
STAT 461: Project

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DEFINING EXPERIMENT & GATHERING DATA

The experiment consisted of baking cookies and measuring the diameter of the finished product. The factors that were chosen were to use melted butter or creamed butter and to chill half of the dough before baking. The recipe was measured out into separate mixing bowls to make the dough instead of mixing all of the dry ingredients and separating afterwards to ensure that the same amount of each ingredient went into the two dough mixtures. This recipe was used:

<https://joyfoodsunshine.com/the-most-amazing-chocolate-chip-cookies/>

The following table outlines the factors that were considered, their levels, and how they are associated. Originally tray position was not considered as a factor, however, when putting the trays into the oven, only one tray would fit on the top rack so the difference in top and bottom racks was added after the fact.

The purpose of the experiment was to see if the melted butter, which creates a more liquidus mixture, would cause the cookies to become larger in diameter. Similarly, one would expect that the chilled dough may affect the cookie size and shape.

Factor	Levels	Fixed?	Nested/Crossed
Butter (b)	Melted (M), Creamed (C)	Fixed	Crossed with Dough & Tray
Dough Temp (d)	Refrigerated (R), NOT Refrigerated (N)	Fixed	Crossed with Butter & Tray
Tray Position (t)	Top (T), Bottom (B)	Fixed	Crossed with Butter & Dough

Below are images of the butter, sugar, and brown sugar created by creaming the butter and sugars together vs simply mixing in melted butter.



Creamed Butter Mixture



Melted Butter Mixture

After the dough was made, each was weighed separately to ensure they were the same weight (753 grams). Afterwards, each type of dough was split in half by weight (377 grams) and placed into 2 separate bowls, covered with plastic wrap, and marked. One bowl from each type of dough was placed in the refrigerator for 2 hours.



Full Weight of Dough



Weight of Dough After Separating



Marked Bowls at Room Temp

Using the possible combinations of butter and dough temperature, R was used draw 2 samples for position assignment for each tray. The following is the output from this procedure.

```
1 > tray1
2 [1] "CN" "CN" "MR" "CN" "MR" "CR" "CR" "MR" "MN" "MN" "CR" "MN"
3 > tray2
4 [1] "CN" "CN" "CR" "CR" "MR" "MN" "CN" "MN" "MR" "MR" "MN" "CR"
```

Listing 1: Randomized Tray Locations

The cookie dough was placed on 2 baking sheets using the above samples as a guide and marked 1-12 on each sheet. To ensure a mostly consistent cookie size, a dough scoop was used and leveled off for each cookie.



Tray 1



Tray 2

The cookies were baked for 9 minutes, removed from the oven and the largest diameter was measured using a pair of calipers.



Creamed Butter Mixture

DATA PLOTS

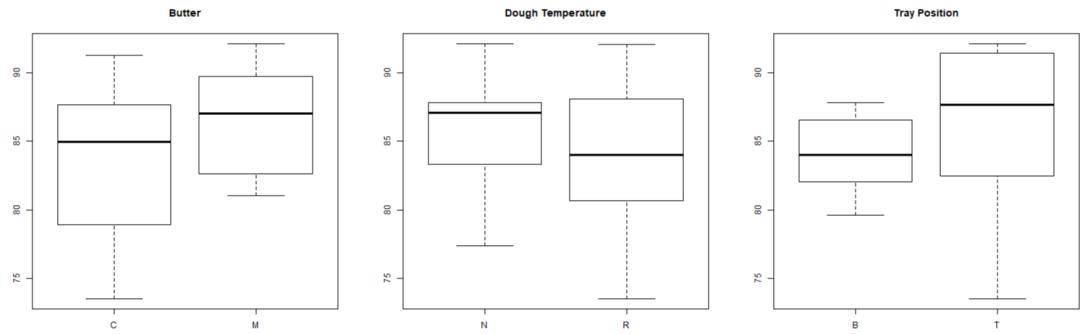


Figure 1: Individual Factor Effects on Cookie Size

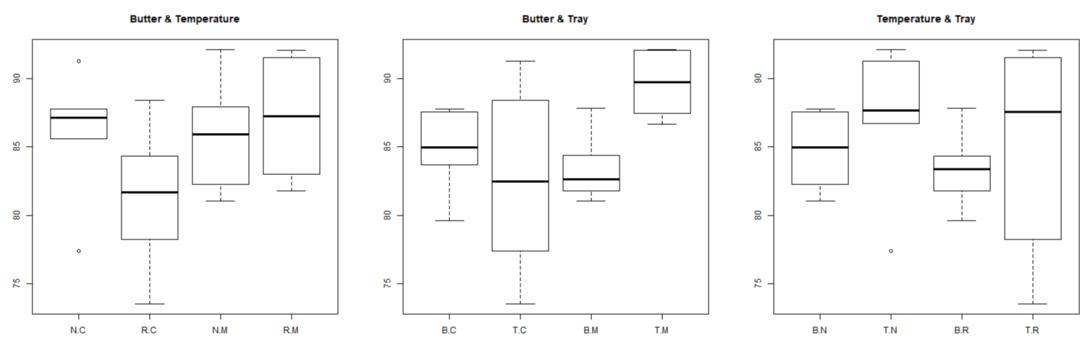


Figure 2: Pairwise Factor Effects on Cookie Size

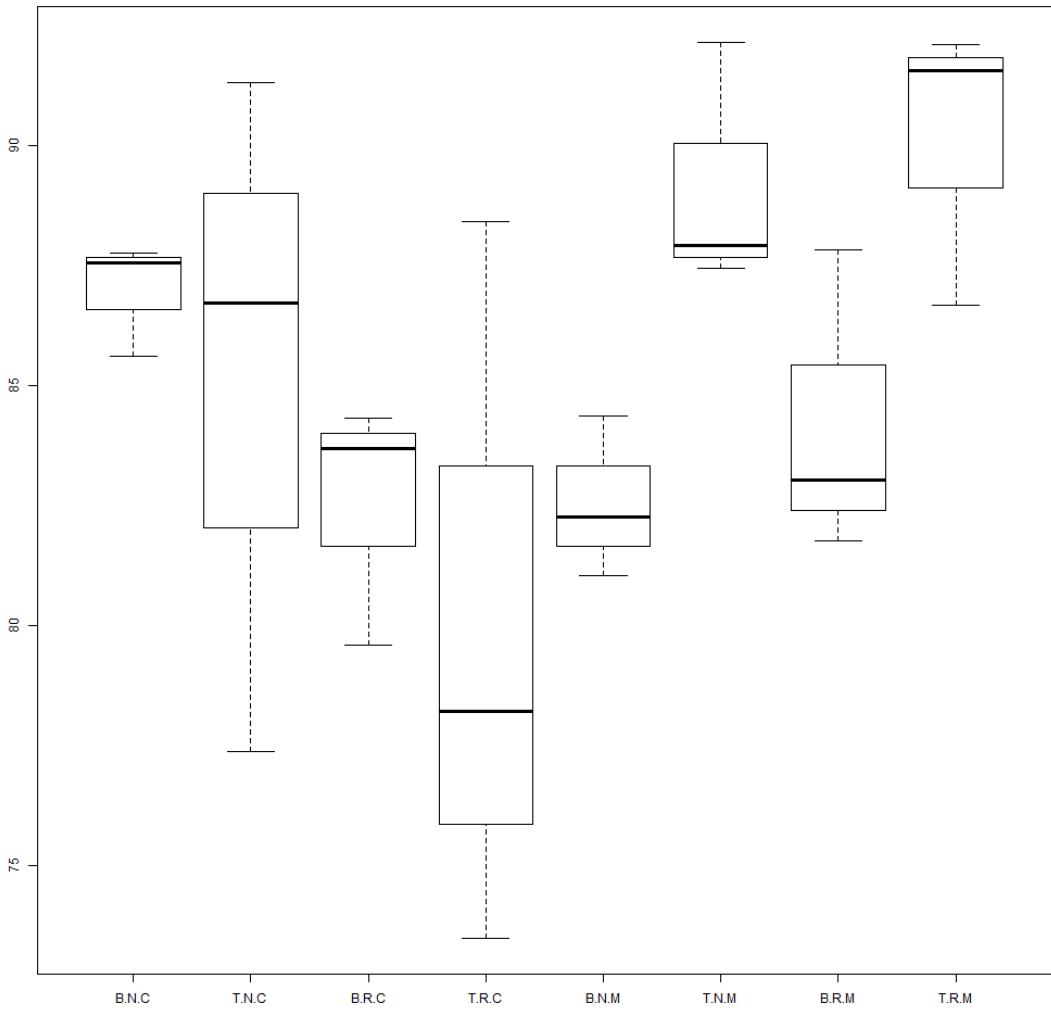


Figure 3: Full Factor Effects on Cookie Size

MODEL

Using the full model with all interactions, we can obtain the following model:

$$Y_{b,d,t,c} = \alpha_b + \beta_d + \gamma_t + (\alpha\beta)_{b,d} + (\alpha\gamma)_{b,t} + (\beta\gamma)_{dt} + \epsilon_{b,d,t,c}$$

$$\epsilon_{b,d,t,c} \sim N(0, \sigma^2)$$

If one were to only examine the main effects, the ME model is as follows:

$$Y_{b,d,t,c} = \alpha_b + \beta_d + \gamma_t + \epsilon_{b,d,t,c}$$

$$\epsilon_{b,d,t,c} \sim N(0, \sigma^2)$$

R ANALYSIS

Looking at the ANOVA table for the full model, we can see that the only truly significant factor is the interaction between the type of butter used and the tray position. The chilled dough and butter type interaction is significant if we relax our alpha value to 0.1.

```

1 > cookieFullModel = aov(size ~ tray + chilled + butter + tray:chilled + tray:butter +
   chilled:butter, data=cookies)
2 > anova(cookieFullModel)
3 Analysis of Variance Table
4
5 Response: size
6              Df Sum Sq Mean Sq F value    Pr(>F)
7 tray          1 25.133  25.133  1.4696  0.24198
8 chilled       1 18.131  18.131  1.0602  0.31760
9 butter         1 48.621  48.621  2.8431  0.11003
10 tray:chilled 1  0.680   0.680  0.0398  0.84430
11 tray:butter   1 106.597 106.597  6.2332  0.02311 *
12 chilled:butter 1  55.085  55.085  3.2211  0.09050 .
13 Residuals    17 290.726 17.102
14 ---
15 Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

Listing 2: Full Model ANOVA Table

For robustness, examining the full model yields the same result that the individual factors are not enough to result in a difference in the size of the cookies.

```

1 > cookieMainModel = aov(size ~ tray + chilled + butter, data=cookies)
2 > anova(cookieMainModel)
3 Analysis of Variance Table
4
5 Response: size
6              Df Sum Sq Mean Sq F value    Pr(>F)
7 tray          1 25.13  25.133  1.1094  0.3048
8 chilled       1 18.13  18.131  0.8003  0.3816
9 butter         1 48.62  48.621  2.1462  0.1585
10 Residuals   20 453.09 22.654
11 ---
12 Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

Listing 3: Main Effects Model ANOVA Table

Moving to check our normality assumptions, the below Q-Q and Residual vs Fitted Plots. The residual vs fitted plot shows relatively constant variance and there is nothing significantly out of place in the Q-Q plot to indicate that our normality assumptions are violated. The tails are both a bit skewed but the majority of the data is within a reasonable variance. Performing a log and square-root transformation on the data yielded minimal change in the normality plots, so the unaltered model was used.

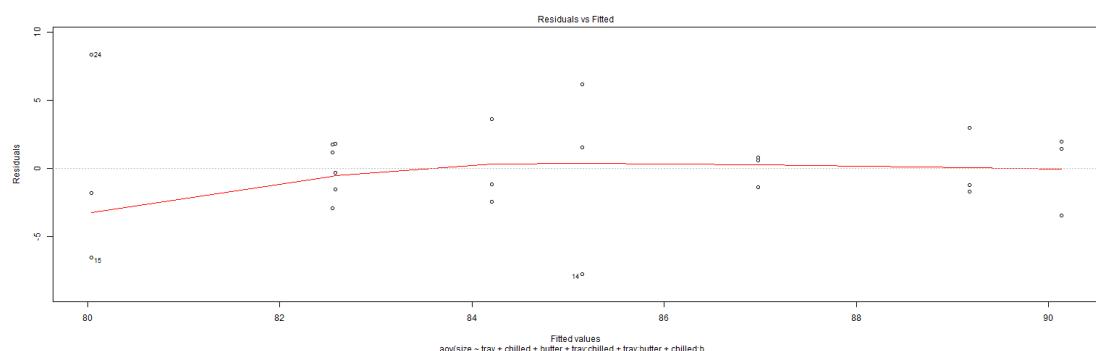


Figure 4: Residual vs Fitted Plot for Full Model

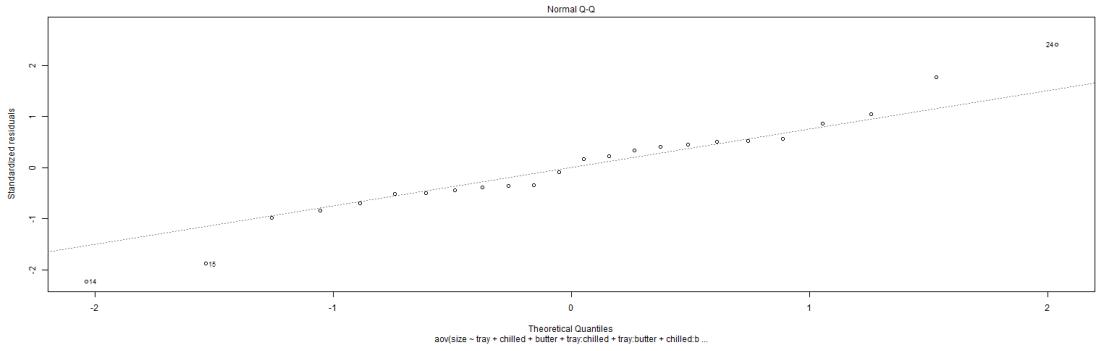


Figure 5: Q-Q Plot for Full Model

Finally, because the only significant terms are interaction terms, an interaction plot was created for the two interaction pairs. These plots are below:

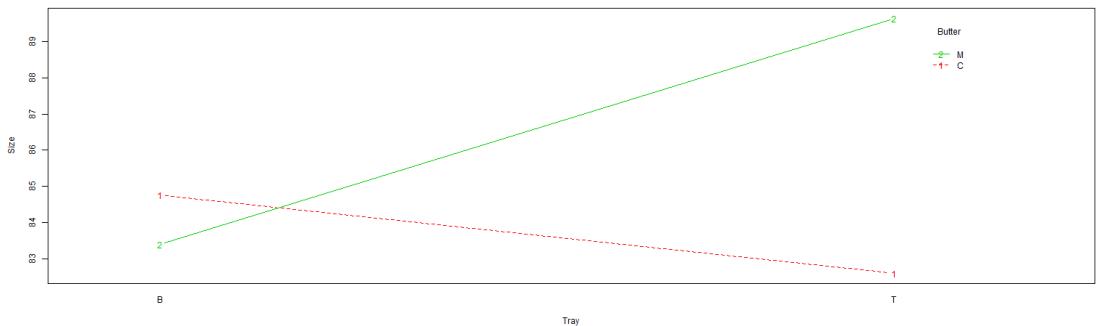


Figure 6: (Tray Position:Butter Type) Interaction Plot

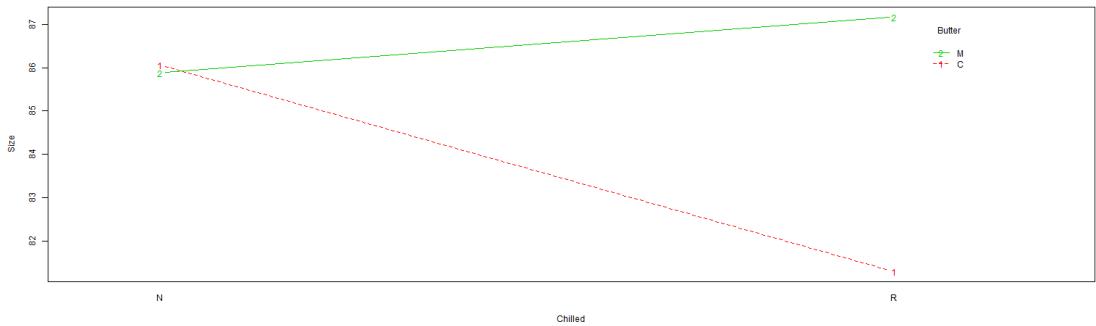


Figure 7: (Dough Temperature:Butter Type) Interaction Plot

CONCLUSIONS

Based on the R analysis, we can see that no individual factor significantly influenced the size of the cookies, however the interaction between type of butter used and position of the tray on the top or bottom rack did significantly impact the cookies. For the melted butter, putting the cookies on the top rack allowed them to spread wider than the creamed butter cookies while the opposite was true for placing the tray on the bottom rack. The dough temperature had a similar pair of interactions between the two types of cookies.

One reason that using the bottom rack, in general, gave smaller cookies is that the bases of the cookies cooked a lot faster which caused them to grow taller (or stay taller) as the base solidified faster. As for improvements to the experiment, knowing that both trays would not fit

on the top rack ahead of time and randomly assigning that using R would have been a better idea than just picking one to move. Another improvement would be to measure the cookies by weight instead of using a dough scoop. A final change would be to measure out the individual cookies first and then simply transfer them to the trays after chilling instead of having to form each cookie as it would allow less time for the dough to reach room temperature before putting them into the oven.

DATA APPENDIX

Size (mm)	Butter	Dough Temperature	Tray Position
85.61	C	N	B
87.56	C	N	B
83.03	M	R	B
87.78	C	N	B
81.78	M	R	B
83.70	C	R	B
84.32	C	R	B
87.83	M	R	B
82.28	M	N	B
81.06	M	N	B
79.60	C	R	B
84.38	M	N	B
91.32	C	N	T
77.38	C	N	T
73.49	C	R	T
78.23	C	R	T
86.69	M	R	T
87.93	M	N	T
86.72	C	N	T
87.45	M	N	T
91.57	M	R	T
92.12	M	R	T
92.17	M	N	T
88.42	C	R	T

Table of Collected Data

CODE APPENDIX

```
1 #####  
2 ###### Setup  
3 #####  
4 ## Install and load libraries  
5 # ipak function taken from: https://gist.github.com/stevenworthington/3178163  
6 ipak = function(pkg) {  
7   new.pkg = pkg[!(pkg %in% installed.packages() [ , "Package" ] )]  
8   if (length(new.pkg))  
9     install.packages(new.pkg, dependencies = TRUE)  
10    sapply(pkg, require, character.only = TRUE)  
11 }  
12 packages = c("ggplot2", "ggplotify", "reshape2", "gridExtra", "TSA", "astsa",  
13             "orcutt", "nlme", "fGarch", "vars", "lsmeans", "multcompView",  
14             "base2grob", "lme4", "lmerTest")  
15 ipak(packages)  
16  
17 #####  
18 #### Randomly assign 3 of each pair of treatments to spots on the tray  
19 #####  
20 options = c(rep("MR",3),rep("MN",3),rep("CR",3),rep("CN",3))  
21 tray1 = sample(options)  
22 tray2 = sample(options)  
23 tray1  
24 tray2  
25  
26 #####  
27 ## Read in Data  
28 #####  
29 cookies=read.table("cookies.txt",header=TRUE)  
30  
31 #####  
32 ## Plot Data in Boxplots  
33 #####  
34 plotWidth=512;  
35 plotHeight=512;  
36  
37 #####  
38 ## Individual Plots  
39 #####  
40  
41 png("./figures/boxplots/boxplot-1-butter.png", width = plotWidth, height = plotHeight)  
42   boxplot(size ~ butter, data=cookies, main = "Butter")  
43 dev.off()  
44  
45 png("./figures/boxplots/boxplot-1-chilled.png", width = plotWidth, height =  
        plotHeight)  
46   boxplot(size ~ chilled, data=cookies, main = "Dough Temperature")  
47 dev.off()  
48  
49 png("./figures/boxplots/boxplot-1-tray.png", width = plotWidth, height = plotHeight)  
50   boxplot(size ~ tray, data=cookies, main = "Tray Position")  
51 dev.off()  
52  
53 #####  
54 ## Pair Plots  
55 #####  
56 png("./figures/boxplots/boxplot-2-butter-chilled.png", width = plotWidth, height =  
        plotHeight)  
57   boxplot(size ~ chilled + butter, data=cookies, main = "Butter & Temperature")  
58 dev.off()  
59  
60 png("./figures/boxplots/boxplot-2-butter-tray.png", width = plotWidth, height =  
        plotHeight)
```

```

61   boxplot(size ~ tray + butter, data=cookies, main = "Butter & Tray")
62 dev.off()
63
64 png("./figures/boxplots/boxplot-2-chilled-tray.png", width = plotWidth, height =
       plotHeight)
65 boxplot(size ~ tray + chilled, data=cookies, main = "Temperature & Tray")
66 dev.off()
67
68 #####
69 ## Full Plot
70 #####
71 png("./figures/boxplot-full.png", width = 2*plotWidth, height = 2*plotHeight)
72 boxplot(size ~ tray + chilled + butter, data=cookies)
73 dev.off()
74
75 #####
76 ## Compile Plots
77 #####
78 singleBoxplots = lapply(sprintf("./figures/boxplots/boxplot-l-%s.png", c("butter",
       "chilled","tray")), png::readPNG)
79 singleBoxGrid = lapply(singleBoxplots, grid::rasterGrob)
80
81 doubleBoxPlots = lapply(sprintf("./figures/boxplots/boxplot-2-%s.png", c("butter-
       chilled","butter-tray","chilled-tray")), png::readPNG)
82 doubleBoxGrid = lapply(doubleBoxPlots, grid::rasterGrob)
83
84 png("./figures/boxplot-individuals.png", width = 3*plotWidth, height = plotHeight)
85 gridExtra::grid.arrange(ncol=3, grobs=singleBoxGrid)
86 dev.off()
87
88 png("./figures/boxplot-pairs.png", width = 3*plotWidth, height = plotHeight)
89 gridExtra::grid.arrange(ncol=3, grobs=doubleBoxGrid)
90 dev.off()
91
92 #####
93 ## Create Model
94 #####
95 cookieFullModel = aov(size ~ tray + chilled + butter + tray:chilled + tray:butter +
       chilled:butter, data=cookies)
96 anova(cookieFullModel)
97
98 cookieMainModel = aov(size ~ tray + chilled + butter, data=cookies)
99 anova(cookieMainModel)
100
101 #####
102 # Check Normality
103 #####
104 png("./figures/normality-residuals.png", width = 3*plotWidth, height = plotHeight)
105 plot(cookieFullModel,1)
106 dev.off()
107
108 png("./figures/normality-qq.png", width = 3*plotWidth, height = plotHeight)
109 plot(cookieFullModel,2)
110 dev.off()
111
112 #####
113 # Examine Interactions
114 #####
115 png("./figures/interaction-tray-butter.png", width = 3*plotWidth, height = plotHeight
       )
116 interaction.plot(x.factor = cookies$tray, trace.factor = cookies$butter,
       response = cookies$size, type ="b", col = 2:3,
       xlab ="Tray", ylab ="Size", trace.label ="Butter")
117 dev.off()
118
119 dev.off()
120
```

```
121 png("./figures/interaction-chilled-butter.png", width = 3*plotWidth, height =
122   plotHeight)
122 interaction.plot(x.factor = cookies$chilled, trace.factor = cookies$butter,
123   response = cookies$size, type ="b", col = 2:3,
124   xlab ="Chilled", ylab ="Size", trace.label ="Butter")
125 dev.off()
```