Cooking Temperature, Cooking Time (Mins)

Estimated Model Coefficients for Ln StDevs

Term	Coef	SE Coef	T	P
Constant	-1.3227	0.3051	-4.335	0.144
PotSize -1	0.3778	0.3051	1.238	0.432
Cooking -1	-0.2043	0.3051	-0.670	0.624
Cooking -1	-0.3448	0.3051	-1.130	0.461
PotSize*Cooking -1 -1	0.1378	0.3051	0.452	0.730
PotSize*Cooking -1 -1	0.1669	0.3051	0.547	0.681
Cooking*Cooking -1 -1	-0.3594	0.3051	-1.178	0.448

Model Summary

S	R-Sq	R-Sq(adj)
0.8629	83.74%	0.00%

Analysis of Variance for Ln StDevs

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	1.1419	1.1419	1.1419	1.53	0.432
Cooking Temperature	1	0.3340	0.3340	0.3340	0.45	0.624
Cooking Time (Mins)	1	0.9514	0.9514	0.9514	1.28	0.461
PotSize*Cooking Temperature	1	0.1520	0.1520	0.1520	0.20	0.730
PotSize*Cooking Time (Mins)	1	0.2228	0.2228	0.2228	0.30	0.681
Cooking Temperature* Cooking Time (Mins)	1	1.0332	1.0332	1.0332	1.39	0.448
Residual Error	1	0.7446	0.7446	0.7446		
Total	7	4.5799				

Figure 2: Taguchi Analysis Using A, B, C, AB, AC, and BC Terms.

The SNR analysis shows that some of the terms are significant, but not in the analysis of means and logarithm of standard deviation. The term with the highest p-value is the interaction term between Cooking Time and Cooking Temperature, BC, so it is a good option to remove it from the model and try running the Minitab analysis again (Figure 3):

Linear Model Analysis: SN ratios versus Pot Size, Cooking Temperature, Cooking Time (Mins)

Estimated Model Coefficients for SN ratios

Term	Coef	SE Coef	T	P
Constant	5.61757	0.3364	16.701	0.004
PotSize -1	-0.03344	0.3364	-0.099	0.930
Cooking -1	-1.47894	0.3364	-4.397	0.048
Cooking -1	-1.31519	0.3364	-3.910	0.060
PotSize*Cooking -1 -1	2.07126	0.3364	6.158	0.025
PotSize*Cooking -1 -1	1.22217	0.3364	3.634	0.068

Model Summary

S	R-Sq	R-Sq(adj)
0.9514	97.72%	92.02%

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	0.0089	0.0089	0.0089	0.01	0.930
Cooking Temperature	1	17.4981	17.4981	17.4981	19.33	0.048
Cooking Time (Mins)	1	13.8379	13.8379	13.8379	15.29	0.060
PotSize*Cooking Temperature	1	34.3209	34.3209	34.3209	37.92	0.025
PotSize*Cooking Time (Mins)	1	11.9495	11.9495	11.9495	13.20	0.068
Residual Error	2	1.8102	1.8102	0.9051		
Total	7	79.4256				

Linear Model Analysis: Means versus Pot Size, Cooking Temperature, Cooking Time (Mins)

Estimated Model Coefficients for Means

Term	Coef	SE Coef	T	P
Constant	0.45375	0.02427	18.695	0.003
PotSize -1	-0.06250	0.02427	-2.575	0.123
Cooking -1	0.09875	0.02427	4.069	0.055
Cooking -1	0.12375	0.02427	5.099	0.036
PotSize*Cooking -1 -1	-0.13125	0.02427	-5.408	0.033
PotSize*Cooking -1 -1	-0.06250	0.02427	-2.575	0.123

Model Summary

S	R-Sq	R-Sq(adj)
0.0686	97.70%	91.96%

Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	0.031250	0.031250	0.031250	6.63	0.123
Cooking Temperature	1	0.078013	0.078012	0.078012	16.55	0.055
Cooking Time (Mins)	1	0.122513	0.122513	0.122513	26.00	0.036
PotSize*Cooking Temperature	1	0.137813	0.137813	0.137813	29.24	0.033
PotSize*Cooking Time (Mins)	1	0.031250	0.031250	0.031250	6.63	0.123
Residual Error	2	0.009425	0.009425	0.004713		
Total	7	0.410263				

Linear Model Analysis: Ln StDevs versus Pot Size, Cooking Temperature, Cooking Time (Mins)

Estimated Model Coefficients for Ln StDevs

Term	Coef	SE Coef	T	P
Constant	-1.3227	0.3333	-3.968	0.058
PotSize -1	0.3778	0.3333	1.133	0.375
Cooking -1	-0.2043	0.3333	-0.613	0.602
Cooking -1	-0.3448	0.3333	-1.035	0.410
PotSize*Cooking -1 -1	0.1378	0.3333	0.413	0.719
PotSize*Cooking -1 -1	0.1669	0.3333	0.501	0.666

Model Summary

S	R-Sq	R-Sq(adj)
0.9428	61.18%	0.00%

Analysis of Variance for Ln StDevs

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	1.1419	1.1419	1.1419	1.28	0.375
Cooking Temperature	1	0.3340	0.3340	0.3340	0.38	0.602
Cooking Time (Mins)	1	0.9514	0.9514	0.9514	1.07	0.410
PotSize*Cooking Temperature	1	0.1520	0.1520	0.1520	0.17	0.719
PotSize*Cooking Time (Mins)	1	0.2228	0.2228	0.2228	0.25	0.666
Residual Error	2	1.7779	1.7779	0.8889		
Total	7	4.5799				

Response Table for Signal to Noise Ratios

Smaller is better

Level	PotSize	Cooking Temperature	Cooking Time (Mins)
1	5.584	4.139	4.302
2	5.651	7.097	6.933
Delta	0.067	2.958	2.630
Rank	3	1	2

Response Table for Means

Level	PotSize	Cooking Temperature	Cooking Time (Mins)
1	0.3912	0.5525	0.5775
2	0.5162	0.3550	0.3300
Delta	0.1250	0.1975	0.2475
Rank	3	2	1

Response Table for Ln(Standard Deviations)

Level	PotSize	Cooking Temperature	Cooking Time (Mins)
1	-0.9449	-1.5270	-1.6676
2	-1.7005	-1.1184	-0.9779
Delta	0.7556	0.4086	0.6897
Rank	1	3	2

Figure 3: Taguchi Analysis Using A, B, C, AB, and AC Terms.

Most of the terms are significant in SNR analysis, except for Pot Size, Cooking Temperature and the interaction between Pot Size and Cooking Time, AC; however, the p-values of Cooking Temperature and AC are close to α, so they are assumed to be significant. For mean analysis, Cooking Time, Cooking Temperature, and AB are significant. For the logarithm of the standard deviation, no terms are significant; this may be due to the uncontrolled nature of the experiments causing fuzzy data. The R^2_{adj} values are acceptable for the SNR and mean analysis, but not for the $\ln s$ analysis.

The above model seems to be the best, since many more models were tried, and they have resulted in less significant data. In addition, it seems that the mere addition of the Amount of Oil term causes the model to be insignificant. The other models that have been tried are found in appendix A. The optimal parameters for the best model are displayed in the table below:

Parameters	Pot Size	Temperature	Time	AB	AC
SNR	-	-1	-1	1×-1= -1	1×-1= -1
Mean	-	1	1	1×1= 1	-
ln(StDev)	-	-	-	-	-

Table 6: Optimal parameters to obtain the best value for each parameter.

Note that even though term A is not significant for any parameter, it is necessary for Minitab so that it can perform the calculation using the terms involving term A.

In both cases it seems that it is best to use a big pot size, since the interaction terms "prefers" the bigger pot. As for minimizing SNR, the terms B and C should be negative, namely $(A, B, C) = (1, -1, -1)$. To minimize mean, the same terms must be positive, namely $(A, B, C) = (1, 1, 1)$. As it can be seen, there is a huge disagreement between the best levels for each of the SNR and mean.

Prediction

Using Minitab's Predict Taguchi Result module, the response variable, and the respective SNR and standard deviation will be calculated. The parameters that will be tested are those that have been determined to be optimal for the model (Table 7):

Run	A	B	C	AB	AC	SNR	Mean	ln(StDev)
1	1	-1	-1	-1	-1	-0.44	0.93	-2.55
2	1	1	1	1	-1	11.74	0.1	-0.847

Table 7: Prediction of Taguchi Results, given the candidates-for-optimality sets of factor levels.

The lost percentage of kernels in the first run is too high. So, even if the SNR value is reduced enough, it is not a viable option. The second run is the best between the two. Even though it has a higher $\ln s$, the expected percentage of unpopped kernels is much less, so the higher variance is much more bearable. It is determined that the best set of factor levels is the second run, whose set of factor levels is $(A, B, C) = (1, 1, 1)$

Confirmation of Results

Pot Size	Cooking Temperature	Cooking Time (Mins)	Moist-Hot	Moist-Cold	Dry-Hot	Dry-Cold	Mean	SNR	StDev	ln(StDev)
1	1	1	0.5	0.03	0.07	0	0.15	11.94	0.2	-1.61
1	1	1	0.28	0.12	0	0	0.1	16.35	0.11	-2.21

Table 8: Results of Confirmation Experiments.

It seems the mean is slightly less than the predicted mean, which was 0.1. The same is true for the StDev and SNR. This is possible due to the fact that the preheating of the pots is a noise factor that has not been accounted for in the experiments and may have caused this discrepancy.

Finals Notes

- Many samples got burnt during the experiments and they have been disposed of.
- The kernels that became popcorns during the experiment were consumed, and those that didn't pop were then reheated under better conditions and were consumed.
- The control factors were determined by available equipment (pot size) and by undergoing a normal popcorn popping process to see how long it takes, how hot the temperature should be, etc.

Conclusion

In conclusion, the conducted robust design study aimed to address the challenge of reducing the percentage of unpopped kernels in FastPop Inc.'s popcorn making process. Through meticulous experimentation and thorough data analysis, optimal levels for control factors, including corn brand, pan size, and cooking time, were identified. The findings of this study provide valuable insights for enhancing yield, cost reduction, and overall customer satisfaction in FastPop Inc.'s popcorn production process. The best yield can happen when the kernels are popped in low temperatures in extended amount of time.

Appendix A

Linear Model Analysis: SN ratios versus Pot Size, Cooking Temperature, Cooking Time (Mins), Amount of Oil (Tsp)

Estimated Model Coefficients for SN ratios

Term	Coef	SE Coef	T	P
Constant	5.61757	0.9206	6.102	0.026
PotSize -1	-0.03344	0.9206	-0.036	0.974
Cooking -1	-1.47894	0.9206	-1.606	0.249
Cooking -1	-1.31519	0.9206	-1.429	0.289
Amounto -1	-0.15790	0.9206	-0.172	0.880
PotSize*Cooking -1 -1	2.07126	0.9206	2.250	0.153

Model Summary

S	R-Sq	R-Sq(adj)
2.6039	82.93%	40.24%

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	0.0089	0.0089	0.0089	0.00	0.974
Cooking Temperature	1	17.4981	17.4981	17.4981	2.58	0.249
Cooking Time (Mins)	1	13.8379	13.8379	13.8379	2.04	0.289
Amount of Oil (Tsp)	1	0.1995	0.1995	0.1995	0.03	0.880
PotSize*Cooking Temperature	1	34.3209	34.3209	34.3209	5.06	0.153
Residual Error	2	13.5602	13.5602	6.7801		
Total	7	79.4256				

Linear Model Analysis: Means versus Pot Size, Cooking Temperature, Cooking Time (Mins), Amount of Oil (Tsp)

Estimated Model Coefficients for Means

Term	Coef	SE Coef	T	P
Constant	0.45375	0.04614	9.834	0.010
PotSize -1	-0.06250	0.04614	-1.355	0.308
Cooking -1	0.09875	0.04614	2.140	0.166
Cooking -1	0.12375	0.04614	2.682	0.115
Amounto -1	-0.02875	0.04614	-0.623	0.597
PotSize*Cooking -1 -1	-0.13125	0.04614	-2.845	0.105

Model Summary

S	R-Sq	R-Sq(adj)
0.1305	91.70%	70.94%

Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	0.031250	0.031250	0.031250	1.83	0.308
Cooking Temperature	1	0.078013	0.078012	0.078012	4.58	0.166
Cooking Time (Mins)	1	0.122513	0.122513	0.122513	7.19	0.115
Amount of Oil (Tsp)	1	0.006613	0.006613	0.006613	0.39	0.597
PotSize*Cooking Temperature	1	0.137813	0.137813	0.137813	8.09	0.105
Residual Error	2	0.034063	0.034063	0.017031		
Total	7	0.410263				

Linear Model Analysis: Ln StDevs versus Pot Size, Cooking Temperature, Cooking Time (Mins), Amount of Oil (Tsp)

Estimated Model Coefficients for Ln StDevs

Term	Coef	SE Coef	T	P
Constant	-1.3227	0.2802	-4.721	0.042
PotSize -1	0.3778	0.2802	1.348	0.310
Cooking -1	-0.2043	0.2802	-0.729	0.542
Cooking -1	-0.3448	0.2802	-1.231	0.343
Amounto -1	0.3051	0.2802	1.089	0.390
PotSize*Cooking -1 -1	0.1378	0.2802	0.492	0.671

Model Summary

S	R-Sq	R-Sq(adj)
0.7925	72.58%	4.01%

Analysis of Variance for Ln StDevs

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	1.1419	1.1419	1.1419	1.82	0.310
Cooking Temperature	1	0.3340	0.3340	0.3340	0.53	0.542
Cooking Time (Mins)	1	0.9514	0.9514	0.9514	1.51	0.343
Amount of Oil (Tsp)	1	0.7446	0.7446	0.7446	1.19	0.390
PotSize*Cooking Temperature	1	0.1520	0.1520	0.1520	0.24	0.671
Residual Error	2	1.2560	1.2560	0.6280		
Total	7	4.5799				

Linear Model Analysis: SN ratios versus Pot Size, Cooking Temperature, Cooking Time (Mins), Amount of Oil (Tsp)

Estimated Model Coefficients for SN ratios

Term	Coef	SE Coef	T	P
Constant	5.61757	1.222	4.596	0.136
PotSize -1	-0.03344	1.222	-0.027	0.983
Cooking -1	-1.47894	1.222	-1.210	0.440
Cooking -1	-1.31519	1.222	-1.076	0.477
Amounto -1	-0.15790	1.222	-0.129	0.918
PotSize*Cooking -1 -1	2.07126	1.222	1.695	0.339
PotSize*Amount o -1 -1	0.44871	1.222	0.367	0.776

Model Summary

S	R-Sq	R-Sq(adj)
3.4568	84.96%	0.00%

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	0.0089	0.0089	0.0089	0.00	0.983
Cooking Temperature	1	17.4981	17.4981	17.4981	1.46	0.440
Cooking Time (Mins)	1	13.8379	13.8379	13.8379	1.16	0.477
Amount of Oil (Tsp)	1	0.1995	0.1995	0.1995	0.02	0.918
PotSize*Cooking Temperature	1	34.3209	34.3209	34.3209	2.87	0.339
PotSize*Amount of Oil (Tsp)	1	1.6107	1.6107	1.6107	0.13	0.776
Residual Error	1	11.9495	11.9495	11.9495		
Total	7	79.4256				

Linear Model Analysis: Means versus Pot Size, Cooking Temperature, Cooking Time (Mins), Amount of Oil (Tsp)

Estimated Model Coefficients for Means

Term	Coef	SE Coef	T	P
Constant	0.45375	0.06250	7.260	0.087
PotSize -1	-0.06250	0.06250	-1.000	0.500
Cooking -1	0.09875	0.06250	1.580	0.359
Cooking -1	0.12375	0.06250	1.980	0.298
Amounto -1	-0.02875	0.06250	-0.460	0.726
PotSize*Cooking -1 -1	-0.13125	0.06250	-2.100	0.283
PotSize*Amount o -1 -1	0.01875	0.06250	0.300	0.814

Model Summary

S	R-Sq	R-Sq(adj)
0.1768	92.38%	46.68%

Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	0.031250	0.031250	0.031250	1.00	0.500
Cooking Temperature	1	0.078013	0.078012	0.078012	2.50	0.359
Cooking Time (Mins)	1	0.122513	0.122513	0.122513	3.92	0.298
Amount of Oil (Tsp)	1	0.006613	0.006613	0.006613	0.21	0.726
PotSize*Cooking Temperature	1	0.137813	0.137813	0.137813	4.41	0.283
PotSize*Amount of Oil (Tsp)	1	0.002813	0.002813	0.002813	0.09	0.814
Residual Error	1	0.031250	0.031250	0.031250		
Total	7	0.410263				

Linear Model Analysis: Ln StDevs versus Pot Size, Cooking Temperature, Cooking Time (Mins), Amount of Oil (Tsp)

Estimated Model Coefficients for Ln StDevs

Term	Coef	SE Coef	T	P
Constant	-1.3227	0.1669	-7.926	0.080
PotSize -1	0.3778	0.1669	2.264	0.265
Cooking -1	-0.2043	0.1669	-1.224	0.436
Cooking -1	-0.3448	0.1669	-2.066	0.287
Amounto -1	0.3051	0.1669	1.828	0.319
PotSize*Cooking -1 -1	0.1378	0.1669	0.826	0.561
PotSize*Amount o -1 -1	-0.3594	0.1669	-2.153	0.277

Model Summary

S	R-Sq	R-Sq(adj)
0.4720	95.14%	65.95%

Analysis of Variance for Ln StDevs

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	1.1419	1.1419	1.1419	5.13	0.265
Cooking Temperature	1	0.3340	0.3340	0.3340	1.50	0.436
Cooking Time (Mins)	1	0.9514	0.9514	0.9514	4.27	0.287
Amount of Oil (Tsp)	1	0.7446	0.7446	0.7446	3.34	0.319
PotSize*Cooking Temperature	1	0.1520	0.1520	0.1520	0.68	0.561
PotSize*Amount of Oil (Tsp)	1	1.0332	1.0332	1.0332	4.64	0.277
Residual Error	1	0.2228	0.2228	0.2228		
Total	7	4.5799				

Linear Model Analysis: SN ratios versus Pot Size, Cooking Temperature, Cooking Time (Mins), Amount of Oil (Tsp)

Estimated Model Coefficients for SN ratios

Term	Coef	SE Coef	T	P
Constant	5.61757	0.4487	12.519	0.051
PotSize -1	-0.03344	0.4487	-0.075	0.953
Cooking -1	-1.47894	0.4487	-3.296	0.188
Cooking -1	-1.31519	0.4487	-2.931	0.209
Amounto -1	-0.15790	0.4487	-0.352	0.785
PotSize*Cooking -1 -1	2.07126	0.4487	4.616	0.136
Cooking*Amounto -1 -1	1.22217	0.4487	2.724	0.224

Model Summary

S	R-Sq	R-Sq(adj)
1.2691	97.97%	85.80%

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	0.0089	0.0089	0.0089	0.01	0.953
Cooking Temperature	1	17.4981	17.4981	17.4981	10.86	0.188
Cooking Time (Mins)	1	13.8379	13.8379	13.8379	8.59	0.209
Amount of Oil (Tsp)	1	0.1995	0.1995	0.1995	0.12	0.785
PotSize*Cooking Temperature	1	34.3209	34.3209	34.3209	21.31	0.136
Cooking Temperature* Amount of Oil (Tsp)	1	11.9495	11.9495	11.9495	7.42	0.224
Residual Error	1	1.6107	1.6107	1.6107		
Total	7	79.4256				

Linear Model Analysis: Means versus Pot Size, Cooking Temperature, Cooking Time (Mins), Amount of Oil (Tsp)

Estimated Model Coefficients for Means

Term	Coef	SE Coef	T	P
Constant	0.45375	0.01875	24.200	0.026
PotSize -1	-0.06250	0.01875	-3.333	0.186
Cooking -1	0.09875	0.01875	5.267	0.119
Cooking -1	0.12375	0.01875	6.600	0.096
Amounto -1	-0.02875	0.01875	-1.533	0.368
PotSize*Cooking -1 -1	-0.13125	0.01875	-7.000	0.090
Cooking*Amounto -1 -1	-0.06250	0.01875	-3.333	0.186

Model Summary

S	R-Sq	R-Sq(adj)
0.0530	99.31%	95.20%

Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	0.031250	0.031250	0.031250	11.11	0.186
Cooking Temperature	1	0.078013	0.078012	0.078012	27.74	0.119
Cooking Time (Mins)	1	0.122513	0.122513	0.122513	43.56	0.096
Amount of Oil (Tsp)	1	0.006613	0.006613	0.006613	2.35	0.368
PotSize*Cooking Temperature	1	0.137813	0.137813	0.137813	49.00	0.090
Cooking Temperature* Amount of Oil (Tsp)	1	0.031250	0.031250	0.031250	11.11	0.186
Residual Error	1	0.002813	0.002813	0.002813		
Total	7	0.410263				

Linear Model Analysis: Ln StDevs versus Pot Size, Cooking Temperature, Cooking Time (Mins), Amount of Oil (Tsp)

Estimated Model Coefficients for Ln StDevs

Term	Coef	SE Coef	T	P
Constant	-1.3227	0.3594	-3.681	0.169
PotSize -1	0.3778	0.3594	1.051	0.484
Cooking -1	-0.2043	0.3594	-0.569	0.671
Cooking -1	-0.3448	0.3594	-0.960	0.513
Amounto -1	0.3051	0.3594	0.849	0.552
PotSize*Cooking -1 -1	0.1378	0.3594	0.384	0.767
Cooking*Amounto -1 -1	0.1669	0.3594	0.464	0.723

Model Summary

S	R-Sq	R-Sq(adj)
1.0165	77.44%	0.00%

Analysis of Variance for Ln StDevs

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	1.1419	1.1419	1.1419	1.11	0.484
Cooking Temperature	1	0.3340	0.3340	0.3340	0.32	0.671
Cooking Time (Mins)	1	0.9514	0.9514	0.9514	0.92	0.513
Amount of Oil (Tsp)	1	0.7446	0.7446	0.7446	0.72	0.552
PotSize*Cooking Temperature	1	0.1520	0.1520	0.1520	0.15	0.767
Cooking Temperature* Amount of Oil (Tsp)	1	0.2228	0.2228	0.2228	0.22	0.723
Residual Error	1	1.0332	1.0332	1.0332		
Total	7	4.5799				

Linear Model Analysis: SN ratios versus Pot Size, Cooking Temperature, Cooking Time (Mins), Amount of Oil (Tsp)

Estimated Model Coefficients for SN ratios

Term	Coef	SE Coef	T	P
Constant	5.61757	0.9206	6.102	0.026
PotSize -1	-0.03344	0.9206	-0.036	0.974
Cooking -1	-1.47894	0.9206	-1.606	0.249
Cooking -1	-1.31519	0.9206	-1.429	0.289
Amounto -1	-0.15790	0.9206	-0.172	0.880
PotSize*Cooking -1 -1	2.07126	0.9206	2.250	0.153

Model Summary

S	R-Sq	R-Sq(adj)
2.6039	82.93%	40.24%

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	0.0089	0.0089	0.0089	0.00	0.974
Cooking Temperature	1	17.4981	17.4981	17.4981	2.58	0.249
Cooking Time (Mins)	1	13.8379	13.8379	13.8379	2.04	0.289
Amount of Oil (Tsp)	1	0.1995	0.1995	0.1995	0.03	0.880
PotSize*Cooking Temperature	1	34.3209	34.3209	34.3209	5.06	0.153
Residual Error	2	13.5602	13.5602	6.7801		
Total	7	79.4256				

Linear Model Analysis: Means versus Pot Size, Cooking Temperature, Cooking Time (Mins), Amount of Oil (Tsp)

Estimated Model Coefficients for Means

Term	Coef	SE Coef	T	P
Constant	0.45375	0.04614	9.834	0.010
PotSize -1	-0.06250	0.04614	-1.355	0.308
Cooking -1	0.09875	0.04614	2.140	0.166
Cooking -1	0.12375	0.04614	2.682	0.115
Amounto -1	-0.02875	0.04614	-0.623	0.597
PotSize*Cooking -1 -1	-0.13125	0.04614	-2.845	0.105

Model Summary

S	R-Sq	R-Sq(adj)
0.1305	91.70%	70.94%

Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	0.031250	0.031250	0.031250	1.83	0.308
Cooking Temperature	1	0.078013	0.078012	0.078012	4.58	0.166
Cooking Time (Mins)	1	0.122513	0.122513	0.122513	7.19	0.115
Amount of Oil (Tsp)	1	0.006613	0.006613	0.006613	0.39	0.597
PotSize*Cooking Temperature	1	0.137813	0.137813	0.137813	8.09	0.105
Residual Error	2	0.034063	0.034063	0.017031		
Total	7	0.410263				

Linear Model Analysis: Ln StDevs versus Pot Size, Cooking Temperature, Cooking Time (Mins), Amount of Oil (Tsp)

Estimated Model Coefficients for Ln StDevs

Term	Coef	SE Coef	T	P
Constant	-1.3227	0.2802	-4.721	0.042
PotSize -1	0.3778	0.2802	1.348	0.310
Cooking -1	-0.2043	0.2802	-0.729	0.542
Cooking -1	-0.3448	0.2802	-1.231	0.343
Amounto -1	0.3051	0.2802	1.089	0.390
PotSize*Cooking -1 -1	0.1378	0.2802	0.492	0.671

Model Summary

S	R-Sq	R-Sq(adj)
0.7925	72.58%	4.01%

Analysis of Variance for Ln StDevs

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PotSize	1	1.1419	1.1419	1.1419	1.82	0.310
Cooking Temperature	1	0.3340	0.3340	0.3340	0.53	0.542
Cooking Time (Mins)	1	0.9514	0.9514	0.9514	1.51	0.343
Amount of Oil (Tsp)	1	0.7446	0.7446	0.7446	1.19	0.390
PotSize*Cooking Temperature	1	0.1520	0.1520	0.1520	0.24	0.671
Residual Error	2	1.2560	1.2560	0.6280		
Total	7	4.5799				

Figure A1: Minitab Analysis for various tried models.

Appendix B

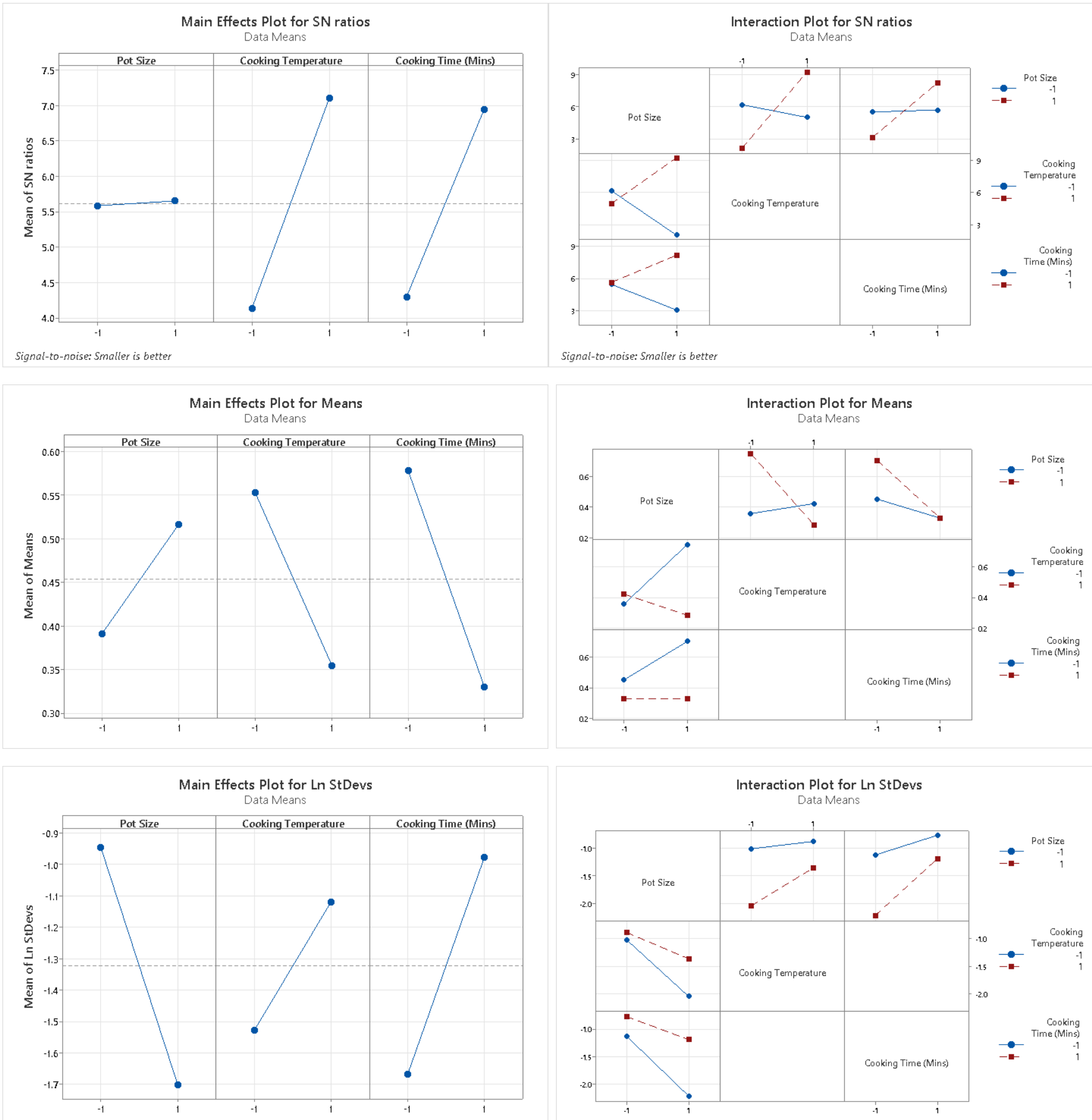

Figure B1: Main effects plots and interaction plots for the optimal model.