University of Arkansas, INEG 5333: Design of Industrial Experiments

Chocolate Chip Cookie Mixture

Term Project: Spring 2023 (submitted to Professor Greg Hutto)

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Project: Chocolate Chip Cookie

Proposal:

Most people like Chocolate Chip Cookies, some like them soft and others like them crispy. The difference between soft and crispy is the thickness, height, and density of the cookie. This experiment will go through and measure the effectiveness that different combinations of the ingredients have on Chocolate Chip Cookies. The objective is to find the cookie resulting in the best taste and appearance.

The objective of the experiment is to identify and analyze the effects of 4 different ingredients, cooking temperatures, and cooking time. The experiment will be a KVC Model, mixture model.

Pre-experimental Planning:

Recognition of and statement of problem

The goal is to achieve the best chocolate chip cookie in taste and appearance.

Selection of the response variables

Response Variable	**Measurement and accuracy**	**Measurement Tool**
Length	1.0 cm	Tape measure
Height	1.0 cm	Tape measure
Density	0.1 g/ml	Measuring cup
Mass	0.1 grams	Kitchen scale
Taste	1-9 scale	Survey
Appearance	1-5 scale	Survey
Softness	1-5 scale	Survey
Penny Test	0-40	pennies

Table 1: Response Variables

Choice of factors, levels, and ranges

Factors held constant

In the table below are the cooking ingredients that were held constant in the experiment.

Ingredients	Recipe Amount	Grams for Recipe Amount	Batch size for 4 cookies
Flour	2 ¼ cups	315	35
Baking Soda	1 tsp	6	0.7
Eggs	2	114	13
Chocolate Chips	2 cups	324	36

Table 2: Constant Factors

Allowed-to-vary Factors and their ranges

Factor	Recipe Amount	Grams	Low	Center for batch of 4 cookies	High
Butter	1 cup	229	17	25	33
Granulated Sugar	¾ cups	165	13	18	24
Brown sugar	¾ cups	180	14	20	26
Vanilla	1 tsp	4	0	.5	1
Temperature (F Degrees)	375		325	350	375
Time (mins)	9-11		12	15	18

Table 3: Chosen Factor Levels

Choice of Experimental Design

There are many different design experiments that could be used. Originally considered a full factorial but due to the time and number runs needed was not feasible with time limitations of the class.

A mixture design experiment was considered for this where the ingredients are not independent. Each of the components together equal 1: $x_1+x_2+\ldots+x_p=1$. In this experiment it would be butter (25) + granulated sugar (18) + brown sugar (20) + vanilla (1) = 64.0. A pure blend mixture design considers the mixture at 100% of one of the ingredients, this is not feasible when you are making cookies.

For this experiment a KCV Design with a subtype split-plot was used. It obeys the mixture constants in a mixture model, but also allows process variables. By using a KVC design one is able to "reduce the overall design size while still preserving the ability to estimate highly informative model" (Vining, 2020). The design was created using design expert. The mixture components were A: butter, B: Gr Sugar, C: Br Sugar, and D: Vanilla. These terms were considered easy to change. The process factors for the design were Time and Temperature and considered hard to change. The build of the design included a total of 30 runs, 2 blocks (Saturday and Sunday), and 11 groups. The design is shown in Table 4 below.

Block	Group	Run	Component 1 A:Butter grams	Component 2 B:GrSugar grams	Component 3 C:BrSugar grams	Component 4 D:Vanilla grams	Factor 5 e:Temp	Factor 6 f:Time
Saturday	1	1	20.3333	16.6667	27	0	325	18
Saturday	1	2	25	24	15	0	325	18
Saturday	1	3	18	24	21.5	0.5	325	18
Saturday	2	4	27	12	24	1	350	15
Saturday	2	5	18	24	22	0	350	15
Saturday	2	6	33	16	15	0	350	15
Saturday	3	7	29.0833	16.3333	17.8333	0.75	350	18
Saturday	3	8	18	18	27	1	350	18
Saturday	3	9	33	12	19	0	350	18
Saturday	4	10	20.3333	16.3333	27	0.333333	375	14
Saturday	4	11	22.6667	24	17.3333	0	375	14
Saturday	4	12	33	14.3333	16	0.666667	375	14
Saturday	5	13	22	24	17	1	350	15
Saturday	5	14	25.1667	17.6667	20.6667	0.5	350	15
Saturday	6	15	18	22.3333	23.3333	0.333333	325	12
Saturday	6	16	25	21	17	1	325	12
Saturday	6	17	33	12	18.5	0.5	325	12
Sunday	7	18	20	22	21	1	375	12
Sunday	7	19	27.3333	21.3333	15	0.333333	375	12
Sunday	8	20	24.5833	20.8333	17.8333	0.75	350	12
Sunday	8	21	24	12	27	1	350	12
Sunday	8	22	27.6667	12	24.3333	0	350	12
Sunday	9	23	24	24	15	1	375	18
Sunday	9	24	23.3333	20.8333	19.5833	0.25	375	18
Sunday	9	25	24	12	27	1	375	18
Sunday	10	26	27.3333	12	24.3333	0.333333	325	15
Sunday	10	27	25.3333	17.8333	20.8333	0	325	15
Sunday	10	28	33	15	15	1	325	15
Sunday	11	29	24.5	24	15	0.5	350	15
Sunday	11	30	25.0833	14.8333	23.8333	0.25	350	15

Table 4: Design Expert Output for KVC Design

Performing the Experiment and Analyzing the Data

Performing the Experiment

Recipe:

The base recipe used for the experiment was The Original Nestle Toll House Chocolate Chip Cookies found on the bag of Chocolate Chips. Omitted from the recipe was the salt and chopped nuts.

Ingredients

- 2 1/4 cups all-purpose flour
- 1 teaspoon baking soda
- 1 teaspoon salt
- 1 cup (2 sticks) butter, softened
- 3/4 cup granulated sugar
- 3/4 cup packed brown sugar
- 1 teaspoon vanilla extract
- 2 large eggs
- 2 cups (12-oz. pkg.) *Nestlé Toll House Semi-Sweet Chocolate Morsels*

Figure 1: Original Nestle Toll House Chocolate Chip Cookie Recipe

Test Runs:

A couple test runs were completed the weekend before the runs for the design experiment. The first was to run The Original Nestle Toll House Chocolate Chip Cookies found on the bag of Chocolate Chips with the all the ingredients as listed. This provided a baseline for taste testing. The cookies were baked at different times and temperature. This was done to make sure the time and temperature factors would not result in burnt or under cooked cookies.

Next test was to run a few different trial runs to test the range of low and high values of the different factors to make sure there were no concerns with the range. These do not meet the mixture design qualifications of the total ingredients equal the same amount. The batch sizes did allow to make at least 4 cookies each. These runs also allowed to determine the best way to mix the ingredients before running the full experiment.

Baking Material & Ingredients:

Ingredients were purchased in bulk to ensure all cookies are made from the same materials. All ingredients were mixed in the same ceramic bowl. Each of the ingredients were placed in the bowl and mixed together. The dough was mixed by hand due the batch size and to make sure the ingredients were mixed together.

To be able to make the batch size of 4 cookies the ingredients were weighed on a kitchen scale. In the table below are the cooking ingredients that were held constant in the experiment to produce 4 cookies per batch.

Constant Factors

Ingredients	4 Cookie Batch (Grams)
Flour	35
Baking Soda	0.7

Eggs	13
Chocolate Chips	36

Table 5: Constant Factors

Allowed-to-vary Factors and their ranges in grams for 4 cookie batch size

Factor	Low	Center	High
Butter	17	25	33
Granulated Sugar	13	18	24
Brown sugar	14	20	26
Vanilla	0	.5	1
Temperature (F Degrees)	325	350	375
Time (mins)	12	15	18

Table 6: Factor Range

Cooking Process:

After each batch was made the cookies were rolled into the same size cookie ball. Each cookie ball was weighed at 25 grams. This made sure the cookies were approximately the same size and weight prior to cooking to reduce nuisance factor of the size of the cookie.

Each of the batch sizes actually ended up resulting in a total of 5 cookies. 4 cookies were cooked together. The 5th cookie was actually cooked separately. This cookie was used for the penny test and density test.

The cookies were made on a non-stick cookie sheet, along with parchment paper. The cookies were placed 1-2 in apart on the cookie sheet. 3 batches of cookies could be made at the same time to reduce the overall cooking time for the experiment. The 3 batches would have the same temperature and cooking time. The parchment paper was labeled with the cookie batch. There are some sample pictures found in the appendix.

The cookie sheet was placed on the second shelf in the oven. Cooking time was measured with a timer on my phone. Once the cookies were finished cooking the parchment paper with the cookies were removed from the cookie sheet and placed onto a cooling rack. The cookies cooled for at least 20-30 mins.

Measuring Variables:

At that time the cookies had been cooled to room temperature each one was measured for length and height; an example is found in the appendix. Each cookie was measured with a tape measure. The weight of the cooked cookie was measured using a kitchen scale in grams. This was the same scale used to measure the cookie before placing in the oven. Once the measurements were performed the cookie was placed in individual bags labeled with a number and letter. These numbers and letters corresponded back to the batch.

The cookies were randomly placed in another set of bags to be used for the taste testing. Each person received a variety of cookies to measure the taste, appearance, and softness. Each person filled out a form rating the appearance, softness and taste. There was a total of 4 cookies in each batch that was part of the survey. Some people received more than one cookie in some of the batches. The directions were verbally explained to each person participating in the taste testing. Each person had 4 days to complete the form and return it. An example of the form can be found in the below Table 7.

Batch (Letter & Number)	Taste (1-9) 1: Low – 9: High	Appearance (1-5) 1: Low – 5: High	Softness (1-5) 1: soft – 5: crispy
Example: AAA 3	1	5	2

Table 7: Survey Form Example

The next day the density of the cookie was calculated on the 5th cookie in the batch. The cookie was placed in zip lock bag with the air removed. Then the bag was placed in a copy of water. The bag was pushed down to the bottom with a paperclip as seen in Figure 2. The delta of the water displacement was recorded. Density was calculated by dividing the mass (grams) by volume (milliliters).

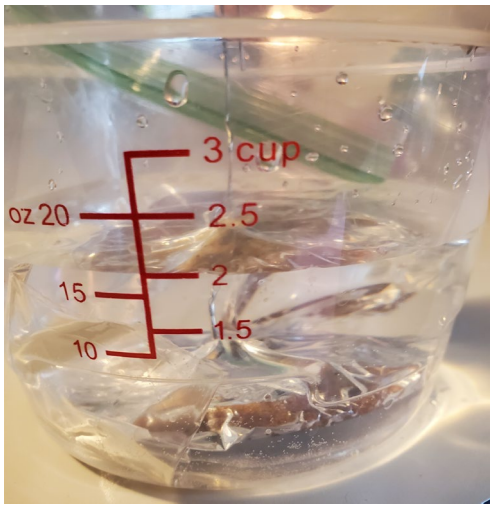

Figure 2: Density measurement

The penny test was also completed on the 5th cookie after the density test was completed. It involved placing the cooked cookie, at room temperature on a cardboard box. On the box a line was drawn two inches from the edge. Each cookie was aligned to the line for the test. The cookie was placed facedown to allow the flat side of the cookie to be faced up to make it easier to place the pennies on the cookie. Each cookie was held with 2 fingers to keep it stable and hold it on the box. Pennies were individually added to the cookie until it started to bend as seen if Figure 3. If the cookie did not bend after 30 cookies, the cookie was given a value of 40. If a cookie started to bend prior to pennies being placed on it, received a score of 0.

Figure 3: Penny Test

All the data for the different variables were compiled into a excel spreadsheet.

Statistical Analysis of the Data

Data in Model and Actual Results:

The cookies were produced according to the batches presented earlier. For the responses, the average of the 4 different cookies in each batch was used.

Table show the results from the ANOVA for the Softness & Penny Test showed significance in the subplot. The other responses showed not significant. This is the data before any adjustments were made to the model. In the appendix is the detailed figures showing the results from the ANOVA fixed response for the Softness and Penny Test

Response	Significant Variables	F-Value of subplot	P-Value of subplot	R^2	Adjusted R^2
Softness	A, Be	6.85	0.0046	0.93	0.65
Penny Test	Ae, BC, e^2	8.25	0.0014	0.94	0.72

Table 8: Summary of ANOVA for Softness & Penny Test

Below you will find the results of the Normal Plot of Residuals as is before any adjustments were made to the outliers for each of the variables. As you can tell in each of the graphs below there are some outliers except length.

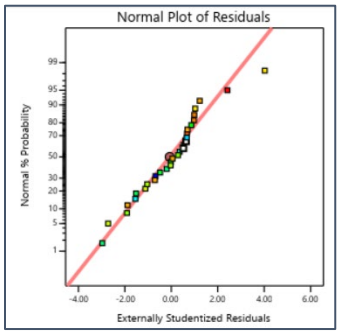

Figure 4: Taste

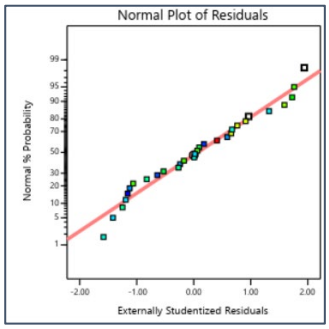

Figure 5: Appearance

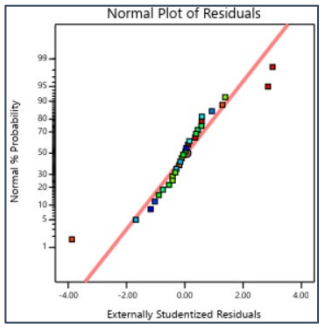

Figure 6: Softness

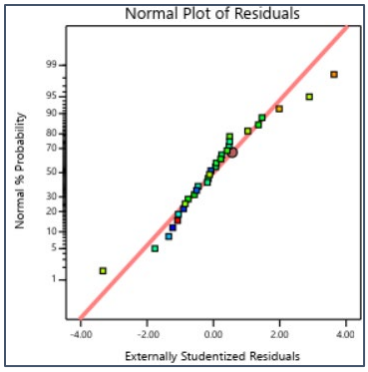

Figure 7: Weight

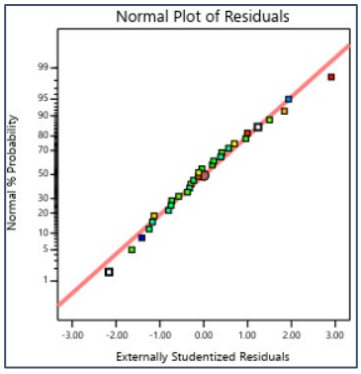

Figure 8: Length

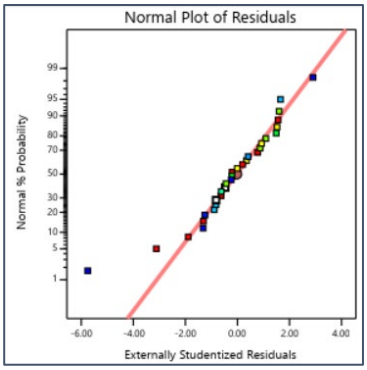

Figure 9: Penny Test

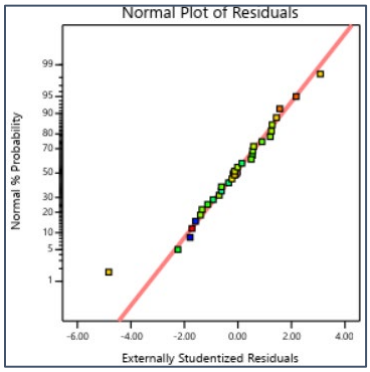

Figure 10: Density

Adjusted Model & Results:

After reviewing the data some adjustments were made to the responses:

- Reviewed the responses for the different batch sets in the excel file. If there was an outlier that could cause the average to be skewed. For example, on taste results showed 9, 7, 9, 3, removed the 3 from the average.
- Added 4 additional center points to the model. The model only had one center point on Saturday. Added 2 additional center points to Saturday and 2 center points to Sunday at different time and temperatures.
- Reviewed the Normal Plot of Residuals to see if any points did not meet the fat pencil test. Decided to ignore 3 points in total, 1 for taste, 2 for softness. Analysis was completed again after the changes. The results show significant subplots for Taste, Softness, Length and Penny Test. Still unsignificant for the other responses. In the Table you will see the Fixed Effects for the four responses. In the appendix are the more detailed results for these four responses.

Length response is significant but looking at the results from the table it not as significant as the responses as softness and penny test. Both the softness and penny test results improved after the adjustments.

Response	Significant Variables	F-Value of subplot	P-value of subplot	R^2	Adjusted R^2
Taste	A, Be	4.28	0.0071	0.87	0.55
Softness	A, B, D, AD, BD, CD, Ce, Df	7.94	0.0006	0.93	0.73
Length	A, B, C, Bf	5.08	0.0304	0.87	0.59
Penny Test	Ae	3.86	0.0088	0.83	046

Table 9: Summary of ANOVA

Another thing to examine is the model graphs, below are the model graphs for the Taste, Softness and Penny Test.

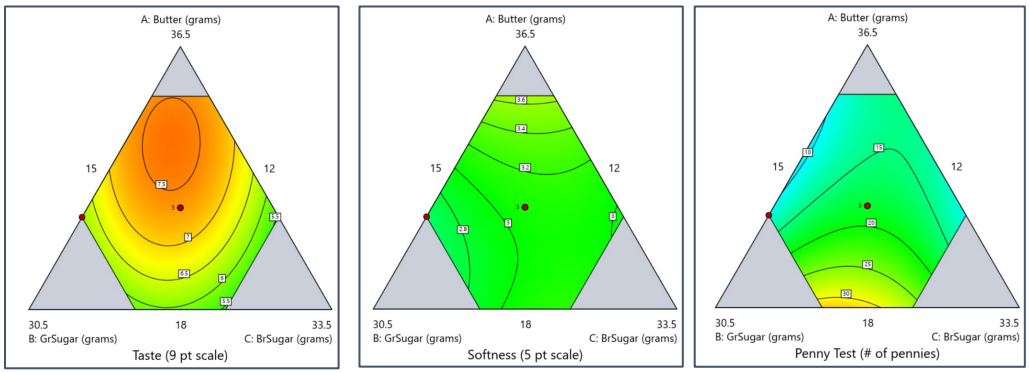

Figure 11: Model Graphs: Taste, Softness & Penny Test

Final Equation and Future Considerations

Results & Summary

From the experiment it has been determined some of the variables are not significant to the type of recipe like the density, appearance and weight of the cookie. The length of the cookie showed significance but due to the higher p-value compared to the other variables it could be ignored in future considerations.

The table below provides a summary of top solution for the different desirability results depending on how a person might like their cookies. The constraints for appearance, weight and density were set with a low importance. These three responses had little significance on the experiment. The table covers the desirable cookie, soft cookie and crispy cookie. For the soft cookie the goal is to minimize the softness: limits 0-3, and importance 5 stars and Penny Test: limits 0-15, and importance 5 stars. For a crispy cookie the goal is to maximize the softness: limits 0-3 and penny test 15-40.

Variables	Desirable Cookie	Soft Cookie	Crispy Cookie
Butter	Center	Center	Low
Gr Sugar	Low	Low	High
Br Sugar	High	High	Low
Vanilla	Low	Center	Low
Temp	Low	Low	High

Time	Low	Low	Center

Table 10: Summary of Desirability Results

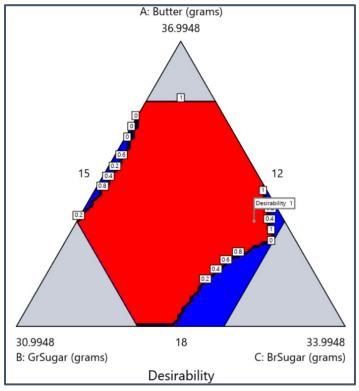

Figure 12: Desirability Result

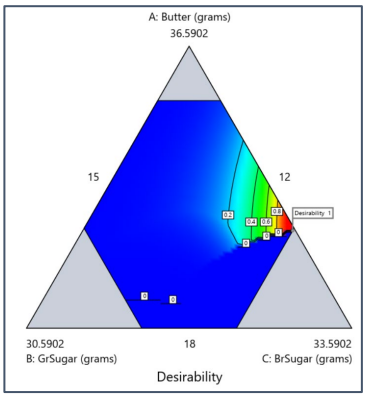

Figure 13: Soft Cookie Results

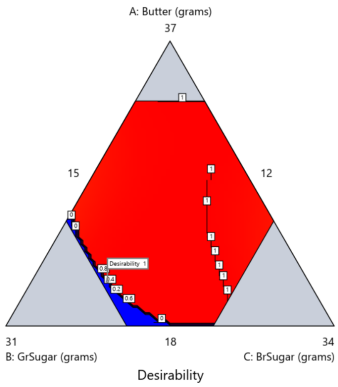

Figure 14: Crispy Cookie Results

Future Considerations

In future experiments some of the following things should be considered or changed to improve on the experiment.

- Change other ingredients, for example flour. Flour weighs more than sugar it could change the density of the cookie and affect the taste of the cookie.
- Different type of scale, use a scale that is more precise
- Density test use vacuum sealer to get all the air out of it
- Bake one cookie at a time, similar to cooking with an easy back oven
- Additional blocks
- Taste panel
    - Use the same people to test all the cookies
    - Have the taste panel taste the cookies like taste testing wine, take a bite and spit it out and cleans the palate between tastes
    - Consider have equal number of people on the panel that like crispy or soft cookies to get a better idea
- Absorption test: how much milk (or water) does the cookie absorb when dunked

Reference

Stat-Ease, Vining G. (2/21/20), *" Background on the KVC Designs"* Retrieved May 1, 2023 from Stat-Ease (statease.com)

Appendix

Cooking Process

Figure 15: Sample of uncooked cookies

Figure 16: Sample of cookies cooling

Measuring Variables

Figure 17: Sample of Measuring cookie

Data in Model and Actual Results:

Fixed Effects [Type III]

Response 3: Softness

REML (REstricted Maximum Likelihood) analysis
Kenward-Roger p-values

Source	Term df	Error df	F-value	p-value	
Whole-plot	3	8.01	1.27	0.3474	not significant
ef	1	8.00	1.42	0.2683	
e^2	1	8.00	0.2720	0.6161	
f^2	1	8.02	3.00	0.1215	
Subplot	17	8.02	6.85	0.0046	significant
Linear Mixture	3	8.02	0.3499	0.7905	
AB	1	8.07	1.54	0.2499	
AC	1	8.03	0.1288	0.7290	
AD	1	8.01	0.9601	0.3558	
Ae	1	8.09	3.39	0.1026	
Af	1	8.00	0.3861	0.5517	
BC	1	8.01	0.8662	0.3792	
BD	1	8.01	1.08	0.3291	
Be	1	8.05	6.24	0.0369	
Bf	1	8.02	0.4452	0.5234	
CD	1	8.01	0.8758	0.3767	
Ce	1	8.01	0.5954	0.4625	
Cf	1	8.02	0.0620	0.8096	
De	1	8.06	2.21	0.1752	
Df	1	8.01	0.9689	0.3537	

Figure 18: Fixed Effects Softness

Fixed Effects [Type III]

Response 6: Penny Test

REML (REstricted Maximum Likelihood) analysis
Kenward-Roger p-values

Source	Term df	Error df	F-value	p-value	
Whole-plot	3	9.00	2.94	0.0915	not significant
ef	1	9.00	0.1082	0.7498	
e^2	1	9.00	7.19	0.0251	
f^2	1	9.00	3.80	0.0829	
Subplot	17	9.00	8.25	0.0014	significant
Linear Mixture	3	9.00	1.80	0.2180	
AB	1	9.00	0.6839	0.4296	
AC	1	9.00	4.71	0.0582	
AD	1	9.00	1.05	0.3320	
Ae	1	9.00	11.76	0.0075	
Af	1	9.00	0.0009	0.9771	
BC	1	9.00	12.48	0.0064	
BD	1	9.00	0.9418	0.3572	
Be	1	9.00	4.02	0.0759	
Bf	1	9.00	0.5846	0.4641	
CD	1	9.00	0.8566	0.3788	
Ce	1	9.00	2.76	0.1313	
Cf	1	9.00	0.6930	0.4267	
De	1	9.00	0.0011	0.9740	
Df	1	9.00	1.06	0.3294	

Figure 19: Fixed Effects Penny Test

Data in Model with Adjusted Results:

Fixed Effects [Type III]

Response 1: Taste

REML (REstricted Maximum Likelihood) analysis
Kenward-Roger p-values

Source	Term df	Error df	F-value	p-value	
Whole-plot	3	12.00	1.77	0.2054	not significant
ef	1	12.00	4.30	0.0603	
e^2	1	12.00	0.3253	0.5790	
f^2	1	12.00	0.0373	0.8501	
Subplot	17	12.00	4.28	0.0071	significant
Linear Mixture	3	12.00	5.15	0.0161	
AB	1	12.00	2.03	0.1800	
AC	1	12.00	2.07	0.1756	
AD	1	12.00	3.71	0.0780	
Ae	1	12.00	1.92	0.1914	
Af	1	12.00	0.9267	0.3547	
BC	1	12.00	4.37	0.0586	
BD	1	12.00	3.96	0.0699	
Be	1	12.00	14.46	0.0025	
Bf	1	12.00	2.57	0.1348	
CD	1	12.00	3.74	0.0770	
Ce	1	12.00	2.13	0.1700	
Cf	1	12.00	1.76	0.2095	
De	1	12.00	4.30	0.0602	
Df	1	12.00	2.06	0.1770	

Figure 20: Response Taste (Adjusted)

Fixed Effects [Type III]

Response 3: Softness

REML (REstricted Maximum Likelihood) analysis
Kenward-Roger p-values

Source	Term df	Error df	F-value	p-value	
Whole-plot	3	11.00	2.36	0.1270	not significant
ef	1	11.00	0.7959	0.3914	
e^2	1	11.00	3.51	0.0876	
f^2	1	11.00	4.73	0.0522	
Subplot	17	11.00	7.95	0.0006	significant
Linear Mixture	3	11.00	2.28	0.1364	
AB	1	11.00	0.0346	0.8559	
AC	1	11.00	0.2202	0.6480	
AD	1	11.00	5.84	0.0342	
Ae	1	11.00	2.80	0.1223	
Af	1	11.00	0.3071	0.5906	
BC	1	11.00	0.3698	0.5554	
BD	1	11.00	6.81	0.0242	
Be	1	11.00	0.0271	0.8723	
Bf	1	11.00	1.46	0.2521	
CD	1	11.00	5.86	0.0339	
Ce	1	11.00	10.55	0.0078	
Cf	1	11.00	1.41	0.2607	
De	1	11.00	1.24	0.2899	
Df	1	11.00	7.40	0.0199	

Figure 21: Response Softness (Adjusted)

Fixed Effects [Type III]

Response 5: length

REML (REstricted Maximum Likelihood) analysis
Kenward-Roger p-values

Source	Term df	Error df	F-value	p-value	
Whole-plot	3	3.13	0.8106	0.5640	not significant
ef	1	3.24	0.6105	0.4877	
e^2	1	3.20	0.1435	0.7286	
f^2	1	3.03	1.63	0.2910	
Subplot	17	5.69	5.08	0.0304	significant
Linear Mixture	3	10.76	0.4158	0.7452	
AB	1	9.90	0.1097	0.7474	
AC	1	10.15	3.20	0.1034	
AD	1	10.93	0.0695	0.7970	
Ae	1	12.01	0.2303	0.6399	
Af	1	11.82	0.0008	0.9774	
BC	1	11.61	0.0994	0.7582	
BD	1	11.01	0.0386	0.8479	
Be	1	11.98	0.0025	0.9610	
Bf	1	11.73	4.82	0.0490	
CD	1	10.87	0.0207	0.8884	
Ce	1	11.93	2.70	0.1266	
Cf	1	11.96	1.00	0.3363	
De	1	9.69	0.0043	0.9490	
Df	1	11.11	0.4870	0.4996	

Figure 22: Response Length (Adjusted)

Fixed Effects [Type III]

Response 6: Penny Test

REML (REstricted Maximum Likelihood) analysis
Kenward-Roger p-values

Source	Term df	Error df	F-value	p-value	
Whole-plot	3	13.00	1.37	0.2944	not significant
ef	1	13.00	0.3558	0.5611	
e^2	1	13.00	2.93	0.1106	
f^2	1	13.00	2.17	0.1643	
Subplot	17	13.00	3.86	0.0088	significant
Linear Mixture	3	13.00	0.5876	0.6338	
AB	1	13.00	0.4705	0.5048	
AC	1	13.00	0.0850	0.7752	
AD	1	13.00	1.38	0.2605	
Ae	1	13.00	5.33	0.0380	
Af	1	13.00	0.0908	0.7680	
BC	1	13.00	1.55	0.2355	
BD	1	13.00	1.30	0.2740	
Be	1	13.00	2.46	0.1411	
Bf	1	13.00	0.2171	0.6490	
CD	1	13.00	1.28	0.2787	
Ce	1	13.00	0.7319	0.4078	
Cf	1	13.00	1.14	0.3060	
De	1	13.00	0.0016	0.9683	
Df	1	13.00	0.0861	0.7738	

Figure 23: Response Penny Test (Adjusted)