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# Enhancing the Efficiency of Infrared Drying of Desiccated Coconut Through Process Optimization and Validation

**Yahya Sahari[1,2], Mohd Shamsul Anuar[1], Mohd Zuhair Mohd Nor[1]* and Nur Hamizah Abdul Ghani[1]**

[1]*Department of Food and Process Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*
[2]*Engineering Research Centre, Malaysian Agricultural Research and Development Institute, 43400 Serdang, Selangor, Malaysia*

## ABSTRACT

Drying desiccated coconut is always challenging due to its sensitivity to heat, which can reduce its color quality. The main goal of this study is to optimize infrared drying (IR) efficiency without affecting the final color quality of desiccated coconut. Single-mode infrared drying was optimized using Response Surface Methodology (RSM) with a central composite rotatable design (CCRD). Using a radiation output of 600 Watts and a fixed distance of 15 cm from the emitter, a single layer of fresh shredded coconut with a wet basis of approximately 51.35±4.0% was dried to less than 3% (w.b). Drying temperature and air velocity were taken into consideration as independent parameters. The selected optimal drying conditions, with the desirability value (D = 0.812), were 61°C drying temperature and 2.2 m/s air velocity. The response of optimal values for drying time, specific energy consumption (SEC), color changes, and whiteness index were 36.826 minutes, 19.821 kWh/kg, 3.431, and 71.762, respectively. Models for predicting these response values had $R^2$ values of more than 0.90. All responses were shown to be significantly impacted by drying temperature and air velocity ($p<0.05$), with drying temperature having a larger effect than air velocity. The optimal drying parameters were validated with a less than 2% deviation.

*Keywords:* Color quality, desiccated coconut, infrared drying, optimization, specific energy consumption

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*E-mail addresses*:
yayasaha82@gmail.com.my (Yahya Sahari)
mshamsul@upm.edu.my (Mohd Shamsul Anuar)
zuhair@upm.edu.my (Mohd Zuhair Mohd Nor)
nurhamizah@upm.edu.my (Nur Hamizah Abdul Ghani)
* Corresponding author

## INTRODUCTION

Coconut is undoubtedly the world's most significant tree crop, providing food and shelter to millions in the tropical region. Coconut (*Cocos nucifera L.)* has long been popular in Southeast Asia. People in over 110 nations worldwide use coconut palm,

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which is farmed on around 12.25 million hectares in over 90 countries. The economic impact of coconuts is estimated to be approximately USD 13.18 billion as export value in 2022 (Alouw, 2023).

In Malaysia, coconuts are grown for both fresh produce and downstream products. Since the demand for products made from coconut increases yearly, Malaysia still needs to import coconut from Indonesia and the Philippines (Nor et al., 2020). Between 2016 and 2020, the average import of fresh coconut was 217 thousand metric tonnes per year in Malaysia (Zainol et al., 2023). The edible part, which is coconut kernel meat, makes up 33% of the coconut, and it has long been a staple of many people's diets for its protein, fat, and carbohydrate sources (Patil et al., 2017; Wynn, 2017). On the other hand, the composition of coconut kernel is predominantly influenced by variety, nut maturity, geographic location, and cultural behaviors (Adoyo et al., 2021). However, according to Ngampeerapong and Chavasit (2019), coconut kernels' macronutrients and bioactive components differed slightly in three distinct nations (Thailand, Indonesia, and Vietnam). After removing the husk and paring the coconut, the edible section of the coconut kernel is obtained by removing the shell and draining the water. The coconut meat/kernel is manually scrapped and grated to make various items. From the nuts' harvesting to drying and storing, a lack of understanding and genuine abilities in coconut postharvest technology has resulted in severe losses. Like many other agricultural products, coconut kernel is also subject to spoilage and quality deterioration due to the presence of important constituents such as high fat, sugar, and moisture content (Lamdande et al., 2018). As a result, many food products would rather be marketed in their dried forms since they are more appealing than their fresh counterparts.

Today, there are a variety of ways to reduce postharvest losses. Drying or dehydration is the most practical and innovative process for increasing shelf life and maintaining long-term product quality. Many researchers have conducted studies on coconut kernel products using artificial dryers in the laboratory or on a pilot scale (Abidin et al., 2014; Aggary & Arowanti, 2012; Jongyingcharoen et al., 2019; Madamba, 2003; Madhiyanon et al., 2009; Niamnuy & Devahastin, 2005; Pestaño, 2015; Yahya et al., 2020). Air is used in most artificial dryers to convey heat to food, and vaporized water is transported to air via convection. Nevertheless, the hot-air drying process has drawbacks, including low energy efficiency, degradation in quality, and prolonged drying times during the falling rate stage (Kipcak et al., 2019). Traditional methods such as sun drying and kiln drying might produce poor dried product quality, such as discoloration, case hardening, and shrinkage of food, resulting in the loss of phenolic components in the final product (Sarkar et al., 2020).

As technology advances, infrared drying is becoming increasingly popular as an effective way of drying food and agricultural products, thereby reducing and complementing the drawbacks of artificial drying. This non-conventional infrared drying technology offers superior energy efficiency, fast heat transfer rates, and uniform heating of products

(Kian-Pour, 2020). Infrared radiation modifies the product's molecule's vibrational state at between 60,000 and 150,000 MHz, providing intermolecular friction and rapid internal heating (Sakare et al., 2020). Studies show that infrared has a more effective moisture diffusivity and a higher thermal sensitivity than hot air drying (Wu et al., 2019). Unlike hot air drying, no medium is needed to transmit infrared radiation energy from the emitter to the product (Adak et al., 2017). Ceramic emitters are one of the most common electrically heated infrared sources for processing agricultural products (Delfiya et al., 2021; Pan, 2021; Sakare et al., 2020). In addition to that, the short drying period makes it ideal for heat-sensitive products like fruits and vegetables (Delfiya et al., 2021; Riadh et al., 2015; Sakare et al., 2020). Moreover, this type of drying has a unique advantage over conventional drying, including effective product heating, outstanding energy efficiency, and high-quality dried products since it prevents the loss of the product's chemical and organoleptic properties (Sossa et al., 2021). Since its huge potential in food drying was discovered, various agricultural and food products have been investigated using either single-mode infrared drying, combination with others or infrared-assisted mode.

Single-mode infrared drying has been successfully studied by Isik et al. (2019) on bee pollen, saffron by Torki-Harchegani et al. (2017), cherry tomatoes by Kipcak and Doymaz (2020), green bean by Doymaz et al. (2015); apple slices by Salehi and Satorabi (2021); stevia leaves by Huang et al. (2021); eggplant slices by Jafari et al. (2020); turmeric by Fernando et al. (2021)—those mentioned studies covered mostly from drying kinetics to optimization and quality evaluation of products. Despite the fact that Shingare and Thorat (2012) looked at the drying kinetics of infrared drying of desiccated coconut, the study lacked optimization and quality assessment. Other research on desiccated coconut using microwave drying was also reported by Moses et al. (2013), whereby changes in the final product's color were minimal at lower power levels. Choosing the best and optimal drying conditions in food processing is crucial for system effectiveness, creating high-quality dried products, and reducing energy usage. One of the most modern statistical and mathematical techniques, called response surface methodology (RSM), is widely used to design, improve, and optimize a range of processes where a specific response is influenced by multiple variables (Šumić et al., 2016). Several studies have successfully used RSM to optimize drying parameters, producing acceptable results (Koca et al., 2018; Majdi et al., 2019; Omolola et al., 2015; Sharma et al., 2020; Tajudin et al., 2021). Unfortunately, no previous research has looked into the possibility of infrared drying on desiccated coconut, with optimization studies in particular.

This study used an infrared drying approach to examine the effects of drying factors (drying temperature and air velocity) on the desiccated coconut's drying performance and color quality. At the end of this study, an optimal drying condition for desiccated coconut using single-mode infrared drying will be validated and suggested.

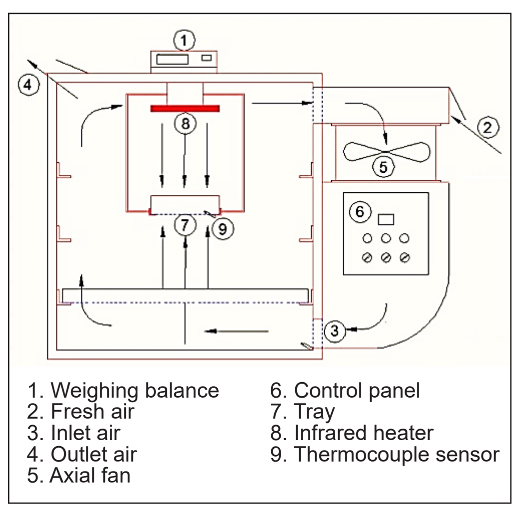
## MATERIALS AND METHODS

The newly harvested local variety of de-husked coconuts was obtained from a wet market in Senawang, Negeri Sembilan, Malaysia. Only intact and matured coconut (10-12 months) was chosen for this experiment, and sprouted coconut was eliminated to maintain product consistency throughout the drying process. The coconuts were processed daily to ensure the freshness of the coconut kernels. Before being transformed into shredded coconut, the de-husked coconut must first go through a number of steps. The coconut was manually broken open to remove the shell before being cut open with a sharp knife. The brown skin, or so-called testa, was then scraped off the de-shelled coconut using a specialized scraper. The white peeled coconut kernel balls were meticulously cleaned and washed with filtered tap water after the coconut water had been removed from them. Following cleaning, a 1.5 horsepower mechanical shredder (Brand: Anson, Malaysia) was used to grind or shred the white coconut kernels into uniform coconut shreds measuring around 4.06±0.89 mm.

### Experimental Apparatus

A picture of the infrared dryer and a schematic diagram are illustrated in Figures 1(a) and (b). The drying chamber was made of stainless steel and well-insulated to prevent heat loss. On the top inner surface of the drying chamber, a ceramic infrared heater with a radiation power of 600 W was installed. Electrical IR emitters were chosen because they are more versatile in power distribution and have a greater conversion efficiency of 78 to 85 percent (Yadav et al., 2020). The control panel attached to the dryer can adjust the output power and infrared drying temperature. With a set distance of 150 mm, a round sample tray of 140 mm in diameter made of woven wire mesh was placed beneath the infrared heater. The Shinko Denshi AJ 820E, Japan underhook weighing scale (820 ±0.01 g) was configured to monitor and display the mass loss of the sample throughout the drying process. A blower was installed to generate and adjust air velocity to increase

(a)




(b)

*Figure 1.* Single-mode infrared dryer: (a) Picture; and (b) schematic diagram

air circulation during infrared drying. A Vane Anemometer (TESTO 416, Germany) was used to measure the input air velocity, and the reading accuracy was 0.2 m/s ±1.5 percent. A Watt-hour meter was also used to calculate the overall energy used by the blower and infrared emitter.

## Experimental Procedures

A layer of white coconut shreds sample weighing about 40 g was placed on a sample tray, and infrared radiation was applied. The infrared drying process was set at 600 W or 3.90 W/cm$^2$ for each experiment run. This study used a ceramic type of infrared emitter (Model: white ceramic emitter; Brand: Infrapara, China) with dimension (L×W×H: 24.5×6.0×3.1 cm) which is considered a far-infrared drying as the peak-wavelength was in the range of (8.25–9.05 µm). Most ceramic emitters used in drying processes have an emission of up to 3 µm (Aboud et al., 2019). It is important to ensure the drying temperature reaches the steady state condition beforehand. As the drying started, moisture content reduction from the sample was continuously recorded, and the experiment ended when it fell below 3% moisture content (w.b). The intended final moisture content was referred to the standard set by (International Coconut Community, 2009), also reported by (Madhiyanon et al., 2009; Niamnuy & Devahastin, 2005; Yahya et al., 2020). The final moisture content of white shredded coconut was determined by hot air oven drying at 105±2°C (Model: 500/1081, Memmert GmbH + Co.KG, Germany) for 24 h (AOAC, 2005). After being allowed to cool for approximately ten minutes at room temperature, the dried samples were packed into aluminum foil bags for further analysis. After the drying procedure was completed, the drying time for each run was recorded.

### *Design of Experiments and Statistical Analysis*

Two numerical independent variables, temperature (50°C, 60°C, and 70°C) and air velocity (1.5, 2.3, and 3.0 m/s), were used in this central composite rotatable design (CCRD). The measured responses were drying time, specific energy consumption (SEC), color changes (ΔE), and whiteness index (WI). Table 1 shows all the factors involved with their levels. Response surface methodology (RSM) of Statistical Software Design Expert 12 (Stat Ease, Inc., Minneapolis, USA) was used to examine the responses to the collected data. Fitting the experimental data was done using the second-order polynomial of Equation 1 (Wang et al., 2019):

$$y = \beta_o + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum \sum_{i<j=1}^{k} \beta_{ij} x_i x_j \qquad [1]$$

Where y values are measured responses (drying time, SEC, ΔE, and WI); $\beta_o$, $\beta_i$, $\beta_{ii}$, and $\beta_{ij}$ are constant regression coefficients of intercept, linear, quadratic, and interaction terms, respectively; $x_i$ and $x_j$ are the coded independent variables. The analysis of variance (ANOVA) was employed to statistically test the experimental data at the significance level of $p = 0.05$. The p-value and coefficient of determination ($R^2$) were also used to assess the model's suitability.

Table 1
*Levels of factors*

| Factors | Type | Unit | -α (1.414) | low (-1) | mid (0) | high (+1) | +α (1.414) |
|---|---|---|---|---|---|---|---|
| IR Temperature (A) | Numerical | °C | 46 | 50 | 60 | 70 | 74 |
| Air velocity (B) | Numerical | m/s | 1.2 | 1.5 | 2.3 | 3.0 | 3.3 |

When different industrial processes are optimized, several responses are often adjusted to define the performance and quality attributes. While others must be maximized, some of these response factors must be minimized. These variables may be antagonistic, meaning that when modifying one response, the opposite effect can result in another, complicating matters. The problem can typically be solved in three different ways, whereby the most typical approach to problem-solving is using the desirability function (Erbay & Icier, 2009; Sharma et al., 2020; Tajudin et al., 2019). The desirability function is the summation of all responses into a single measurement in the following Equation 2 (Majdi et al., 2019; Manohar et al., 2013):

$$D(X) = d_1 \times d_2 \times \ldots\ldots d_n{}^{1/n} = [\prod_{i-1}^{n} di(Yi)]^{1/n} \qquad [2]$$

Where *Yi (i* = 1, 2 ... *n)* are the dependent parameters while *n* is the total number of responses measured in the optimization study, the *di* represents the desirability index for each response variable, which varies from 0 to 1. The desire function, or "D," expresses the degree of desirability of the dependent parameters at a selected level of independent variables.

### *Validation of Models*

The suitability of the second-order polynomial model for predicting the optimum condition values was confirmed by conducting experiments under the suggested optimal parameters and predicted values. Response data from the obtained experimental and predicted values were compared to evaluate the model's veracity. The percentage error (*PE*) between the experimental and predicted values was determined by using the formula given in Equation 3:

$$PE(\%) = \frac{M_{ev} - M_{pv}}{M_{ev}} \times 100 \qquad [3]$$

Where $M_{ev}$ is the experimental value, and $M_{pv}$ is the predicted value. According to Nordin et al. (2019), a less than 10% error indicates a good fit between experimental and predicted values.

### *Specific Energy Consumption (SEC)*

Equations 4 and 5 were deployed to determine the total energy used by the dryer at particular infrared drying parameters (Kaveh et al., 2021; Sahari et al., 2023):

$$E_T = \left(E_{IR+fan}\right).t \quad [4]$$

$$SEC = \frac{E_T}{m_w} \quad [5]$$

Where $E_T$ is the overall energy consumption (kWh), SEC is the specific energy consumption (kWh/kg), $m_w$ reflects the water evaporation weight loss (kg), $E_{IR+fan}$ is the total IR emitter and fan power (Watt), and *t* is the time (hour).

### *Color Changes (ΔE)*

Color is an important consideration for consumers when making food product purchases. It also holds for the desiccated coconut's color quality. A chroma meter (Minolta Co., Osaka, Japan) model CR-400/410 was utilized to evaluate the color of the dried coconuts and fresh coconut shreds. Prior to use, the color analyzer was calibrated to guarantee the accuracy of the results. Three color parameters were identified: $L^*$ (lightness), $a^*$ (red/green), and $b^*$ (yellow/blue). Both fresh and dried samples were filled in a standard transparent petri dish during the measuring process. The color difference (ΔE) was then calculated by Equation 6:

$$\Delta E = \sqrt{[(L^* - L_o^*)^2 + (a^* - a_o^*)^2 + (b^* - b_0^*)^2]} \quad [6]$$

Where ΔE is the color difference between fresh and dried samples (desiccated coconut). $L^*_o$, $a^*_o$ and $b^*_o$ are the values for fresh coconut shreds, while $L^*$, $a^*$ and $b^*$ are the values for desiccated coconut. Each color measurement was taken thrice at three sample locations to determine the average color change (Sahari et al., 2023).

### *Whiteness Index (WI)*

Besides the color change attribute, the whiteness index (WI) can also describe color quality. Pathare et al. (2013) state that the whiteness index is a measure of whiteness that incorporates yellow-blue and brightness into a single term. The Whiteness index was also applied to products derived from coconut residue, according to Jongyingcharoen et al. (2019). The WI can be calculated by the following Equation 7 (Nurkhoeriyati et al., 2021):

$$WI = 100 - \sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}} \quad [7]$$

## RESULTS AND DISCUSSION

For two factors and four responses, 13 experiments were designed (Table 2). Temperature and air velocity, two independent variables, were combined in the tests with response values from experimental results. It should be noted that using CCRD, the center point from the combination of temperature and air velocity of every pre-treatment was repeated 5 times, in this case (60°C and 2.3m/s). Since it was rotatable CCD, the minimum and maximum temperature and air velocity factor parameters were also extended to 46°C and 74°C and 1.2 and 3.3 m/s, respectively. Ultimately, the optimization aimed to find minimum drying time, SEC, and color changes while targeting the maximum value of the whiteness index of desiccated coconut.

Table 2
*Results for two factors and four measured responses*

| | | Factor | | Response | | | |
|---|---|---|---|---|---|---|---|
| **Std** | **Run** | **Temperature (°C)** | **Air velocity (m/s)** | **Drying time (min)** | **SEC (kWh/kg)** | **ΔE** | **WI** |
| 1 | 1 | 50 | 1.5 | 61.79 | 33.90 | 4.37±0.179 | 70.88±0.152 |
| 6 | 2 | 74 | 2.3 | 25.85 | 17.67 | 9.42±1.311 | 66.50±1.272 |
| 12 | 3 | 60 | 2.3 | 36.85 | 19.91 | 3.51±0.488 | 71.63±0.486 |
| 4 | 4 | 70 | 3.0 | 39.85 | 22.21 | 5.62±0.724 | 69.89±0.693 |
| 7 | 5 | 60 | 1.2 | 37.98 | 20.90 | 5.86±0.903 | 69.42±0.873 |
| 13 | 6 | 60 | 2.3 | 46.41 | 25.07 | 3.02±1.181 | 72.14±1.184 |
| 3 | 7 | 50 | 3.0 | 77.95 | 43.95 | 3.55±1.127 | 71.70±1.131 |
| 2 | 8 | 70 | 1.5 | 35.38 | 16.61 | 7.69±0.985 | 67.98±1.124 |
| 10 | 9 | 60 | 2.3 | 42.53 | 22.27 | 2.19±0.098 | 73.00±0.110 |
| 5 | 10 | 46 | 2.3 | 65.18 | 38.71 | 4.44±0.727 | 70.80±0.708 |
| 8 | 11 | 60 | 3.3 | 63.20 | 38.10 | 4.21±0.246 | 71.01±0.243 |
| 11 | 12 | 60 | 2.3 | 31.38 | 17.86 | 4.17±0.919 | 70.99±0.890 |
| 9 | 13 | 60 | 2.3 | 40.46 | 22.45 | 2.71±0.833 | 72.45±0.848 |

### Effect of Infrared Drying Parameters on Drying Time

Figure 2 depicts how drying variables affect the drying time of desiccated coconut. By referring to the 3D surface of Figure 2, the increment of drying temperature decreased the drying time significantly. Higher drying temperatures may increase thermal flux from the drying medium, raising the temperature differential between the drying medium and the drying product and enhancing the heat transfer rate (Zeng et al., 2019). A comparable result was also reported in the optimization of the infrared drying process of pumpkin (Sadeghi et al., 2020) and garlic slices (Zhou et al., 2017).

Conversely, an increase in air velocity increases in drying time. It could be due to the cooling effect on the product being dried at higher air velocity, reducing heat and mass transfer rate in most infrared drying processes (Sadeghi et al., 2020; Srinivas et al., 2018). According to Muga et al. (2021), the cooling effect of the drying air on the IR emitter as a result of convective heat losses is responsible for the IR emitter's temperature decrease with increased drying air velocity.

In other words, individual factors (drying temperature and air velocity) played a significant role in determining the drying behavior of desiccated coconut. It can be proven by the ($p$-value <0.05) of both factors in Table 3. Nevertheless, drying temperature had a greater effect on drying time compared to air velocity. It was evident from the data in Table 2 that the shortest drying time of 25.85 minutes was recorded at the highest drying temperature of 74°C and a medium air velocity of 2.3 m/s. Park et al. (2015) also mentioned the phenomenon when the drying rate of slice radishes was predominantly influenced by infrared drying temperature rather than air velocity.

The declining trend of drying time was obvious at elevated drying temperature or infrared power during infrared drying, as reported by Bhat et al. (2020) and Doymaz et al. (2015). On the other hand, the longest drying time of 77.95 minutes was observed at a lower drying temperature of 50°C and a

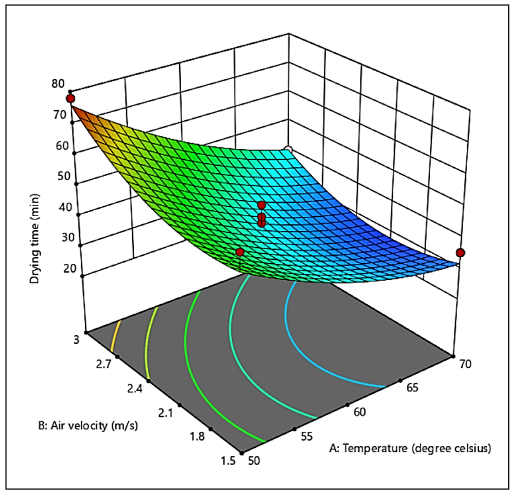



*Figure 2.* 3D surface of drying time against temperature and air velocity

Table 3
*ANOVA results for drying time response*

| Term | Sum of squares | df | Mean square | F-value | p-value |
|---|---|---|---|---|---|
| Model | 2656.16 | 5 | 531.23 | 15.79 | 0.0011 (significant) |
| A-Temperature | 1779.01 | 1 | 1779.01 | 52.90 | 0.0002 |
| B-Air velocity | 389.98 | 1 | 389.98 | 11.60 | 0.0114 |
| AB | 32.51 | 1 | 32.51 | 0.9665 | 0.3583 |
| $A^2$ | 139.76 | 1 | 139.76 | 4.16 | 0.0809 |
| $B^2$ | 366.39 | 1 | 366.39 | 10.89 | 0.0131 |
| Residual | 235.42 | 7 | 33.63 | | |
| Lack of Fit | 104.62 | 3 | 34.87 | 1.07 | 0.4569 (not significant) |
| Pure Error | 130.80 | 4 | 32.70 | | |
| Cor Total | 2891.59 | 12 | | | |
| $R^2$: 0.9186 | | | Adjusted $R^2$: 0.8604 | | Predicted $R^2$: 0.6616 |

$p$-value less than 0.05 is significant at $\alpha = 0.05$
Lack of fit is not significant at a $p$-value of more than 0.05

higher air velocity of 3.0 m/s. From the statistical analysis, the effect of drying temperature (A) was superior to air velocity (B) with the larger value of coefficient estimate ($\beta_i$) and *F*-value. The coefficient estimate was -15, indicating that the mean drying time would decrease by 15 points for every increment of degrees Celsius.

Meanwhile, the interaction between the drying temperature and the air velocity was insignificant ($p>0.05$) concerning drying time. Although both linear terms for the drying temperature and air velocity happened to be significant, only a quadratic term of air velocity showed a relatively large effect ($p<0.05$) on drying time. Therefore, the interaction term of AB and the quadratic term of drying temperature were excluded from the model equation. Equation 8 of the optimized model was recommended for predicting drying time with *p*-value <0.05, 0.8590 of *R*-squared and insignificant lack of fit. Notably, the residuals in Figure 3 follow approximately a straight line, indicating a normal distribution for the residuals.

$$\textit{Drying time} = 42.09 - 15.10A + 6.98B + 6.84B^2 \quad [8]$$

## Effect of Infrared Drying Parameters on Specific Energy Consumption (SEC)

Table 4 illustrates that the model's F-value is 26.72, indicating its suitability and significance. It is also proven by the *p*-value, which is less than 0.05. Figure 4 illustrates the 3D surface graph of SEC, which has a pattern quite similar to that of the 3D surface of drying time. While drying temperature and air velocity remain significant factors ($p<0.05$), the effect of drying temperature was more pronounced when compared with air velocity based on its *p*-value of less than 0.0001 and higher *F*-value. Another study employing infrared drying

Table 4
*ANOVA results for specific energy consumption (SEC) response*

| Term | Sum of squares | df | Mean square | F-value | p-value |
|---|---|---|---|---|---|
| Model | 970.65 | 5 | 194.13 | 26.72 | 0.0002 (significant) |
| A-Temperature | 586.83 | 1 | 586.83 | 80.78 | <0.0001 |
| B-Air velocity | 198.83 | 1 | 198.83 | 27.37 | 0.0012 |
| AB | 4.24 | 1 | 4.24 | 0.58 | 0.4698 |
| $A^2$ | 82.72 | 1 | 82.72 | 11.39 | 0.0118 |
| $B^2$ | 126.81 | 1 | 126.81 | 17.46 | 0.0041 |
| Residual | 50.85 | 7 | 7.26 | | |
| Lack of Fit | 20.83 | 3 | 6.94 | 0.9254 | 0.5055 (not significant) |
| Pure Error | 30.02 | 4 | 7.50 | | |
| Cor Total | 1021.50 | 12 | | | |
| $R^2$: 0.9052 | | Adjusted $R^2$: 0.9147 | | | Predicted $R^2$: 0.8079 |

*p*-value less than 0.05 is significant at $\alpha = 0.05$
Lack of fit is not significant at a *p*-value of more than 0.05

on white mulberries (Golpour et al., 2020) and garlic slices (Younis et al., 2018) also found that the infrared power factor was more effective at lowering drying time than air velocity.

It is noteworthy that only the quadratic term of air velocity was significant in the drying time response. However, the quadratic terms of temperature ($A^2$) and air velocity ($B^2$) were significant at $p<0.05$ in the SEC response. Therefore, changing the drying temperature and air velocity will significantly affect SEC, hence the cost of energy consumption. The longest drying time at 50°C and 3.0 m/s also contributed to the highest SEC, indicating that drying time response was somehow related to SEC. When the interaction between drying temperature and air velocity (AB) was insignificant in the drying time response, the same trend was observed in the SEC response. The removal of AB interaction from the model equation has increased the value of adjusted $R^2$ and predicted $R^2$ from 0.9147 to 0.9191 and 0.8079 to 0.8474, respectively. Based on the value of $R^2$ (0.9461), a quadratic model (Equation 9) to predict SEC was suggested in the infrared drying of desiccated coconut. There was a normal distribution of residual, which reflects the accuracy of prediction in the SEC response data as the plots lie along a straight line (Figure 5).

$$SEC = 21.16 - 8.65A + 5.01B + 3.50A^2 + 4.35B^2 \quad [9]$$

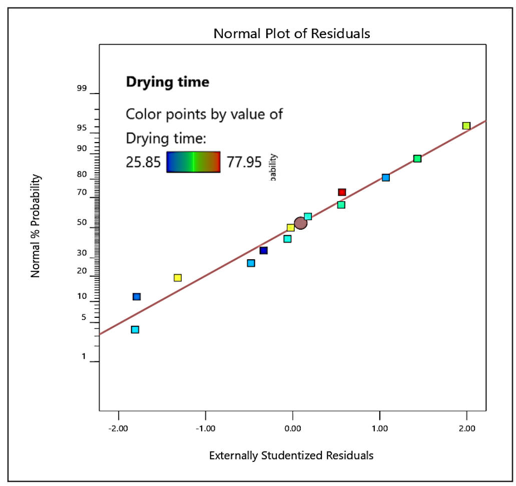



*Figure 3.* Normal plot of residuals for drying time

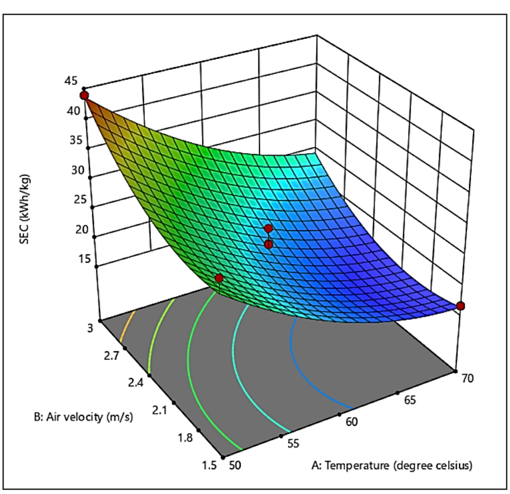



*Figure 4.* 3D plot of specific energy consumption against temperature and air velocity

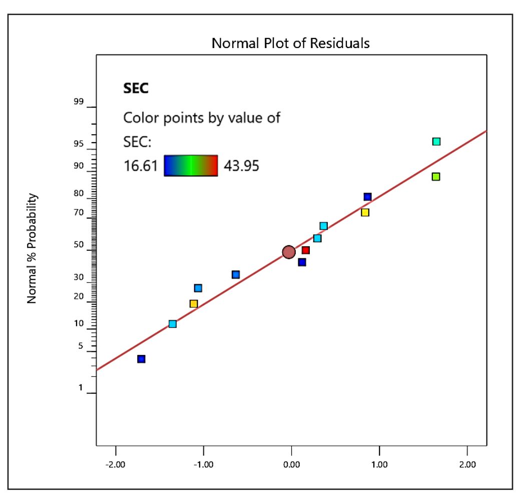



*Figure 5.* The normal plot of residuals for SEC

## Effect of Infrared Drying Parameters on Color Changes (ΔE)

In order to compare the color changes, the color of fresh shredded coconut was first measured beforehand, and the measured values of L*, a*, and b* were 76.46±0.30, -5.59±0.08 and 6.14±0.20 respectively. When it came to color change response, drying temperature and air velocity were both significant, although drying temperature's effect was discovered to be more pronounced than air velocities. It is evident by the higher *F*-value (35.47) and the coefficient estimate value, $\beta_i$ (1.56). Jafari et al. (2020) also reported similar results, observing that air velocity significantly affected the color changes of eggplant during infrared drying. Drying temperature contributed in a different way to color changes compared to other earlier responses. Since higher drying temperatures resulted in a positive effect of reducing drying time for desiccated coconuts, the effect on color changes was totally inversed. Again, the drying temperature was a dominant factor in determining the color changes of desiccated coconut, followed by air velocity. Nevertheless, in this case, the quadratic term of drying temperature had the highest *F*-value and the least *p*-value among all terms, as seen in Table 5. Unlike drying temperature in model responses drying time and SEC, the drying temperature factor in color changes had a positive sign, which reflects that an increment of 1.56 points of color changes would happen in every degree Celsius increases.

On the other hand, air velocity exhibits the ability to reduce color changes with a negative linear effect of coefficient estimate (-0.6505). In other words, a higher drying temperature, especially at 74°C, may have an advantage in reducing drying time but not preserving the desiccated coconut's color. Figure 6 illustrates that the minimum ΔE of desiccated coconut (2.19) was in the middle range of air velocity and drying temperature

Table 5
*ANOVA results for color changes (ΔE) response*

| Term | Sum of squares | df | Mean square | F-value | p-value |
|---|---|---|---|---|---|
| Model | 46.07 | 5 | 9.21 | 16.77 | 0.0009 (significant) |
| A-Temperature | 19.50 | 1 | 19.50 | 35.47 | 0.0006 |
| B-Air velocity | 3.35 | 1 | 3.35 | 6.10 | 0.0429 |
| AB | 0.3551 | 1 | 0.3551 | 0.6461 | 0.4480 |
| $A^2$ | 20.67 | 1 | 20.67 | 37.60 | 0.0005 |
| $B^2$ | 3.90 | 1 | 3.90 | 7.09 | 0.0323 |
| Residual | 3.85 | 7 | 0.5496 | | |
| Lack of Fit | 1.55 | 3 | 0.5166 | 0.8994 | 0.5153 (not significant) |
| Pure Error | 2.30 | 4 | 0.5744 | | |
| Cor Total | 49.92 | 12 | | | |
| $R^2$: 0.9229 | | Adjusted $R^2$: 0.8679 | | | Predicted $R^2$: 0.7096 |

*p*-value less than 0.05 is significant at $\alpha = 0.05$
Lack of fit is not significant at a *p*-value of more than 0.05

(60°C and 2.3 m/s). In terms of the model, the coefficient determination ($R^2$), Adj-$R^2$, and Pred-$R^2$ values were 0.9229, 0.8679, and 0.7096, respectively, as shown in Table 5. Besides the higher $R^2$ value, the difference between Adj-$R^2$ and Pred-$R^2$ values was also less than 0.2, which reflects a reasonable agreement. On top of that, it is clearly seen from Table 5 that the model for color change response was significant at $p<0.05$ with a non-significant lack of fit of ($p>0.05$). Since the interaction term (AB) was insignificant, the term was removed; hence, the model of equation 10 was suggested with higher adjusted and predicted $R^2$ values (0.8737 and 0.7624), respectively. All these values and findings indicated that model equation 10 can be suggested to predict the response for given levels of each factor on the color changes of desiccated coconut. It was also supported by the residual data in Figure 7, which found no outliers.

$$\text{\textit{Color changes}} = 3.17 + 1.56A - 0.6505B + 1.75A^2 + 0.7620B^2 \quad [10]$$

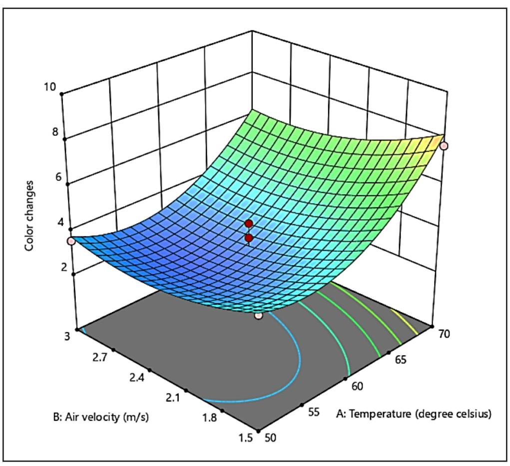



*Figure 6*. 3D plot of color changes against temperature and air velocity

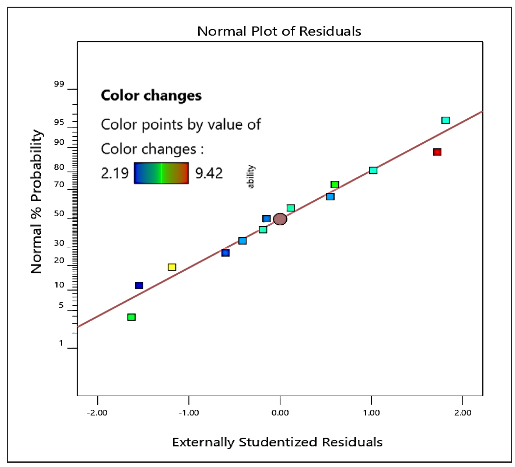



*Figure 7*. Normal plot of residuals for color changes

## Effect of Infrared Drying Parameters on Whiteness Index (WI)

Table 6 shows that both linear (A, B) and quadratic terms ($A^2$, $B^2$) of drying temperature and air velocity substantially affected the whiteness index of desiccated coconut. In view of this, drying temperature (linear and quadratic terms) remains the main factor for WI response, and this can be proven by the $p$-value of less than 0.05 with higher $F$-values of 27.17 and 29.49, respectively, compared to air velocity. Overall, the whiteness index of desiccated coconut varies from 66.50±1.272 to 73.00±0.110 for all conditions of variables (temperature and air velocity) during infrared drying. It's noteworthy to note in Figure 8 that the curvature of the 3D surface of WI was somewhat different from that of the 3D surface of color changes.

Table 6
*ANOVA results for whiteness index (WI) response*

| Term | Sum of squares | df | Mean square | F-value | p-value |
|---|---|---|---|---|---|
| Model | 36.02 | 5 | 7.20 | 13.33 | 0.0018 |
| A-Temperature | 14.69 | 1 | 14.69 | 27.17 | 0.0012 |
| B-Air velocity | 3.04 | 1 | 3.04 | 5.63 | 0.0495 |
| AB | 0.2712 | 1 | 0.2712 | 0.5017 | 0.5017 |
| $A^2$ | 15.94 | 1 | 15.94 | 29.49 | 0.0010 |
| $B^2$ | 3.46 | 1 | 3.46 | 6.41 | 0.0392 |
| Residual | 3.78 | 7 | 0.5406 | | |
| Lack of Fit | 1.41 | 3 | 0.4713 | 1.74 | 0.5570 (not significant) |
| Pure Error | 2.37 | 4 | 0.5926 | | |
| Cor Total | 39.81 | 12 | | | |
| $R^2$: 0.9049 | | Adjusted $R^2$: 0.8370 | | | Predicted $R^2$: 0.6567 |

*p*-value less than 0.05 is significant at $\alpha = 0.05$
Lack of fit is not significant at a *p*-value of more than 0.05

The minimum value of color changes (2.19±0.098), for example, indicates the highest value of the whiteness index (73.00±0.110) when desiccated coconut is dried using infrared drying at (60°C and 2.3 m/s). Nevertheless, the whiteness index was at its lowest at (74°C and 2.3 m/s). In other words, the lower the color changes, the higher the whiteness index of desiccated coconut. This result may have been caused by the destruction of some temperature-sensitive color-attributing pigments at higher temperatures, which would increase color variance and lower the whiteness index (Bhat et al., 2020). Therefore, it can be said that the WI of desiccated coconut was inversely related to the color changes that occurred during infrared drying.

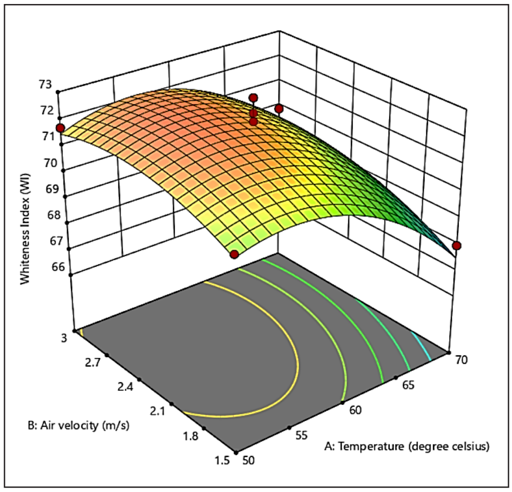


*Figure 8.* 3D plot of whiteness index against temperature and air velocity

Using hot air drying, Jongyingcharoen et al. (2019) also conducted another study and found that the drying duration also affected the dried coconut's whiteness index (WI), with shorter drying times producing whiter dried coconut. The longer drying times with lower drying temperatures probably led to the enzymatic browning of desiccated coconut. This phenomenon could also be seen at the lowest drying temperature and air velocity during infrared drying. Nevertheless, the non-enzymatic browning of desiccated coconut caused by the radiation of higher temperatures was more impactful to the whiteness index. Meanwhile, the optimized model in equation 11 was introduced after removing the insignificant interaction term (AB). The probability plot of whiteness index residuals in Figure 9 further verified the model's suitability.

$$\textit{Whiteness Index (WI)} = 72.0 - 1.35A + 0.6197B - 1.54A^2 - 0.7184B^2 \quad [11]$$

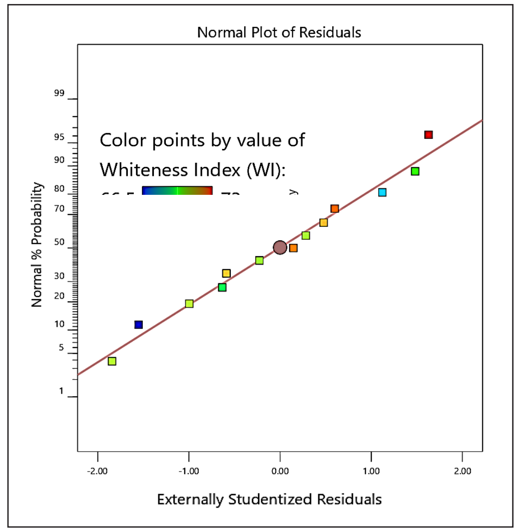



*Figure 9*. Normal plot of residuals for whiteness index

## Optimization of Infrared Drying Process Parameter and Validation of Model

The optimization aimed to maximize the desiccated coconut's whiteness index while minimizing the drying time, SEC, and color changes. Solution 1 in Table 7 was chosen as the optimum condition for infrared drying of desiccated coconut. The optimum IR temperature and air velocity for drying desiccated coconut in an infrared dryer were 61°C and 2.2 m/s, respectively. These independent variables led to the following dependent variables: drying time of 36.826 minutes, SEC of 19.821 kWh/kg, color changes (ΔE) of 3.431, and whiteness index (WI) of 71.762, with desirability of 0.827. Tables 8 and 9 compare the results between experiments and predicted under the optimum conditions.

Table 7
*Result and solutions of optimization by desirability value of RSM*

| Number | Temperature (°C) | Air velocity (m/s) | Drying time (min) | SEC (kWh/kg) | ΔE | WI | Desirability |
|---|---|---|---|---|---|---|---|
| 1 | 61.059 | 2.172 | 36.826 | 19.821 | 3.431 | 71.762 | 0.827 (Selected) |
| 2 | 61.096 | 2.180 | 36.833 | 19.836 | 3.429 | 71.764 | 0.827 |

Table 8
*The predicted and measured experimental values for four responses at optimum drying condition*

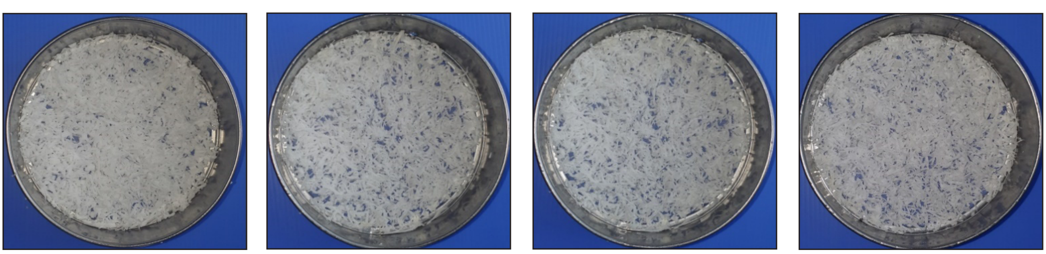
| Run | Drying time (min) | SEC (kWh/kg) | Color changes (ΔE) | Whiteness Index (WI) |
|---|---|---|---|---|
| Experiment 1 | 36.930 | 19.960 | 3.286 | 71.890 |
| Experiment 2 | 36.100 | 19.511 | 3.636 | 71.576 |
| Experiment 3 | 37.020 | 20.008 | 3.565 | 71.618 |
| Predicted value | 36.826 | 19.821 | 3.431 | 71.762 |

Table 9
*Validation of optimum infrared drying conditions for desiccated coconut*

| Response | Selected range | Predicted value | Experimental values[1] | Relative Difference[2] | % error[3] |
|---|---|---|---|---|---|
| Drying time (min) | Minimum | 36.826 | 36.683±0.507 | 0.017 | 0.39 |
| SEC (kWh/kg) | Minimum | 19.821 | 19.826±0.274 | -0.076 | 0.03 |
| ΔE | Minimum | 3.431 | 3.496±0.185 | -0.063 | 1.86 |
| WI | Maximum | 71.762 | 71.695±0.170 | 0.285 | 0.09 |

[1]Experimental values were expressed as mean ± standard deviation
[2](Predicted-Experimental)
[3]The % error $= \left[\left|M_{ev} - M_{pv}\right|/M_{ev}\right] \times 100$

Verification experiments under optimum conditions show the percentage error values of less than 2%, demonstrating the appropriateness of the developed models. According to (Nordin et al., 2019; Sadeghi et al., 2019; Tajudin et al., 2021), a percentage error of less than 10% was considered acceptable. Therefore, the optimum process parameters of discovered infrared drying can be recommended for producing high-quality desiccated coconut in which the drying time and SEC were decreased while maintaining the final product's color quality. The optimal conditions for validation are shown in Figure 10, where there is no discernible color difference between fresh shredded coconut and desiccated coconut. It unquestionably shows that the color of desiccated coconut could be conserved and retained under ideal infrared drying conditions.



(a) (b) (c) (d)

*Figure 10.* Pictures of fresh sample (a) and dried samples at optimal infrared drying conditions (b, c and d) for validation

## CONCLUSION

This study demonstrated the effects of infrared drying conditions with a fixed power intensity of 600 Watts and an emitter distance of 15 cm from the thin layer desiccated coconut sample. The drying temperature, followed by air velocity, was the most significant factor affecting all responses. Nevertheless, the interaction factor was insignificant in every response with $p$>0.05. Aside from a quicker drying period at a higher temperature of 74°C, it appeared to have a detrimental impact on color changes in comparison to freshly shredded coconut. On the other hand, higher air velocity prolonged the drying time and increased the SEC. The drying time response was closely related to the SEC response, as the results and the 3D surface plot had almost the same pattern. In contrast, minimum color changes would determine the desiccated coconut's maximum whiteness index value. Although higher air velocity had no advantage in reducing drying time and SEC, it plays a vital role in achieving the product's final quality by retaining the whiteness index of desiccated coconut. The optimal experimental conditions for infrared drying of desiccated coconut were 61°C (drying temperature) and 2.2 m/s (air velocity) with minimum drying time, SEC, ΔE, and maximum WI. Suggested models for each response were well accepted with ($p$<0.05), insignificant lack of fit, and higher value of coefficient determination. The variance between predicted and experimental results was (<10.0%) within the acceptable range, providing strong validation for the optimization models. These optimized models could be used as a reference for the commercial application of infrared drying on desiccated coconut.

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