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Process Optimization of Salt Recovery from *Nypa Fruticans* Fronds using Response Surface Methodology

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ABSTRACT

Salt, primarily sodium chloride (NaCl), has been a pivotal component of the human diet and a universal condiment since ancient times due to its ability to enhance flavour, act as a preservative and meet physiological needs. Despite the availability of traditional unrefined salts, the production processes of nypa salt, derived from *Nypa fruticans*, have not been systematically investigated and there are no standard methods for its production. This study addresses this gap by recovering salt from *Nypa fruticans* fronds using the calcination (ashing) method and optimizing the process conditions influencing salt recovery using Response Surface Methodology (RSM). The optimal conditions, determined to be 12 hours of drying time, a calcination temperature of 1200°C, a soaking time of 10 minutes and a soaking temperature of 40°C, resulted in a predicted pH of 10.76 and a yield of 1.441%. These conditions were verified through additional trials, confirming model's reliability and offering a sustainable method for salt production from *Nypa fruticans* fronds.

1. Introduction

Salt, primarily sodium chloride (NaCl), has been a pivotal component of the human diet and a universal condiment since ancient times due to its ability to enhance flavour, act as a preservative and meet physiological needs [1]. Salt can be sourced from various environments and broadly categorized into two types: sea salt, extracted from evaporated seawater and rock salt, mined from underground deposits formed over geological timescales [2,3]. In addition to these traditional sources, salt extraction from halophilic plants and oil palm demonstrates the resourcefulness of

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particular communities. Halophilic plants, adapted to saline environments, store salt in their tissues and the ashes of burnt plant material, like oil palm, can contain salt residues that are collected and utilized [4,5].

A notable example is the high ash content observed in *Nypa fruticans* fronds [6], making it a potentially valuable source of salt material. The production of nypa salt, locally known as "garam apong" in Sarawak, involves two conventional methods: the ashing method and the brine dehydration method. In the ashing method, the stems and trunks of nypa palms undergo a drying and incineration process, followed by brine dehydration in which the harvested fronds are crushed to release brine, which is then evaporated to yield concentrated salt [7-9].

Despite the availability of unrefined salts on the market, celebrated for their unique qualities and purported health benefits, their production process is frequently questioned. Specifically, the physical and chemical properties of nypa salt, derived from *Nypa fruticans*, have not been systematically investigated and there are no standard methods for its production [10-13]. This gap in knowledge and standardization underscores the need for comprehensive studies to understand the production processes of nypa salt.

The present study aims to address this gap by achieving the following objectives:

i. To recover salt from *Nypa fruticans* fronds using the ashing method
ii. To optimize the process conditions influencing salt recovery using Response Surface Methodology (RSM).

2. Methodology
2.1 Materials

Mature fronds of *Nypa fruticans* were systematically chosen and harvested from the geographical region of Pusa, Sarawak. The harvested fronds were then stored at a chilled temperature and cut into smaller pieces using a chainsaw and knife before further processing.

2.2 Recovery of Nypa Salt from Nypa fruticans Fronds

A weighed amount of nypa frond pieces were placed on an aluminium tray and dried in the oven at 60°C for a specified time. Subsequently, the dried nypa fronds were subjected to calcination within a furnace, involving exposure to elevated thermal conditions and, generating residual matter commonly ash. The resultant ash was subsequently dissolved within a medium of demineralized water for a specified period at assigned soaking temperature.

Following dissolution, the resultant solution was subjected to a filtration process. The filtrate obtained through this filtration process was subsequently poured onto a tray and dried in an oven overnight at 60°C. The crystallized salt was then carefully scrapped from the tray and kept in an air-tight container for further analysis.

2.3 Determination of pH and Yield

The pH and yield of nypa salt were selected as the responses in the optimization process. The pH of the salt solution (1% w/v) was determined using a pH meter, while the yield of salt was calculated using Eq. (1):

$$Yield\ (\%) = \frac{Weight\ of\ extracted\ salt}{Initial\ weight\ of\ fronds} \times 100 \quad (1)$$

2.4 Experimental Design and Statistical Analysis

The process conditions of salt recovery affecting yield and pH of the nypa salt extracted were optimized using Design Expert ® Version 12 RSM Software (Stat-Ease Inc. USA). Using optimum process conditions, the Box-Behnken Design (BBD) was deployed to recover salt from nypa fronds. The range of constraints was determined (Table 1) through preliminary experiments and computed into the software to generate a set of experimental runs.

Table 1
Range of constraints

Variables	Minimum	Midpoint	Maximum
A: Drying Time (hrs)	12	18	24
B: Calcination Temperature (°C)	600	900	1200
C: Soaking Time (min)	10	20	30
D: Soaking Temperature (°C)	40	50	60

As a result, 30 experimental runs were generated as depicted in Table 2. The data of both responses were subjected to a series of analyses such as analysis of variance (ANOVA), Lack-of-Fit (LOF), R-square (R^2) and predicted error sum of square (PRESS) determinations as well as residuals plotting for fitting the second order polynomial model as shown in Eq. (2).

Table 2
Box-Behnken design used for RSM and experimental data of the investigated responses

Std.	Run.	A: Drying Time (hrs)	B: Calcination Temperature (°C)	C: Soaking Time (min)	D: Soaking Temperature (°C)	pH	Yield (%)
30	1	18	900	20	50	10.03	3.12
29	2	18	900	20	50	10.12	2.95
16	3	18	1200	30	50	10.75	3.39
12	4	24	900	20	60	10.32	3.35
8	5	18	900	30	60	10.08	3.43
17	6	12	900	10	50	9.93	2.02
27	7	18	900	20	50	10.05	2.98
21	8	18	600	20	40	9.44	2.25
3	9	12	1200	20	50	10.57	2.93
9	10	12	900	20	40	9.94	2.79
20	11	24	900	30	50	10.23	3.35
6	12	18	900	30	40	10.02	3.22
11	13	12	900	20	60	9.85	3.33
22	14	18	1200	20	40	10.84	2.22
28	15	18	900	20	50	10.05	2.95
19	16	12	900	30	50	9.69	3.39
14	17	18	1200	10	50	10.72	2.52
2	18	24	600	20	50	9.55	3.04
5	19	18	900	10	40	10.12	1.55
24	20	18	1200	20	60	10.82	3.33
18	21	24	900	10	50	10.12	2.83
15	22	18	600	30	50	9.37	3.29
26	23	18	900	20	50	10.02	3.12
25	24	18	900	20	50	10.11	2.65
7	25	18	900	10	60	9.94	3.13
1	26	12	600	20	50	9.11	3.23
13	27	18	600	10	50	9.45	2.52
10	28	24	900	20	40	10.27	2.84

4	29	24	1200	20	50	10.89	3.3
23	30	18	600	20	60	9.67	3.25

$$Y = \beta_o + \beta_a\mathrm{A} + \beta_b\mathrm{B} + \beta_c\mathrm{C} + \beta_d\mathrm{D} + \beta_{ab}\mathrm{AB} + \beta_{bc}\mathrm{BC} + \beta_{ac}\mathrm{AC} + \beta_{ad}\mathrm{AD} + \beta_{bd}\mathrm{BD} + \beta_{cd}\mathrm{CD} + \beta_{aa}\mathrm{A}^2 + \beta_{bb}\mathrm{B}^2 + \beta_{cc}\mathrm{C}^2 + \beta_{dd}\mathrm{D}^2 \quad (2)$$

Where, Y is the responses; A, B, C and D are the independent variables for drying time, calcination temperature, soaking time and soaking temperature, respectively. β_o is the intercept or linear coefficient at the centre point of the model. β_a, β_b, β_c and β_d are the linear coefficients for the main effects of A, B, C and D, respectively. β_{ab}, β_{bc}, β_{ac}, β_{ad}, β_{bd} and β_{cd} are the interactive coefficients for the interaction terms AB, BC, AC, AD, BD and CD, respectively. β_{aa}, β_{bb}, β_{cc} and β_{dd} are the coefficients for the quadratic terms A^2, B^2, C^2 and D^2, respectively.

2.5 Model Optimization

The selection of pH and yield as responses in the optimization process for nypa salt is justified based on their direct relevance to culinary applications and the improvement of meat products. The pH of nypa salt is critical for influencing the taste and quality of food, especially in enhancing meat's water holding capacity (WHC). A consistent pH level ensures stability and quality. Additionally, optimizing the yield of nypa salt is essential for efficient and cost-effective production, allowing for maximum utilization of raw materials and minimal waste. This is necessary as salt is commonly used to improve meat products' WHC and cooking yield [14-16]. Optimizing these parameters will enhance the properties of nypa salt and contribute to the overall quality and market acceptability of the meat products in which it is used.

The optimization of process conditions for nypa salt recovery is essential, as both pH and yield responses are influenced by factors such as drying time, calcination temperature and soaking parameters, which need to be carefully controlled to maximize the yield and achieve the desired pH levels. For the optimization step, the following criteria tabulated in Table 3 are considered:

Table 3
Optimization setting

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Drying Time	minimize	12	24	1	1	5
B:Calcination Temperature	in range	600	1200	1	1	3
C:Soaking Time	minimize	10	30	1	1	5
D:Soaking Temperature	in range	40	60	1	1	3
pH	none	9.11	10.89	1	1	3
Yield	Maximize	3	4	1	1	5

These criteria are essential for optimizing the recovery of nypa salt, aiming to minimize the drying and soaking times while maintaining the calcination temperature and soaking temperature within specified ranges. The recovery process would be more time-effective, ensuring efficient combustion, complete ashing, accelerated mineral extraction and transformation and ultimately, higher pH and yield of the nypa salt without compromising on the quality of the final product. The optimization targets are to obtain the pH between 9.11 and 10.98 and maximize a yield between 3.00 to 4.00.

2.6 Model Verification

The model verification was deployed by running the confirmation runs at the end of BBD. The variation between the predicted and actual responses must be within the 95% prediction interval (PI) [17].

3. Result and Discussion

3.1 Model Fitting, ANOVA and Model Reduction

The implementation of the model fitting aims to identify suitable models, including linear, two-factor interaction (2FI), quadratic and cubic, based on data-dependent variables and optimization goals. As shown in Table 4, the fit summary from the Design Expert® software suggests that the quadratic model and 2FI model is the most suitable for interpreting the effects of factors on pH and yield responses, respectively. However, unless in scarce rare cases, a response model well-fitted with the 2FI model would usually yield a non-optimizable data space. The commonly used 2FI model in RSM is limited by its linear nature, which may fail to capture crucial non-linear interactions in complex systems, as noted in the literature [18,19].

Therefore, for yield response, despite the initial suggestion of the 2FI model by the software, the quadratic model is chosen due to its superior fit and predictive performance, as well as its ability to capture non-linear relationships better, aligning with the recommendations in the literature. The quadratic model has a p-value of 0.1788, slightly lower than the 2FI model's but still very close, suggesting significant description of the variations in the response.

Table 4
Fit summary of model

Response	Source	p-value	R^2	Adjusted R^2	Predicted R^2	PRESS
pH	Linear	< 0.0001	0.9658	0.9603	0.9472	0.3154
	2FI	0.1696	0.9778	0.9662	0.9300	0.4181
	Quadratic*	0.0044	0.9915	0.9835	0.9571	0.2564
	Cubic#	0.5176	0.9960	0.9833	0.6279	2.22
Yield	Linear	< 0.0001	0.7545	0.7153	0.6284	2.29
	2FI*	0.0316	0.8736	0.8071	0.6367	2.24
	Quadratic	0.1788	0.9148	0.8353	0.6130	2.39
	Cubic#	0.6779	0.9531	0.8057	-2.3330	20.54

Notes: Predicted Error Sum of Square (PRESS), *Suggested model, #Aliased model

The ANOVA results for the quadratic model are illustrated in Table 5. If a p-value is less than 0.05, the model term of the factor is significant to the response; however, if the p-value is greater than 0.10, the model term is not significant to the response [16]. Some terms are not shown in the table as they were non-significant and were dropped from the initial model after model reduction. Model reduction of non-significant and higher-order terms should improve the model and possibly lead to better data fitting [20]. For yield response, terms AB, BC, BD, A^2, B^2 and C^2 were removed.

Referring to the Table 5, for pH response, some model terms' p-values fall within the range of 0.05 to 0.10. Model terms in RSM with such values are considered marginally significant or borderline significant. This range suggests some evidence against the null hypothesis, implying potential significance, but not strong enough to meet the conventional 0.05 level [21].

In RSM applications, researchers often encounter such p-values when optimizing processes like ammoniacal nitrogen removal, biodiesel production, spray-drying guava powder and chromium(VI) removal [22-25] terms suggest a need for further investigation or model refinement to improve accuracy.

Table 5
ANOVA for the model of BBD using pH and yield as the response

Response	Source	SS	df	MS	F-Value	p-value
pH	Model	5.93	14	0.4233	124.35	<0.0001
	A	0.4370	1	0.4370	128.39	<0.0001
	B	5.33	1	5.33	1566.84	<0.0001
	C	0.0016	1	0.0016	0.4798	0.4991
	D	0.0002	1	0.0002	0.0612	0.8080
	AB	0.0036	1	0.0036	1.06	0.3201
	AC	0.0306	1	0.0306	9.00	0.0090
	AD	0.0049	1	0.0049	1.44	0.2488
	BC	0.0030	1	0.0030	0.8887	0.3608
	BD	0.0156	1	0.0156	4.59	0.0490
	CD	0.0144	1	0.0144	4.23	0.0575
	A^2	0.0129	1	0.0129	3.78	0.0708
	B^2	0.0141	1	0.0141	4.16	0.0595
	C^2	0.0169	1	0.0169	4.95	0.0418
	D^2	0.0261	1	0.0261	7.66	0.0144
	Residual	0.0511	15	0.0034		
	Lack of Fit	0.0423	10	0.0042	2.42	0.1703
	Pure Error	0.0087	5	0.0017		
	Cor Total	5.98	29			
Yield	Model	5.47	7	0.7808	24.63	<0.0001
	A	0.0867	1	0.0867	2.73	0.1124
	B	0.0010	1	0.0010	0.0318	0.8601
	C	2.52	1	2.52	79.52	<0.0001
	D	2.04	1	2.04	54.41	<0.0001
	AC	0.1806	1	0.1806	5.70	0.0260
	CD	0.4692	1	0.4692	14.80	0.0009
	A^2	0.1656	1	0.1656	5.22	0.0323
	Residual	0.6975	22	0.0317		
	Lack of Fit	0.5496	17	0.0323	1.09	0.5053
	Pure Error	0.1479	5	0.0296		
	Cor Total	6.16	29			

Notes: Sum of Squares (SS), Mean Square (MS)

The Lack of Fit (LoF) value and agreement between adjusted R-squared and predicted R-squared also play a role in identifying an appropriate model for data fitting [26]. A LoF F-value of 2.42 and 1.09, for both pH and yield responses, suggests that the Lack of Fit is not statistically significant compared to pure error. There is a 17.03% and 50.53% chance, that such an LoF F-value could occur due to noise. This result indicates a desirable non-significant lack of fit, suggesting a good fit for the model [17].

R-squared (R^2) values reflect the percentage of variation in the response caused by changes in the independent variables. The adjusted R^2 is the degree of variation the model depicts, whereas the predicted R^2 is the predicted degree of variation the model depicts [17]. As depicted in Table 6, the

R^2 values for both pH and yield response were 0.9915 and 0.8868, respectively, which were satisfactorily higher than the minimum standardized R^2 value (>0.8). The Predicted R^2 reasonable agrees with the Adjusted R^2, with a difference of less than 0.2. The Adequate Precision ratio is well above 4, indicating an adequate signal-to-noise ratio. Thus, this model is suitable for navigating the design space [17,27].

The model reduction has lowered the (predicted error sum of square) PRESS values to 1.40 for yield response compared to before model reduction. The PRESS value indicates how well the model fits the points in the design. A low PRESS value in the reduced BBD model indicates good model fitting [17].

Table 6
Fit statistics of the reduced model

Statistics	Response	
	pH	Yield
Standard Deviation	0.0583	0.1781
Mean	10.07	2.94
C.V%	0.5794	6.05
R^2	0.9915	0.8868
Adjusted R^2	0.9835	0.8508
Predicted R^2	0.9571	0.7722
Adequate Precision	41.6317	21.2173
PRESS	0.2564	1.40

Notes: Predicted Error Sum of Square (PRESS)

Overall, the model using both responses has met adequacy criteria, as evidenced by a p-value < 0.05, a LoF p-value >0.05 and a difference between the predicted and adjusted R^2 within 0.2 [14,28].

The quadratic models in both responses were expressed in the coded second-order mathematical equation, as shown in Eqs. (3) and (4). They established the relationship between the independent variables and the responses of pH and yield.

$$pH = 10.06 + 0.1908A + 0.6667B - 0.0117C + 0.0042D - 0.0300\,AB + 0.0875AC + 0.0350AD + 0.0275BC - 0.0625BD + 0.0600CD - 0.0433A^2 + 0.0454B^2 - 0.0496C^2 + 0.0617D^2 \quad (3)$$

$$Yield = 2.88 + 0.0850A + 0.0092B + 0.4583C + 0.4125D - 0.2125AC - 0.3425CD + 0.1517A^2 \quad (4)$$

3.2 Diagnostic Plots

To further validate the model fitting and adequacy using pH and yield as the responses, the diagnostic step was deployed by examining the diagnostics plots like normal probability *vs*. externally studentized residuals and residuals *vs*. run [17]. Figure 1(a) and Figure 1(b) illustrate the normal probability plots for pH and yield responses, respectively.

From both figures, no abnormalities were observed in their models, as all residuals were normally distributed along a straight line, indicating that no model transformation is needed. However, if an S-shaped curve (megaphone pattern) is observed in the normal probability plot and the response ratio of max to min exceeds 10, it indicates an abnormality in the model response, necessitating model transformation for improved adequacy [17]. Referring to these figures, no S-shape is observed and the ratio of max to min for both responses was less than 10, with values of 1.19539 and 2.2129 for pH and yield response, respectively (Table 7).

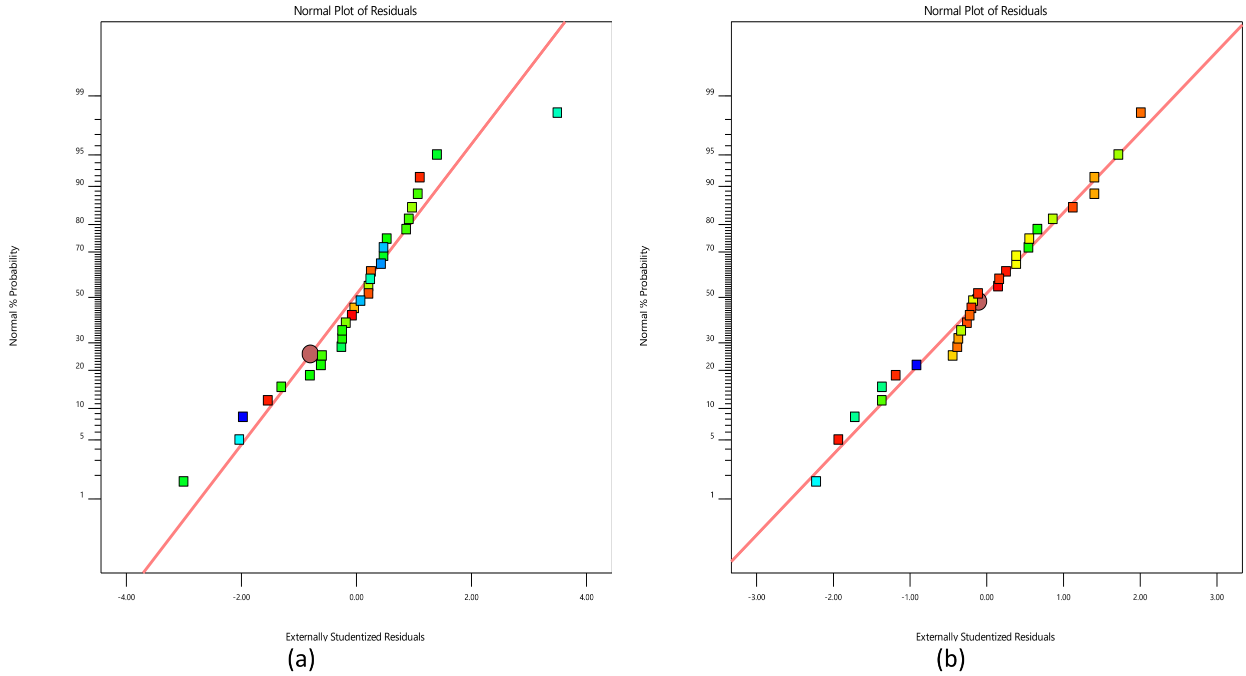
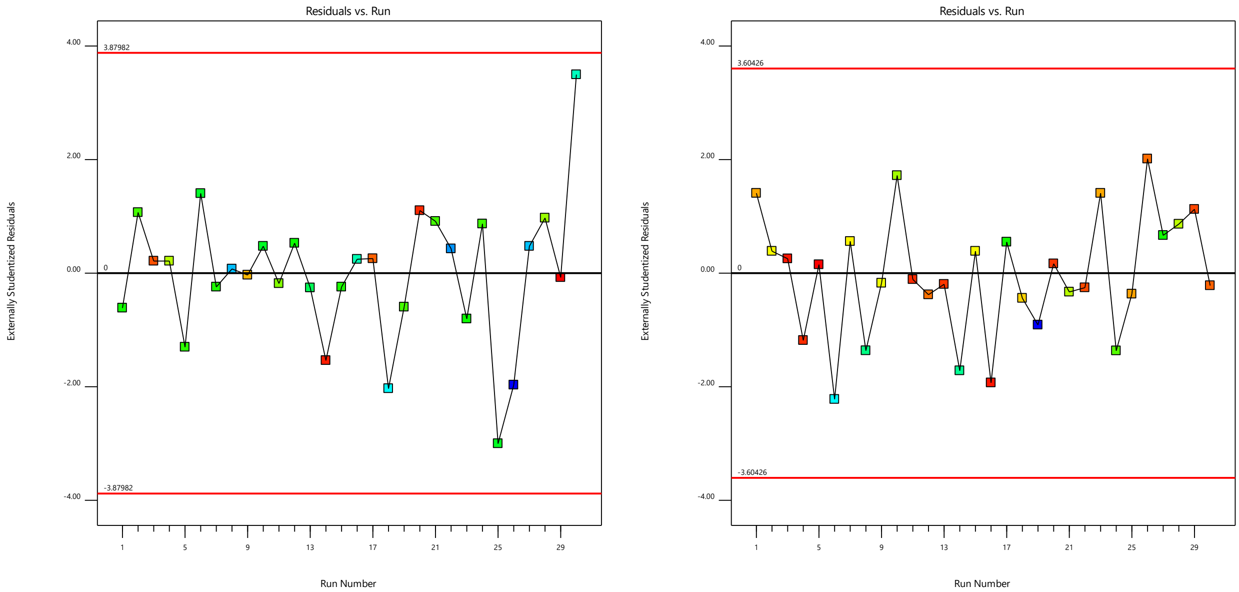


Fig. 1. Normal probability plot for the reduced BBD model (a) pH (b) Yield

Table 7
Ratio max to min of each response

Response	Range of response	Ratio max to min
pH	9.11 – 10.89	1.19539
Yield	1.55 – 3.43	2.2129

Figure 2(a) and 2(b) depict the plots of residuals versus run numbers for both responses. These were analysed to check for lurking variables affecting the validity of the model for both responses [29]. In both cases, the residuals were randomly scattered within the red-line boundaries of ±3.8 (pH) and ±3.6 (yield), as set by the Design Expert analytical software. Thus, no serious outlier was observed in the responses and no time-related influences affected them. Since randomization was fully utilized during the experiment, it protected trends that could compromise the analysis [17,28].



(a) (b)

Fig. 2. Residuals *vs*. run number plot for the BBD model (a) pH (b) Yield

3.3 Effects of Process Conditions on the pH of Nypa Salt

From Figure 3, the highest pH of the salt was observed for nypa fronds dried for 24 hours, calcined at 1200°C and subsequently soaked in demineralized water for 20 minutes at 50°C. Graphically, at similar soaking times and temperatures, an increase in calcination temperature along and a gradual rise in drying time showed an increasing trend in pH, as illustrated by the noticeable colour transition from blue to red.

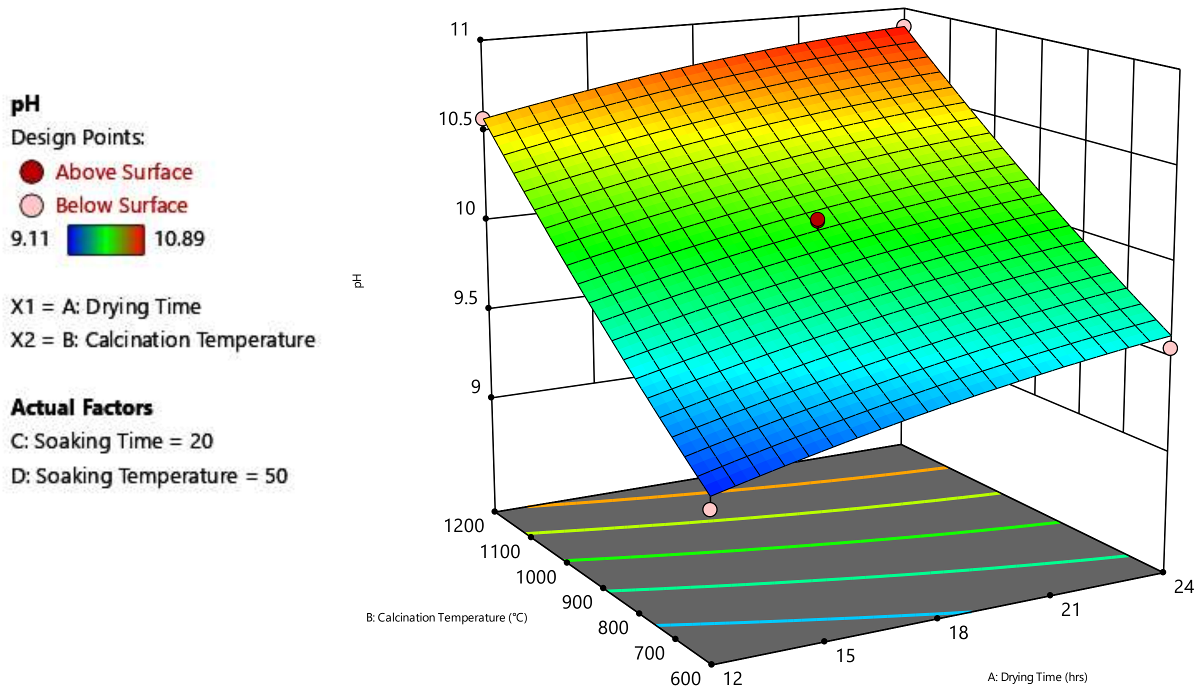


Fig. 3. 3D plots for the BBD model using pH as the response

Referring to Eq. (3), increasing the drying time (A) positively influences the pH, with a coefficient of 0.1908. This indicates that longer drying times result in higher pH values. The quadratic term $-0.0433A^2$ suggests that this effect diminishes at higher levels, potentially reducing pH after a certain point. Sufficient drying ensures that the sample combusts more efficiently. Complete moisture removal allows the sample to reach high temperatures more efficiently, guaranteeing thorough combustion and complete ashing [30]. If the sample is not entirely dried, moisture can interfere with combustion, potentially lowering the temperature and slowing down the ashing process. Moisture can also lead to incomplete combustion, causing the formation of unwanted residues or incomplete ashing [31,32], which ultimately affects the pH of the ash.

Calcination temperature (B) has a stronger positive effect on pH, with a coefficient of 0.6667. This means that increasing calcination temperature significantly raises the pH. The positive quadratic term $0.0454B^2$ further suggests that this effect might accelerate at higher temperatures. Higher calcination temperatures enhance the decomposition and transformation of mineral phases in the sample, leading to an increased concentration of alkaline minerals like calcium, potassium, magnesium and sodium, which elevate the pH [33,34].

The interaction effects of AC, AD, BC and CD positively affect the pH by enhancing mineral extraction, optimizing combustion and decomposition processes, improving mineral transformation and facilitating efficient dissolution and extraction of alkaline minerals. Proper optimization of these interaction effects can lead to increased alkaline minerals in the ash, influencing the pH and alkalinity of the salt positively [31-34].

3.4 Effects of Process Conditions on the Yield of Nypa Salt

Portrayed by Figure 4, the red peak of yield value was observed at the area where nypa fronds dried for 24 hours, calcined at 1200°C and soaked in demineralized water for 20 minutes at 50°C. A low-gradient increasing pattern was observed at the same soaking time and temperature, with an increment in drying time at the highest temperature of 1200°C.

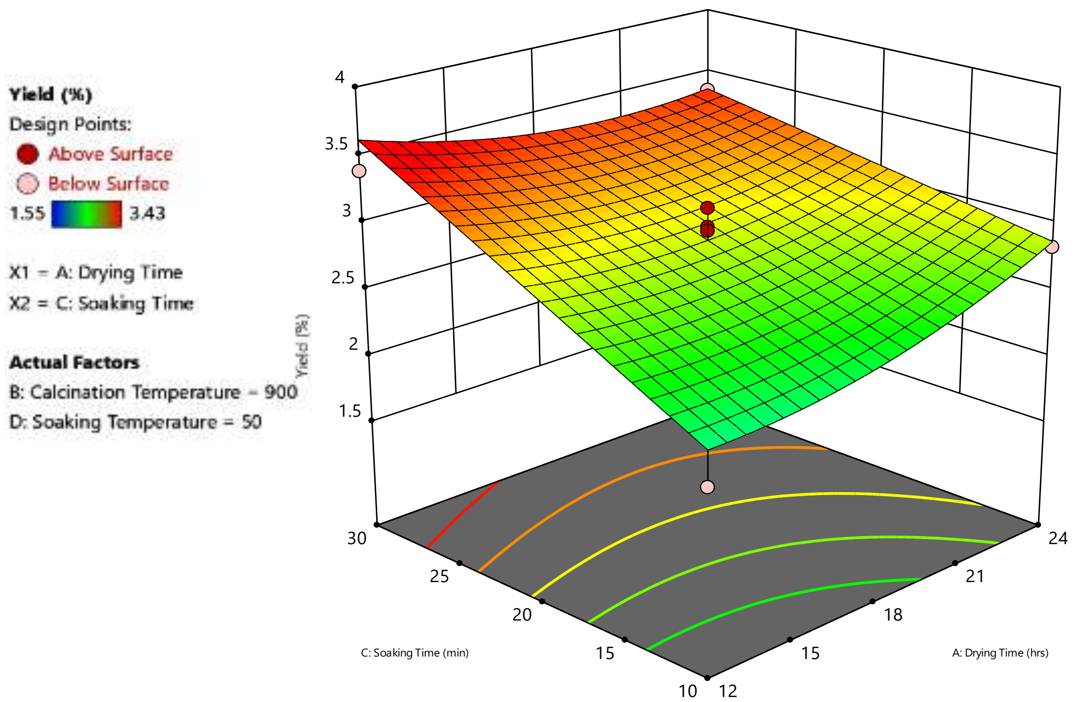


Fig. 4. 3D Plots for the BBD Model using Yield as the Response

Eq. (4) indicates that factors A, B, C and D each have a positive impact on the yield, meaning that an increase in the values of A, B, C and D results in a higher yield.

The coefficient 0.0850A indicates that drying time has a positive linear effect on yield. Increasing the drying time results in a higher yield. Additionally, the quadratic term $0.1517A^2$ is positive, suggesting that the effect of drying time on yield accelerates at higher levels. Sufficient drying time ensures that the sample combusts more efficiently, allowing it to reach the required high temperatures for thorough combustion and complete ashing [35]. Incomplete drying can interfere with the combustion process, potentially lowering the temperature, slowing down ashing, leading to incomplete combustion and ultimately affecting the yield [30].

A negligible positive impact on the yield is observed with increased calcination temperature (B). The coefficient 0.0092B indicates that calcination temperature has a very slight positive linear effect on yield. Increasing the calcination temperature accelerates the decomposition and transformation of mineral phases in the sample, facilitating the complete decomposition of organic matter and conversion of mineral phases to their respective oxides or carbonates [33]. This process enhances the concentration of alkaline minerals in the ash, thereby potentially increasing the yield.

Increasing soaking time and temperature significantly increases the yield, making it one of the most influential parameters in this equation. Longer soaking times and higher soaking temperature allow for better extraction and dissolution of alkaline minerals from the sample, thereby increasing the yield [36].

Nevertheless, simultaneous increases in drying and soaking time, as well as soaking time and temperature, can lead to a decrease in yield due to overexposure to heat, loss of alkaline minerals, excessive dissolution and degradation of the sample and altered mineral transformation [37].

3.5 Optimization Step

The optimum condition, with the highest desirability (1.000), was determined to be 12 hours of drying time, a calcination temperature of 1100°C, a soaking time of 10 minutes and a soaking temperature of 60°C. These conditions are predicted to result in a pH of 10.24 and a yield of 3.036%.

3.6 Model Verification

At the end of RSM, the verification procedure was taken by running additional three trials, which had been tabulated in Table 8.

Table 8
Results of pH and yield with optimized conditions

Trial	pH	Yield (%)
1	10.39	3.22
2	10.22	2.88
3	10.30	3.12

The analytical software calculated the actual mean values and standard deviation (SD) to compare them with the predicted values for verification. In this case, Table 9 indicates that the actual mean values for both responses fell within the 95% prediction interval (PI), confirming the validity of the model [17,37].

Table 9
Model verification of BBD in optimizing process conditions

Response	Predicted Mean	Standard Deviation	95% PI Low	Data Mean	95% PI High
pH	10.2398	0.0583429	10.0694	10.3033	10.4102
Yield (%)	3.03615	0.178051	2.63326	3.07333	3.44005

Notes: Prediction interval (PI)

4. Conclusion

This study comprehensively investigated salt recovery from *Nypa fruticans* fronds using the ashing method, aiming to fill the existing knowledge gap on the production processes of nypa salt. The salt recovery process was optimized using RSM, targeting the improvement of the pH and yield of nypa salt.

Optimal conditions for maximizing the desirability, determined to be 12 hours of drying time, a calcination temperature of 1100°C, a soaking time of 10 minutes and a soaking temperature of 60°C, resulted in a predicted pH of 10.30 and a yield of 3.07%. These conditions were verified through additional trials, demonstrating that the actual mean values of both responses fell within the 95% prediction interval, confirming the model's reliability.

The study underscores the significance of optimizing the process parameters to efficiently enhance the quality and yield of nypa salt. The optimized conditions are time-effective and sustainable, ensuring efficient combustion, complete ashing and accelerated mineral extraction and transformation.

Further studies are recommended to investigate the physicochemical properties of recovered nypa salt via the optimized conditions, as well as to explore broader applications of nypa salt and its potential health benefits and market acceptability.

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