Rice Cooking Time Mean Comparisons: An Application of Factorial Experiment

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1. Objectives of experiment:

Rice is considered as a main food staple for more than 3.5 billion people around the world, particularly in Asia, Latin America, and parts of Africa. As both of us belong to Asia so having it regularly is common for us. Time management is crucial for graduate students; thus, we are trying to save our time from daily activities and spend that on studying. This thinking evokes a question in our mind that how can we reduce our rice cooking time?

To answer this particular question, we are performing this experiment and our aim is to compare the treatment means of cooking time and extract the treatments which will provide least cooking time. In addition to this, our general purpose is to fit a model which will also help us to get the minimum cooking time.

2. All sources of variation:

We considered factors that can affect the cooking time of rice. The amount of water, the temperature of water, the amount of oils, the amount of rice for cooking, and a brand of a rice cooker. For the experiment, we will have three continuous factors: the amount of water, the temperature of the water, and the amount of oils. Each factor consists of two levels. The levels of the first factor; low: 960 milliliters, high: 1120 milliliters. The levels of the second factor; low: 20 degrees of Celsius, high: 45 degrees of Celsius. The level of the third factor: low: 0 milliliters, high: 15 milliliters. Our experimental unit is rice since we will apply the treatments to rice. Our response is time(seconds) to cook rice.

The variations of the amount of rice for cooking can affect the cooking time. However, we will not use this as a factor for this experiment. As a student, we usually cook rice for one person each time. So, we'll set this variation as constant with 3 cups of rice.

A rice cooker would be another factor that could affect cooking time. So, if we use multiple rice cookers for this experiment, we should set the rice cookers as a blocking factor. However, we will use only one rice cooker “Aroma” we already have used. In order to keep the same condition for the rice cooker as possible as we can, we will have enough cooling time for the rice cooker after each run.

3. Response measurements:

Our response is the time (seconds) is required to cook rice. We will measure the time using a stopwatch on a smartphone. As long as we press a start button on the rice cooker, we will start the stopwatch to measure elapsed time. We will stop the stopwatch when the rice cooker makes a beeping sound for completion.

4. Analysis strategy:

Our goal is to compare the considered treatment means and determine which treatment combination makes the least cooking time. So, after measuring cooking time, we will use SAS proc mixed and JMP to fit a full factorial model with three factors. This model will have three main effects, 3 two factor interactions and one three factor interactions effect. We will look at the F test to determine whether three factor interactions are significant by looking at the F test for three factor interactions. If not, we will see the F test for two factor interactions. If not, finally, we will check the F test for main effects. Based on the F test, we will decide a working model for the analysis. After that we will also check the constant variance assumption and normality assumption.

From our considered model, we may get some idea about the treatment combinations which will give us our desired response. Then we will select those interesting treatment combinations and perform the Tukey Adjusted Treatment Comparisons for verifying our results and get some detailed idea about the significant difference between the considered treatment combinations.

5. Pilot experiment:

In our experiment, we didn't perform any specific pilot experiment because the culture where we belong where cooking rice is a regular routine task. We usually cook rice twice a day which helps us to have good knowledge about the experiment. Thus, we have implemented our regular knowledge to perform this experiment. However, we prepared a measuring cup and spoon as well as a thermometer. Also, we set a protocol for the experiment.

6. Reflect on pilot experiment:

As we mentioned earlier, we have good experience about this experiment, so we didn't perform the pilot experiment. However, here we will explain how the previous knowledge helps us to define the factors from the beginning of the experiment. We have selected the factors that we commonly used for cooking and as another level of the factor, we have selected higher values of the norm. For example, we know that rick is cooked by the water and as the water gets boiled the rice is cooked. So, if we give hot water so this will reduce the time of boiling water. In addition to this, we have also kept in mind that, if we spent time heating the water that will eventually take our time. So, we collected the hot water from the water tap. We have used our regular measuring cup to measure the amount of water and in this case, we consider the regularly used water amount as the high level of the factor and take less water with that for the low level. We have done this because our rice will be cooked when all the water is vapored. So, if we give less water then the vaporization time will be less which eventually reduces our cooking time. Finally, for our third factor, we used oil so that the rice didn't get burnt. Thus, we have used the regular oil amount as our high level, and we want to see the result without oil which is another level of the factor oil. This is how our previous knowledge helps us to determine the factors and their levels. Here, we have mentioned how we have used our prior knowledge for selecting the factors along with their levels and how we have conducted this experiment.

7. The experimental design:

We have 3 continuous factors with 2 levels for each. So, for this experiment, we have total $2^3 = 8$ treatment combinations and we will have 2 runs for each treatment. Thus, the design for this experiment is $2^3 \times 2$ factorial design. There will be a total of 16 runs in this experiment. For this experiment, we will set the first factor as the amount of water, the second factor as the temperature of the water, and the third factor as the amount of oils. To randomize our design, we will use a R function "sample". The randomization order along with the response is provided in the following:

Run Orders	1	2	3	4	5	6	7	8
Treatments	-+-	---	++-	---	+++	+++	-+-	-++
Cooking Time	1218	1474	1426	1482	1387	1401	1242	1269

Run Orders	9	10	11	12	13	14	15	16
Treatments	+--	--+	+--	++-	+-+	--+	-++	+-+
Cooking Time	1526	1450	1583	1450	1478	1431	1251	1461

8. Experimental procedure and challenges

This experiment will be conducted in Sheikh Yasir Arafat apartment. This is because the group member has all factors we will use for the experiment in his home, and he cooks rice at least twice a day. For the first two runs, we will do the experiment together. After that, Sheikh Yasir Arafat will conduct it by a protocol. We will leave the rice cooker on a table in the kitchen. The protocol is as follows. First, we wash 3 cups of rice exactly twice with normal water (20 degrees Celsius) in the rice cooker pot. Second, we measure the temperature of water by using a thermometer and the amount of water with a measuring cup. Third, we put the water into the rice cooker pot. Fourth, we put the amount of oil into the pot with a measuring cup. Fifth, we press a cooking button on the rice cooker and start a stopwatch simultaneously. Sixth, we prepare to stop the stopwatch when the rice cooker shows 1 minute left for cooking on the monitor. Seventh, we press the stop on the stopwatch when we hear the second beeping sound. Eight, we wash the pot and have around 6 hours for cooling. Ninth, we do the next run.

9. Analysis and conclusions:

Here, we have performed the $2^3 \times 2$ full factorial design which includes the main effects, 2 factors and 3 factors interactions. From Table1, we have seen that the 3-factor interactions are insignificant, thus we have removed these 3-factor interactions from our consideration and run the model again. Table 2 suggests that the remaining factors of the model are significant. We have also performed the lack of fit test which provides a p-value of 0.50. Thus, there is no lack of fit in our suggested model (Ref. Table 3). We have also plotted the factors by the response and didn't observe any issue regarding the variability as the number of replications is only two (Ref. Figure 1). The studentized residuals plot by the predicted cooking time is exhibiting some non-constant variance, however, which is not severe. Normality assumption of the studentized residuals is satisfied (Ref. Figure 2).

Finally, our fitted model is

$$\begin{aligned}\widehat{Cooking\ Time} = {} & 1408.06 - (77.56 \times \text{Temperature}) + (55.94 \times Water) - (17.06 \times \text{Oil}) \\ & + (29.56 \times \text{Temperature} \times Water) + (13.56 \times \text{Temperature} \times \text{Oil}) \\ & - (15.19 \times Water \times \text{Oil})\end{aligned}$$

Here, the factors are coded such as $\text{Temperature} = \frac{\text{Temperature}_{\text{uncoded}} - 32.5}{12.5}$, $Water = \frac{Water_{uncoded} - 1040}{80}$, and $\text{Oil} = \frac{Oil_{uncoded} - 7.5}{7.5}$.

As our goal is to minimize the response so we need to select the high level of Temperature, high level of Oil, and low level of Water. We believe that this combination will give us the minimum cooking time. As we need to find out three or four interesting treatment combinations, now we will perform the Tukey adjusted treatment comparisons.

From Table 4, we have seen that the treatment combination $\{Temperature = 45, Water = 960, Oil = 0\}$ and $\{Temperature = 45, Water = 960, Oil = 15\}$ are producing the lowest response and these are significantly different from the other treatment combinations because the adjusted p-value is very low and the difference between these two treatment combinations are significant which implies they are almost the same (Ref. Table 5). We have also got the other two treatment combinations $\{Temperature = 45, Water = 1120, Oil = 0\}$ and $\{Temperature = 45, Water = 1120, Oil = 15\}$, though they are producing higher cooking time than the previous two considered treatment combinations but they are significantly different than the other, and comparison between them is insignificant. Thus, we can also consider them as important treatment combinations.

Our aim is to compare the treatment means and extract the treatment combinations which will produce less cooking time. From our analysis, we have observed that $\{Temperature = 45, Water = 960, Oil = 0\}$ and $\{Temperature = 45, Water = 960, Oil = 15\}$ treatment combinations are different than the other considered treatment combinations. These two treatment combinations are also producing the minimum cooking time.

10. Reflection:

This experiment trained us to think about the sources of variation and conduct the experiment in such a way that the unnecessary variations can't affect the results. We have also learnt how to select the factors and their levels logically. For calculating the response, we are actually dependent on the signal of the rice cooker, and we are not sure whether any electrical malfunction exists or not. If we could perform this experiment manually like cooking rice in a pot instead of a rice cooker which may help us to overcome this problem. The lack of fit test provided a pretty high p-value which implies our fitted model is a good one and we have observed some significant results which will help us for future cooking time.

Appendix:

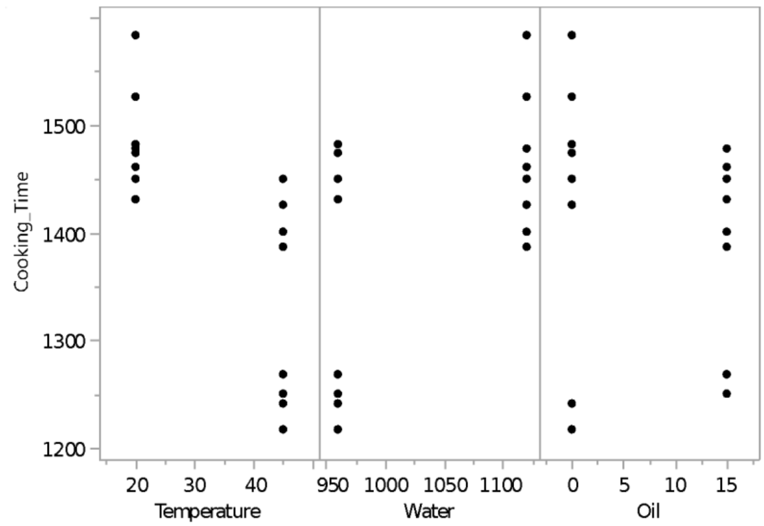

Figure 1: Plot of the Factors (Temperature, Water and Oil) by Cooking Time.

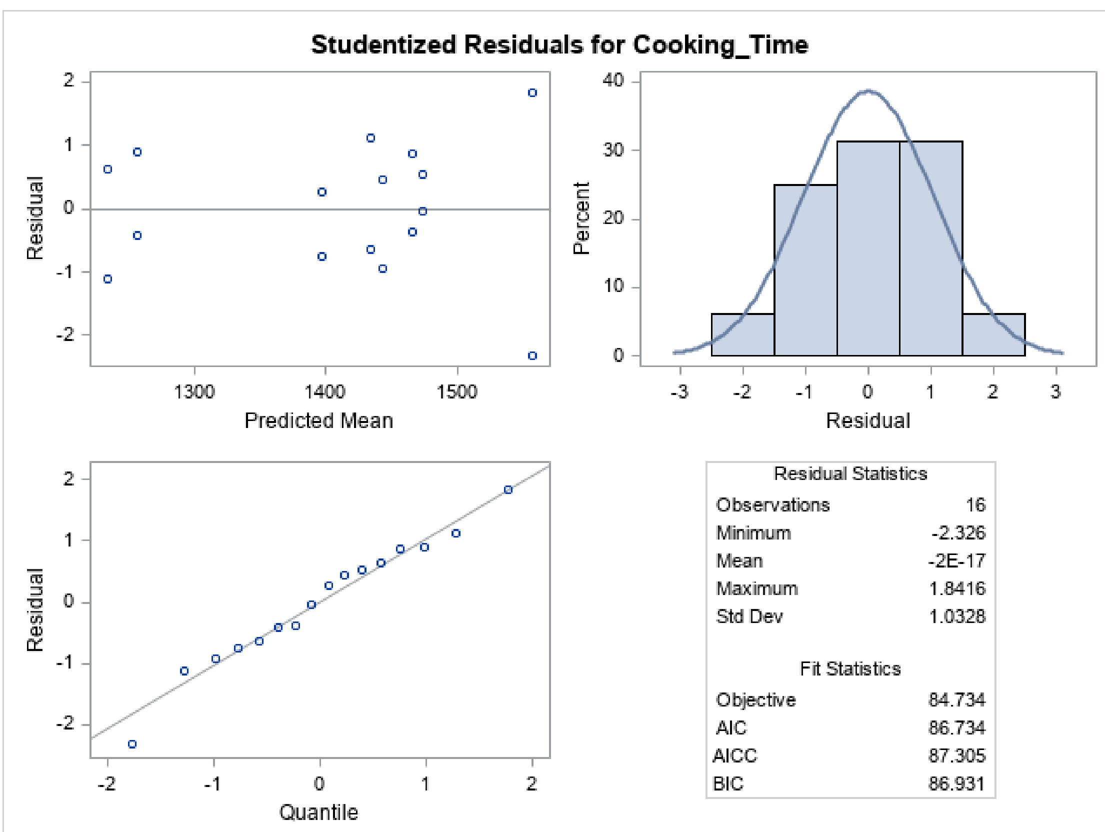

Figure 2: Studentized Residuals Analysis of the fitted model.

Table 1: Parameter Estimates of the Full Factorial $2^3 \times 2$ design.

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1408.0625	4.691665	300.12	<.0001*
Temperature(20,45)	-77.5625	4.691665	-16.53	<.0001*
Water(960,1120)	55.9375	4.691665	11.92	<.0001*
Temperature*Water	29.5625	4.691665	6.30	0.0002*
Oil(0,15)	-17.0625	4.691665	-3.64	0.0066*
Temperature*Oil	13.5625	4.691665	2.89	0.0202*
Water*Oil	-15.1875	4.691665	-3.24	0.0119*
Temperature*Water*Oil	-3.3125	4.691665	-0.71	0.5002

Table 2: Parameter Estimates of the Reduced model.

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1408.0625	4.559074	308.85	<.0001*
Temperature(20,45)	-77.5625	4.559074	-17.01	<.0001*
Water(960,1120)	55.9375	4.559074	12.27	<.0001*
Temperature*Water	29.5625	4.559074	6.48	0.0001*
Oil(0,15)	-17.0625	4.559074	-3.74	0.0046*
Temperature*Oil	13.5625	4.559074	2.97	0.0156*
Water*Oil	-15.1875	4.559074	-3.33	0.0088*

Table 3: Lack of Fit Test of the Reduced model.

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	1	175.5625	175.563	0.4985
Pure Error	8	2817.5000	352.188	**Prob > F**
Total Error	9	2993.0625		0.5002
				Max RSq
				0.9839