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## Research Article

# Impact of Size Reduction, Drying Temperature, and Drying Time on Overripe Tempe Powder Quality Parameters

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**Abstract:** Tempe is a popular Indonesian plant-based protein source. Overripe tempe, an extended fermentation period of fresh tempe, has been explored as a flavor enhancer in various Indonesian cuisines. This study aimed to determine the optimal processing conditions for overripe tempe powder using RSM and central composite design in Design Expert 13.0®. Drying temperature (60°C – 80°C) and time (180 – 240 min) were tested as numerical factors, while sample shape (slices or pellets) was a categorical factor, resulting in 20 randomized experiments. The quality parameters of the produced powder—moisture content, angle of repose, browning index, whiteness index, and sensory attributes (clumpiness, color, aroma, and taste intensity)—were used to develop model equations. Correlation analysis of the models showed that drying temperature and time significantly influenced moisture content, clumpiness, and aroma intensity. Optimization of the response models identified grinding and drying at 80°C for 240 min as the best conditions. Validation confirmed that the resulting powder met the regulated moisture content standard and offered benefits such as shorter drying time and improved flowability compared to previous methods.

**Keywords:** Drying; Overripe tempe powder; Powder quality; Response surface methodology; Size reduction

## 1. Introduction<sup>1</sup>

Tempe derived from soybeans is a popular source of plant-based protein in Indonesia and worldwide (Shurtleff and Aoyagi, 2022). Tempe is a vitamin B12 contributor, with *R. oligosporus* being the main isolated culture in tempe production (Kustyawati et al., 2020). Fermentation of soybeans by *Rhizopus* spp. for up to 48 h results in tempe with white mycelium. An extended fermentation period of 48–72 h will result in overripe tempe with

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a softer texture, brownish mycelium, and a distinctly pungent aroma, known as tempe semangit (Hassanein et al., 2015). An extended fermentation period of more than 72 h results in tempe bosok (Utami et al., 2016). The longer the fermentation time, the more free amino acids are formed, including aspartic acid and glutamic acid, which contribute to the umami profile and potential to enhance flavor (Nuraini et al., 2022). The utilization of tempe semangit as a flavor enhancer is found not only in various traditional Javanese dishes but also in various studies, such as overripe tempe flour (Mulyana et al., 2014), seasoning (Gunawan-Puteri et al., 2015; Metty et al., 2022), instant stock (Gunawan-Puteri et al., 2017), porridge (Gunawan Puteri et al., 2018; Gunawan-Puteri et al., 2018), cookies (Kusumawaty et al., 2020, Kusumawaty et al., 2023), and nuggets (Harefa, 2020).

Fresh overripe tempe, with its higher moisture content and extended fermentation period, is particularly prone to microbial contamination (Skowron et al., 2022). The use of overripe tempe in powder form offers advantages over fresh tempe in terms of practicality, versatility, lower microbial risk, and shelf life. Powdered overripe tempe is convenient for various applications, such as condiments, soups, sauces, snacks, and other products. The low moisture content in powder forms contributes to its extended shelf life, inhibiting microbial growth and reducing the possibility of spoilage (Rifna and Dwivedi, 2021). Achieving a low moisture content also improves powder recovery, as it corresponds to a higher glass transition temperature, which decreases the risk of stickiness during handling (Shofinita et al., 2024). This aspect makes storage and transport more efficient and less susceptible to quality degradation.

The drying process is fundamental in reducing moisture content, lowering the growth of harmful microorganisms, and extending the shelf life of a powder product. Drying enhances microbial safety by creating an environment that is unsuitable for the growth of pathogens and spoilage microorganisms (Bourdoux et al., 2016). Several factors, including the characteristics of the materials (initial moisture content and thickness) and drying conditions (drying temperature, duration, and air flow), affect the effectiveness of the drying process. (Hassanein et al., 2015) stated that a rapid drying process could lead to the formation of a crust on the tempe surface, which disrupts moisture evaporation. The drying challenges emphasize the importance of optimizing drying factors to ensure that the final product meets quality and safety standards.

Broad applications of two-stage drying have been implemented in some studies by combining different drying temperature (Akhtaruzzaman et al., 2022; Namsanguan et al., 2004). The two-stage drying process can effectively reduce the drying time to a much faster level (Ostermeier et al., 2020). This approach has been applied to the production of overripe tempe powder; however, the existing process has shown constraints in the context of food safety and industrial application. Although it meets the standard moisture content, drying at room temperature exposes the overripe tempe, a high moisture and protein content ingredient, to microbial contamination. The long drying time (17 h) is also not applicable to industries with limited working hours. Food product exposure at low temperatures for a long period exhibits inefficiency in the process and might increase the risk of microbial contamination because it is a comfort zone for microbes to grow (US Food and Drug Administration (USFDA), 2023). High-protein foods are prone to spoilage, which causes bacteria to produce off-odors by breaking down the food components (Rawat, 2015). Attempts by Errat, 2022 to dry tempe at shorter time and higher temperatures failed to produce overripe tempe powder that meets the same targeted moisture content from the existing standard process. High moisture content leads to the degradation of food components and increases the risk of microbial contamination, thereby reducing the shelf life of the product (Herawati et al., 2021).

To address the abovementioned issues, this study aimed to find the best combination of drying factors—sample shape (through size reduction methods of grinding and slicing), drying temperature, and drying time—that resulted in overripe tempe powder meeting the required quality standards, particularly moisture content. The impact of these factors on quality parameters was evaluated using RSM coupled with CCD. The study also sought to reduce drying time without compromising sensory properties and compared the optimized product with an existing standard process to assess its overall quality. Implementing the best drying design may support better efficiency in producing overripe tempe powder.

## **2. Methods**

### **2.1 Materials**

Overripe tempe and frozen overripe tempe were obtained from PT Pangan Bijak Indonesia, Bogor, West Java, Indonesia. The overripe tempe was processed as a standard reference of overripe tempe powder, and the frozen overripe tempe was stored in a freezer at -18 °C for a maximum of 2 days before further treatment.

### **2.2 Preparation of Overripe Tempe Powder**

The overripe tempe powder was produced by following the existing standard production method of overripe tempe powder in PT PBI. The standard reference was produced at PT PBI by grinding 1 kg of overripe tempe into tempe pellets with a grinding machine (Getra, TJ12, China) and drying the pellets with a compartment dryer for 17 h at room temperature (25-30 °C). The compartment dryer is a custom-built wooden chamber equipped with a fan and an internal tray system, designed to provide uniform air circulation for drying samples under controlled conditions. The pellets were further dried in an oven (Getra, RFL-12SS, China) at 120 °C for 25 min, and the dried pellets were milled into overripe tempe powder using a food processor (Panasonic, MX-AC400WSR, China).

### **2.3 Experimental Design by Response Surface Methodology**

The impact of the treatment on the quality parameter of the overripe tempe powder was further evaluated using the RSM method and CCD in Design Expert 13.0® software (Stat-Ease Inc., Minneapolis, USA). In this study, modifications were applied by varying the type of overripe tempe shapes and drying time and initial drying temperature. The factors used were shapes as a categorical factor and drying temperature and time as numerical factors. The variables in the categorical factors were slicing and grinding, while the limits defined in the numerical factors were 60-80 °C for temperature and 180-240 min for time. The center points were set to 2 in the CCD, and the alpha values for the numerical factors were determined as follows: the designated -alpha values were 56 °C and 168 min, and the designated +alpha values were 84 °C and 252 min. The combination of numeric factor, categorical factor, and center points resulted in 20 experiments for the initial drying stage.

One kilogram of frozen overripe tempe went through the aforementioned treatments. Slicing was performed using a slicing machine (Torrey, R300A, Mexico) with a thickness of 1.5 mm, while the grinding process was performed using a grinding machine (Getra, TJ12, China). Both the ground and sliced overripe tempe underwent low-temperature drying with an oven dryer (Memmert, ULM-700, Germany) at 56-84 °C for 168-252 min according to the experimental design from Design Expert 13.0® software (Table 1). After the initial drying process, the next size reduction process and high-temperature drying

used the same equipment and parameters as the existing standard process, but the order of the second size reduction and high-temperature drying was swapped. The final products were evaluated for their moisture content, angles of repose, color, and sensory properties (clumpiness level, color, aroma, and taste intensity). The moisture content was analyzed using the oven method at 105°C for 3 h (AOAC, 2005). The best drying factors were selected using the optimization feature in the Design Expert 13.0®. The selected drying process parameters were analyzed using the software's point prediction tools by evaluating the analysis of variance and fit statistics. The selected drying design through 5 replications was done by analyzing the mean values differences between predicted and experimental verification ( $\alpha = 0.05$ ).

## 2.4 Physicochemical Analysis

### 2.4.1 Angle of the Repose

The angle of repose was measured according to ASTM C1444-00 (ASTM, 2005) with modifications. The sample was weighed 100 g and dropped from a height of 15 cm through a funnel. The sample was poured onto a white paper-covered flat surface. The base diameter and the peak height of the sample pile were measured. The angle of repose was calculated using the formula presented in equation 1.

$$\text{Angle of repose}(\circ) = \arcsin \times \left( \frac{\text{height}}{\frac{1}{2} \times \text{diameter}} \right) \quad (1)$$

### 2.4.2 Color Evaluation

Color as a physical property was evaluated by calculating the browning index and whiteness index. The values of  $L^*$  (lightness),  $a^*$  (redness), and  $b^*$  (yellowness) were obtained using a chromometer (PCE-SCM 6, United Kingdom).  $L^*$  indicates lightness from dark to light, with a scale of 0 to 100,  $a^*$  indicates greenness to redness, with a scale from -128 to +127, and  $b^*$  indicates blueness to yellowness, with the same scale from -128 to +127. The equipment was calibrated using a white plate before the measurement. The browning index (Ergüneş and Tarhan, 2006) and whiteness index (Torbica et al., 2012) were calculated using the formula presented in equation 2 and equation 3, respectively.

$$\text{Browning index} = \frac{100(x - 0.31)}{0.17}, \quad \text{where } x = \frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^*} \quad (2)$$

$$\text{Whiteness index} = 100 - \sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}} \quad (3)$$

### 2.4.3 Sensory Evaluation

Overripe tempe powder was evaluated by 15 trained panelists for its sensory (color, clumpiness, aroma, and taste intensity) using a 7-scale rating intensity test. The trained panelists comprised researchers, lecturers, and staff from the Swiss German University, Tangerang, Indonesia. The panelists were trained for up to 50 h on savory products and spices. Before sensory evaluation, the participants were informed about the direct risk and provided consent before participating. They had the right to withdraw their consent, and participation in this research was not compulsory. The panelists evaluated the overripe tempe powder and gave a score from 1 to 7 for each attribute. For color intensity, observed by sight, a score of 1 represents “very light/pale” and a score of 7 represents “very dark.” For the clumpiness level, observed by pouring the powder into the palm and pressing it

with the thumb, a score of 1 represents “no clumps” and a score of 7 represents “high level of clumps.” Aroma, observed by smelling, score 1 represents “very weak roasted aroma” and score 7 represents “very strong roasted aroma”. Taste intensity, observed by tasting, score 1 represents “very weak” and score 7 represents “very strong”.

## 2.5 Statistical Analysis

The data collected from the drying design were subjected to statistical analysis of variance and Pearson correlation using Design Expert 13.0®. Statistical significance was determined at a 95% confidence level ( $\rho \leq 0.05$ ). Pearson correlation was used to determine the relationship between each quality parameter. The final comparison between the existing product and the final selected product was analyzed using a one-sample analysis of the t-test. The results were significant at 95% confidence level ( $\rho \leq 0.05$ ) and were expressed with different letter superscripts.

## 3. Results and Discussion

The existing standard production process used a low-temperature drying process for the initial drying stage and a high-temperature drying process for the final drying stage. After the initial drying stage, the existing standard production process resulted in overripe tempe pellets with a moisture content of 16.86%. The final product, overripe tempe powder, had a moisture content of 3.43%, meeting the Indonesian seasoning moisture content standards specified in SNI 01-4273-1996 and SNI 01-4281-1996. Even though the final moisture content met the standards, the process was subjected to safety risk in the initial drying stage and at the step right after grinding with the food processor, where no further treatment was applied to eliminate the microbial risk and not suitable for industrial operation. Low-temperature drying at room temperature for 17 h was also not applicable at the industrial level with limited working hours. It also increased the risk of unwanted microbial growth while being exposed to the danger zone’s temperature range (US Food and Drug Administration (USFDA), 2023). Errat, 2022 improved overripe tempe powder production by reducing drying time, increasing the temperature, and replacing the equipment with a dehydrator for low-temperature drying. However, the dried overripe tempe was burnt and had a higher moisture content (33.43%) than the existing process of air-dried overripe tempe, which was 16.86%.

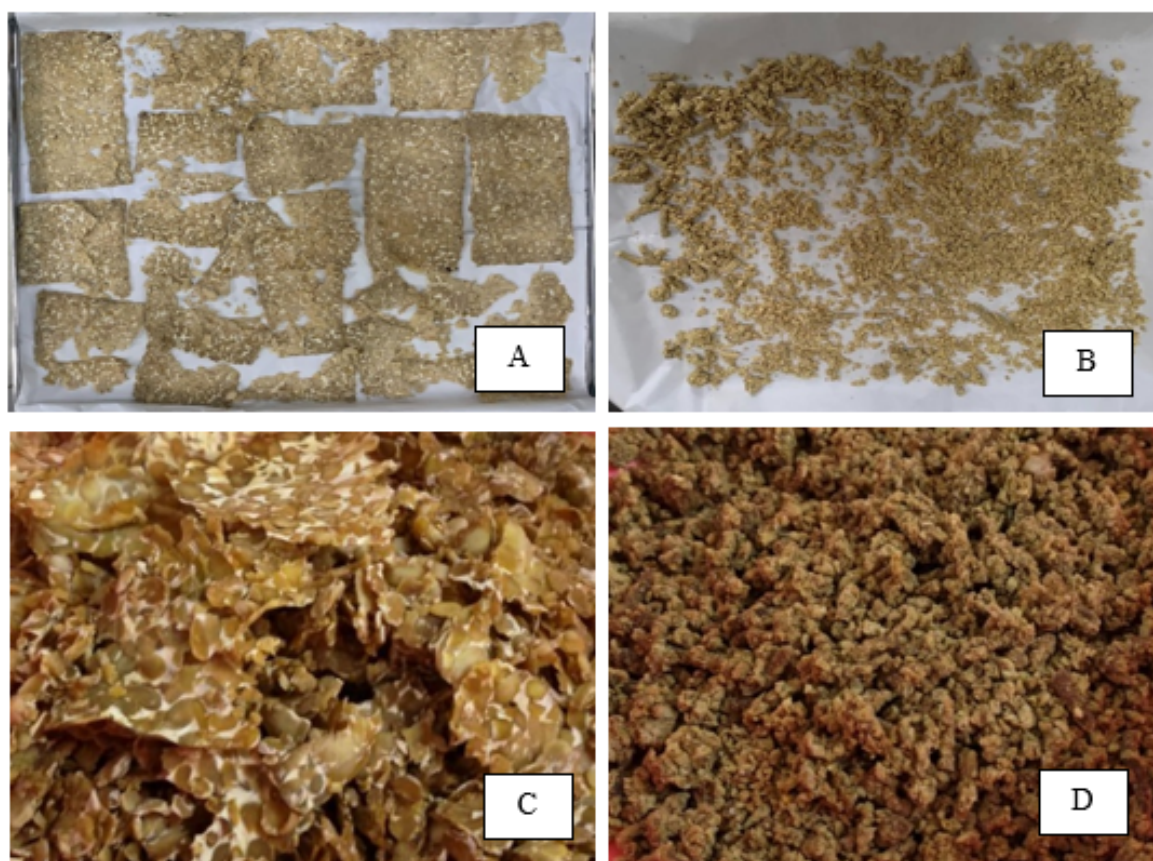
### 3.1 Impact of Size Reduction, Drying Temperature, and Drying Time in Low-Temperature Drying

The drying parameters of the previous study (Errat, 2022) were set at 80 °C for 240 min; however, the resulting moisture content was still very high, and the product was burned. Thus, it was recommended by Errat, 2022 to initially dry at a lower temperature and continue with the final drying at a higher temperature. A further recommendation was to modify the type of overripe tempe shapes into slices and ground form. The drying method implemented in our study combined low-temperature for the initial drying and high-temperature for the second drying. High-temperature drying was not applied in the initial drying because it might cause protein denaturation that would result in an undesirable texture property (Hassanein et al., 2015). Therefore, the overripe tempe drying process required two drying stages, i.e., low-temperature drying at the first stage and high-temperature drying at the final stage. In our study, an oven dryer was used for the initial drying stage, and oven baking was used for the final drying stage.

Based on the recommendations from the previous study, we continued to examine



the impact of size reduction type, drying temperature, and drying time on overripe tempe powder quality parameters. Since the surface area and thickness of the material influence the drying rate, a material with a greater cross-sectional area enhances the water diffusion, and the thinner the material, the faster it will dry (Yando and Paramita, 2018). In the initial low-temperature drying stage, the drying temperature was set between 60 °C and 80 °C, and the drying time was set at a minimum of 180 min to a maximum of 240 min. The adjustments were based on the consideration of the temperature limit for microbial growth in the danger zone (US Food and Drug Administration (USFDA), 2023), previous study (Errat, 2022), and employee working hours. The dried overripe tempe pellet and sliced overripe tempe (Figure 1) were ground in an oven before the final drying stage at a high temperature (120°C, 25 min).



**Figure 1** Variations in overripe tempe: freshly sliced (A), freshly ground (B), dried sliced (C), and dried pellet (D)

A set of 20 designed experiments (Table 1) was generated by software for the initial drying stage by incorporating numeric factors, categoric factors, and center points. Variations in the sample shapes (slices and pellets) were categorized as categorical factors, temperature and time limits were categorized as numeric factors, and the center points were set to 2. The moisture content, angle of repose, browning index, whiteness index, color intensity, clumpiness level, aroma intensity, and taste intensity of the final overripe tempe powder were evaluated. The impact of the drying factors on the quality parameter was evaluated using RSM from Design Expert 13.0® software with central composite design. Table 1 shows the design experiment and the aforementioned experimental response data. The responses analyzed with software were data from the final overripe tempe powder of the second drying in oven baking (120 °C, 25 min).

The lowest moisture content achieved was 1.88%, with the highest intensity of aroma

and taste (Table 1). This condition was observed in the drying model with the maximum temperature and duration of the grinding process (80°C, 240 min). The trial drying design numbers 5, 7, 11, and 19 were able to achieve a moisture content below 4%, which is in accordance with the Indonesian national standard from SNI 01-4273-1996 and SNI 01-4281-1996 with temperature and time variations of 70 °C, 252 min and 80 °C, 240 min, respectively, both in the form of overripe tempe pellets and slices. The different types of sample shapes did not significantly affect moisture removal; however, drying temperatures above 70 °C and drying times above 240 min resulted in better moisture release.

**Table 1** Design experiment and responses of overripe tempe drying trial design

| No | Independent variable |         |         | Dependent variable / responses |        |       |       |      |      |       |       |
|----|----------------------|---------|---------|--------------------------------|--------|-------|-------|------|------|-------|-------|
|    | T (°C)               | t (min) | SS      | MC (%)                         | AR (°) | BI    | WI    | CI*  | CL** | AI*** | TI*** |
| 1  | 56                   | 210     | Pellets | 32.08                          | 30.96  | 68.37 | 50.47 | 2.33 | 5.67 | 2.60  | 4.67  |
| 2  | 84                   | 210     | Slices  | 4.06                           | 23.57  | 72.35 | 54.53 | 1.80 | 1.27 | 3.93  | 4.27  |
| 3  | 70                   | 210     | Slices  | 16.36                          | 30.76  | 91.93 | 45.72 | 5.47 | 5.07 | 3.33  | 4.80  |
| 4  | 60                   | 240     | Pellets | 21.14                          | 29.75  | 77.88 | 46.65 | 4.13 | 4.73 | 3.40  | 4.80  |
| 5  | 80                   | 240     | Pellets | 1.88                           | 33.38  | 66.94 | 54.71 | 2.93 | 1.60 | 4.40  | 5.07  |
| 6  | 60                   | 180     | Slices  | 29.12                          | 29.6   | 75.52 | 51.98 | 2.40 | 3.67 | 2.80  | 3.93  |
| 7  | 80                   | 240     | Slices  | 3.64                           | 23.89  | 65.11 | 53.83 | 3.27 | 2.27 | 3.80  | 4.67  |
| 8  | 84                   | 210     | Pellets | 8.43                           | 23.67  | 80.41 | 50.55 | 3.20 | 2.47 | 3.87  | 3.73  |
| 9  | 60                   | 180     | Pellets | 35.08                          | 32.14  | 68.11 | 50.67 | 2.40 | 4.93 | 3.47  | 4.53  |
| 10 | 56                   | 210     | Slices  | 32.58                          | 30.25  | 78.33 | 47.85 | 3.60 | 5.73 | 2.80  | 5.33  |
| 11 | 70                   | 252     | Slices  | 3.93                           | 26.61  | 61.81 | 57.26 | 1.53 | 1.53 | 3.80  | 3.20  |
| 12 | 70                   | 168     | Pellets | 26.88                          | 30.88  | 75.31 | 48.16 | 3.80 | 4.07 | 3.73  | 4.87  |
| 13 | 70                   | 210     | Pellets | 12.10                          | 27.03  | 82.54 | 47.23 | 3.07 | 2.60 | 4.07  | 3.80  |
| 14 | 70                   | 168     | Slices  | 18.87                          | 29.28  | 82.41 | 44.73 | 5.07 | 4.27 | 3.87  | 4.60  |
| 15 | 70                   | 210     | Slices  | 13.74                          | 26.09  | 80.07 | 47.50 | 4.20 | 2.67 | 3.73  | 4.07  |
| 16 | 60                   | 240     | Slices  | 14.61                          | 28.79  | 76.63 | 47.18 | 3.87 | 3.60 | 3.27  | 3.93  |
| 17 | 80                   | 180     | Slices  | 11.11                          | 26.02  | 73.49 | 45.15 | 4.87 | 3.07 | 4.00  | 4.00  |
| 18 | 80                   | 180     | Pellets | 13.85                          | 31.30  | 82.10 | 44.76 | 4.93 | 3.53 | 4.20  | 3.73  |
| 19 | 70                   | 252     | Pellets | 3.88                           | 26.61  | 76.45 | 51.79 | 2.53 | 1.80 | 4.20  | 3.93  |
| 20 | 70                   | 210     | Pellets | 5.13                           | 29.86  | 82.74 | 51.44 | 3.20 | 1.86 | 4.33  | 3.67  |

**Note:** T = temperature; t = drying time; SS = sample shapes; MC = moisture content;

AR = angle of repose; BI = browning index; WI = whiteness index; CI = color intensity;

CL = clumpiness level; AI = aroma intensity (roasted aroma); TI = taste intensity.

\* score 1 represents “very light/pale” and score 7 represents “very dark”;

\*\* score 1 represents “no clumps” and score 7 represents “high level of clumps”;

\*\*\* score 1 represents “very weak” and score 7 represents “very strong”.

The angle of repose of all drying designs was 35°, which can be classified as free-flowing powder (Koç et al., 2021). The browning index indicates the brown color level and is an essential parameter associated with browning (Ergüneş and Tarhan, 2006). The whiteness index determines the degree of whiteness of food products to the extent of color change during processing (Torbica et al., 2012). A higher browning index value indicates a greater browning reaction, and a higher whiteness index value indicates a higher level of whiteness. The highest browning index was observed on drying design number 3 with a value of 91.93, with the same trend observed by sensory evaluation of color intensity

that exhibited the highest color intensity. Conversely, the lowest browning index and color intensity values were found in drying design number 11. At the maximum drying condition (80 °C, 240 min), neither browning nor whiteness index exhibited the maximum values from the experimental results (91.93) and was not burned. Therefore, the drying temperature can be increased without causing the product to burn.

For the sensory evaluation of all 20 design experiments, a moisture content of more than 30% corresponded to a high level of clumping ( $> 5.0$ ). Low clumpiness levels ( $< 3.0$ ) were observed in trials with a moisture content of 10%. A higher moisture content also affected the aroma intensity, where a higher final moisture content ( $> 30\%$ ) showed weaker intensity of roasted aroma ( $< 3.0$ ). The highest intensity of roasted aroma was observed at the lowest moisture content in design number 5 (Table 1). The taste intensity of the overripe tempe powder reached its highest value at both high and low moisture content values, indicating that moisture content did not significantly impact taste intensity. Furthermore, a higher taste intensity corresponded to a higher level of clumpiness.

Negative and positive correlations define the correlation between temperature and time with the quality parameter (Table 2). The closer the value is to 1 or -1 indicates strong correlation between each parameter. Temperature and time significantly affected the moisture release in the drying process ( $r \approx -1$ ). The correlation between temperature and clumpiness level ( $r = -0.7$ ) showed that high temperature resulted in nonclumpy powder. Additionally, a positive correlation ( $r = 0.8$ ) was observed between temperature and aroma intensity, with higher temperature enhancing the overripe tempe powder's aroma intensity. Drying time also showed a moderate positive correlation with the whiteness index ( $r = 0.5$ ). The strongest positive correlation was observed between moisture content and clumpiness level ( $r = 0.9$ ). The lower moisture content indicated a lower level of clumpiness with fewer clumps observed by sensory evaluation. The strongest negative correlation was observed between color intensity and whiteness index ( $r = -0.9$ ), where a higher whiteness index conformed to a lighter color intensity.

**Table 2** Pearson correlation of temperature and time to the quality parameters for overripe tempe powder

|    | T    | t    | MC   | AR   | BI   | WI   | CI  | CL   | AI   | TI |
|----|------|------|------|------|------|------|-----|------|------|----|
| T  |      |      |      |      |      |      |     |      |      |    |
| t  | 0.0  |      |      |      |      |      |     |      |      |    |
| MC | -0.8 | -0.5 |      |      |      |      |     |      |      |    |
| AR | -0.5 | -0.3 | 0.5  |      |      |      |     |      |      |    |
| BI | -0.0 | -0.3 | 0.1  | 0.1  |      |      |     |      |      |    |
| WI | 0.2  | 0.5  | -0.4 | -0.2 | -0.7 |      |     |      |      |    |
| CI | 0.1  | -0.4 | 0.1  | 0.2  | 0.7  | -0.9 |     |      |      |    |
| CL | -0.7 | -0.4 | 0.9  | 0.6  | 0.3  | -0.6 | 0.4 |      |      |    |
| AI | 0.8  | 0.1  | -0.8 | -0.2 | 0.0  | 0.1  | 0.1 | -0.8 |      |    |
| TI | -0.3 | -0.1 | 0.4  | 0.4  | 0.0  | -0.2 | 0.2 | 0.6  | -0.4 |    |

**Note:** T = temperature; t = drying time; MC = moisture content; AR = angle of repose; BI = browning index; WI = whiteness index; CI = color intensity; CL = clumpiness level; AI = aroma intensity (roasted aroma); TI = taste intensity.

Verevka and Gao, 2025 emphasized the importance of correlation analysis as a precursor to regression modeling, ensuring that the final model retains only significant predictors.



Based on this approach, the selection of quality parameters for further optimization was based on significance analysis with analysis of variance. Table 3 shows the ANOVA for all dependent variables. Responses 1, 2, 3, 4, 6, and 7 indicated the existence of significant ( $p < 0.05$ ) effects between the independent and dependent variables, whereas responses 5 and 8 did not. All p-values from the lack of fit analysis were not statistically significant for all responses. The insignificant lack of fit indicated that the data were well-fitted with the model when it was applied. The closest  $R^2$  value to 1 indicates that the regression coefficient model can accurately predict the optimal value. The  $R^2$  values of responses 1, 3, 4, 6, and 7 indicated a strong correlation with the factors, whereas the  $R^2$  values of responses 2, 5, and 8 indicated a weak correlation. If the difference between predicted  $R^2$  and adjusted  $R^2$  is less than 0.2, there is a reasonable agreement between them. Responses 1 and 6 showed reasonable agreement, whereas other responses may indicate the possibility of a large block effect and problem in the model or data. Responses 5 and 6 with negative predicted  $R^2$  values indicated that the overall means might be a better predictor of the responses than the current model. Adequate precision with a value of more than 4 was preferable as it can measure the SNR. Responses 1–7 indicated adequate signals where the models could navigate the design, whereas response 8 indicated inadequate signals to navigate the design. Based on ANOVA and fit statistics analysis, responses 5 and 8 cannot be optimized, whereas the other responses can be further optimized by point prediction.

**Table 3** Analysis of variance of the models for physicochemical and sensory analysis (moisture content, angle of repose, browning index, whiteness index, color intensity, clumpiness level, aroma intensity, and taste intensity)

| Analysis              | Dependent variables / responses |          |         |         |         |         |         |         |
|-----------------------|---------------------------------|----------|---------|---------|---------|---------|---------|---------|
|                       | 1 MC (%)                        | 2 AR (°) | 3 BI    | 4 WI    | 5 CI    | 6 CL    | 7 AI    | 8 TI    |
| <i>P-value</i>        |                                 |          |         |         |         |         |         |         |
| Model                 | < 0.0001*                       | 0.0196*  | 0.0101* | 0.0070* | 0.1511  | 0.0006* | 0.0019* | 0.8514  |
| Lack of fit           | 0.8676                          | 0.7277   | 0.8116  | 0.5534  | 0.3108  | 0.8485  | 0.6826  | 0.2506  |
| <i>Fit Statistics</i> |                                 |          |         |         |         |         |         |         |
| $R^2$                 | 0.9746                          | 0.4513   | 0.7749  | 0.6999  | 0.4709  | 0.6517  | 0.9289  | 0.2559  |
| Adjusted $R^2$        | 0.9398                          | 0.3485   | 0.6112  | 0.5614  | 0.2266  | 0.5864  | 0.8311  | −0.2852 |
| Predicted $R^2$       | 0.8584                          | 0.1370   | 0.2889  | 0.3207  | −0.2488 | 0.4894  | 0.5646  | −1.6035 |
| Adequate precision    | 16.1520                         | 6.5790   | 7.4077  | 8.5443  | 5.1538  | 8.4350  | 9.9345  | 2.3127  |
| <i>Summary</i>        | ✓✓                              | ✓✓       | ✓       | ✓       | ×       | ✓✓      | ✓       | ×       |

**Note:** MC = moisture content; AR = angle of repose; BI = browning index; WI = whiteness index; CI = color intensity; CL = clumpiness level; AI = aroma intensity (roasted aroma); TI = taste intensity. \* represents statistical significance ( $p < 0.05$ ). ✓ = recommended; ✓✓ = highly recommended; × = not recommended; ×× = highly not recommended.

The responses selected as dependent variables that were further optimized were moisture content, angle of repose, browning index, whiteness index, and aroma intensity. Sensory properties, such as color and aroma, are also important parameters in seasoning products (Pamungkas, 2022). Sensory properties other than moisture content, such as color and taste intensities, could not be further optimized due to the incompatibility of ANOVA and fit statistic analysis. Browning index and whiteness index values are able to represent the sensory evaluation of color intensity, while the moisture content, with a better  $R^2$  value of 0.9746, can represent the clumpiness level.

The goals of each independent variable were set based on the desired criteria. The

moisture content was minimized with an upper limit value of 4.00 as the limit of seasoning moisture content standards (BSN, 1996a;BSN, 1996b), which should be less than 4%. Based on the moisture goal (moisture content < 4%), 100 options were provided by the software using variable shapes (slices and pellets), drying temperature above 70 °C, and drying time of more than 200 min. Additional criteria were determined based on consumer parameter quality aspects, including angle of repose, browning index, whiteness index, and sensory acceptance, to select the solutions. The angle of repose was set to minimize to obtain the angle of repose of 35° required for the free flow characteristic of powder (Koç et al., 2021). The browning index was set to minimize burntness, whereas the whiteness index was set to the opposite. The aroma intensity was set to maximize with the lower limit set to 4.00, indicating a slightly strong roasted aroma. The highest importance level (Table 4) was adjusted to moisture content as the primary parameter in determining the drying quality. Table 4 shows the optimization criteria between the dependent and independent variables.

**Table 4** Optimization of independent and dependent variables for oven-dried overripe tempe powder

| Variable                    | Goal     | Lower limit | Upper limit | Lower weight | Upper weight | Importance |
|-----------------------------|----------|-------------|-------------|--------------|--------------|------------|
| <b>Independent Variable</b> |          |             |             |              |              |            |
| Temperature (°C)            | In range | 60          | 80          | 1            | 1            | +++        |
| Drying time (min)           | In range | 180         | 240         | 1            | 1            | +++        |
| Sample shapes               | In range | Slices      | Pellets     | 1            | 1            | +++        |
| <b>Dependent Variable</b>   |          |             |             |              |              |            |
| Moisture content (%)        | Minimize | 1.88        | 4.00        | 1            | 1            | +++++      |
| Angle of repose (°)         | Minimize | 23.57       | 33.38       | 1            | 1            | +++        |
| Browning index              | Minimize | 61.81       | 91.93       | 1            | 1            | +++        |
| Whiteness index             | Maximize | 44.73       | 57.26       | 1            | 1            | +++        |
| Aroma intensity             | Maximize | 4.00        | 4.40        | 1            | 1            | +++        |

The interactions between responses and factors were analyzed using Design Expert 13.0® software to determine the selected drying model. The model equation generated from the software is presented in equations (5)-(9) that contribute to the responses from the model:

*Moisture content (%)*

$$= 11.8400 - 9.0000X_1 - 6.3800X_2 - 3.2200X_3 + 1.1300X_1X_2 - 0.2962X_1X_3 - 0.9605X_2X_3 + 3.7700X_1^2 + 0.7610X_2^2 - 0.6338X_1X_2X_3 + 2.1600X_1^2X_3 + 2.6900X_2^2X_3 \quad (4)$$

$$Angleofrepose(^{\circ}) = 28.5200 - 1.5900X_1 - 0.8186X_2 + 1.0400X_3 \quad (5)$$

*Browning index*

$$= 84.3400 - 0.1273X_1 - 2.5200X_2 - 0.1600X_3 + 4.3000X_1X_2 - 2.6400X_1X_3 - 2.0400X_2X_3 + 5.0900X_1^2 + 5.5300X_2^2 \quad (6)$$

*Whiteness index*

$$= 49.6100 - 0.7218X_1 - 2.0500X_2 - 0.0350X_3 + 3.4300X_1X_2 - 0.4362X_1X_3 - 0.6572X_2X_3 \quad (7)$$

*Aroma intensity*

$$\begin{aligned}
&= 3.8600 - 0.4306X_1 - 0.6066X_2 - 0.3309X_3 + 0.0500X_1X_2 - 0.0124X_1X_3 \\
&\quad - 0.0389X_2X_3 - 0.2689X_1^2 + 0.0372X_2^2 - 0.1175X_1X_2X_3 + 0.1492X_1^2X_3 \\
&\quad + 0.0829X_2^2X_3
\end{aligned} \quad (8)$$

where  $X_1$ ,  $X_2$ , and  $X_3$  represent the temperature, drying duration, and tempe shape, respectively. The mathematical model can be used to determine and assess the effect of variables on each response.

The best variable combinations that resulted in tempe powder with the desired properties were tempe pellets with drying temperatures of 78.294 °C–80 °C for 240 min (Table 5). The desirability scores ranged from 0 to 1, with 0 being the least desired and 1 being the most desired. The preferred score should be  $> 0.75$ . All solutions were in accordance with the preferred desirability score. The sliced overripe tempe did not meet the selected criteria because the final moisture content was higher than that of the ground tempe. The moisture that escapes through gaps during the slicing process impacts the higher moisture transfer rates under the same drying conditions, in which a longer drying time may be required (Paul and Martynenko, 2022). The selection of the drying model was based on the highest desirability score (0.805) with the parameter of overripe tempe ground dried at 80 °C for 240 min. This indicates that the overripe tempe powder produced under the selected conditions achieved 80.5% of the specified selection criteria. Increasing the temperature above 80 °C is still promising because the product did not burn as reported in the previous study (Errat, 2022); otherwise, the drying time could not be extended due to the restricted working hours.

**Table 5** Solutions with predicted responses and desirability scores by Design Expert 13.0®

| No | T(°C)  | t(min) | SS      | MC (%) | AR (°) | BI     | WI     | AI*   | Des   |
|----|--------|--------|---------|--------|--------|--------|--------|-------|-------|
| 1  | 80.000 | 240    | Pellets | 1.859  | 27.145 | 71.607 | 54.750 | 4.340 | 0.805 |
| 2  | 79.843 | 240    | Pellets | 1.812  | 27.170 | 71.793 | 54.692 | 4.345 | 0.804 |
| 3  | 79.589 | 240    | Pellets | 1.743  | 27.211 | 72.090 | 54.597 | 4.353 | 0.803 |
| 4  | 78.294 | 240    | Pellets | 1.508  | 27.417 | 73.501 | 54.116 | 4.384 | 0.792 |

**Note:** T = temperature; t = drying time; SS = sample shapes; MC = moisture content; AR: angle of repose; BI: browning index; WI: whiteness index; AI: aroma intensity. \*score 1 represents "very weak" and score 7 represents "very strong".

The selected drying design (80 °C for 240 min using ground tempe) showed that the overripe tempe did not burn and produced overripe tempe powder with a targeted moisture content, better flowability, and lower safety risk. The use of RSM to identify the ideal drying conditions enabled an effective analysis of the interaction effects of temperature, drying time, and sample shape on the quality parameters of overripe tempe powder. This finding aligns with Arifan et al., 2022 and Esraa et al., 2022, who demonstrated the effectiveness of RSM in optimizing multivariable processes. Ismail et al., 2025 also verified that MVO involving complex factors, such as temperature and time, can significantly enhance process efficiency.

The final step in the modeling process was to verify the predicted model with experimental verification. The selected conditions (ground overripe tempe dried at 80 °C for 240 min) were verified experimentally with five batch replicates, and the results are shown in Table 6. The predicted values were calculated based on the software responses

to achieve the set target. The actual values were obtained from the experiment with the selected drying parameters.

**Table 6** Predicted and validated results of drying parameters (moisture content, browning index, whiteness index, aroma intensity, and taste intensity) for ground overripe tempe dried at 80 °C for 240 min

|                                    | Response / observation parameter |        |       |       |                 |                 |
|------------------------------------|----------------------------------|--------|-------|-------|-----------------|-----------------|
|                                    | MC (%)                           | AR (°) | BI    | WI    | AI <sup>r</sup> | TI <sup>r</sup> |
| <b>Prediction by Design Expert</b> |                                  |        |       |       |                 |                 |
| Mean                               | 1.86                             | 27.15  | 71.61 | 54.75 | 4.34            | 4.35            |
| Standard deviation                 | 2.66                             | 2.34   | 4.54  | 2.43  | 0.21            | 0.63            |
| Standard error                     | 2.42                             | 1.53   | 3.78  | 2.00  | 0.19            | 0.53            |
| <b>Experimental verification</b>   |                                  |        |       |       |                 |                 |
| Trial 1                            | 1.80                             | 29.61  | 55.37 | 61.45 | 4.13            | 4.14            |
| Trial 2                            | 4.02                             | 23.39  | 74.67 | 50.91 | 3.88            | 3.86            |
| Trial 3                            | 1.64                             | 27.83  | 58.96 | 58.75 | 4.50            | 3.71            |
| Trial 4                            | 2.89                             | 25.37  | 69.29 | 55.61 | 4.38            | 3.43            |
| Trial 5                            | 1.14                             | 32.69  | 69.25 | 56.51 | 5.45            | 4.90            |
| Actual Mean                        | 2.30                             | 27.78  | 65.51 | 56.65 | 4.47            | 4.01            |
| Actual Standard Deviation          | 1.16                             | 3.62   | 8.03  | 3.92  | 0.60            | 0.56            |
| Relative deviation mean (%)        | 23.66                            | 2.32   | 8.52  | 3.47  | 3.00            | 7.82            |
| 95% PI low                         | -3.73                            | 23.90  | 63.29 | 50.43 | 3.90            | 3.19            |
| 95% PI high                        | 7.44                             | 30.39  | 79.92 | 59.07 | 4.78            | 5.51            |
| Confirmation summary               | ✓                                | ✓      | ✓     | ✓     | ✓               | ✓               |

**Note:** MC = moisture content; AR: angle of repose; BI: browning index; WI: whiteness index; AI: aroma intensity; TI: taste intensity. \*score 1 represents "very weak" and score 7 represents "very strong".

✓ = acceptable

The moisture content of overripe tempe powder samples processed under the selected conditions ranged from 1.14% to 4.02%. The angle of repose values ranged from 23.39° to 32.69°. The browning and whiteness index ranged from 55.37 to 74.67 and 50.91 to 61.45, respectively. The whiteness index was lower than that of the tempe flour studied by Herawati et al., 2023, which was 65.33. This is influenced by the extended fermentation time of fresh tempe, which results in a brownish mycelium color (Gunawan-Puteri et al., 2015). The mean relative deviations from the moisture content, angle of repose, browning index, and whiteness index were 23.66%, 2.32%, 8.52%, and 3.47%, respectively.

The aroma intensity of overripe tempe powder samples processed under selected conditions ranged from 3.88 to 5.45. This score showed that the overripe tempe powder aroma ranged from a slightly weak roasted aroma to a strong roasted aroma. The taste intensity score ranged from 3.43 to 4.90, indicating slightly weak to slightly strong intensity. The mean relative deviations from the aroma and taste intensities were 3.00% and 7.82%, respectively.

Differences were observed between the predicted and experimental values for all responses. As shown in Table 6, the mean value of experimental verification for all responses lies between the 95% interval prediction limits, indicating that the difference between the predicted and actual values is not greater than 5% ( $\alpha = 0.05$ ). This confirms that the verification is acceptable and that the model is sufficient for producing overripe tempe powder.

### 3.2 Physicochemical and Sensory Properties of Existing and Selected Processes

Table 7 presents the physicochemical and sensory properties of the tempe powder obtained from the selected and existing standard processes. The selected process achieved the targeted moisture content below 4% (BSN, 1996a;BSN, 1996b), angle of repose ( $< 35^\circ$ ), aroma intensity ( $\geq 4.0$ ), and taste intensity ( $\geq 4.0$ ) with a much shorter drying time (4 h vs. 17 h). The moisture content and taste intensity of the selected product were not significantly different ( $p > 0.05$ ) from those of the existing standard processes, whereas the browning index, whiteness index, and aroma intensity were significantly different ( $p \leq 0.05$ ). The flowability of the optimized products was better than that of the existing product with lower angle of repose values ( $27.78^\circ$ ) and categorized as free-flow powder, whereas the existing product values were higher than  $35^\circ$ , indicating some cohesiveness. The selected products had darker colors and weaker aromas than the existing products. A possible reason is that the Maillard reaction occurred in the first stage of drying of the overripe tempe and resulted in higher browning. The weaker aroma of the selected product was due to the high temperature at the first stage of drying, which might have increased the volatility of the product (Andriani et al., 2014).

**Table 7** Quality comparison between product from existing standard process and selected process in this study

| Parameter                    | Product from existing standard process | Product from selected production process |
|------------------------------|----------------------------------------|------------------------------------------|
| Moisture content (%)         | 3.43 <sup>a</sup>                      | 2.30 <sup>a</sup>                        |
| Angle of repose ( $^\circ$ ) | 36.94 <sup>a</sup>                     | 27.78 <sup>b</sup>                       |
| Browning index               | 47.94 <sup>b</sup>                     | 65.51 <sup>a</sup>                       |
| Whiteness index              | 61.86 <sup>a</sup>                     | 56.68 <sup>b</sup>                       |
| Aroma intensity*             | 5.50 <sup>a</sup>                      | 4.47 <sup>b</sup>                        |
| Taste intensity*             | 3.50 <sup>a</sup>                      | 4.01 <sup>a</sup>                        |

**Note:** \* score 1 represents "very weak" and score 7 represents "very strong". The consisted of 15 replicates conducted by trained panelist and they followed a standardized protocol to ensure consistency across measurements. Means with a raw with different superscripts are significantly different ( $p \leq 0.05$ ).

## 4. Conclusion

Applying low-temperature drying in an oven dryer and high-temperature drying in an oven baking on the selected drying method in this study has verified significant advancements. The result required a much shorter drying time (4 h) than the standard reference to produce overripe tempe powder that met the required quality parameter with better flowability. Different types of sample shapes did not significantly affect the quality of overripe tempe powder, whereas temperatures above  $70^\circ\text{C}$  significantly affected moisture removal and enhanced aroma intensity. Moreover, a longer drying time (above 240 min) resulted in better moisture release. This study reveals that to achieve the moisture content target ( $< 4\%$ ), the drying conditions should be above  $70^\circ\text{C}$  and 200 min. If other drying quality parameters were included, the best drying condition would be overripe tempe ground dried at  $80^\circ\text{C}$  for 240 min. The selected drying design ( $80^\circ\text{C}$ , 240 min) showed that the overripe tempe did not burn and produced overripe tempe powder with standardized moisture content, better flowability, and lower safety risk.



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## Author Contributions

SAF, CHW, and MDPTG performed initial conceptualization of the research; SAF, CHW, NES, and MDPTG performed research methodology; SAF and NES performed statistical analysis, data collection, and data review. SAF and MDPTG wrote the original manuscript draft; Entire authors were reviewed and edited for the final manuscript.

## Conflict of Interest

The authors declare that there are no conflicts of interest.

## Declaration of AI

The authors declare that the entire content of this paper is the product of original human thought and writing. We confirm that no Artificial Intelligence (AI) tool was used to generate, synthesize, or substantially modify any portion of this manuscript.

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