https://doi.org/10.17221/94/2024-RAE

Optimisation of the temperature and drying time of kaffir lime leaves (*Citrus hystrix* DC.) using Response Surface Methodology

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Citation: Widyasanti A., Putri S.N., Budiarto R., Shah N.N.A.K. (2025): Optimisation of the temperature and drying time of kaffir lime leaves (*Citrus hystrix* DC.) using Response Surface Methodology. Res. Agr. Eng., 71: 155–162.

Abstract: This study optimised the drying process of kaffir lime leaves (*Citrus hystrix* DC.) to extend the shelf life and preserve the quality by reducing the moisture content. A Central Composite Design (CCD) under the Response Surface Methodology (RSM) framework was employed, with the temperature (55 °C, 60 °C, 65 °C) and drying time (5, 5.5, 6 h) as the variables. Experiments were conducted with a mechanical food dehydrator, and the parameters evaluated included the water content and drying yields. The optimal condition was identified as 60 °C for 5 h, resulting in a drying yield of 33.3% and a final moisture content of 7.153 (% w.b.), which meets the quality standards for dried products. The novelty of this research lies in the application of RSM to determine effective drying conditions for kaffir lime leaves, which are not widely used, but have good economic potential. The research proved that drying with the right conditions can greatly improve the quality and stability of dried kaffir lime leaves.

Keywords: drying optimisation; herbal product processing; kaffir lime leaves; Response Surface Methodology (RSM)

The kaffir lime plant (*Citrus hystrix* DC.), which belongs to the *Rutaceae* family, is widely known in Southeast Asia, including Indonesia. This plant has a unique feature: fragrant leaves, which are not found in other citrus species in Indonesia (Budiarto et al. 2019a). The use of kaffir lime leaves as a spice is more common in Indonesia compared to its use as a raw material for essential oils (Budiarto et al. 2019b). Kaffir lime leaves are often an essential ingredient in various traditional Indonesian and Asian dishes, such as rawon beef soup, soto, rendang, curry, fried tempeh, laksa, and tom yum. Spice consumption has seen an increasing trend in recent years, driven by the promotion of exotic and tradi-

https://doi.org/10.17221/94/2024-RAE

tional food ingredients by the food industry as part of a healthy modern lifestyle (Budiarto et al. 2021).

Indonesia is one of the largest spice-producing countries in the world, ranking fourth with a total production of 113 649 tonnes and a total export value of USD 652.3 million in 2016 (FAO 2016). Although there were fluctuations in export volumes during the 2017–2021 period, spices' contribution to total agricultural exports remained significant, reaching 32.83% in 2021 (Badan Pusat Statistik 2022).

As a cooking spice, spices are usually dried and turned into powders to facilitate storage and use, as well as to enhance the product's shelf life (Hambali et al. 2008). In Indonesia, one of the regions producing kaffir lime leaves is Tulungagung, East Java. In this area, kaffir lime is widely cultivated in home gardens and dry land independently (Zamzamiyah and Ashari 2021). However, the development of the kaffir lime leaf agribusiness still faces challenges, especially regarding the limited shelf life and traditional post-harvest handling methods (Su'aidah and Taruna 2021).

One of the main factors influencing the shelf life and quality of kaffir lime leaves is their high water content, approximately 62.22% (Setiyoningrum et al. 2018). A high water content in foodstuffs can facilitate metabolic processes, leading to the degradation of the active compounds, such as citronellal, which easily evaporates. Drying is one of the effective methods to reduce the water content, extend the shelf life, and maintain the quality of active compounds in kaffir lime leaves (Nugroho et al. 2020). The effectiveness of the drying process highly depends on the appropriate temperature and drying time. Setting too high a temperature can cause discolouration and a decrease in the nutritional value of the product, while too low a temperature can result in sticky and wet products that require longer drying times (Histifarina et al. 2004).

Therefore, optimising the drying process is crucial to maintaining the quality of the final product. An optimisation approach commonly used in engineering is the Response Surface Methodology, which can consider interactions between various process variables (Assagaf et al. 2013). This study is designed to determine the optimal drying conditions in the production of kaffir lime leaves by considering the effects of the drying temperature and time using the Response Surface Methodology (RSM).

MATERIAL AND METHODS

Fresh kaffir lime leaves (*Citrus hystrix* DC.) of the Puri Agrohorti variety were sourced from Bale Tatanen, Universitas Padjadjaran. The drying experiments were conducted using a PAPALOLO SS-10H Drying Stainless Steel Food Dehydrator Machine with 10 Trays, having dimensions of 35 cm × 40 cm × 43 cm and a power consumption of 800 W. The dehydrator's temperature settings ranged from 30 °C to 90 °C, and the time settings varied from 30 min to 24 hours. The device had 10 trays having dimensions of 30 cm × 28 cm.

Experimental design of the drying process. Drying was performed using a food dehydrator at three different temperatures (55 °C, 60 °C, and 65 °C) and three different drying times (5 h, 5.5 h, and 6 hours). This study employed an experimental method with optimisation conducted using Response Surface Methodology (RSM) based on a Central Composite Design (CCD). The design and data analysis were performed using Design Expert (version 13) software. In this study, two independent variables were considered: temperature, denoted as X_1, and the drying time, denoted as X_2, each evaluated at five coded levels: −α, −1, 0, +1, and +α. The main goal of this design was to evaluate the effects of these two variables on two key responses: the moisture content and drying yield of kaffir lime leaves. The CCD consisted of 13 experimental runs, including 4 factorial points (combinations of levels −1 and +1), 4 axial (star) points (at levels −α and +α), and 5 centre points at 60 °C and 5.5 h, used to estimate the experimental error and assess the model adequacy. Table 1 shows the range and levels of each independent variable used in the experiment.

To further clarify the CCD setup, the experimental matrix generated by Design Expert including factorial, axial, and centre points is presented in Table 2.

Moisture content analysis. The moisture content was determined using the thermogravimetric method based on (AOAC 2005). Approximately 3 g of the sample was placed in a pre-dried aluminium dish and dried in an oven at 105 °C for 3 hours. The dish was cooled in a desiccator for 15 min before weighing. This cycle was repeated until a constant weight was achieved (maximum difference of 0.02 g). The moisture content was calculated using the following equation:

https://doi.org/10.17221/94/2024-RAE

Table 1. Range and levels of independent variables

X, variable	Level variable				
	−α	−1	0	+1	+α
A: Temperature (°C)	52.9	55	60	65	67.1
B: Time (hours)	4.8	5	5.5	6	6.2

Table 2. The experimental matrix generated by Design Expert

Run	Temperature (°C)	Time (hours)	Coded temperature (X_1)	Coded time (X_2)
1	67.1 (70*)	5.5	1.414	0
2	60	4.8 (5*)	0	–1.414
3	60	6.2 (6*)	0	1.414
4	60	5.5	0	0
5	60	5.5	0	0
6	60	5.5	0	0
7	65	5	1	–1
8	55	6	–1	1
9	55	5	–1	–1
10	52.9 (50*)	5.5	–1.414	0
11	60	5.5	0	0
12	60	5.5	0	0
13	65	6	1	1

*The actual conditions applied in the research

$$\text{Moisture content}\,(\%) = \frac{b-(c-a)}{b} \times 100\% \tag{1}$$

where: a – weight of the empty dish (g); b – mass of the wet sample (g); c – weight of the dish with the dried sample (g).

Yield calculation. The yield was calculated by comparing the initial weight of the fresh kaffir lime leaves to the final weight of the dried leaves using the following formula:

$$\text{Yield}\,(\%) = \frac{M_b}{M_a} \times 100\% \tag{2}$$

where: M_a – mass of the fresh kaffir lime leaves (g); M_b – mass of the dried kaffir lime leaves (g).

Statistical analysis. The data were analysed using Response Surface Methodology (RSM) with Design Expert (version 13) to determine the optimal temperature and drying time that resulted in the best moisture content and yield. The analysis considered factors such as the temperature (°C) and drying time (hours) as the main variables influencing the results.

RESULTS AND DISCUSSION

Moisture content and drying yield analysis. The moisture content and yield of kaffir lime leaves were significantly influenced by the drying temperature and time. The results indicated that higher temperatures and longer drying times generally led to a reduction in the moisture content, but also decreased yield due to the evaporation of water and volatile compounds. Table 3 presents the moisture content and yield for each drying condition.

Based on Table 3, it can be seen that the moisture content of the kaffir lime leaf powder varies between 5.645% and 12.705% (% w.b.). The lowest moisture content was obtained at 70 °C for 5.5 h (run 1), while the highest moisture content was obtained at 50 °C for 5.5 h (run 10). This variation in moisture content indicates that the temperature and drying duration affect the moisture content; higher temperatures and longer drying times result in a lower moisture content. According to Aisah et al. (2021), higher temperatures and drying times accelerate the moisture reduction. According to SNI 01-3709-1995 (National Standardisation Agency 1995), the maximum moisture content for spice powder was 12 (% w.b.). Out of 13 samples, one sample (run 10) did not meet the standard with a moisture content of 12.705%.

Based on Table 3, it can be seen that the drying yield values range from 30.7% to 35.6%. The low-

Table 3. Moisture content and yield of kaffir lime leaves at different drying conditions

Run	Temperature (°C)	Time (hours)	Moisture content (% w.b.)	Yield of drying (%)
1	67.1 (70*)	5.5	5.645	30.7
2	60	4.8 (5*)	7.442	33.5
3	60	6.2 (6*)	6.619	32
4	60	5.5	6.631	32.9
5	60	5.5	7.055	33
6	60	5.5	6.753	33.1
7	65	5	6.399	32
8	55	6	9.289	34
9	55	5	10.978	35.3
10	52.9 (50*)	5.5	12.705	35.6
11	60	5.5	6.998	32.9
12	60	5.5	6.685	32.6
13	65	6	5.931	31.7

*The actual conditions applied in the research

https://doi.org/10.17221/94/2024-RAE

est yield was obtained at 70 °C for 5.5 h (run 1), while the highest yield was achieved at 50 °C for 5.5 h (run 10). This variation is influenced by the moisture content in the material, where reducing the moisture content during drying can lower the yield. The difference in yield values indicates that the temperature and drying duration affect the yield, with higher temperatures and longer drying times tending to result in lower yields (Sahupala et al. 2019).

Optimisation of the drying conditions using RSM. Response Surface Methodology (RSM) was employed to optimise the drying process. A quadratic model was found to be the best fit for moisture content, while a linear model was used for yield (Table 4). The RSM equation or model for the process optimisation of the kaffir lime leaves powder drying to the moisture content and yield response are shown in Equation (3) and (4), respectively:

$$Y_1 = 263.358 - 6.816A - 13.201B + 0.122AB + 0.047A^2 + 0.458B^2 \quad (3)$$

$$Y_2 = 56.934 - 0.313A - 0.930B \quad (4)$$

where: Y_1 – expected response moisture content (% w.b.); Y_2 – expected response drying yield (%); A – drying temperature applied in unit °C; B – drying time applied in unit hours; AB – interaction term between the drying temperature and drying time in a second-order (quadratic) regression mode; A^2 – quadratic of the drying temperature; B^2 – quadratic of the drying time.

Based on Table 4, the moisture content response is modelled using a quadratic model, while the yield response is modelled using a linear model as the chosen models based on the R^2 values, which are higher than those of other models (linear, 2FI, cubic). Additionally, all the responses have significant models with P-values less than 0.05, and all the responses have P-values greater than 0.05 for lack of fit, indicating that the moisture content response is well explained by the model and fits well in describing the response data (Swasana 2019). The surface shapes of the interaction between components that result in response values can be more clearly seen in the three-dimensional graphs shown in Figure 1.

Figure 1 presents a visual representation of the results for the moisture content and yield testing in the form of three-dimensional curves marked with different colours. Areas appearing a bluish colour indicate lower response values, while areas appearing a reddish colour indicate higher response values. The lowest values, marked in blue, are obtained from the drying treatments with the highest temperature and longest drying time (65 °C, 6 hours). Conversely, the red areas or high moisture content values are obtained from the drying treatments with the lowest temperature and shortest time (55 °C, 5 hours).

The results of this study show that drying temperature and duration significantly affect the moisture content and yield of kaffir lime leaves powder. This pattern is consistent with previous research on other herbal plants. For instance, a study by Erbay and Icier (2009) used Response Surface Methodology to analyse olive leaves and discovered that the moisture content of dried leaves is the main indicator showing the success of the drying process optimisation, and important quality properties of olive leaves. Raising the drying temperature to about 40–60 °C (with moderate humidity) produced acceptable final moisture content and good retention. Similar results were found when ginger was dried by Afolabi et al. (2014), who found that a balance between process efficiency and final product quality was achieved with moderate drying times and temperatures. The drying time and rate decreased with increase in drying air temperature from 40 °C to 70 °C, while drying rate decreased with increase in slice thickness. However, previous study showing that higher drying temperatures accelerate moisture removal but can decrease yield and degrade bioactive compounds in basil and turmeric (Komonsing et al. 2022; Saha et al. 2022; Akbar et al. 2024).

In particular, the volatilisation of terpenoid chemicals like citronellal and limonene is a critical factor

Tabel 4. Model analysis for moisture content and yield

Response	Model	RSM equation	Significance (P < 0.05)	Lack of fit (P < 0.05)	R^2
Moisture content	quadratic	(3)	< 0.0001	0.0584	0.9848
Yield	linear	(4)	< 0.0001	0.0804	0.9507

RSM = Response Surface Methodology

https://doi.org/10.17221/94/2024-RAE

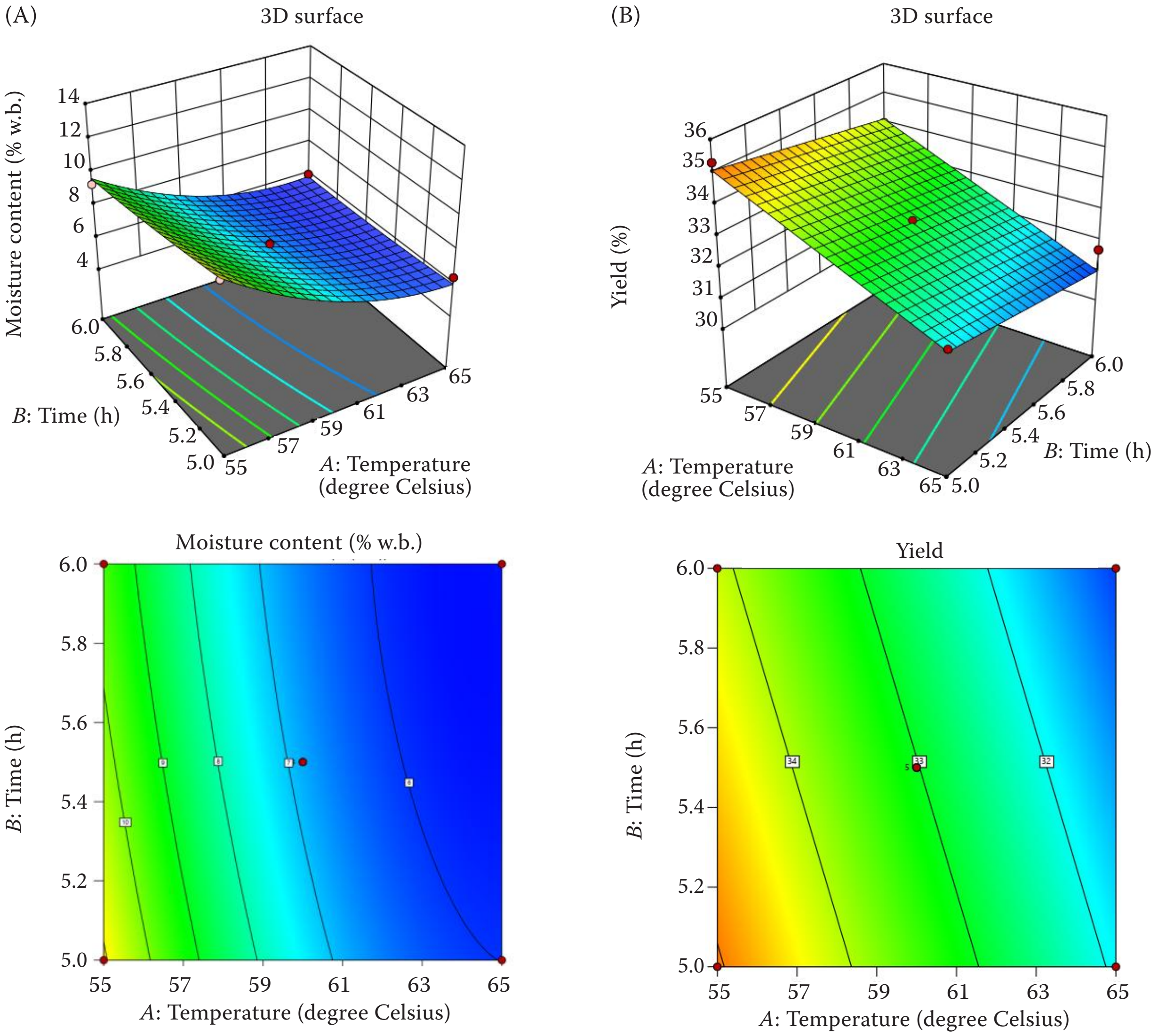

Figure 1. 3D plot and contour plot of two responses

(A) Response of moisture content (% w.b.); (B) response of drying yield

in determining the quality of aroma in heat-sensitive and aroma-rich crops like kaffir lime leaves. Because these substances are extremely volatile and prone to degrading at high temperatures, drying for an extended period of time or at high temperatures increases the likelihood of losing their distinctive scent. According to Hossain and Bala (2010), ginger and other spices' essential oil content was considerably decreased by raising the drying temperature. Therefore, setting the optimal drying conditions must consider not only the efficiency of moisture removal, but also the preservation of bioactive and aromatic compounds that define the sensory and commercial value of the product.

Drying optimisation of kaffir lime leaves. Optimisation was carried out after obtaining the mathematical model for each response. In general, the goal of optimisation is to obtain the response or treatment that best fits the desired conditions. Based on Table 5, the temperature and time variables for drying were the same as the previous treatments, namely in the range of 55–65 °C and 5–6 h with an importance level of 3 (+++) as recommended by the RSM application. The target optimisation for the moisture content and yield responses desired is to dry kaffir lime leaves with the minimum moisture content with the highest importance level of 5 (+++++) and to dry kaffir lime leaves with the maximum yield with the highest importance level of 5 (+++++). The yield response was optimised with a target maximisation to achieve high yields, while the moisture content response was optimised

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Table 5. Drying optimisation design for kaffir lime leaves on RSM

Variable component and response	Target	Lower limit	Upper limit	Importance level
Drying temperature (°C)	in range	55	65	3 (+++)
Drying time (hours)	in range	5	6	3 (+++)
Moisture content (% w.b.)	minimise	5.645	12.705	5 (+++++)
Yield (%)	maximise	30.7	35.6	5 (+++++)

RSM = Response Surface Methodology

with a minimisation target to achieve a moisture content according to Indonesia National Standard (SNI) No. 01-3790-1955, which requires that the moisture content must not exceed 12 (% w.b.).

The recommended optimum drying conditions for kaffir lime leaves based on Design Expert can be seen in Table 6. The determination of the optimal conditions is based on the highest desirability value. The higher the desirability value, the better it meets each constraint or need previously set. Desirability values range from 0–1, each representing the minimum and maximum desired response values (Ramadhani et al. 2017). According to Table 6, the optimum drying conditions suggested by RSM are drying at 59.574 °C (rounded to 60 °C) for 5 hours. These conditions were selected based on their high desirability score (0.658), indicating that the drying process meets the set quality parameters. Drying under these conditions is predicted to produce a moisture content response of 7.580% and a yield of 33.622%.

From an economic standpoint, implementing optimal conditions 60 °C for 5 h provides a balance between the energy efficiency, processing time, and product quality. Over-drying at high temperatures can diminish the yield and scent quality, which lowers the product's market value, particularly in markets for premium spices and herbs. On the other hand, prolonged drying at lower temperatures raises production costs and energy usage. For industrial-scale applications, optimisation techniques like RSM are therefore very relevant since they save operating costs while preserving product quality that complies with regulations (e.g. SNI 01-3709-1995 for the maximum moisture content).

Validation of optimum parameters. The confirmation validation results can be seen in the optimal solution confirmation table in Table 7, which shows that the validation results for each response are still within the 95% PI low and 95% PI high prediction ranges. In Table 7, the average response value for moisture content is lower, at 7.153%, compared to the previous prediction of 7.548%. The moisture content validation result is also within the prediction range, i.e. between 0.632% (95% low PI) and 2.431% (95% high PI). The yield response obtained from the validation result is 33.3%, which is lower than the prediction of 33.506%. The moisture content yield validation result is within the prediction range, between the lowest and highest predicted values.

A percentage close to 100% indicates high model accuracy. As shown in Table 8, the validation re-

Table 6. Optimisation parameters generated

No.	Drying temperature (°C)	Drying time (hours)	Moisture content (% w.b.)	Yield (%)	Desirability
1	59.574	5.000	7.580	33.622	0.658
2	59.657	5.000	7.534	33.596	0.658
3	59.756	5.000	7.481	33.565	0.658

Table 7. RSM optimum solution confirmation

Response	Optimum prediction	Standard deviation	*n* (number of data)	Standard error prediction	Lowest prediction (PI low)	Actual result	Highest prediction (PI high)
Moisture content (% w.b.)	7.548	0.337	1	0.368	6.676	7.153	8.419
Yield (%)	33.506	0.332	1	0.347	32.732	33.3	34.281

PI = prediction interval; RSM = Response Surface Methodology

https://doi.org/10.17221/94/2024-RAE

Table 8. RSM validation for moisture content (% w.b.) and yield (%)

Response	Percent of validation (%)
Moisture content (% w.b.)	94.767
Yield (%)	99.385

RSM = Response Surface Methodology

sults under the optimum conditions recommended by Design Expert 13 using the RSM-Central Composite Design yield validation percentages of 94.767% for moisture content and 99.385% for yield. These results demonstrate strong agreement between the experimental and predicted values. According to Apriliyanti et al. (2017), an acceptable model deviation is typically less than 5%, which both responses satisfy. The slight discrepancy between the predicted and actual values is considered acceptable due to the inherent variability in the experimental conditions. These findings reinforce the reliability and robustness of the predictive model, confirming its effectiveness in optimising the process parameters.

CONCLUSION

The mathematical model generated for optimising the drying of kaffir lime leaves using Response Surface Methodology (RSM) demonstrated statistical significance, with a quadratic model effectively predicting the moisture content and a linear model for drying yield. Validation of the optimisation results showed high accuracy, with a validation percentage of 94.767% for the moisture content and 99.385% for the drying yield. The optimised drying conditions of kaffir lime leaves, achieved with a temperature of 60 °C for 5 h, yielded an actual moisture content of 7.153 (% w.b.) and a drying yield of 33.3%. These conditions were found to be ideal for producing high-quality dried kaffir lime leaves that meet industry standards. This model provides a reliable approach for determining the optimal drying conditions of kaffir lime leaves and can be scaled for industrial applications. The findings hold significant implications for large-scale production, where consistent drying processes are essential for maintaining product quality. However, future research could explore the application of multi-objective optimisation models, considering not only quality, but also cost-efficiency, to further improve the economic feasibility, scalability, and sustainability of kaffir lime leaf drying techniques in commercial production.

Acknowledgement: The authors are grateful for the research facilities provided by Postharvest and Process Technology Laboratory, Faculty of Agro-Industrial Technology, Universitas Padjadjaran.

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Received: December 3, 2024
Accepted: June 6, 2025
Published online: September 24, 2025