How Much Air is in Your Bag of Chips?

By Katrina Apiado and Ranjeet Nebhnani
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Abstract

This experiment was conducted with the purpose of identifying the potato chip brands with the highest and lowest chip-to-air ratio. Four of the most popular brands of potato chips packaged in plastic bags were studied: *Lay's*, *Ruffles*, *Kettle* and *Cape Cod*. The null hypothesis states that the chip density mean of each brand is equal to one another. There were 4 levels of potato chip brands and a sample size of 5 for each bag, resulting in 20 experimental runs being performed. The null hypothesis was ultimately rejected and there was enough evidence to conclude that there was at least one brand of chips whose chip density is different from the other brands. This experiment was conducted using one-way ANOVA to conclude the main results of this experiment. These findings are significant since it shows the packaging of different potato chip brands are significantly different from each other. Finding the average chip density of each chip brand is useful in everyday life so the average consumer can be informed of which bags of chips are over-inflated and can be better informed when purchasing their favorite snack.

Introduction

Objective

To identify which brand of potato chips has the lowest and highest chip-to-air ratio.

Background

Potatoes are arguably the most popular vegetable in the United States. It's estimated that we consume about 110 pounds of potatoes per person every single year. Of course, that fun fact takes into account all of the ways potatoes are consumed, but for now let's look at one interesting method of preparing potatoes. Since its inception in 1853 in New York, potato chips have become one of the most popular and common snacks in America and abroad. According to the United States Department of Agriculture, all potato production in 2019 totaled 424 million cwt [100 pounds] with 59.6 million cwt of potatoes being used for potato chips. From this massive amount of production being put into the potato chip industry, we can assume the market for this endearing snack must be sizable. In 2016 the potato chips market size was valued at USD 7.74 billion for the United States alone. This value is expected only to increase every year in the next few years.

The average consumer contributing to this enormous market has been faced with a unique disappointment when buying their own potato chips. It seems almost every bag of potato chips is half-empty upon opening it! Historically, potato chips have been packaged in cans, paper bags, cellophane, plastic, aluminum foil and cardboard tubes. But today, the most common way to see them is in a plastic bag which is why this issue with potato chips is ordinary. This intentional empty volume in your average bag of potato chips is referred to as “slack fill.” Though it may make purchasing a bag of chips somewhat annoying, this extra amount of space is meant to protect the chips inside from being crushed into crumbs during the chipping process. It’s also important to note these bags of chips are not just being filled with regular air. Potato chip bags are puffed with nitrogen which keeps the chips from spoiling before the bag is opened. Thankfully, the packaging of potato chips does serve a purpose to keep consumers happy. But that does not relieve the annoyance of choosing the bag with the most chips and least air. The Fair Packaging and Labeling Act passed in 1966 requires manufacturers to print the weight and volume of their product so consumers can know exactly what they are getting. However, it would arguably be more annoying to mathematically try to figure out which bag of chips has the highest chip-to-air ratio while grocery shopping. The ultimate goal of this report is to identify which brand of potato chips has the lowest and highest chip-to-air ratio.

Hypotheses

Null Hypothesis: There is no difference in the average chip density of a bag of potato chips between each of the different brands.

$H_0 = \mu_{Lay's} = \mu_{Ruffles} = \mu_{Kettle} = \mu_{Cape\ Cod}$

Alternative Hypothesis:

H_1 = There is at least one brand of chips whose chip density is different from the other brands.

Experimental Design

Variables

The factor of this experiment is the different potato chip brands. There are 4 levels of this factor: *Lay's*, *Ruffles*, *Kettle*, and *Cape Cod*. The control variable is the person conducting the experiment, in which the same weighing scale was used by the person on the same day. The response variable is the chip-to-air ratio, where we can use the density equation to calculate this value. The density equation—*m* being the weight of the chips in grams and *V* being the volume of the bag in liters—is as follows:

$$\rho = \frac{m}{V}$$

Procedure

Materials needed for this experiment include five bags of each potato chip brand (for a total of twenty bags of chips), 4-gallon plastic tub, 4-quart mixing bowl, food weighing scale, measuring cup, twenty Ziplocs, a Sharpie marker, a towel, paper towels, water and Excel.

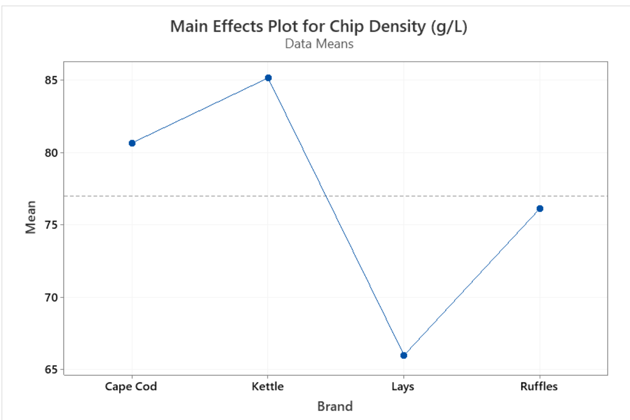
1. Collect all needed materials.
2. Set up the Excel spreadsheet for each brand and label three columns: "Weight (g)," "Volume (L)," "Chip-to-Air Ratio (g/L)."
3. Fill the tub halfway with water.
4. Mark a line on the tub with the Sharpie marker to show the current level of the water.
5. Take one bag of chips and submerge the bag until the bag is completely underneath the water.
6. Mark a new line on the tub with the Sharpie marker for the new level of water.
7. Remove the water in between the current and new line.
8. Use the measuring cup to fill up water and carefully measure how much was used from the current to the new line.
9. Record the measurement into the "Volume (L)" column in Excel.
10. Wipe the wet bag of chips with a towel until dry.
11. Put the mixing bowl on the food weighing scale and zero the scale.
12. Open the bag of chips and remove its contents into the mixing bowl.
13. Record the measurement into the "Weight (g)" column in Excel.
14. Open a Ziploc to save the contents of the bag of chips.
15. Wipe down the interior of the mixing bowl with a damp paper towel to remove excess crumbs.

16. Divide the “Weight (g)” by “Volume (L)” and input that value into the “Chip-to-Air Ratio (g/L)” column in Excel.
17. Repeat the process until all bags of chips have been measured.

The data recorded and values calculated can be seen in the Experimental Data under Appendix A.

Data Analysis and Discussion

One-Way Analysis

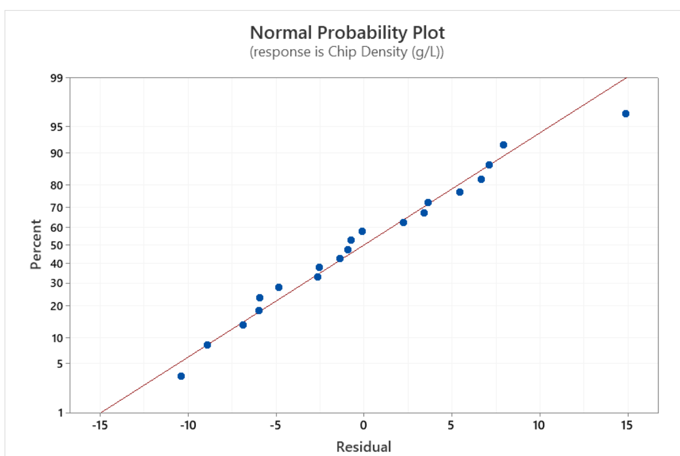


Analysis of Variance

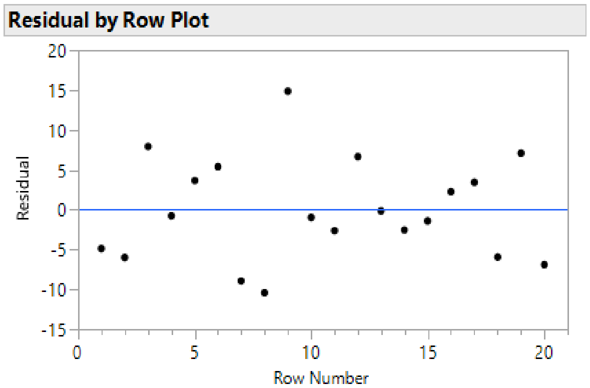
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Brand	3	1010.4	336.80	6.87	0.003
Error	16	784.1	49.00		
Total	19	1794.4			

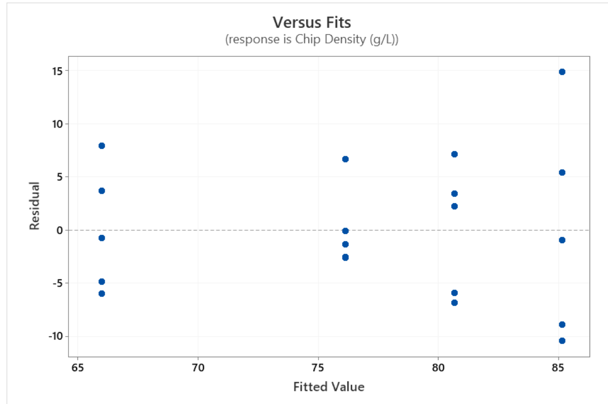
It can be seen on the Main Effects Plot that Lay’s has a lower chip density, which would result in a lower Chip-to-Air ratio. Under the Analysis of Variance, the F-value is greater than 1, which indicates significance and corresponds with a low P-value.

Checking Assumptions



The data points are linear and consistent with a normal distribution, showing that there is normalcy in the data.





The Residual by Row plot displays a randomness in the data indicating that the data points are independent from one another. The Residuals versus Fits plot verifies the assumption that the residuals are randomly distributed and have constant variance.

Pairwise Comparisons

Tukey's Method

Grouping Information Using the Tukey Method and 95% Confidence

Brand	N	Mean	Grouping	
Kettle	5	85.15	A	
Cape Cod	5	80.65	A	
Ruffles	5	76.13	A	B
Lays	5	65.97		B

Means that do not share a letter are significantly different.

From the table using Tukey's Method, Kettle and Cape Cod are in Group A and Ruffles is in both Groups A and B. Lay's is the only brand in Group B. Therefore, Lay's is significantly different. (Refer to Appendix B)

Fisher's Method

Grouping Information Using the Fisher LSD Method and 95% Confidence

Brand	N	Mean	Grouping	
Kettle	5	85.15	A	
Cape Cod	5	80.65	A	
Ruffles	5	76.13	A	
Lays	5	65.97		B

From the table using Fisher's Method, Kettle, Cape Cod, and Ruffles are in Group A while Lay's is the only brand in Group B. Therefore, Lay's is significantly different. (Refer to Appendix B)

Analysis

From the one-way ANOVA table, it can be seen that the P-value is 0.03, which is less than 0.05. Therefore, we can reject the null hypothesis at a 95% confidence interval. By rejecting the null hypothesis with 95% confidence, it is reasonable to conclude that not all chip-to-air ratio means are equal. By applying Tukey's Method, Lay's is significantly different from the other brands in that it was the only brand to be assigned to Group B. To differentiate between the chip-to-air ratios, Fisher's Method was used and it is shown that Lay's is significantly different from the rest.

Conclusion

Based on the data analyses of our experiment, there was at least one brand of potato chips with a chip density that was significantly different from the others. We can reject the null hypothesis that all of these bags of chips have the same chip density at a 95% confidence interval. Though we were not able to conclude a definitive best brand based on chip density, we were able to identify a definitive worst brand with regard to chip density. Because it was grouped separately in both pairwise comparison methods, we concluded that Lay's was the brand with the lowest chip density of all the brands tested in this experiment. Ruffles was in the same group as Lay's using Tukey's method, unlike Cape Cod and Kettle. Because of this, Kettle and Cape Cod are considered to be equally favorable in their high chip density since their differences are statistically insignificant. Thus we have two best brands of chips based on chip density: Kettle and Cape Cod.

After collecting the data from the trials, the potential sources for error in this experiment were obvious. The biggest potential for error in the experimental process in this report was finding the volume of the bags of chips through the water displacement method. Firstly, the bucket that was used for this method did not have volumetric measurements along the side. Because of this, the experimenters manually marked the bucket with measurements which, though not extraordinarily inaccurate, is completely subject to human error. This error could be fixed with a more accurate bucket with pre-made volumetric markings. Also, the water displacement method for finding the volume of irregularly shaped objects is commonly used for solid objects that are more dense than water. However, because the bags of chips float on water, each bag was manually held down just under the surface of the water. Finding the volume of the bag this way could result in the experimenter not completely submerging each bag the exact same way causing slight errors in measurements. Using this method also means that the volume of the experimenter's hand that is submerged is not taken into account, making each chip density calculation slightly inaccurate. This error could be easily fixed by securing a bag of chips to a dense object with a known volume and solving for the volume of chips by subtracting the dense object's volume from the overall change in volume.

Though not an error, the small sample size for each brand definitely affected the ranking of each brand to be inconclusive. The main reason the sample size was limited to 20 bags of chips total was the cost to the experimenters who were on a budget. Ideally, conducting this experiment would result in each brand of chips being significantly different from each other. This could be achieved if there were greater sample sizes for each brand which would theoretically result in each brand having its own group when utilizing pairwise comparison methods.

Further investigation into the chip density of common chip brands should be conducted. This experiment exclusively focused on potato chip brands for the sake of simplicity, but applying these methods to other types of chips, like corn chips, or comparing the different ways chips are prepared (air-fried vs. oven-baked). Though it was not achieved in this experiment, a comprehensive list that ranks chip brands based on the chip density of their bags would greatly help the average consumer get the most for their money when buying a bag of chips.

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Appendix A

Experimental Data

	Trial 1		
	Weight (g)	Volume (L)	Chip-to-Air Ratio (g/L)
Lay's	220	3.6	61.11
Ruffles	226	3.075	73.50
Kettle	240	2.65	90.57
Cape Cod	228	2.75	82.91

	Trial 2		
	Weight (g)	Volume (L)	Chip-to-Air Ratio (g/L)
Lay's	219	3.65	60.00
Ruffles	207	2.5	82.80
Kettle	141	1.85	76.22
Cape Cod	227	2.70	84.07

	Trial 3		
	Weight (g)	Volume (L)	Chip-to-Air Ratio (g/L)
Lay's	218	2.95	73.90
Ruffles	228	3.00	76.00
Kettle	142	1.90	74.74
Cape Cod	213	2.85	74.74

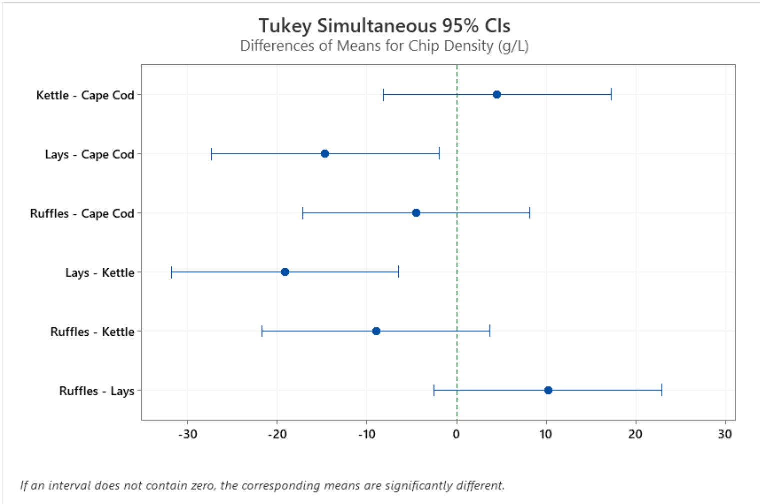
	Trial 4		
	Weight (g)	Volume (L)	Chip-to-Air Ratio (g/L)
Lay's	212	3.25	65.23
Ruffles	241	3.275	73.59
Kettle	245	2.45	100.00
Cape Cod	215	2.45	87.76

	Trial 5		
	Weight (g)	Volume (L)	Chip-to-Air Ratio (g/L)
Lay's	220	3.16	69.62
Ruffles	228	3.05	74.75
Kettle	240	2.85	84.21
Cape Cod	214	2.90	73.79

	Average of 5 Trials		
	Weight (g)	Volume (L)	Chip-to-Air Ratio (g/L)
Lay's	217.8	3.32	65.56
Ruffles	226.0	2.98	75.84
Kettle	201.6	2.34	86.15
Cape Cod	219.4	2.73	80.37

Appendix B

Tukey's Method

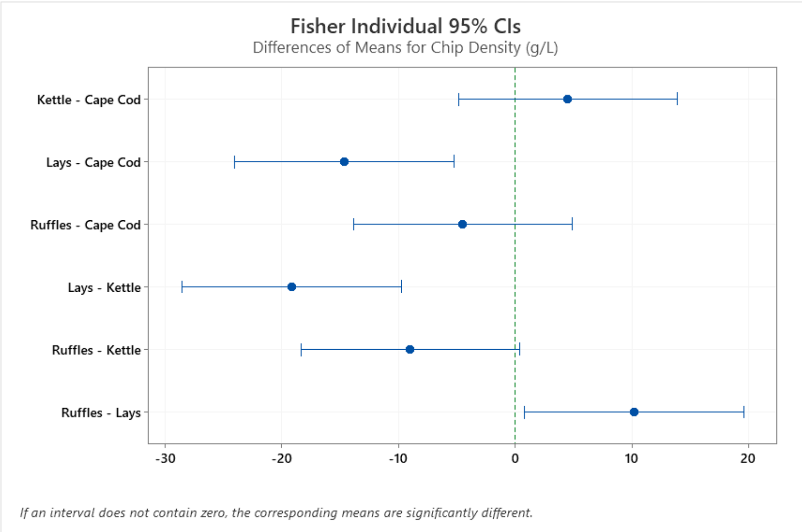


Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Kettle - Cape Cod	4.49	4.43	(-8.19, 17.17)	1.01	0.743
Lays - Cape Cod	-14.68	4.43	(-27.36, -2.00)	-3.32	0.020
Ruffles - Cape Cod	-4.53	4.43	(-17.21, 8.15)	-1.02	0.739
Lays - Kettle	-19.17	4.43	(-31.85, -6.49)	-4.33	0.003
Ruffles - Kettle	-9.02	4.43	(-21.70, 3.66)	-2.04	0.216
Ruffles - Lays	10.16	4.43	(-2.52, 22.83)	2.29	0.141

Individual confidence level = 98.87%

Fisher's Method



Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Kettle - Cape Cod	4.49	4.43	(-4.89, 13.88)	1.01	0.325
Lays - Cape Cod	-14.68	4.43	(-24.07, -5.30)	-3.32	0.004
Ruffles - Cape Cod	-4.53	4.43	(-13.91, 4.86)	-1.02	0.322
Lays - Kettle	-19.17	4.43	(-28.56, -9.79)	-4.33	0.001
Ruffles - Kettle	-9.02	4.43	(-18.40, 0.37)	-2.04	0.059
Ruffles - Lays	10.16	4.43	(0.77, 19.54)	2.29	0.036

Simultaneous confidence level = 81.11%