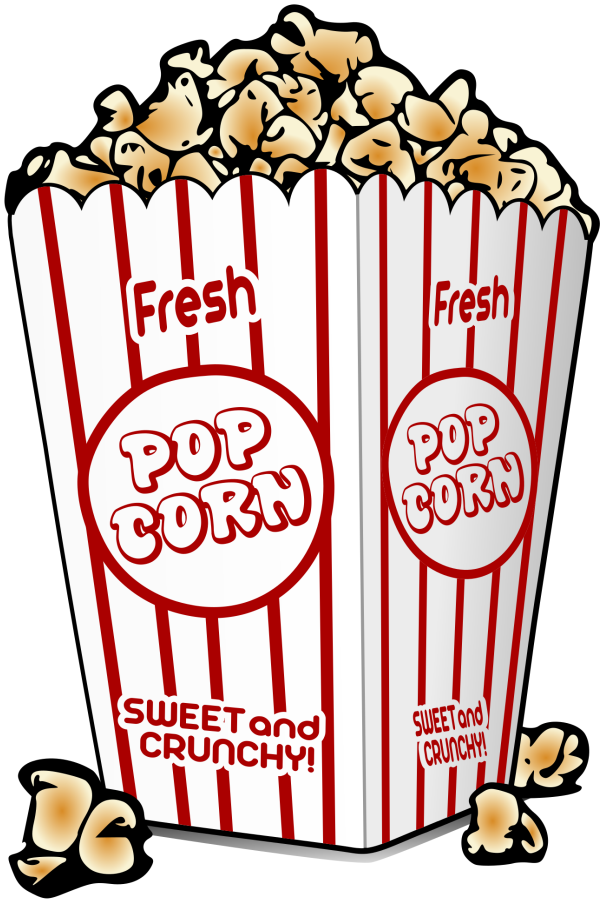
Perfecting Popcorn

A Randomized Complete Block Design



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Abstract

Popcorn is an essential movie snack for people of all ages. Watching a movie – either in a movie theater or at home – is not complete without a bag of warm, buttery, freshly popped popcorn. For those who watch from the comfort of their home, they must take an extra step in popping the popcorn themselves. It can be tricky to find the perfect amount of time to place the popcorn in the microwave for: a balanced must be obtained between an edible, yet unburnt snack to enjoy. This Randomized Complete Block Design tests the ideal length of time for a bag of popcorn to heat in the microwave. The effect being tested consists of the duration of time in the microwave. Different microwaves are used to decrease the treatment error. The response measure of the variable is the number of unpopped kernels in the bag after being microwaved. At the conclusion of the experiment, it is discovered that the duration of time the popcorn is in the microwave is significant in perfecting the buttery movie snack. It is found that using Tukey's pairwise comparison technique, that optimal microwave time is between the times two minutes and thirty seconds and three minutes and thirty seconds.

Introduction

For those watching a movie from home yet craving a full, cinematic, movie-theater experience, a microwaveable bag of popcorn is the perfect item to have on hand. They make movie viewing anywhere feel as if one is sitting in a theater. However, these bags are only supplied with the unpopped kernels, and it is the job of the microwave to turn the kernels into the buttery, flavorful popcorn for movie viewers to enjoy. Understandably, it is difficult for the popcorn bag brands to put a single time recommendation on their product for their thousands of buyers to adhere to. One can wait next to the microwave and listen for the popping sound to slow down to know

when it is time to remove the bag. Using this tactic is not ideal for those who would like to put their popcorn in the microwave and forget about it until they hear the timer go off. Many factors can disrupt the cooking time in the microwave, including: the wattage of the microwave, where the popcorn bags are stored prior to use (temperature, humid/dry climate), type of flavor or seasoning the kernels are prepackaged in, material of prepackaging, among many additional factors. The goal of this experiment was to dive deeper into these "what ifs" and determine the ideal settings to create a delicious movie theater snack from home.

Methods

This experiment aimed to determine the ideal length of time for a bag of movie theater microwavable popcorn to be in the microwave, as well as the ideal microwave to use. A Randomized Complete Block Design (RCBD) in the context of analysis of variance (ANOVA) was utilized to test this. The experimental units used were microwavable bags of "Extra Butter Premium Popcorn" from the brand *Pop-Secret*. The nine microwavable bags used all came from the same pack purchased from Target to eliminate any differences, and therefore reduce potential errors in the experiment. Three time durations were chosen– 1:30, 2:30, and 3:30. These durations were specifically chosen because the *Pop-Secret* bags of popcorn claim the popcorn would be ready in the microwave in as quick as 90 seconds, but no longer than four minutes. Since there was quite a large interval of time recommended for microwaving, then it can be assumed there is a difference in heating methods. Three different microwaves were used for this experiment in order to decrease the treatment error, making the total number of observations nine. After running the ANOVA test, the application of Tukey's test is employed for conducting pairwise comparisons to determine optimal time.

Results

	Microwave #1	Microwave #2	Microwave #3	Totals
1:30	279	311	140	730
2:30	31	91	15	137
3:30	11	10	8	29
Totals	321	412	163	896

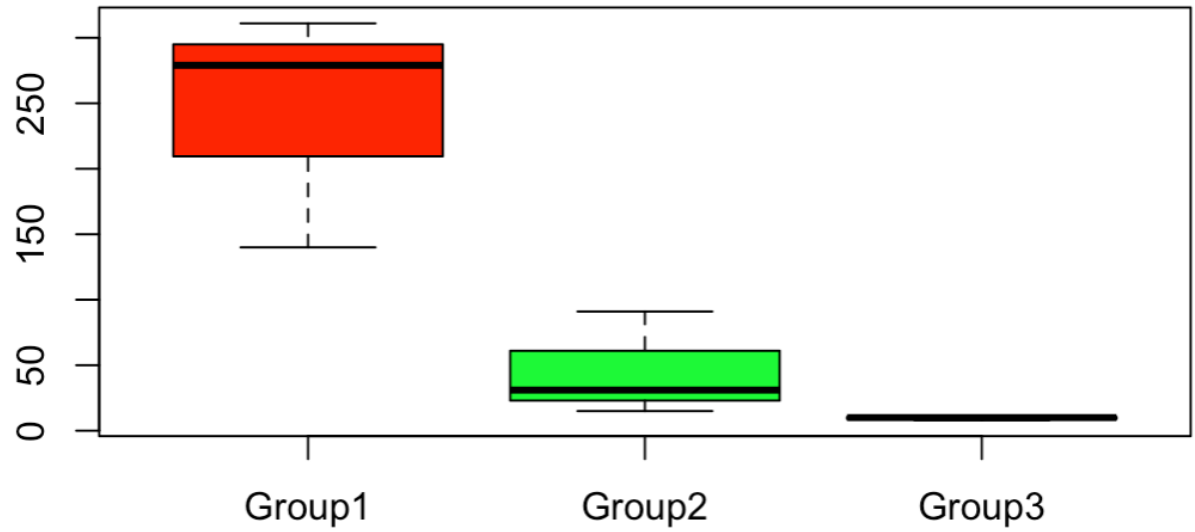
Data Gathered

Data was collected on the number of unpopped kernels in each bag after they had been microwaved for the set duration of time. Results showed that microwaving the popcorn bags for 1:30 just barely began to pop the kernels, leaving much of the popcorn inedible. As many as 300 pieces of popcorn were left unpopped at this duration! For all three trials at the 1:30 time duration, kernels could be heard popping starting at about the one minute mark, and 1:30 seemed to be a bit short of the ideal time.

With the three bags of popcorn that were microwaved at the 2:30 duration, it was obvious that the majority of the kernels had popped at the last minute. This was consistent with the findings in the table– the average number of kernels unpopped at the 1:30 level was 243.33, while the average number of kernels unpopped at the 2:30 level was 45.67 kernels.

Although the popcorn bags that were microwaved at the 3:30 duration had fewer unpopped kernels (and therefore would be interpreted as a more sufficient time duration), the popcorn that was popped had come out extremely burnt. The burning smell could be noticed at around 3:00 for all three bags, and after they were pulled out of the microwave at the conclusion of the three minutes and 30 seconds, many crispy black inedible pieces were found. The popcorn pieces that

were not completely burnt were obviously not as moist and buttery as the popcorn popped for 1:30 and 2:30. These results showed that although this time duration resulted in the most amount of popcorn kernels popped, it was not exactly the most ideal duration of time for the best popcorn.



Box Plot for Select Times made in R

The box plot shows a graphical representation of the distribution of the dataset. It provides a visual of how the factor levels differ in mean and variance. Group 1 (1:30) data has a high mean in respect to Group 2 (2:30) data and Group 3 (3:30) data. As the times increase, the mean and variance decrease. Group 2 and 3 appear to be closest in mean and variance while Group 1 is very different in both cases. There are no groups that have zero unpopped kernels. Thus, it is ruled out that optimal pop time means zero unpopped kernels are found. The minimum number of unpopped kernels is Group 3 and is eight. Since burning time was reached in Group 3, it is possible that optimal pop time is achieved shortly after two minutes and thirty seconds.

Effects Model:

$$Y_{ij} = \mu + \tau_i + \beta_j + \epsilon_{ij}$$
$$i = 1, 2, ..., a$$
$$j = 1, 2, ..., b$$

Where:
- Y_{ij} is the observation on the ith treatment in the jth block .
- μ is the overall mean of the response variable.
- τ_i is the effect of the ith treatment subject to $\sum_{i=1}^{a} \tau_i = 0$.
- β_j is the effect of the jth block subject to $\sum_{j=1}^{b} \beta_j = 0$.
- ϵ_{ij} is the random error term associated with the ith treatment in the jth block.
- ϵ_{ij} $N(0, \sigma^2)$

Formulas made in R

Assumptions:

- ➢ Randomization - The assignments of treatments to experimental units is done randomly.
- ➢ Homogeneity - The blocks are homogeneous
- ➢ Independence - The observations within each block are independent of each other.

Hypothesis of Interest:

$$H_o : \tau 1 = \tau 2 = \tau 3 = 0$$
$$H_a : \text{at least } 1 \ \tau_i \neq 0$$

Formulas made in R

The interest of this experiment was to test if there was a difference between the duration of times a bag of popcorn kernels is in the microwave.

Formulas and Calculations:

$SS_{TOTAL} = \sum_{i=1}^{3}\sum_{j=1}^{3} y_{ij}^2 - CF = 114712.2$

$SS_{TREATMENT} = \frac{1}{3}\sum_{i=1}^{3} y_{i.}^2 - CF = 94968.22$

$SS_{BLOCK} = \frac{1}{3}\sum_{j=1}^{3} y_{j.}^2 - CF = 10582.89$

$SS_{BLOCK} = SS_{TOTAL} - SS_{TREATMENT} - SS_{BLOCK} = 9161.111$

$MS_{TREATMENT} = \frac{SS_{TREATMENT}}{2} = 47484.11$

$MS_{BLOCK} = \frac{SS_{BLOCK}}{2} = 5291.444$

$MS_{ERROR} = \frac{SS_{ERROR}}{4} = 2290.278$

$F_{\alpha;df_1,df_2} = F_{0.05;2,4} = 6.94$

$F_{TREATMENT} = \frac{MS_{TREATMENT}}{MS_{ERROR}} = 20.7329$

$F_{BLOCK} = \frac{MS_{BLOCK}}{MS_{ERROR}} = 2.310394$

Formulas made in R

Source	SS	df	MS	F	Significance
Treatment	94968.22	2	47484.11	20.7329	***
Block	10582.89	2	5291.444	2.310394	
Error	9161.111	4	2290.278		
Total	114712.2	8			

ANOVA Table

Tukey's Test:

Critical Value

$\frac{q_\alpha(a,N-a)}{\sqrt{2}} = \frac{q_{0.05}(3,6)}{\sqrt{2}} = 3.09$

Minimum Significant Difference

$\frac{q_\alpha(a,N-a)}{\sqrt{2}}[\sqrt{MSE(\frac{2}{N})}] = 3.09(\sqrt{2290.278(\frac{2}{9})} = 22.56$

95% Confidence Interval

$(\bar{y_{1.}} - \bar{y_{2.}}) \pm 22.56 = 197.66 \pm 22.56 = (175.1, 220.22)$

$(\bar{y_{1.}} - \bar{y_{3.}}) \pm 22.56 = 233.66 \pm 22.56 = (211.1, 256.22)$

$(\bar{y_{2.}} - \bar{y_{3.}}) \pm 22.56 = 36 \pm 22.56 = (13.44, 58.56)$

Formulas made in R

Since burning time is found to be around three minutes and there was no time interval that produced zero unpopped kernels, we can assume that each unburnt bag of popcorn should

produce a few unpopped kernels. It is shown that any bag that produced less than 12 unpopped kernels also produced burnt popcorn. Thus, the goal is to have around 20 unpopped kernels. The third confidence interval for the difference in mean in the list compares the 2:30 group and 3:30. In this case, the number 20 falls within the interval. This suggests that, with 95% confidence, the optimal time could be between 2:30 and 3:30. Although since burning time is around 3:00, it is narrowed down further that optimal poptime could be between 2:30 and 3:00.

Conclusion

After obtaining and analyzing the results of this experiment, it was concluded 2:30 is the ideal time duration for popcorn kernel bags to be in the microwave for. This time duration had the majority of kernels popped, yet the popcorn was tasty and not burnt. Based on the results of this experiment, it can be assumed that somewhere in between 2:30-3:00 is the perfect duration of time to microwave a bag of popcorn. Thus, if a similar version of this experiment was to be run again, it would be beneficial to decrease the increments of time and test between 2:30 and 3:30. For example, test three bags of popcorn at each of the following durations of time– 2:30, 2:45, 3:00, and 3:15. This would allow a more in depth analysis of the results found in this experiment and therefore a more precise duration of time.

This result was not entirely surprising, because the brand of popcorn used in this experiment, *Pop-Secret,* recommended a time of between 90 seconds and four minutes in the microwave. Since this is a fairly large range, it makes sense for 90 seconds to be too short and four minutes to be too long. It was reasonable to assume, prior to running the experiment, that the optimal poptime would be somewhere in between the two– around 2:30-3:00.

Given another opportunity to expand on these findings, this experiment could be replicated using different brands of popcorn, or different flavors of popcorn. Only one brand of popcorn which came from the same pack purchased was used in order to eliminate any potential outliers. Perhaps other brands fill each bag with a different amount of kernels, which would make any cross-brand analyses fairly inconclusive.