Analysis of Flour Type, Liquid Type, and Leavening Agent on the Height of Pancakes

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Introduction:

The last several times I have made pancakes, I have noticed that my pancakes appeared to be flatter and denser than the pancakes you would get at a restaurant. In order to produce fluffier pancakes, I then tried several different recipes with different ingredients and methods, all leading to varying results when it comes to the fluffiness of the pancakes. These varying results across recipes has led me to be interested in more formally testing what factors may lead to fluffier pancakes. This report aims to formally investigate if flour type, liquid type, or leavening agent impacts the fluffiness of a pancake. More specifically, this report focuses on the effects of all-purpose flour vs. gluten free flour, the use of milk vs. seltzer water, and the use of baking powder vs. baking soda when it comes to the height of a pancake. Assessment of any significant factors will be performed using a final statistical model to determine which levels of significant factors lead to the fluffiest pancakes.

Methods:

The data were produced from an experiment designed and executed by the author of this report. The observed response variable used to capture the fluffiness of the pancake was the height of a pancake in millimeters. The three factors of interest are flour type (all-purpose vs. gluten free), liquid type (milk vs. seltzer water), and leavening agent (baking powder vs. baking soda). All factors are fixed factors. A summary of these factors and factor levels can be found in Table A1 in Appendix A.

To screen these three factors to determine which may be important when it comes to the fluffiness, measured using the height of a pancake, a 2^3 factorial design was implemented. This design results in 8 treatment combinations. There were two replications of each treatment combination, yielding 16 total responses. 16 single serve batches of pancakes were made which yielded 16 pancakes, and the height of each pancake was recorded.

Minitab was used to generate the experimental design and the randomization of the treatment order. The same single serve pancake recipe (listed in Object A1 in Appendix A) was

used for each of the 16 batches, with the three factors of interest in this experiment being the only elements that varied between batches. One at a time, each of the 16 batches was independently created, and then ¼ of a cup of the batter was measured onto a pan over medium heat. Each pancake cooked for one minute and thirty seconds on the first side, and then was flipped to cook for one minute on the second side. Once removed, the height of the pancake at its center was immediately recorded using a toothpick. All conditions, such as stove temperature, cook time, mixing tools, and placement of the pancake on the pan were held constant across batches. The randomization order, experiment design, and response data can be found in Table A2 in Appendix A.

Data:

Minitab was used to conduct all analyses within this report, and all analyses were conducted at a 95% level of significance. The distribution of the response for each of the three factors and their levels can be seen in Figures 1 through 3. There does not appear to be any factor level that greatly results in a larger pancake height, and no definitive conclusions on significance of factors can be made solely based on these figures. From these plots and the data in table A2 in Appendix A, we can also see there are no missing values or major outliers in the data. No additional patterns arise that would lead to concern and would need to be accounted for in the analysis. Additional summary statistics of the data that were analyzed can be found in Tables A3 through A6 in Appendix A.

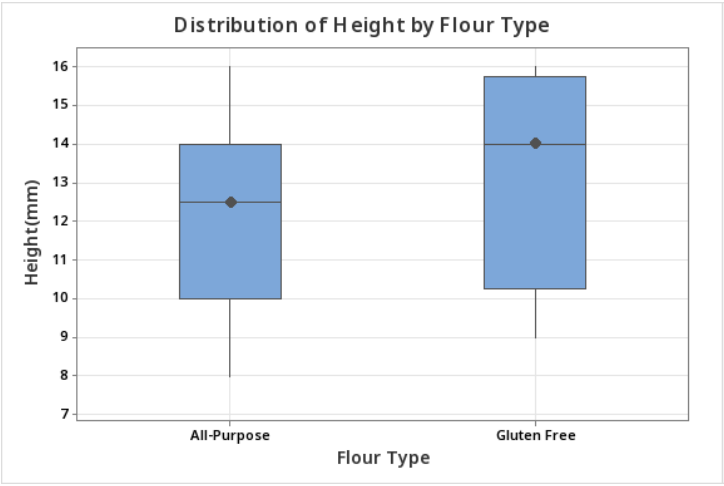

Figure 1: Height Distribution by Flour Type

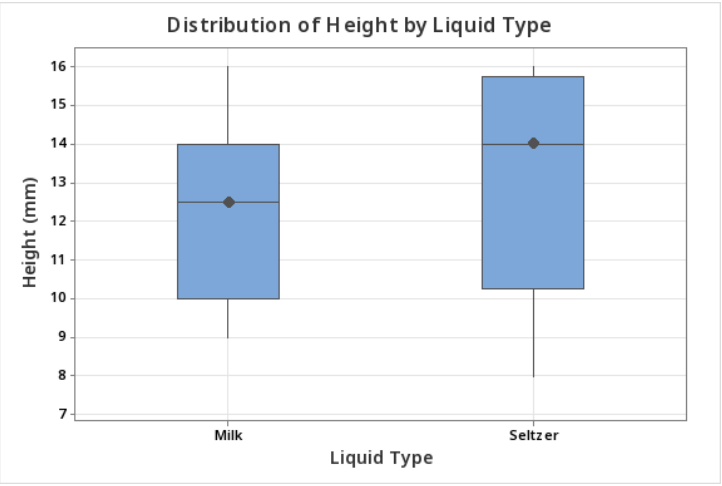

Figure 2: Height Distribution by Liquid Type

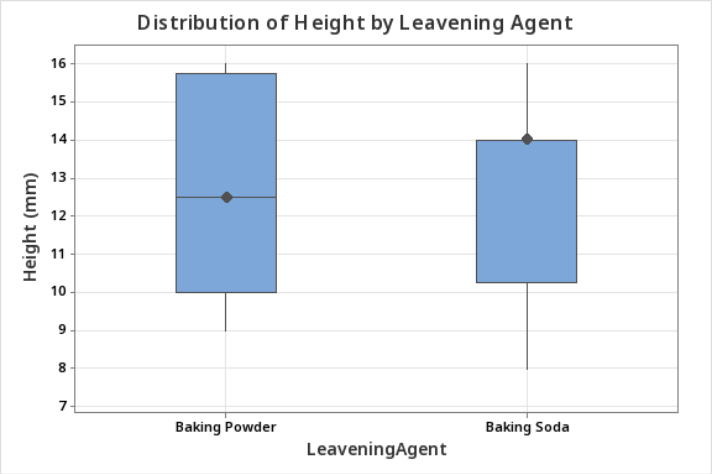

Figure 3: Height Distribution by Leavening Agent

The full statistical model that was considered included the three factors flour type, liquid type, and leavening agent, as well all two-way interaction terms and the three-way interaction term. This full model was fit in Minitab and the three-way interaction term was found to not be significant in the model with a p-value of 0.694. The ANOVA table of this full model can be seen in Table A7 in Appendix A, along with the Normal Plot of the Full model in Figure A1. Since the three-way interaction term was not significant, it was then removed from the model and the model was re-run.

The reduced model found the LiquidType*LeaveningAgent interaction term to be significant (p=0.000). Both the FlourType*LiquidType and FlourType*LeaveningAgent interaction term were found to not be significant (with p=0.121 and p=0.061 respectively). The ANOVA table for this reduced model can be seen in Table A8 in Appendix A. Since the latter two interaction terms were not significant, these terms were removed from the model and the analysis was re-run.

This further reduced model contains the three main effect factors as well as the LiquidType*LeaveningAgent interaction term. None of the main effects were found to be significant (FlourType: p=0.19, LiquidType: p=0.317, LeaveningAgent: p=1) while the interaction term remained significant (p=0.000). The full ANOVA output can be seen in Table A9 in Appendix A. Since the Flour Type factor was not significant, this term was removed from the model. The Liquid Type and Leavening Agent factors were not removed to preserve hierarchy of the model, since their interaction term was significant. The ANOVA table for the final reduced model can be seen in Table A10 in Appendix A.

This final statistical model is: $y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha_i\beta_j) + \epsilon_{ijk}$ where y_{ijk} is the height of the pancake with the j[th] leavening agent (j=baking powder, baking soda), i[th] liquid type (i=milk, seltzer water), and k[th] pancake (k=1,2), μ is the overall mean, and $\epsilon_{ijk} \overset{iid}{\sim} N(0, \sigma^2)$. α_i is the effect of the i[th] liquid type ($\sum_i \alpha_i = 0$) and β_j is the effect of the j[th] leavening agent ($\sum_j \beta_j = 0$). $(\alpha_i\beta_j)$ is the interaction of the i[th] liquid and j[th] leavening agent ($\sum_i(\alpha_i\beta_j) = 0, \sum_j(\alpha_i\beta_j) = 0$).

The residuals from the reduced final model were used to verify the ANOVA model assumptions. The normal probability plot in Figure 4 can be used to assess the normality assumption. The residuals appear to fall close to the diagonal line in this plot which supports the normality assumption. The Anderson Darling test affirms normality of the residuals with a p-value>0.349. Equal variance can be assessed using the residuals vs. fitted value plot in Figure 5. There may be a slight pattern observed in the residuals when plotted against the fitted values, with there being a larger spread in the residuals at lower fitted values and a smaller spread at higher fitted values. However, given the small sample size and the robustness of the ANOVA model, we proceeded with the model without transformation and take caution when it comes to interpreting the results. Additionally, the errors are assumed to be independent from one another based on how the experiment was designed and executed and there doesn't appear to be any outliers.

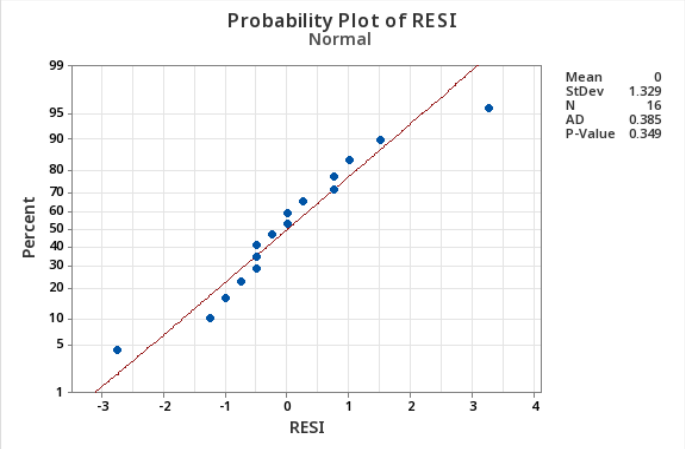

Figure 4: Normal Probability Plot of the Residuals

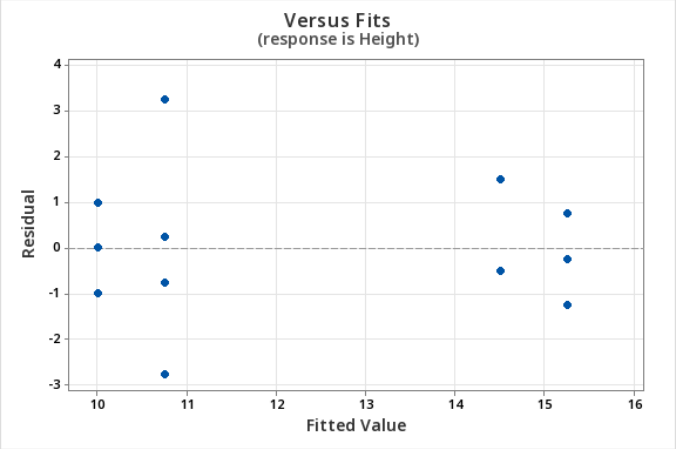

Figure 5: Residuals vs. Fitted Values

As previously stated, the analysis yielded significant results for only the LiquidType*LeaveningAgent term. The F-statistic of this term in the final model was 36.68 with

1 numerator degree of freedom and 12 denominator degrees of freedom. The p-value for this term is 0.000. Therefore, at a 5% level of significance, we can conclude the interaction of liquid type and leavening agent significantly influences the fluffiness, or height, of pancakes.

To determine which levels of the Liquid Type and Leavening Agent factors lead to the largest height of pancakes, the interaction plot for the LiquidType*LeaveningAgent term was reviewed. As seen in Figure 6, the largest pancake height results from a combination of the high level of Liquid Type and the low level of Leavening Agent. This corresponds to the combination of seltzer water and baking powder leading to the largest average response, or fluffiest pancakes.

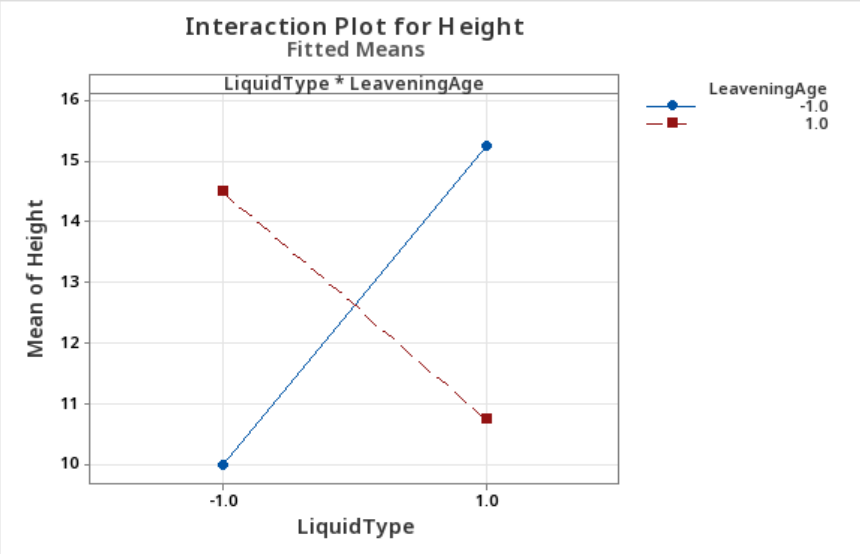

Figure 6: LiquidType*LeaveningAgent Interaction Plot

Conclusion:

This analysis investigated the impact of flour type, liquid type, and leavening agent on the height of pancakes. The final reduced model included the liquid type and leavening agent factors as well as their interaction. Only the interaction of the liquid type and leavening agent factors was found to be significant at a 0.05 level of significance when it comes to the resulting height of pancakes. The interaction plot of this term indicated the combination of seltzer water and baking powder leads to the fluffiest pancakes.

Due to the small sample size, certain limitations were encountered during the analysis. The small sample size led to difficultly assessing if the model violated the ANOVA equal variance

assumptions, leading caution needed when interpreting the results. To address these limitations, it is recommended to replicate this experiment with a larger sample size and re-run the analysis.

Future investigations exploring what factors lead to the fluffiest pancakes with the largest rise could broaden the scope further than this report to include additional factors such as stove temperature, cooking time, and mixing methods. These additional factors may offer a more comprehensive understanding of what factors significantly influence pancake height.

Appendix A

Table A1: Summary of Factors

Factor	Low Level	High Level
Flour Type	All-Purpose Flour	Gluten Free Flour
Liquid Type	Milk	Seltzer Water
Leavening Agent	Baking Powder	Baking Soda

Object A1: Single Serving Pancake Recipe

Ingredients:

- 2 Tablespoon Flour (All-purpose OR Gluten Free)
- 1/4 Teaspoon baking powder OR 1/16 Teaspoon Baking Soda
- 2 Tablespoons Liquid (Milk OR Seltzer Water)
- 1/2 Tablespoon Sugar
- 1/4 beaten egg
- 1/2 Tablespoon melted unsalted butter

Steps:

- Heat non-stick pan over medium heat, and allow to come to temperature
- Mix all ingredients together in a large clean bowl
- Once combined, measure out ¼ a cup of the batter onto a heated pan
- Flip the pancake after a minute and a half to allow the second side to cook
- Take the pancake off the heat after one minute

Table A2: Experiment Data

StdOrder	RunOrder	CenterPt	Blocks	FlourType	LiquidType	LeaveningAgent	Height
4	1	1	1	1	1	-1	15
1	2	1	1	-1	-1	-1	10
5	3	1	1	-1	-1	1	14
13	4	1	1	-1	-1	1	14
3	5	1	1	-1	1	-1	14
6	6	1	1	1	-1	1	14
8	7	1	1	1	1	1	11
12	8	1	1	1	1	-1	16
10	9	1	1	1	-1	-1	10
16	10	1	1	1	1	1	14
7	11	1	1	-1	1	1	8
11	12	1	1	-1	1	-1	16
15	13	1	1	-1	1	1	10
9	14	1	1	-1	-1	-1	11
2	15	1	1	1	-1	-1	9
14	16	1	1	1	-1	1	16

Table A3: Summary Statistics for the Flour Type Factor

Flour Type	N	Mean	StDev	Variance	Minimum	Q1	Median	Q3	Maximum
All-Purpose	8	12.125	2.748	7.554	8.000	10.000	12.500	14.000	16.000
Gluten Free	8	13.125	2.748	7.554	9.000	10.250	14.000	15.750	16.000

Table A4: Summary Statistics for the Liquid Type Factor

Liquid Type	N	Mean	StDev	Variance	Minimum	Q1	Median	Q3	Maximum
Milk	8	12.250	2.550	6.500	9.000	10.000	12.500	14.000	16.000
Seltzer Water	8	13.00	2.98	8.86	8.00	10.25	14.00	15.75	16.00

Table A5: Summary Statistics for the Leavening Agent Factor

Leavening Agent	N	Mean	StDev	Variance	Minimum	Q1	Median	Q3	Maximum
Baking Powder	8	12.63	2.92	8.55	9.00	10.00	12.50	15.75	16.00
Baking Soda	8	12.625	2.669	7.125	8.000	10.250	14.000	14.000	16.000

Table A6: Summary Statistics for all Data

Variable	N	Mean	StDev	Variance	Minimum	Q1	Median	Q3	Maximum
Height	16	12.625	2.705	7.317	8.000	10.000	14.000	14.750	16.000

Table A7: ANOVA Table: Full model

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	97.750	13.9643	9.31	0.003
Linear	3	6.250	2.0833	1.39	0.315
FlourType	1	4.000	4.0000	2.67	0.141
LiquidType	1	2.250	2.2500	1.50	0.256
LeaveningAgent	1	0.000	0.0000	0.00	1.000
2-Way Interactions	3	91.250	30.4167	20.28	0.000
FlourType*LiquidType	1	4.000	4.0000	2.67	0.141
FlourType*LeaveningAgent	1	6.250	6.2500	4.17	0.076
LiquidType*LeaveningAgent	1	81.000	81.0000	54.00	0.000
3-Way Interactions	1	0.250	0.2500	0.17	0.694
FlourType*LiquidType*LeaveningAgent	1	0.250	0.2500	0.17	0.694
Error	8	12.000	1.5000		
Total	15	109.750			

Figure A1: Normal Plot: Full model

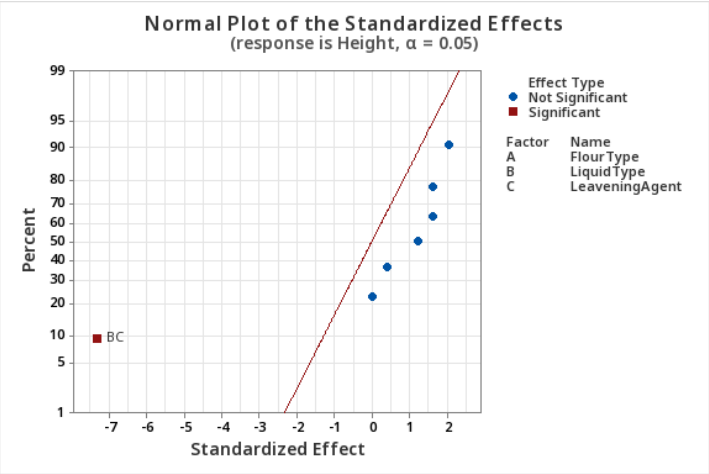

Table A8: ANOVA Table: Model without Three-Way Interaction

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	6	97.500	16.2500	11.94	0.001
Linear	3	6.250	2.0833	1.53	0.272
FlourType	1	4.000	4.0000	2.94	0.121
LiquidType	1	2.250	2.2500	1.65	0.231
LeaveningAgent	1	0.000	0.0000	0.00	1.000
2-Way Interactions	3	91.250	30.4167	22.35	0.000
FlourType*LiquidType	1	4.000	4.0000	2.94	0.121
FlourType*LeaveningAgent	1	6.250	6.2500	4.59	0.061
LiquidType*LeaveningAgent	1	81.000	81.0000	59.51	0.000
Error	9	12.250	1.3611		
Lack-of-Fit	1	0.250	0.2500	0.17	0.694
Pure Error	8	12.000	1.5000		
Total	15	109.750			

Table A9: ANOVA Table: Model with Main Effects and Liquid Type*LeaveningAgent Interaction

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	4	87.250	21.8125	10.66	0.001
Linear	3	6.250	2.0833	1.02	0.422
FlourType	1	4.000	4.0000	1.96	0.190
LiquidType	1	2.250	2.2500	1.10	0.317
LeaveningAgent	1	0.000	0.0000	0.00	1.000
2-Way Interactions	1	81.000	81.0000	39.60	0.000
LiquidType*LeaveningAgent	1	81.000	81.0000	39.60	0.000
Error	11	22.500	2.0455		
Lack-of-Fit	3	10.500	3.5000	2.33	0.150
Pure Error	8	12.000	1.5000		
Total	15	109.750			

Table A10: ANOVA Table: Final Reduced Model

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	3	83.250	27.7500	12.57	0.001
Linear	2	2.250	1.1250	0.51	0.613
LiquidType	1	2.250	2.2500	1.02	0.333
LeaveningAgent	1	0.000	0.0000	0.00	1.000
2-Way Interactions	1	81.000	81.0000	36.68	0.000
LiquidType*LeaveningAgent	1	81.000	81.0000	36.68	0.000
Error	12	26.500	2.2083		
Lack-of-Fit	4	14.500	3.6250	2.42	0.134
Pure Error	8	12.000	1.5000		
Total	15	109.750			