Warm soaking effect on moisture-uptake of paddy rice with models' comparison

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Abstract: One of the most important parameters in processing paddy rice (PR) is the amount of water present in the PR. In this work, effect of variable warm soaking parameters (SPs) and models comparison on moisture uptake (MU) of three samples of PR was examined. The sampled PR examined were Desi Red, FARO 44, and FARO 61 obtained from rice farmers in Akure, Ondo state, Nigeria. The initial and final weights of PR were determined before and after soaking in water using digital weighing balance of model SF-400. The amount of MU was determined using Agricultural Engineering Standard. Four different soaking temperatures (55°C, 60°C, 65°C and 70°C) were used. Data analysis was done using Stat-Ease 360 model and Excel 2013 model. Central Composite Design was employed as experimental design method. The independent variables were soaking temperature and soaking time while dependent variable was the amount of MU. The suggested working models were Mean, linear, 2FI, Quadratic, and Cubic models. Model selection depends on sequential p-value, coefficient of determination (R^2), Predicted R^2 and the Adjusted R^2. Models selected to explain the effect of SPs were significant on MU of Desi Red ($P < 0.05$; $R^2 = 90.02\%$) and FARO 44 ($P < 0.05$; $R^2 = 48.79\%$) but slightly significant on FARO 61 PR ($P = 0.0520$; $R^2 = 78.21\%$). Quadratic model was the best model to explain the interaction between SPs and MU of Desi Red and FARO 61. While linear model was the best to explain the interaction between SPs and MU of FARO 44. Research findings are adequate to navigate design space and can be used for design characterization of paddy rice MU.

Keywords: paddy rice, soaking parameters, moisture uptake, models

Citation: Babatunde, Y., and B. A. Isaac. 2026. Warm soaking effect on moisture-uptake of paddy rice with model's comparison. Agricultural Engineering International: CIGR Journal, 28(1):112-122.

1 Introduction

One of the frequently consumed cereals in our world today is rice, and rice is high in energy called calorie (Sharafi et al., 2019). This calorie is good for supply of energy to human daily activities and proper functioning of human body. To achieve this, paddy rice must be properly processed to the level of pleasant consumption. Paddy rice processing starts with soaking at a particular temperature and time for the required moisture uptake. Moisture is so important in rice processing and must be managed in order to subdue the activities of microbes (Oko, 2016). However, knowing that the effect of rice moisture content is crucial for both industrial processing and quality control of the final product after processing (Zhou, 2018), it is essential to study the models that can explain the effect of soaking temperature and time on moisture uptake. Rice processing consists of some unit operations namely; cleaning, parboiling, drying, tempering, hulling, whitening, sorting, and

Received date: 2025-03-12 **Accepted date:** 2025-08-03

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de-stoning (Zabidin et al., 2018). Most researchers do not go deeper into studying models that can explain their experimental data. Models help in prediction and optimization processes of machine parameters and rice quality grading. It was observed that different soaking durations may lead to varying levels of moisture uptake, which could further influence processing outcomes, breeding and amylose determination (Ramírez, 2019). Danbaba et al. (2014), observed the effect of soaking temperature, steaming time and drying time on the head rice yield of parboiled rice. But they did not report the effect of soaking temperature and time on moisture uptake of trio paddy rice. They also did not report model comparison and specification on moisture uptake of each paddy rice variety. The behavioral patterns of variable paddy rice model comparison, model effectiveness, paddy rice moisture uptake and the use of Stat-Ease 360 for analysis were examined in this study.

2 Materials and methods

2.1 Paddy rice varieties

The three varieties (Desi Red, FARO 44, and FARO 61) of paddy rice used for this research were purchased from rice farmer in Akure, Ondo state, Nigeria (7° 8' 13" N latitude and 5° 15' 29" E longitude).

2.2 Sample preparation

The soaking experiment started with weighing paddy rice using digital weighing balance into the experimental cans with 100 g of paddy rice each. Then, clean water was boiled to the desired soaking temperature of 55°C, 60°C, 65°C, and 70°C, using 1-5-inches LCD digital thermometer to determine water temperature values. Each paddy rice was soaked at four different temperatures (55°C, 60°C, 65°C, and 70°C) with clean water for 2, 3, and 4 hours each as presented in Plate 1. After soaking at different hours, all the samples were weighed again to get the final weight. The amount of moisture uptake picked by each paddy rice was calculated using Equation 1 as given by Philippine Agricultural Engineering Standard (PAES 215:2004).

$$Mu = \frac{W_2 - W_1}{W_2} \times 100\% \qquad (1)$$

Where;

Mu = Moisture uptake, %;

W_2 = Final weight of paddy rice after absorbing water, g;

W_1 = Initial weight of paddy rice before soaking in water, g.

Plate 1 Soaking of paddy rice in bows

2.3 Experimental design

The Central Composite Design (CCD) was used to evaluate the effect of soaking temperature and time (factors) on moisture uptake (response) and their interactions on response variables (Ooi et al., 2018).

3 Results and discussion

3.1 Warm soaking experiment for the variable

paddy rice

The average moisture uptake obtained for Desi Red paddy rice during the warm soaking experiment was 24.30%, 23.45%, 23.85%, and 24.81% at soaking temperatures of 55°C, 60°C, 65°C, and 70°C respectively as presented in Table 1. While the average moisture uptake observed from soaking FARO 44 and FARO 61 were 18.52%, 19.68%, 21.03%, 19.54% and 17.34%, 16.65%, 17.13%, 18.01% respectively as indicated in Table 1. This shows that Desi Red paddy rice picks more moisture during warm soaking experiment than FARO 44 and FARO 61 at different soaking temperatures. However, paddy rice soaked at temperature of 55°C, 65°C, and 70°C has the highest moisture uptake value of 24.30%, 21.03%, and 18.01% for Desi Red, FARO 44 and FARO 61 respectively. It is, therefore, advisable to soak Desi red, FARO 44, and FARO 61 paddy rice at soaking temperature of 55°C, 65°C, and 70°C, respectively, for better moisture uptake. This reveals that optimum moisture uptake of these three-paddy rice is between 55°C – 70°C. It could be viewed that various paddy rice responded to variable optimum soaking temperature. This observation was in line with the report of Odenigbo et al. (2013). Although, they opined that the optimum temperature for soaking diverse varieties of rice was in the range of 60°C - 80ºC. This is also a sign that different paddy rice varieties have different biological responses to heat and different cellulose compositions.

3.2 Effect of soaking temperature and time on Desi Red paddy rice moisture uptake

The average moisture uptake obtained varies from 23.45% to 24.30% for Desi Red paddy rice as shown in Table 1. In order to examine the effects of soaking temperature and time on moisture uptake of Desi Red paddy rice, Linear, 2FI, Quadratic and Cubic models (Table 2) were initially presented by Stat-Ease 360 to explain the effect. However, 2FI model was suggested later as indicated in Table 2. Because 2FI model has the lowest sequential p-value of 0.0097. But its coefficient of determination (R^2) was lower than quadratic model. Quadratic model has a better interactive power among the variables (soaking temperature, time, moisture uptake) as shown in Table 2. More so, quadratic model has the highest adjusted coefficient of determination (Adjusted R^2) and coefficient of determination (R^2) not considering the Aliased (Cubic model) as revealed in Table 2. This shows that the best relationship between soaking temperature and time (independent) and moisture uptake (dependent) can only be explained at high precision by quadratic model. Therefore, the effect of soaking temperature and time on moisture uptake was statistically significant at $p < 0.05$ as indicated in Table 3. This was in line with the observation of Kashaninejad et al. (2007), but they did not consider Desi Red paddy rice, and their soaking temperatures ranges from 25-70 ºC. The F-value of 10.83 implies the model is significant. P-values less than 0.0500 indicates model terms are significant. In this case, *B* (time) and *AB* (soaking temperature and time) are significant model terms. While values (p-value) greater than 0.05 indicate that the model terms are not significant. This reveals that the interaction between *A* and *B* favours moisture uptake significantly ($p < 0.05$) but the interaction of *A* (soaking temperature) only, do not have a significant effect on moisture uptake of Desi Red. This shows that soaking time of Desi Red paddy rice seems to have more significant effect on moisture uptake. This is an indication that the cellulose of Desi Red is not as hard as other paddy rice that requires high temperature to soften the cellulose in order to allow water intake. The coefficient of determination (R^2) of the relationship was 90.02% while Adjusted R^2, Predicted R^2 and Adequate Precision were 81.71%, 36.83% and 11.0089 respectively as presented in Table 2. The model equation in Equation 2 reveals the relationship between the variables, and it can be used for industrial design parameters forecasting of heavy-duty machine beyond the scope of this work.

The normal plot of residual and normal box-cox plot for power transform was presented in Figure 1. The blue vertical line shows adequacy of the experimental data obtained which does not require transformation and that is why the lambda value is equal to 1. The contour surface (Figure 2) revealed that moisture uptake of` Desi Red is at best with higher soaking time and higher soaking temperature and that interaction only occurred where there was light-red/yellow colour. Figure 3 shows that moisture uptake increases with the increase in soaking time and soaking temperature, but the effect of soaking time is more pronounced. Slightly similar observation was made by Wahengbam et al. (2019) who opined that the rate of water uptake increased with the increase in temperature. They made this observation during moisture absorption by grains but they did not consider Desi Red paddy rice moisture uptake. They also used temperature that ranges from 40°C – 65°C to predict water absorption (Wahengbam et al., 2019).

Table 1 Warm soaking experiment on Desi Red paddy

Soaking Temperature, ° C	Soaking Time, hrs.	Desi Red MU, %	FARO 44 MU, %	FARO 61 MU, %
55	2	21.26	13.04	18.70
55	3	23.08	21.26	16.67
55	4	28.57	21.26	16.67
Average	3	24.30	18.52	17.34
60	2	21.88	15.97	17.36
60	3	23.66	23.08	15.25
60	4	24.81	20.00	17.36
Average	3	23.45	19.68	16.65
65	2	23.08	20.00	16.67
65	3	23.66	20.63	17.36
65	4	24.81	22.48	17.36
Average	3	23.85	21.03	17.13
70	2	24.24	18.03	16.67
70	3	24.81	19.35	18.03
70	4	25.37	21.26	19.35
Average	3	24.81	19.54	18.01

Table 2 Model summary and comparison on MU of Desi Red

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	Sequential p-value	Remark
Linear	1.36	0.5701	0.4746	0.0268	0.0224	
2FI	0.9252	0.8225	0.7560	0.3128	0.0097	Suggested
Quadratic	0.8011	*0.9002	0.8171	0.3683	0.1778	Used
Cubic	0.6284	0.9693	0.8874	0.1308	0.2613	Aliased

*Highest R^2 value without considering aliased model

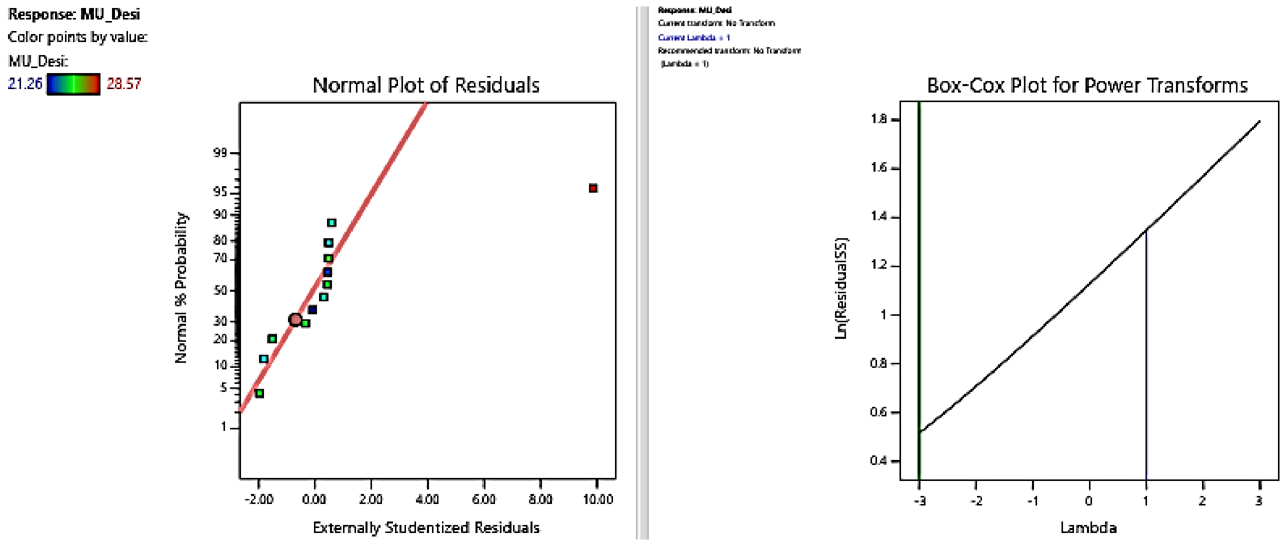

Figure 1 Residual plot analysis for Desi Red paddy rice

Table 3 ANOVA on Desi Red moisture uptake

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	34.74	5	6.95	10.83	0.0058	Significant
A-Temp	0.5472	1	0.5472	0.8527	0.3914	
B-Time	21.45	1	21.45	33.43	0.0012	Significant
AB	9.74	1	9.74	15.18	0.0080	Significant
A^2	2.46	1	2.46	3.83	0.0981	
B^2	0.5400	1	0.5400	0.8415	0.3944	
Residual	3.85	6	0.6417			
Cor Total	38.59	11				

$$MU\_Desi = +23.24 + 0.2865A + 1.64B - 1.48AB + 1.02A^2 + 0.4500B^2 \quad (R^2 = 90.02\ \%) \tag{2}$$

Where,

MU_Desi = Moisture up for Desi Red, %;

A = Temperature, ℃ ;

B = Soaking time, h.

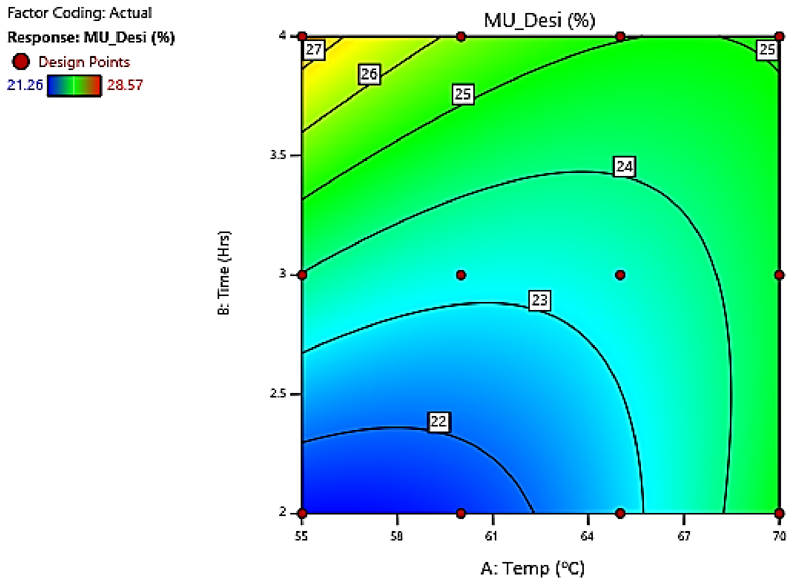

Figure 2 Contour plot for Desi Red moisture uptake

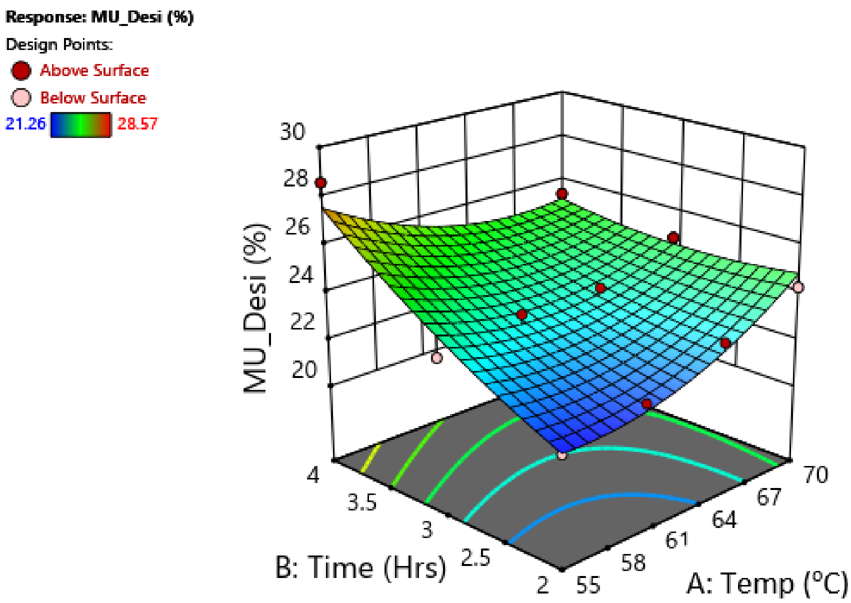

Figure 3 Response surface plot for Desi Red moisture uptake

3.3 Effect of soaking temperature and time on FARO 61 paddy rice moisture uptake and models comparison

In Table 1, the average moisture uptake observed for FARO 61 paddy rice varies from 16.65% to 18.01%. FARO 61 has the least range of moisture uptake among the three paddy rice examined (Table 1). For an orderly examination of the effects of soaking temperature and time on FARO 61 paddy rice moisture uptake, Linear, 2FI, Quadratic, and Cubic models are the likely models that could be used to explain the behavioural patterns of the effect of soaking temperature and time on moisture uptake as presented in Table 4. 2FI and quadratic models were suggested by Stat-Ease 360 software as presented in Table 5 and the Table shows that 2FI model has a lower sequential p-value (0.0255) than quadratic model (0.1005). Each of these two models may be used to explain the interaction between the variables but quadratic model was used eventually to explain the effect of soaking temperature and time on moisture uptake because it has a better coefficient of determination (R^2) whose value was 0.7821 than 2FI model whose value was 0.5313 as shown in Table 5. Moreover, a reasonable agreement exists between the Predicted and Adjusted R^2 values for the quadratic model (0.2935 vs. 0.6005), whereas a significant discrepancy was observed for the 2FI model (-0.1343 vs. 0.3555) (Table 5). This shows that quadratic model can best explain the interaction between soaking temperature and time (independent variables) and moisture uptake (dependent variable) based on the above-mentioned statistical philosophies. It is, therefore, convenient to use quadratic model to explain this effect than 2FI model. However, the model (quadratic) shows a borderline significance ($p = 0.0520$, Table 6), suggesting a slight effect of the model on the response, though it may not be statistically decisive in this wise. But the interactive effect of soaking temperature and time (*AB*, Table 6) was significant on moisture uptake (response) at $P < 0.05$ as indicated in Table 6. The F-value of 12.10 in Table 6 implies that, the interaction between 'A' and 'B' variables was significant with P-value less than 0.0500. In this instance, *AB* (soaking temperature & time) was a significant model term. While P-values greater than 0.05 indicate that the model terms are not significant. This reveals that the interaction between *A* and *B* favours moisture uptake significantly ($p < 0.05$) but the individual interaction of *A* (soaking temperature) and *B* (soaking time) separately, are not significant on moisture uptake of FARO 61. The *AB* source in Table 6 gave a better sum of squares and mean square values than *A* or *B* source. The coefficient of determination (R^2) of the relationship was 0.7821 which recommended that the model could describe 78.21% of the variability in the response. The model equation in Equation 3 reveals the relationship between the variables, which can be used to maneuver the design parameters to predict future design of machines.

Table 4 Sequential Model Sum of Squares on FARO 61 moisture uptake

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	3586.29	1	3586.29			
Linear vs Mean	1.15	2	0.5747	0.4558	0.6478	
2FI vs Linear	5.49	1	5.49	7.50	0.0255	Suggested
Quadratic vs 2FI	3.13	2	1.57	3.45	0.1005	Suggested
Cubic vs Quadratic	1.12	3	0.3717	0.6931	0.6147	Aliased
Residual	1.61	3	0.5362			
Total	3598.79	12	299.90			

The residual plot of the model is presented in Figure 4 with normal box-cox plot for power transform and normal residual plot. The lambda value of 1 (blue vertical line, Figure 4) is a testament to the adequacy of the experimental data obtained which does not require transformation. Figure 5 revealed the contour surface plot that moisture uptake of` FARO 61 is best at both lower and higher soaking time and soaking temperature and interaction occurred where there was red and deep yellow colour. Figure 6 shows that moisture uptake increases with the increase in soaking time and soaking temperature, and the effect is more pronounced at higher soaking time and temperature. Similar observation was made by Akhter et al. (2014) with dissimilar temperature and time range.

Table 5 Model summary and comparison on MU of FARO 61

Source model	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	Sequential p-value	Remark
Linear	1.12	0.0920	-0.1098	-0.8126	0.6478	
2FI	0.8557	0.5313	0.3555	-0.1343	0.0255	Suggested
Quadratic	0.6738	0.7821	0.6005	0.2935	0.1005	Suggested
Cubic	0.7323	0.8713	0.5280	-1.0593	0.6147	Aliased

Table 6 ANOVA on FARO 61 moisture uptake

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	9.77	5	1.95	4.31	0.0520	slightly significant
A-Temp	0.9250	1	0.9250	2.04	0.2033	
B-Time	0.2245	1	0.2245	0.4944	0.5083	
AB	5.49	1	5.49	12.10	0.0132	Significant
A^2	1.86	1	1.86	4.11	0.0891	
B^2	1.27	1	1.27	2.80	0.1455	
Residual	2.72	6	0.4540			

$$MU\_FARO61 = +16.33 + 0.3725A + 0.1675B + 1.11AB + 0.8869A^2 + 0.6900B^2 \quad (R^2 = 78.21\%) \tag{3}$$

MU_FARO61 = Moisture up for FARO-61, %;

A = Temperature, ℃;

B = Soaking time, h.

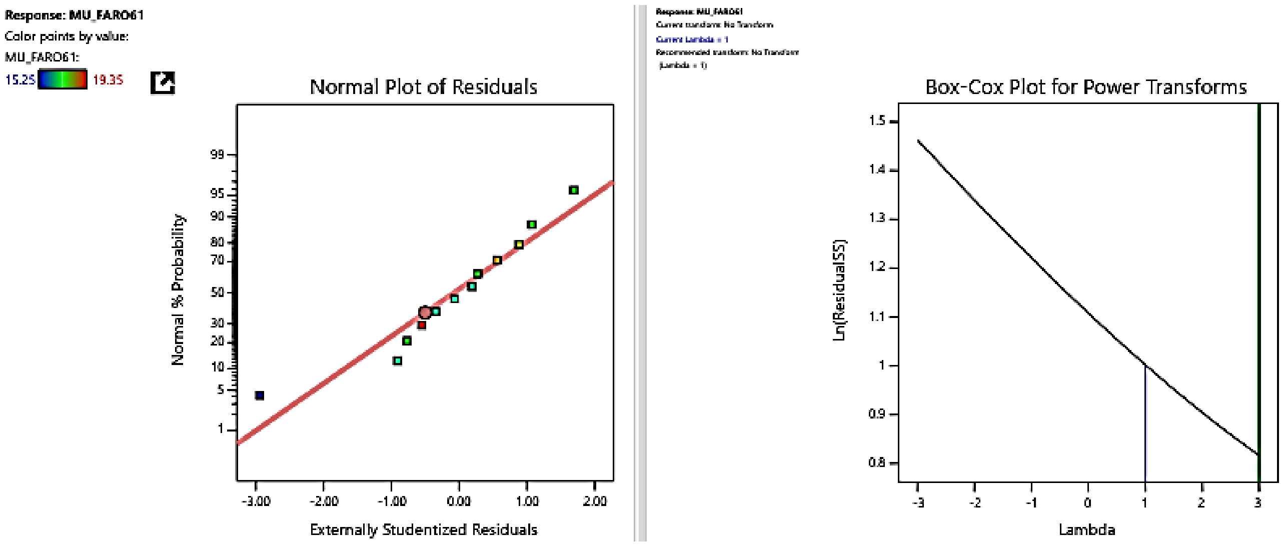

Figure 4 Residual plot analysis for FARO 61 paddy rice

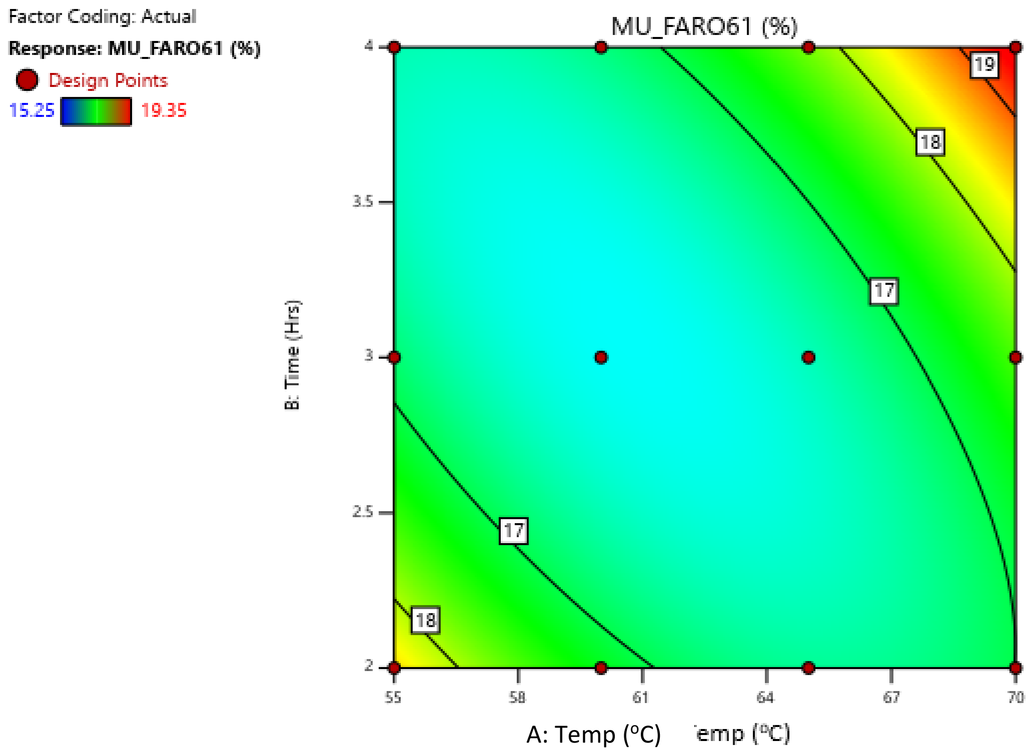

Figure 5 Contour plot for FARO 61 moisture uptake

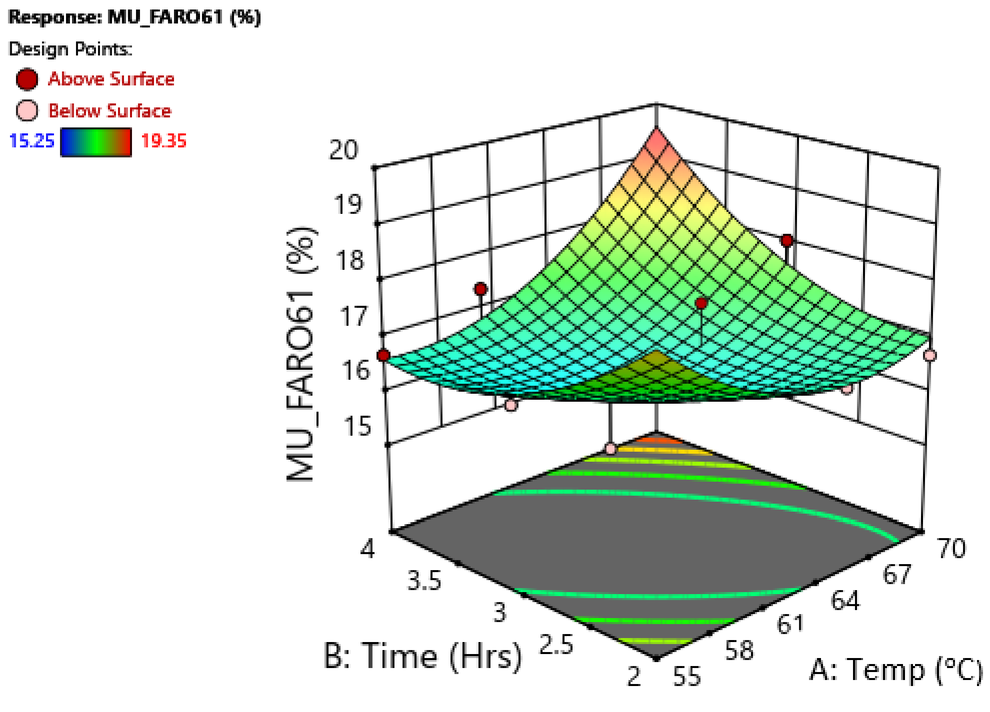

Figure 6 Response surface plot for FARO 61 moisture uptake

3.4 Effect of soaking temperature and time on FARO 44 paddy rice moisture uptake and models comparison

The average moisture uptake observed for FARO 44 paddy rice varies from 18.52% to 21.03% as shown in Table 1. For proper investigation of the effects of soaking temperature and time on FARO 44 paddy rice moisture uptake, five sequential models (Linear, 2FI, Quadratic and Cubic) were presented as likely models that can be used as presented in Table 7. Among these models, Linear model was suggested by Stat-Ease 360 software as showed in Table 8 and it was used during analysis because it has a better sequential p-value and fair reasonable agreement between the Predicted R^2-value (0.0739) and the Adjusted R^2-value (0.3741) than other models in

Table 8. Although quadratic model has a better interaction between the independent and dependent variables using coefficient of determination (R^2), but has a very poor and unreasonable agreement between the Predicted R^2 (0.0084) and the Adjusted R^2 (0.5488) values as generated from quadratic model (Table 8). It is therefore safe to use the suggested linear model by Stat-Ease 360 . The effect of soaking temperature and time on moisture uptake of FARO 44 was statistically significant at $p < 0.05$ as revealed in Table 9. The effect of soaking time (B, Table 9) only was significant on moisture uptake (response) at $P < 0.05$. The Model F-value of 4.29 implies the model is significant. P-values less than 0.0500 indicate model terms are significant. In this case, B is a significant model term. Values greater than 0.1000 indicate the model terms are not significant. The coefficient of determination (R^2) of the relationship was 0.4879 which acclaimed that the model could describe 48.79% of the variability in the response. The model equation in Equation 4 can be used to predict moisture uptake for FARO-44 paddy rice beyond this present study.

The lambda value of 1 presented in Figure 7 is an indication of a good experimental data. The residual plot of the model was presented in Figure 7 with normal box-cox plot for power transformation and normal residual plot. The plot shows that no transformation is needed in this analysis. Figure 8 revealed the contour surface plot that moisture uptake of FARO 44 has strong interaction with soaking parameters where red-yellow colour is depicted on the contour plot. This interaction occurs at higher soaking time. Figure 9 shows that moisture uptake increases with the increase in soaking time and soaking temperature but the effect is more pronounced at higher soaking time with red colour mesh on the plot in Figure 9.

Table 7 Sequential Model Sum of Squares on FARO 44 moisture uptake

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	4655.50	1	4655.50			
Linear vs Mean	43.27	2	21.63	4.29	0.0492	Suggested
2FI vs Linear	6.82	1	6.82	1.41	0.2684	
Quadratic vs 2FI	16.76	2	8.38	2.30	0.1809	
Cubic vs Quadratic	16.36	3	5.45	3.00	0.1958	Aliased
Residual	5.46	3	1.82			
Total	4744.18	12	395.35			

Table 8 Model summary and comparison on MU of FARO 44

Source	Std. Dev.	R²	Adjusted R²	Predicted R²	Sequential p-value	Remark
Linear	2.25	0.4879	0.3741	0.0739	0.0492	Suggested
2FI	2.20	0.5649	0.4017	-0.1183	0.2684	
Quadratic	1.91	0.7539	0.5488	0.0084	0.1809	
Cubic	1.35	0.9384	0.7741	0.1803	0.1958	Aliased

Table 9 ANOVA on FARO 44 moisture uptake

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	43.27	2	21.63	4.29	0.0492	significant
A-Temp	2.95	1	2.95	0.5843	0.4642	
B-Time	40.32	1	40.32	7.99	0.0198	
Residual	45.41	9	5.05			
Cor Total	88.68	11				

$$MU\_FARO44 = 19.69+0.665A+2.245B \quad (R^2 = 48.79\%) \tag{4}$$

MU_FARO44 = Moisture up for FARO 44, %; A = Temperature, ℃; B = Soaking time, h.

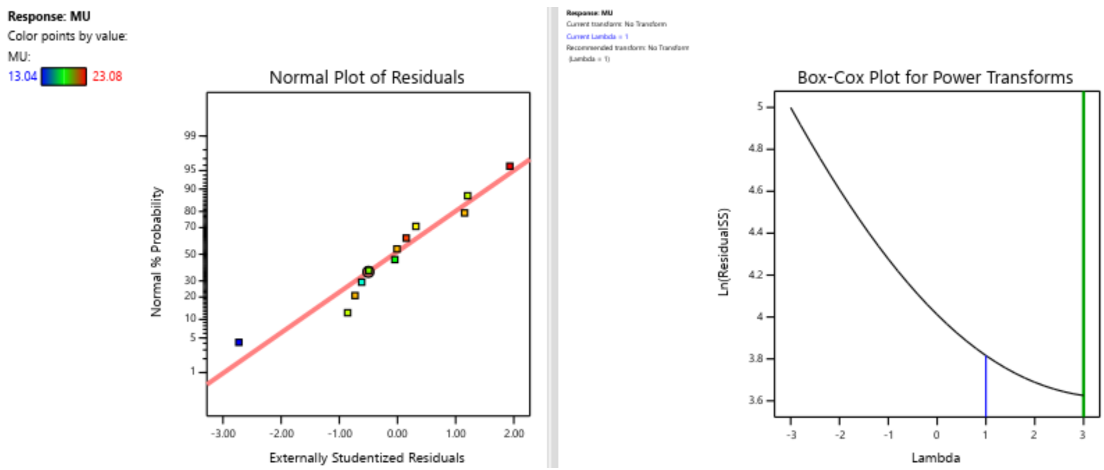

Figure 7 Residual plot analysis for FARO 44 paddy rice

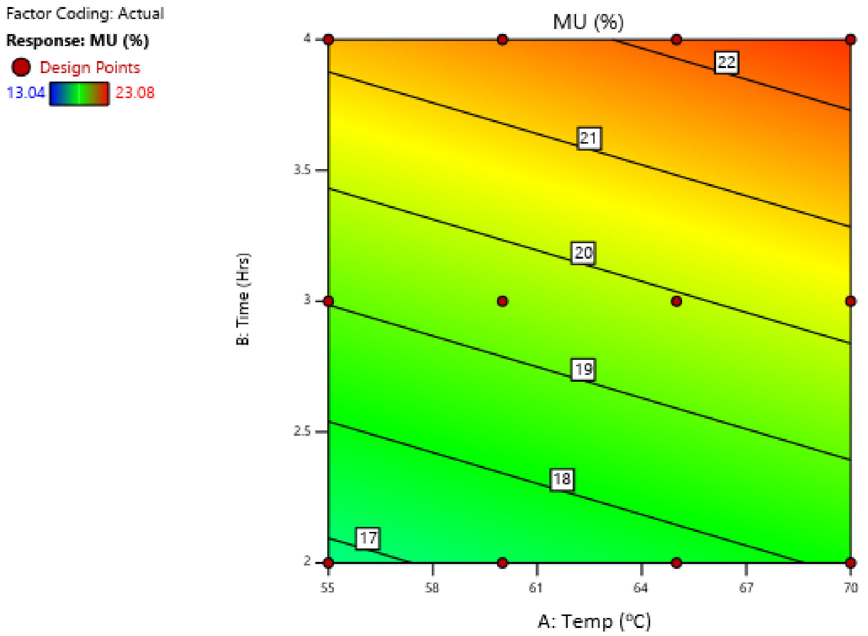

Figure 8 Contour plot for FARO 44 moisture uptake

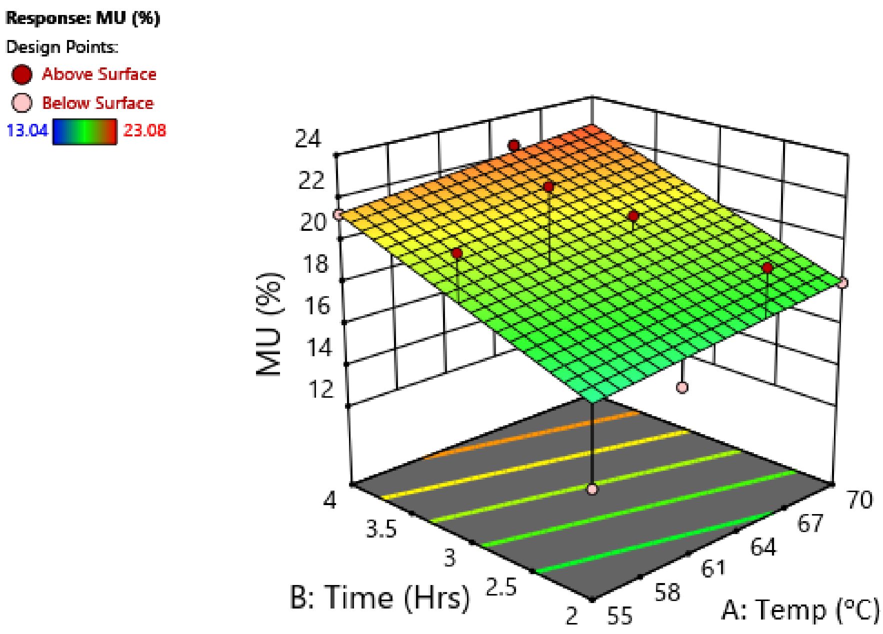

Figure 9 Response surface plot for FARO 44 moisture uptake

4 Conclusion

The research findings may be concluded as itemised**:**

(1) Desi Red paddy rice has the highest average moisture uptake value range (23.45% to 24.30%) among the three paddy rice varieties investigated.

(2) The effect of soaking temperature and time on moisture uptake was significant at $P < 0.05$ for Desi Red and FARO 44 but slightly significant for FARO 61.

(3) Out of all the models compared, quadratic model was seen to have the best coefficient of determinations (R^2).

(4) Model selection and comparison to explain the effect of soaking temperature and time on moisture uptake depends on sequential p-value, coefficient of determination (R^2), Predicted R^2, and the Adjusted R^2. The Predicted R^2 value must have reasonable agreement with the Adjusted R^2 value for consideration.

(5) The models with high interaction between the factor variable and response variable are better for Anova analysis.

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