IEE 572 PROJECT: (Final Report)

The experiment of growing/Sprouting Lentils under various circumstances

Submitted To:

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RECOGNITION OF PROBLEM STATEMENT

Can we design a home-growing system for lentils that optimizes space utilization, resource efficiency, and harvest quantity? Traditional home-growing methods for lentils often result in low yields, making them impractical for sustainable food production in small spaces. We will try to investigate the effect of using various factors on the final output of the experiments which will be helpful to us to understand the importance of various factors on growing lentils at home.

The experiment aims to investigate the ideal conditions for growing lentils in a home growing system under optimal conditions for growing lentils in conjunction with either cotton or soil using the Design of Experiments (DOE) approach. The primary objective is to design an optimal experiment using a 2^4 factor factorial approach. This means it will identify the key factors that significantly influence the lentil growth such as location, watering period, base type, and soil type. The parameters that were chosen for this experiment are light exposure, frequency of irrigation which will impact the moisture of the base, and the materials in which the Lentil plants are growing either cotton or soil.

CHOICE OF FACTORS, LEVELS AND RANGES

Several factors such as the pH of water, pot type, pot size, type of fertilizer, etc., can influence the response variable. But for our experiment, the below-mentioned factors will be considered:

- Type of lentil: The choice of lentil variety can significantly impact plant growth and overall experiment results.
- Type of base: Planting base composition is a critical factor influencing plant development. For this experiment, we will be choosing both ground soil and cotton as the planting ground.
- Watering period: The watering period, the interval at which plants receive water, significantly influences their growth and overall health. This factor is crucial for assessing the optimal water level and plan for the experiment.
- Location: The location factor, specifically considering California and Arizona, plays a pivotal role in determining the environmental conditions that impact plant growth in these regions.

The parameters chosen, along with their ranges of values of levels are shown in the table below.

Parameters	**Level 1**	**Level 2**
Lentil type	Green Lentils	White peas
Base type	Cotton Cloth	Paper Towel/Tissue
Watering period (t)	8 Hours	12 Hours
Location	Tempe,AZ	Santa Clara,CA

NUISANCE FACTORS

Some of the factors that are most likely to affect the process include but are not limited to:

- Temperature: The temperature is subject to variations based on location, room conditions, or controlled environments.
- Light: Exposure to light plays a vital role in the growth of the plant. But it is uncontrollable as it ranges from full sun to partial shade, sunrise to sunset, and daylight duration.
- Plant pests: Plant pests pose a challenge as they are inherently uncontrollable and their impact depends on situational factors.
- Soil microorganism: Soil microorganism is the factor that can help us get diverse yield outcomes based on the composition of the soil microorganism.

SELECTION OF RESPONSE VARIABLE

- Plant growth: Plant growth can be defined as the vertical height of the plant. It represents the ultimate desired outcome that contributes significantly to maximizing production yield. Assessment of plant growth can be conducted at various stages or time intervals as needed.
- Germination rate: Germination rate stands for the percentage of seeds that sprout from the total number of seeds planted.
- Ph of plant tissue/ Plant health: Maintaining an optimal level of plant health is an important response, and this can be assessed by measuring the pH of plant tissue post-experiment. Additionally, we can also measure the plant health at different time frames to get the proper pH level of the plant

CHOICE OF DESIGN

For our experiment, we have decided to go with a 2^4 Factorial design which comprises 4 factors and 2 levels. This would give us 16 combinations of the selected process parameters.

Furthermore, the selected combinations of the parameters will be replicated one time, resulting in a total of 32 runs of the experiment.

Once the experiments are performed and data is extracted they will be analyzed for insights into experiments.

CONDUCTING THE EXPERIMENT:

For the experimental study, we have chosen Green Lentils and White Peas as the selected legume types. In determining the optimal growth medium in lieu of traditional soil, our investigation has identified Cotton cloth and Tissue as the preferred substrate materials for the experiment.

Our experimental design involves conducting trials in two distinct geographical locations, namely Arizona and California, to ascertain whether spatial variation influences plant growth. Additionally, we will be collecting growth data at two time points: specifically, at 8 hours and 12 hours post-germination.

To enhance the reliability and precision of our findings, we have opted to replicate the experiment, resulting in a total of 32 experimental runs. This approach is intended to minimize experimental error and yield more robust conclusions.


STATISTICAL ANALYSIS

Prior to replication, figure one shows the parameter combination before randomization of all the selected factors. A customized design in JMP was used in our design with lentil type, watering period, location and base type as continuous factors and germination rate as the response variable. Therefore, there were 32 runs in total since there was only one replicated run.

Sl No	Lentil type	Watering period	Location	Base type
1	White Peas	8 Hours	California	Cotton
2	White Peas	12 Hours	California	Cotton
3	White Peas	8 Hours	California	Tissue
4	White Peas	12 Hours	California	Tissue
5	Green Lentils	8 Hours	California	Cotton
6	Green Lentils	12 Hours	California	Cotton
7	Green Lentils	8 Hours	California	Tissue
8	Green Lentils	12 Hours	California	Tissue
9	White Peas	8 Hours	Arizona	Cotton
10	White Peas	12 Hours	Arizona	Cotton
11	White Peas	8 Hours	Arizona	Tissue
12	White Peas	12 Hours	Arizona	Tissue
13	Green Lentils	8 Hours	Arizona	Cotton
14	Green Lentils	12 Hours	Arizona	Cotton
15	Green Lentils	8 Hours	Arizona	Tissue
16	Green Lentils	12 Hours	Arizona	Tissue

Figure 1: Parameter combination before Randomization

Figure 2 shows the selected data randomization.

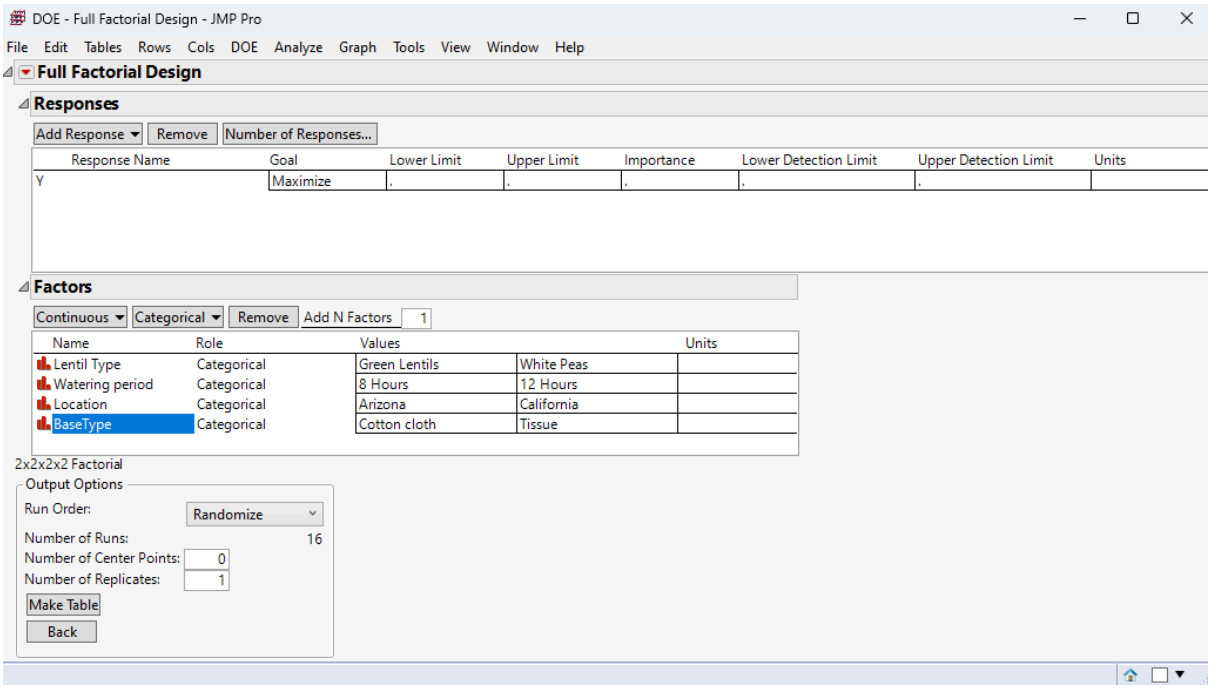
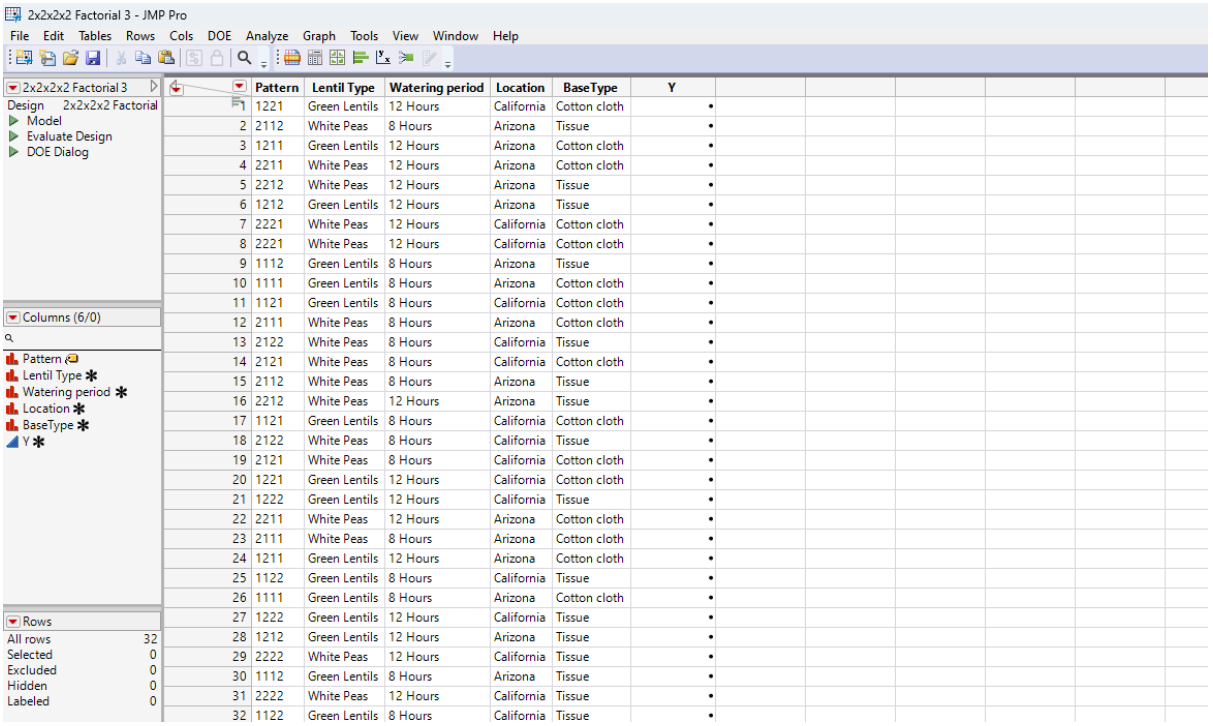


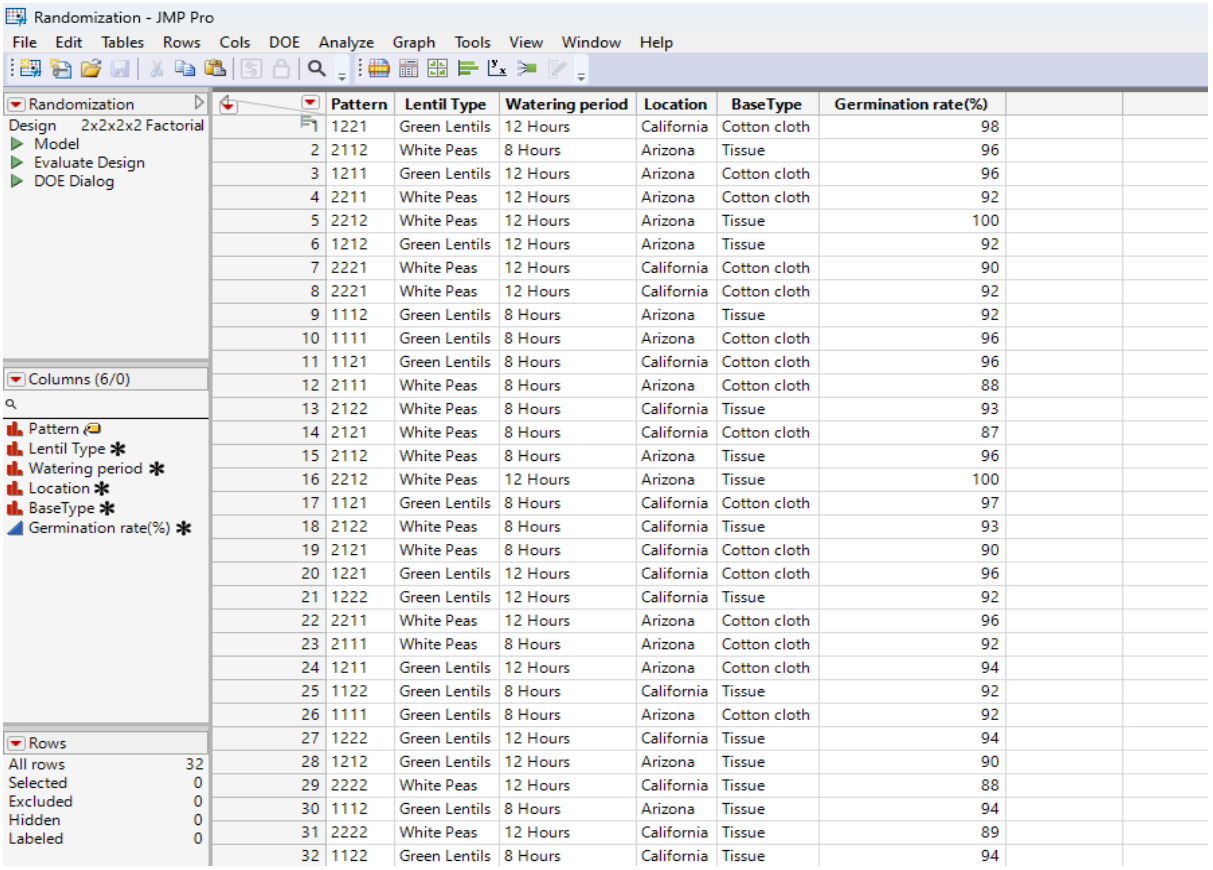
Figure 2: Data Randomization

The goal of this experiment is illustrated by the created table that is displayed in Figures 3 and 4. It observes any patterns in Y (Germination Rate%) that are related to or a direct result of changes in Factors, such as location, base, etc. Thus, four factors—lentil type, watering period, location and base type—have been selected for analysis. Conducting the experiment with two distinct seeds Green Lentils and White Peas will enable us to examine the phenomena across several seed varieties. As a result, during the experiment, the type of seeds will be examined in relation to the treatments. The results of the experiment are displayed as a germination rate percentage in Figure 4.



	Pattern	Lentil Type	Watering period	Location	BaseType	Y
1	1221	Green Lentils	12 Hours	California	Cotton cloth	•
2	2112	White Peas	8 Hours	Arizona	Tissue	•
3	1211	Green Lentils	12 Hours	Arizona	Cotton cloth	•
4	2211	White Peas	12 Hours	Arizona	Cotton cloth	•
5	2212	White Peas	12 Hours	Arizona	Tissue	•
6	1212	Green Lentils	12 Hours	Arizona	Tissue	•
7	2221	White Peas	12 Hours	California	Cotton cloth	•
8	2221	White Peas	12 Hours	California	Cotton cloth	•
9	1112	Green Lentils	8 Hours	Arizona	Tissue	•
10	1111	Green Lentils	8 Hours	Arizona	Cotton cloth	•
11	1121	Green Lentils	8 Hours	California	Cotton cloth	•
12	2111	White Peas	8 Hours	Arizona	Cotton cloth	•
13	2122	White Peas	8 Hours	California	Tissue	•
14	2121	White Peas	8 Hours	California	Cotton cloth	•
15	2112	White Peas	8 Hours	Arizona	Tissue	•
16	2212	White Peas	12 Hours	Arizona	Tissue	•
17	1121	Green Lentils	8 Hours	California	Cotton cloth	•
18	2122	White Peas	8 Hours	California	Tissue	•
19	2121	White Peas	8 Hours	California	Cotton cloth	•
20	1221	Green Lentils	12 Hours	California	Cotton cloth	•
21	1222	Green Lentils	12 Hours	California	Tissue	•
22	2211	White Peas	12 Hours	Arizona	Cotton cloth	•
23	2111	White Peas	8 Hours	Arizona	Cotton cloth	•
24	1211	Green Lentils	12 Hours	Arizona	Cotton cloth	•
25	1122	Green Lentils	8 Hours	California	Tissue	•
26	1111	Green Lentils	8 Hours	Arizona	Cotton cloth	•
27	1222	Green Lentils	12 Hours	California	Tissue	•
28	1212	Green Lentils	12 Hours	Arizona	Tissue	•
29	2222	White Peas	12 Hours	California	Tissue	•
30	1112	Green Lentils	8 Hours	Arizona	Tissue	•
31	2222	White Peas	12 Hours	California	Tissue	•
32	1122	Green Lentils	8 Hours	California	Tissue	•

Figure 3: Randomize Run Order Full Factorial Design– 2x2x2x2 Factorial Design



	Pattern	Lentil Type	Watering period	Location	BaseType	Germination rate(%)
1	1221	Green Lentils	12 Hours	California	Cotton cloth	98
2	2112	White Peas	8 Hours	Arizona	Tissue	96
3	1211	Green Lentils	12 Hours	Arizona	Cotton cloth	96
4	2211	White Peas	12 Hours	Arizona	Cotton cloth	92
5	2212	White Peas	12 Hours	Arizona	Tissue	100
6	1212	Green Lentils	12 Hours	Arizona	Tissue	92
7	2221	White Peas	12 Hours	California	Cotton cloth	90
8	2221	White Peas	12 Hours	California	Cotton cloth	92
9	1112	Green Lentils	8 Hours	Arizona	Tissue	92
10	1111	Green Lentils	8 Hours	Arizona	Cotton cloth	96
11	1121	Green Lentils	8 Hours	California	Cotton cloth	96
12	2111	White Peas	8 Hours	Arizona	Cotton cloth	88
13	2122	White Peas	8 Hours	California	Tissue	93
14	2121	White Peas	8 Hours	California	Cotton cloth	87
15	2112	White Peas	8 Hours	Arizona	Tissue	96
16	2212	White Peas	12 Hours	Arizona	Tissue	100
17	1121	Green Lentils	8 Hours	California	Cotton cloth	97
18	2122	White Peas	8 Hours	California	Tissue	93
19	2121	White Peas	8 Hours	California	Cotton cloth	90
20	1221	Green Lentils	12 Hours	California	Cotton cloth	96
21	1222	Green Lentils	12 Hours	California	Tissue	92
22	2211	White Peas	12 Hours	Arizona	Cotton cloth	96
23	2111	White Peas	8 Hours	Arizona	Cotton cloth	92
24	1211	Green Lentils	12 Hours	Arizona	Cotton cloth	94
25	1122	Green Lentils	8 Hours	California	Tissue	92
26	1111	Green Lentils	8 Hours	Arizona	Cotton cloth	92
27	1222	Green Lentils	12 Hours	California	Tissue	94
28	1212	Green Lentils	12 Hours	Arizona	Tissue	90
29	2222	White Peas	12 Hours	California	Tissue	88
30	1112	Green Lentils	8 Hours	Arizona	Tissue	94
31	2222	White Peas	12 Hours	California	Tissue	89
32	1122	Green Lentils	8 Hours	California	Tissue	94

Figure 4: Randomize Run Order Full Factorial Design with Experimental output– 2x2x2x2 Factorial Design

Figure 5 shows the Fit model specification as it involves defining the structure of the model, it specifies the different variables, degree, and attributes.

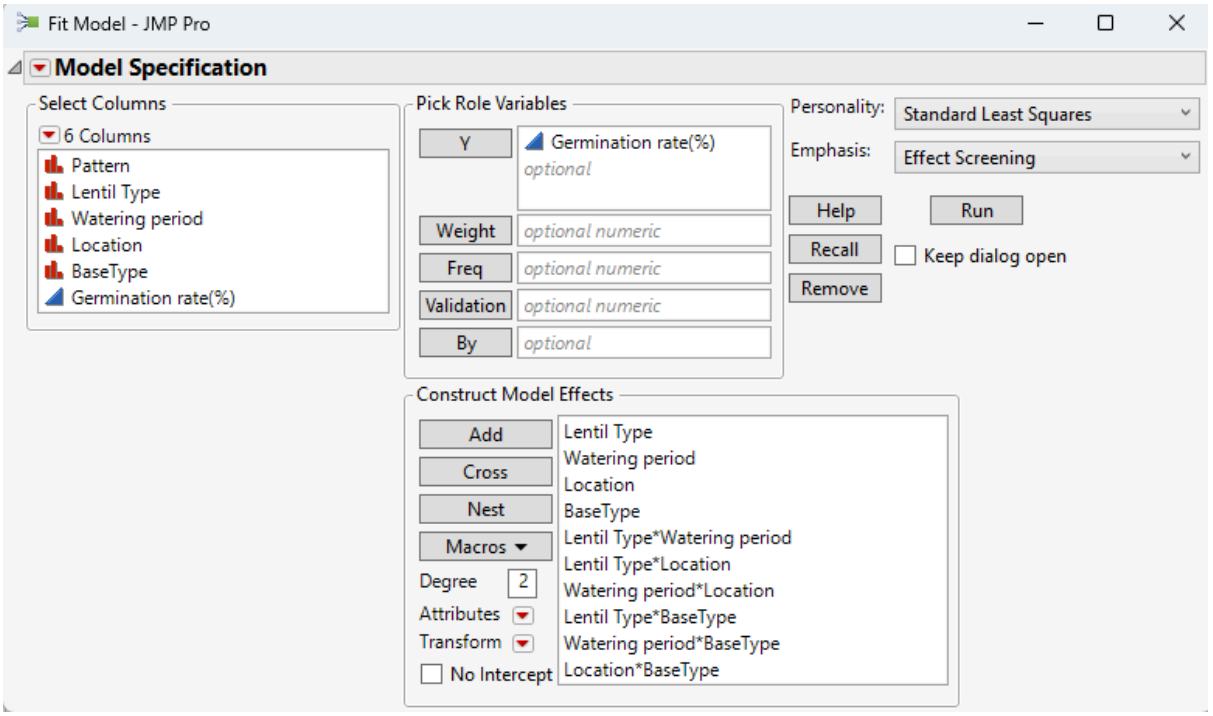


Figure 5: Fit Model Specification

Figure 6 shows all the effects associated with one and another. As observed all the factors Location, Lentil Type, Watering Period and Base Type are significant comparing to Lentil Type * Base Type and Lentil Type * Location whose P values are very less shows that there is a good amount of interaction between the factors.

Effect Summary

Source	Logworth	PValue
Lentil Type*BaseType	3.944	0.00011
Lentil Type*Location	3.759	0.00017
Location	1.435	0.03672 ^
Location*BaseType	1.435	0.03672
Lentil Type	1.277	0.05279 ^
Watering period*BaseType	1.125	0.07491
Watering period*Location	0.841	0.14416
Lentil Type*Watering period	0.587	0.25903
Watering period	0.472	0.33746 ^
BaseType	0.102	0.79153 ^

Figure 6: Effect Summary

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Lentil Type	1	1	16.531250	4.2127	0.0528
Watering period	1	1	3.781250	0.9636	0.3375
Location	1	1	19.531250	4.9772	0.0367*
BaseType	1	1	0.281250	0.0717	0.7915
Lentil Type*Watering period	1	1	5.281250	1.3458	0.2590
Lentil Type*Location	1	1	81.281250	20.7133	0.0002*
Watering period*Location	1	1	9.031250	2.3015	0.1442
Lentil Type*BaseType	1	1	87.781250	22.3697	0.0001*
Watering period*BaseType	1	1	13.781250	3.5119	0.0749
Location*BaseType	1	1	19.531250	4.9772	0.0367*

Figure 7: Effect Tests for the Factors considered

Figure 8 shows both Summary of Fit and the ANOVA table results. The Summary of Fit shows that R Square is ~ 75.7% and Adjusted R Square is ~ 64.1% which makes the model a good fit as it captures a significant portion of the variation.
The ANOVA table result that was all carried out on the software has ten degrees of freedom. The F-statistic value is 6.5445.

Summary of Fit

RSquare	0.75707
RSquare Adj	0.64139
Root Mean Square Error	1.980936
Mean of Response	93.34375
Observations (or Sum Wgts)	32

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	10	256.81250	25.6813	6.5445
Error	21	82.40625	3.9241	Prob > F
C. Total	31	339.21875		0.0002*

Figure 8: Summary of Fit and ANOVA Results

Figure 9 shows the Prediction Profiler which helps understand the relationship between the predator variables and the response variable in the experiment. As it can be seen from the diagram of the lentil type the green lentils leads to higher germination rate mean and maximum value as well as for the base type where the cotton cloth has as well higher germination rate (%). Based on a graph for the Watering Period it can be seen that the watering period for every 12 hours will yield higher mean and maximum germination rate (%) across the experiment. This also applies to locations where Arizona has higher mean and maximum germination rate than California.

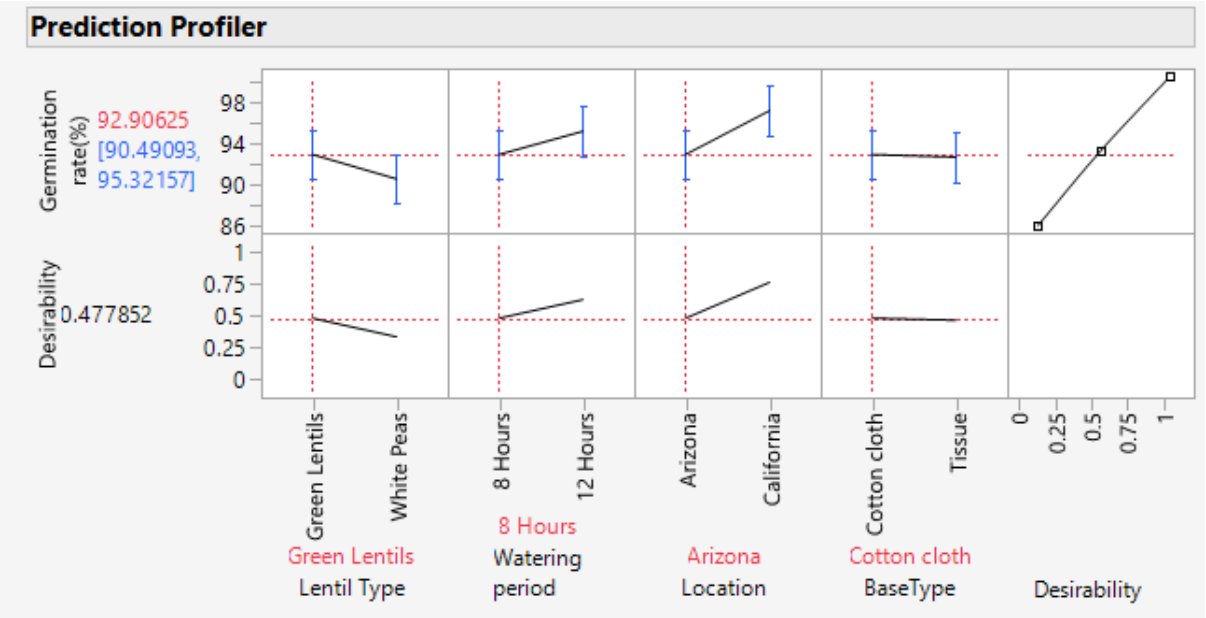


Figure 9: Prediction Profiler

Fig 10 portrays a plot comparing the actual and the predicted tensile strengths. A more detailed observation of the plot helps us to comprehend that all data sets obtained are lying within the prediction cone. This proves that there are no significant outliers in the model. The predicted Root Mean Square Error (RMSE) calculated by the software is 1.9809

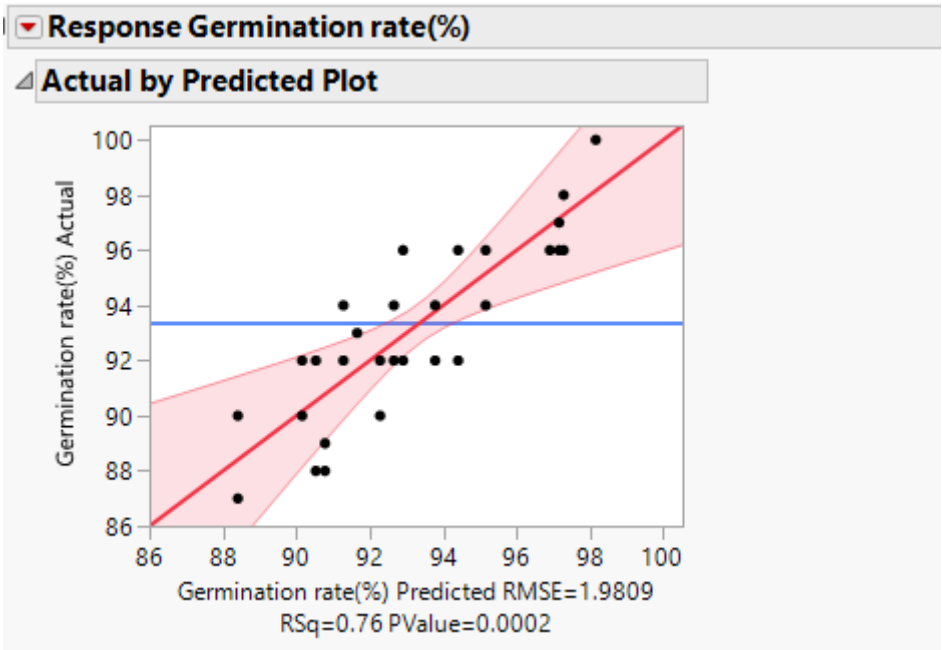


Figure 10: Actual by Predicted Plot

The parameter estimate as shown in figure 11 , also known as a coefficient, represents the effect of a one-unit change in the predictor variable while keeping all other predictors constant. These estimates are determined using least-squares estimation to calculate the unknown parameters of the model.

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Intercept	93.34375	0.350183	266.56	<.0001*	92.615504	94.071996
Lentil Type[Green Lentils]	0.71875	0.350183	2.05	0.0528	-0.009496	1.4469961
Watering period[8 Hours]	-0.34375	0.350183	-0.98	0.3375	-1.071996	0.3844961
Location[Arizona]	0.78125	0.350183	2.23	0.0367*	0.0530039	1.5094961
BaseType[Cotton cloth]	-0.09375	0.350183	-0.27	0.7915	-0.821996	0.6344961
Lentil Type[Green Lentils]*Watering period[8 Hours]	0.40625	0.350183	1.16	0.2590	-0.321996	1.1344961
Lentil Type[Green Lentils]*Location[Arizona]	-1.59375	0.350183	-4.55	0.0002*	-2.321996	-0.865504
Watering period[8 Hours]*Location[Arizona]	-0.53125	0.350183	-1.52	0.1442	-1.259496	0.1969961
Lentil Type[Green Lentils]*BaseType[Cotton cloth]	1.65625	0.350183	4.73	0.0001*	0.9280039	2.3844961
Watering period[8 Hours]*BaseType[Cotton cloth]	-0.65625	0.350183	-1.87	0.0749	-1.384496	0.0719961
Location[Arizona]*BaseType[Cotton cloth]	-0.78125	0.350183	-2.23	0.0367*	-1.509496	-0.053004

Figure 11: Parametric Estimates

RESULTS

Figure 12 and figure 13 shows the Least Square Means. By reducing the total of the offsets or residuals of points from the plotted curve, the least squares method is a statistical technique for determining the best fit for a set of data points.

Lentil Type

Least Squares Means Table

Level	Least Sq Mean	Std Error	Lower 95%	Upper 95%	Mean
Green Lentils	94.062500	0.49523398	93.032605	95.092395	94.0625
White Peas	92.625000	0.49523398	91.595105	93.654895	92.6250

Watering period

Least Squares Means Table

Level	Least Sq Mean	Std Error	Lower 95%	Upper 95%	Mean
8 Hours	93.000000	0.49523398	91.970105	94.029895	93.0000
12 Hours	93.687500	0.49523398	92.657605	94.717395	93.6875

Location

Least Squares Means Table

Level	Least Sq Mean	Std Error	Lower 95%	Upper 95%	Mean
Arizona	94.125000	0.49523398	93.095105	95.154895	94.1250
California	92.562500	0.49523398	91.532605	93.592395	92.5625

BaseType

Least Squares Means Table

Level	Least Sq Mean	Std Error	Lower 95%	Upper 95%	Mean
Cotton cloth	93.250000	0.49523398	92.220105	94.279895	93.2500
Tissue	93.437500	0.49523398	92.407605	94.467395	93.4375

Figure 12: Least Square Means - Factors

Lentil Type*Watering period

Least Squares Means Table

Level	Least Sq Mean	Std Error	Lower 95%	Upper 95%
Green Lentils,8 Hours	94.125000	0.70036661	92.668508	95.581492
Green Lentils,12 Hours	94.000000	0.70036661	92.543508	95.456492
White Peas,8 Hours	91.875000	0.70036661	90.418508	93.331492
White Peas,12 Hours	93.375000	0.70036661	91.918508	94.831492

Lentil Type*Location

Least Squares Means Table

Level	Least Sq Mean	Std Error	Lower 95%	Upper 95%
Green Lentils,Arizona	93.250000	0.70036661	91.793508	94.706492
Green Lentils,California	94.875000	0.70036661	93.418508	96.331492
White Peas,Arizona	95.000000	0.70036661	93.543508	96.456492
White Peas,California	90.250000	0.70036661	88.793508	91.706492

Watering period*Location

Least Squares Means Table

Level	Least Sq Mean	Std Error	Lower 95%	Upper 95%
8 Hours,Arizona	93.250000	0.70036661	91.793508	94.706492
8 Hours,California	92.750000	0.70036661	91.293508	94.206492
12 Hours,Arizona	95.000000	0.70036661	93.543508	96.456492
12 Hours,California	92.375000	0.70036661	90.918508	93.831492

Lentil Type*BaseType

Least Squares Means Table

Level	Least Sq Mean	Std Error	Lower 95%	Upper 95%
Green Lentils,Cotton cloth	95.625000	0.70036661	94.168508	97.081492
Green Lentils,Tissue	92.500000	0.70036661	91.043508	93.956492
White Peas,Cotton cloth	90.875000	0.70036661	89.418508	92.331492
White Peas,Tissue	94.375000	0.70036661	92.918508	95.831492

Watering period*BaseType

Least Squares Means Table

Level	Least Sq Mean	Std Error	Lower 95%	Upper 95%
8 Hours,Cotton cloth	92.250000	0.70036661	90.793508	93.706492
8 Hours,Tissue	93.750000	0.70036661	92.293508	95.206492
12 Hours,Cotton cloth	94.250000	0.70036661	92.793508	95.706492
12 Hours,Tissue	93.125000	0.70036661	91.668508	94.581492

Location*BaseType

Least Squares Means Table

Level	Least Sq Mean	Std Error	Lower 95%	Upper 95%
Arizona,Cotton cloth	93.250000	0.70036661	91.793508	94.706492
Arizona,Tissue	95.000000	0.70036661	93.543508	96.456492
California,Cotton cloth	93.250000	0.70036661	91.793508	94.706492
California,Tissue	91.875000	0.70036661	90.418508	93.331492

Figure 13: Least Square Mean – Factors Cross

Figure 14 shows the residual germination rate (%) by predicted germination rate (%) plot and the studentized Residual. The residual by predicted plot does not effectively show any particular pattern and spread of data and as result of that the data points are more randomized completely satisfying the randomization principles. However, the studentized residuals gives more idea on the particular pattern and where it identifies the influential points in the data in this case the data point are within the upper control limit and the lower control +4 and -4 which indicate a good model fit .

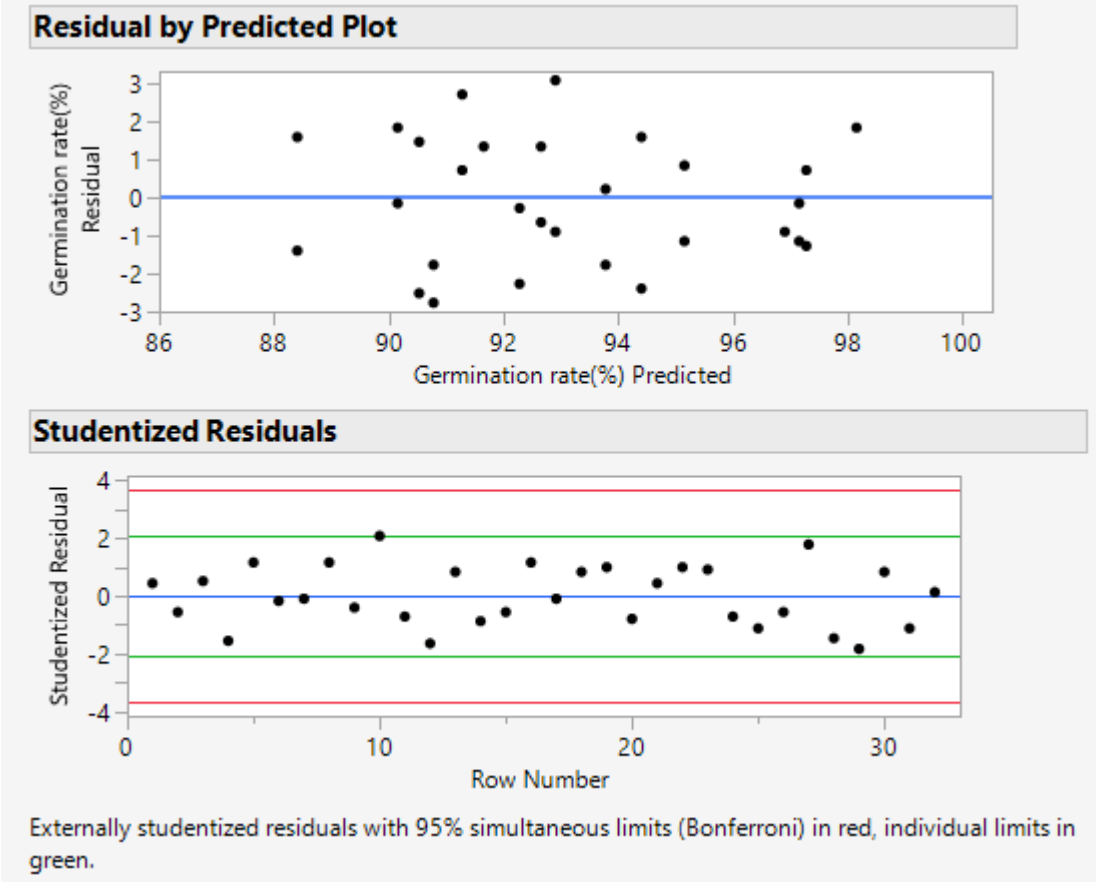


Figure 14: Residual Plot against Predicted Plot

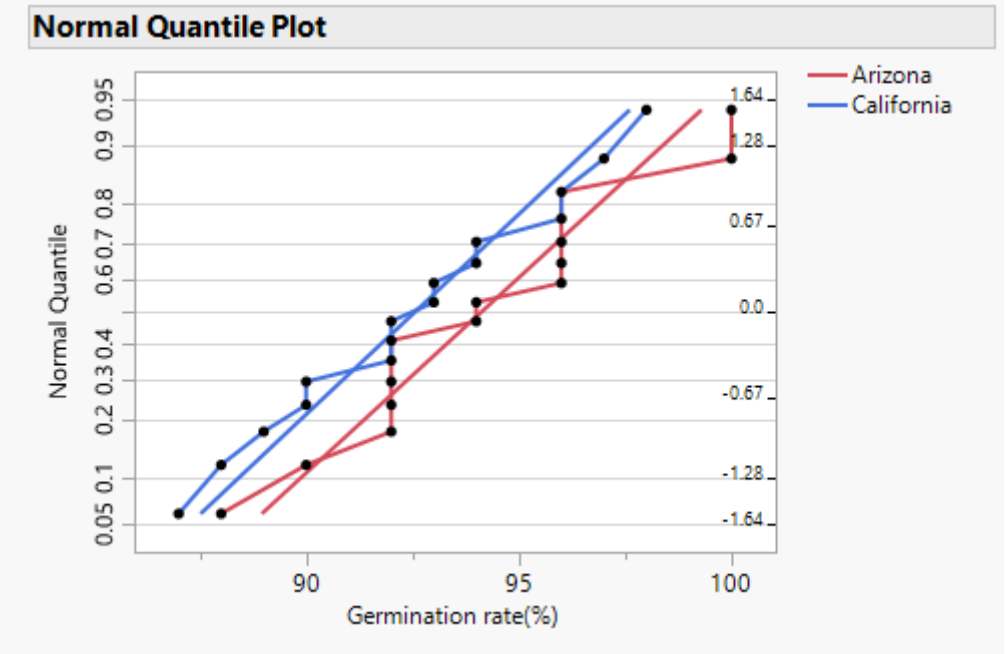


Figure 15: Normal Quantile Plot

CONCLUSION:

In conclusion, this research explored the ideal circumstances for Sprouting/growing green lentils & White Peas in a home-growing system utilizing a 2^4 factorial design with location, lentil type, base type, and watering period as variables. The important results include:

1. There were significant interactions between some factors. For example, the relationship between lentil type and base type shows that the lentil variety selected may alter the efficiency of the base material for the growth of selected lentil type.
2. The location has an influence on germination rate, with Arizona having a higher rate than California. This might be due to variations in temperature or direct sunlight between the two places.
3. Watering every 12 hours resulted in a higher germination rate compared to watering every 8 hours. which suggests the effective watering period relevantly affects the germination rate.
4. The highest germination rate can be observed at 100% for Pattern 2212 as shown in figure 4. The lowest germination rate can be observed at 87 % for Pattern 2121 as shown in figure 4. If we take the cumulative average of all the experiments, Green lentils germinated at a higher rate than white peas keping all the scenarios in mind. specifically For white peas, the germination rate was higher if we used Paper towel/Tissue as a base type.

5. if we assume the result regardless of the lentil type, Cotton cloth resulted in a higher germination rate than paper towels for the overall experiment**.** which indicates that cotton cloth might be more suitable base for lentil growth based on the situation. for the best results, figure 4 can be helpful to understand the individual results based on the variations of the 4 selected factors and how it influences the rate of germination.

The model that we have developed from the experimental data explains a significant portion of the variation in germination rate using given Analysis, Graph and a model.