Vol. 13, No. 2 (2024): 525 - 535 http://dx.doi.org/10.23960/jtep-l.v13i2.525-535

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Engineering Characteristics of Curcuma Flour (*Curcuma xanthorrhiza* Roxb.) from Convection Drying

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Article History:

Received : 29 July 2023
Revised : 30 August 2023
Accepted : 30 December 2023

Keywords:

Convection dryer,
Curcuma,
Drying,
Engineering characteristics,
Flour.

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ABSTRACT

Curcuma is a herbs having a lot of advantages for human health. The fresh rhizome has a lot of disadvantages especially from the volume and low quality. To maintain the quality, curcuma should be processed to curcuma flour. This study was carried out to determine the engineering properties including water content, color, bulk density, water absorption, oil absorption, and angle of repose of curcuma flour ground after convection drying. The research method used in this study was CRD (completely randomized design) with 2 factors, namely drying temperature (40 °C, 50 °C, and 60 °C) and flouring or milling duration (6, 8, and 10 min). Curcuma rhizome was pre-treated with a convection drying. After milling process, the flour was sieved to have particle size of 60 mesh. Statistical analysis included ANOVA (Analysis of Variance), Duncan post-hoc test, and correlation test. The result revealed the curcuma flour has engineering properties including bulk density (0.35 – 0.38 g/ml), water content (7.97% – 11.77%), water absorption (2.78 – 3.79 ml/g), angle of repose (27.99° – 30.44°), color brightness L (67.07 – 71.78), red-green chrome a (7.67 – 8.92), yellow-blue chrome b (51.37 – 55.13), and total color change ΔE (57.42 – 62.12).

1. INTRODUCTION

Curcuma or "temulawak" (*Curcuma xanthorrhiza* Roxb.) is a spice plant commonly found in Indonesia. According to Badan Pusat Statistik, curcuma production in Indonesia reached 24,561,046 kg in 2017 (BPS, 2017). Based on statistical data cited from biofarmaka plant statistics for the years 2016 and 2017 (BPS, 2017), the harvested area of curcuma reached 1144 ha in 2016 and 1082 ha in 2017. The growth achieved over the two-year harvest period was only 5.45%. According to BPS (2019), curcuma production in Indonesia over three years from 2017 to 2019 experienced an increase.

Curcuma can be categorized as a perishable commodity with a short shelf life after harvest. This is because curcuma contains a high water content ranging from 80 - 90% at the time of harvest (Manalu *et al*., 2012). One way to extend the shelf life of curcuma is through drying and milling into flour. Agricultural drying specifically involves the reduction of moisture from agricultural products until equilibrium moisture content is achieved. Drying is considered an important method for processing agricultural products. Therefore, an effective drying system that can control temperature and drying time through convection drying is important.

The processing of curcuma into flour through drying processes must first consider the quality standards of curcuma flour. Treatment during drying and milling will affect the quality of the resulting flour. According to Widjanarko *et al*. (2015), one important factor affecting milling results is the variable of milling duration. This variable is closely related to process efficiency and determines the particle size of the resulting flour. Consequently, the chemical and physical properties of the milled flour will be affected. However, information on the engineering properties of curcuma flour evaluated with convection drying is still scarce. Therefore, this research was conducted to evaluate the engineering properties of curcuma flour, providing information to maintain quality and serve as reference data for further processing of curcuma flour. The observed engineering properties include moisture content, color, bulk density, water absorption capacity, and angle of repose.

2. MATERIALS AND METHODS

2.1. Location and Time of Research

This research was conducted from March to May 2023 at the Agricultural Product Engineering Lab., Department of Agricultural Engineering, Faculty of Agricultural Technology, University of Jember.

2.2. Tools and Materials

The tools used in this research included: convection oven, digital scale, aluminum cup, desiccator, blender, 60-mesh sieve, plastic containers, funnel, measuring glass, test tube, knife, timer, grater, Color Reader CR 10, and centrifuge. The materials used in this research were curcuma rhizomes obtained from curcuma farmers in Gumukmas, Jember. Fresh curcuma rhizomes were selected, and efforts were made to ensure there was no damage to the material. Other materials used included water and distilled water.

2.3. Research Procedure

The procedure for milling curcuma included raw material preparation, sorting, washing, peeling, slicing, drying, milling, and sieving. The milled material (curcuma flour) was then analyzed for engineering properties including moisture content, color, density, water absorption capacity, and angle of repose.

2.4. 2.4. Research Design

The experimental design in this research was a Completely Randomized Design with two factors: drying temperature and milling duration. The drying temperature was 40 °C, 50 °C, and 60 °C, while the milling duration was 6, 8, and 10 min. Each treatment combination was repeated three times, resulting in 27 experimental units.

2.5. Measurement of Engineering Properties

2.5.1. Moisture Content Measurement (AOAC, 2012)

Moisture content measurement was conducted by weighing a sample of 3 g. An empty cup was heated in an oven at a temperature of 105 °C for 15 min. After heating, the cup was placed in a desiccator for 15 min, then weighed. The sample was put in the cup and then weighed and placed in an oven at a temperature of 105 °C for 6 h. After heating, the cup was placed in a desiccator for 15 min and weighed again. The moisture content was calculated as follows:

$$M = \frac{(\mathrm{e}-f)}{(\mathrm{e}-\mathrm{c})} \text{ x } 100\% \tag{1}$$

where M is wet basis moisture content (%wb), c is weight of empty cup (g), e is weight of cup and sample before drying (g), and f is weight of cup and sample after drying (g).

2.5.2 Color Measurement (Hunter, 1987)

Color measurement used the Hunter method, consisting of three color variables: L, a, and b. Measurement was conducted by shooting three points on the curcuma flour using a colorimeter. The following formulas were used:

$$L_{sample} = L_{standard} + \Delta L \tag{2}$$

$$a_{sample} = a_{standard} + \Delta a \tag{3}$$

$$b_{sample} = b_{standard} + \Delta b \quad (4)$$

where L is brightness level of the flour, a is redness-greenness value, and b is yellowness-blueness value. The values of L, a, and b were used to determine color changes. Color change (ΔE) was determined based on Equation 5.

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (5)$$

with ΔE is color change due to heating treatment, ΔL^* is difference between initial and final L values after treatment, Δa^* is difference between a values before and after drying treatment, and Δb^* is difference between b values before and after drying treatment.

2.5.3. Bulk Density Measurement (Cresswell & Hamilton, 2002)

Bulk density measurement was conducted by pouring curcuma flour into a measuring glass without compaction, then the weight of the flour was measured. Bulk density (ρ) was calculated from mass (m) and volume V according to:

$$\rho = m/V \quad (6)$$

2.5.4. Water Absorption Capacity Measurement (Beuchat, 1977)

Water absorption capacity measurement was conducted by weighing 1 g of sample and mixing it with 10 ml of distilled water in a test tube, then shaking for 1 min and allowing to stand for 30 min at room temperature. The subsequent process involved centrifugation at a speed of 3500 rpm for 30 min. Non-absorbed water was discarded, while absorbed water represented the water absorption capacity (WAC).

$$\text{WAC (ml/g)} = (i - h - g)/h \quad (7)$$

where i is weight of test tube + sample + water (g), h is weight of sample (g), and g is weight of test tube (g).

2.5.5. Angle of Repose Measurement (Khalil, 1999)

The angle of repose was measured by flowing flour from a height (15 cm) through a funnel onto a flat surface lined with white paper. The distance between the funnel hole and the flat surface was 3 cm. The height (t) and the diameter (d) of the pile was measured. The angle of repose (δ) was determined using Equation 8.

$$\delta = Arc\ tan\left(\frac{2t}{d}\right) \quad (8)$$

2.6. Data Analysis

Data analysis was conducted using Microsoft Excel and SPSS, including two-way ANOVA testing, Duncan's test with a significance level of 0.95, interaction test, and product moment correlation test. Two-way ANOVA used Microsoft Excel with $\alpha = 0.05$. The testing criteria were determined based on the tabled F value and the calculated F value. If the calculated F value was greater than the tabulated F value, it indicated a significant difference, meaning that the treatment factors of drying temperature and duration of milling had an effect on observed engineering properties.

3. RESULTS AND DISCUSSION

3.1. Engineering Properties of Curcuma Flour at Various Drying Temperatures and Milling Durations

3.1.1. Bulk Density

Bulk density is a physical property of a material related to the ratio of the mass to the volume of the container filled with a certain mass of the material in bulk form (Mustofa, 2020). Bulk density is one of the physical qualities of powder closely associated with the storage of a substance, particularly for considering the transportation of agricultural materials in large quantities to determine the efficiency of storage containers (Purbasari & Pujiana, 2022). The graph illustrating the relationship between the bulk densities of curcuma powder and drying temperatures at various milling durations is presented in Figure 1. It is observed that the observation variable of bulk density decreases with increasing temperature and longer duration. The bulk density value is influenced by the drying temperature, with higher temperatures resulting in lower bulk density. This occurs because drying at high temperatures leads to low moisture content, reducing the weight of the material and affecting the material's mass during bulk density measurement (Purbasari & Pujiana, 2022). The smallest bulk density value is obtained at a duration of 6 min compared to durations of 8 min and 10 min at a temperature of 40 °C, where the bulk density value increases. This is consistent with the statement of Hakim *et al*. (2014) that the bulk density value is influenced by the shape, size distribution, and porosity of the material. A milling duration of 6 min results in the smallest bulk density due to the larger porosity of the material.

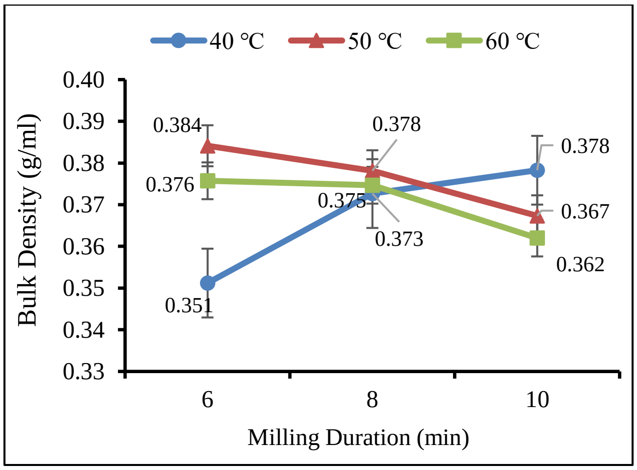

Figure 1. Relationship between bulk density and drying temperature at various milling durations

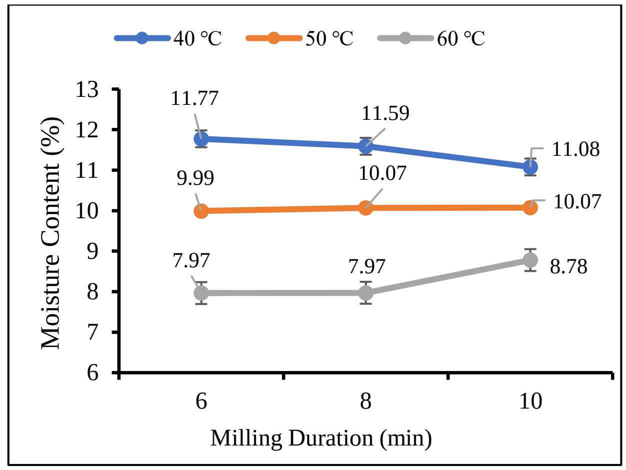

Figure 2. Relationship between final moisture content and drying temperature at various milling durations

3.1.2. Moisture Content

Moisture content indicates the amount of water contained in a material. The graph showing the relationship between curcuma flour moisture content and drying temperature at various milling durations is presented in Figure 2. The observed moisture content of curcuma flour ranged from 7.97% to 11.77%. The highest moisture content was obtained at a temperature of 40°C, while the lowest moisture content was obtained at a temperature of 60°C. The variation in moisture content is influenced by the heat temperature used; the higher the temperature, the lower the resulting moisture content. Fauzi *et al*. (2017) stated that using higher drying temperatures can decrease the moisture content in food products, and higher temperatures can evaporate more water from the material. The heat energy in the drying air can evaporate water molecules on the surface of the material, thereby increasing the vapor pressure of the material due to the decrease in surrounding air humidity (Mahayana, 2011). The increase in vapor pressure of the material causes the flow of water vapor from the material to the air, thereby increasing the evaporation rate of the material and reducing the moisture content.

The effect of milling duration on moisture content indicates that the longer the milling duration, the lower the moisture content at 40 °C, and the higher the moisture content at 50 °C and 60 °C. The increase in moisture content is estimated to occur because during this activity, the material absorbs moisture from the environment, as stated by Winarno (2004), that dried materials have a high hygroscopic property, making it easy to absorb moisture from the environment. Meanwhile, the decreased moisture content at 40°C is estimated because prolonged milling will evaporate the water molecules contained in the material.

3.1.3. Water Absorption Capacity

Water absorption capacity refers to the ability of flour to absorb water. Water absorption capacity depends on the resulting product because if the water absorption capacity is low, it will face difficulties in adding water (Purbasari &

Putri, 2021). The graph illustrating the relationship between the water absorption capacity of curcuma powder and drying temperature at various milling durations is presented in Figure 3. It shows that the highest value in the observation variable of water absorption capacity towards temperature and milling duration is obtained from the combination of treatment with a temperature of 60°C and a duration of 10 min, which is 3.79 ml/g. Understanding the water absorption capacity of curcuma powder is necessary to determine the extent of water absorption when applied to blending materials. High water absorption capacity occurs at high temperatures because high temperatures result in lower moisture content. This is supported by the statement of Winarno (2004) that higher drying temperatures will result in materials having high hygroscopic properties, making it easier for the material to absorb water because the particle's binding force to water is greater.

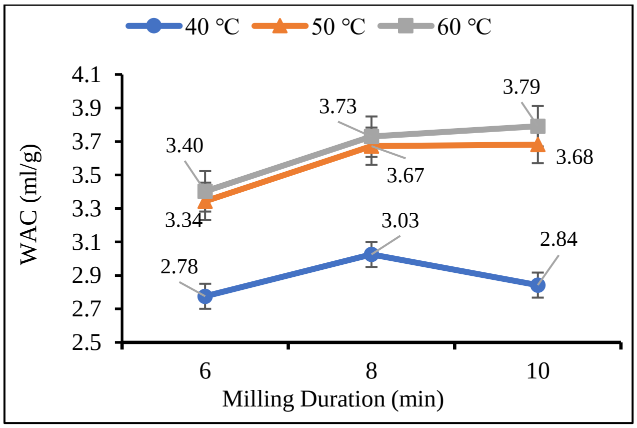

Figure 3. Relationship between water absorption capacity (WAC) and drying temperature at various milling durations

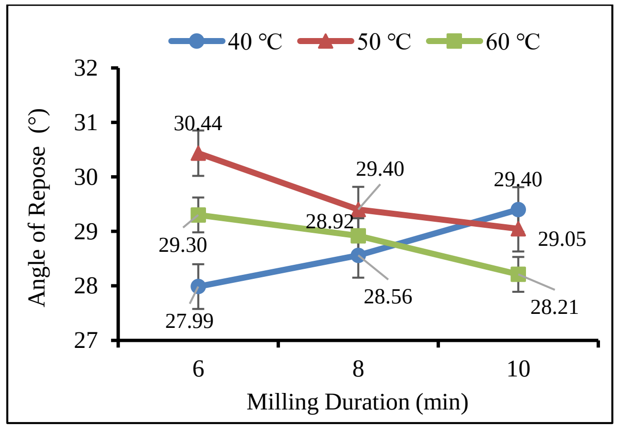

Figure 4. Relationship between angle of repose and drying temperature at various milling durations

3.1.4. Angle of Repose

Angle of repose measurement is conducted by pouring the material onto a flat surface until it forms a cone, then obtaining the diameter and height of the pile. According to Priastuti *et al.* (2016), angle of repose measurement is performed to determine the friction height of the material with the medium when designing hoppers in processing machines. The angle of repose value affects the emptying of the material in the hopper. The graph illustrating the relationship between the angle of repose of curcuma powder and drying temperature at various milling durations is presented in Figure 4. The angle of repose tends to decrease with higher temperature treatments and longer milling durations. According to Retnani *et al.* (2009), as the moisture content of the powder increases, the freedom of movement between particles decreases, resulting in a larger angle of repose compared to powders dried at high temperatures. Putu *et al.* (2020) stated that a smaller angle of repose indicates better quality of the material due to the uniform particle size, resulting in a good powder flow index. The smallest angle of repose is obtained from a drying temperature of 40 °C with a milling duration of 6 min, which is 27.99°. At 40 °C, the angle of repose increases with longer durations compared to temperatures of 50 °C and 60 °C. The shortest milling duration yields the smallest angle of repose because prolonged milling impacts the fineness of the material and the freedom of movement between particles (Purbasari & Pujiana, 2022).

3.1.5. Color

a. Brightness Level (*L*)

Brightness level (*L*) is a value indicating the brightness of a material. The brightness level ranges from 0 to 100, where a higher *L* value indicates a brighter material, while conversely, a lower brightness value means a darker material (Hartulistiyoso *et al.*, 2011). The graph showing the relationship between the brightness level (*L*) of curcuma flour and drying temperature at various milling durations is presented in Figure 5. Based on Figure 5, the highest brightness level was obtained from the combination of drying temperature treatment at 60°C with a milling duration of 10 min at

71.78. Meanwhile, the lowest value was obtained from the combination of drying temperature treatment at 40 °C with a milling duration of 6 min at 67.07. Drying temperature at 60 °C resulted in the highest *L* value compared to temperatures of 40 °C and 50 °C. According to Purbasari (2019), the highest *L* value was obtained at 60 °C, indicating a brighter yellowish color of the flour. This means that higher temperatures result in lower moisture content, leading to a brighter color of the material.

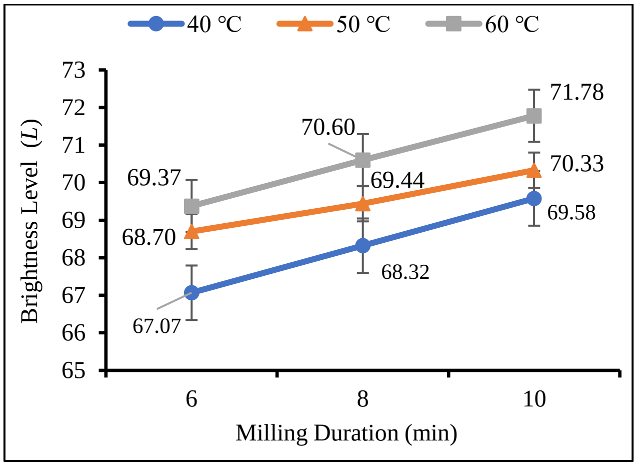

Figure 5. Relationship between brightness level (*L*) and drying temperature at various milling durations

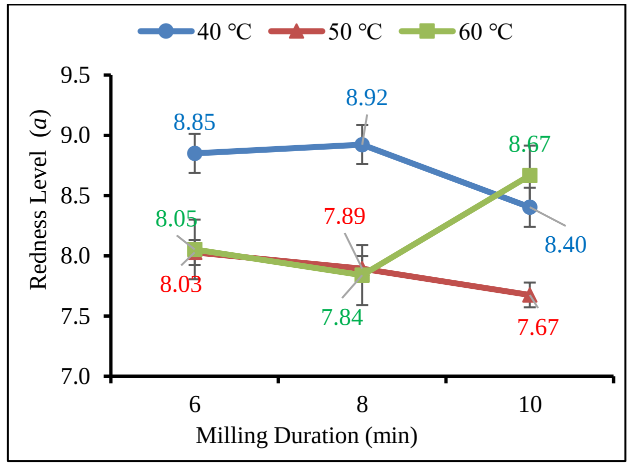

Figure 6. Relationship between redness level (*a*) and drying temperature at various milling durations

The highest brightness level (*L*) was obtained at the longest milling duration of 10 min, while the lowest brightness level (*L*) was obtained at the shortest milling duration of 6 min. This is in line with the statement by Mawarni & Widjanarko (2015) that longer milling can increase the brightness of flour because prolonged milling helps release impurity compounds present in the material.

b. Redness Level (*a*)

The value *a* indicates the redness level of a substance. The value a ranges from -80 to 100, with negative values indicating greener coloration, while positive values indicate redder coloration (Purbasari & Putri, 2021). The graph depicting the relationship between the redness level (*a*) of ginger powder and drying temperature at various milling durations is presented in Figure 6 as follows. It is evident that treatment with a drying temperature of 40 °C and a milling duration of 8 min yields the highest redness value (*a*) of 8.92. Meanwhile, treatment with a drying temperature of 50 °C and a milling duration of 10 min yields the smallest a value, which is 7.67. At 60 °C and milling duration of 10 min, the redness level (*a*) is high due to the elevated temperature, which causes the substance to become reddish or brownish in color. The value of *a* increases with higher temperature treatments. This is supported by the statement (Purbasari, 2019) that higher drying temperatures result in larger *a* values, meaning the product color approaches red. Prolonged milling duration influences a decreasing redness level (*a*) because extended milling causes the color to fade.

c. Yellowness Level (*b*)

The value *b* indicates the yellowness level of a substance. The magnitude of *b* or yellowness level ranges from -50 to 70. Negative values indicate bluer coloration, while positive values indicate yellower coloration (Purbasari & Putri, 2021). The graph illustrating the relationship between the yellowness level (*b*) of ginger powder and drying temperature at various milling durations is presented in Figure 7. It can be observed that treatment with a drying temperature of 50 °C and a milling duration of 6 min yields the highest *b* value, which is 55.13. Conversely, treatment with a drying temperature of 60 °C and a milling duration of 10 min yields the smallest b value, which is 51.37. The yellowness level increases at 50 °C and decreases again at 60 °C. The yellowness level tends to decrease with longer milling durations. At a temperature of 60 °C and a duration of 8 min, the *b* value increases due to the high curcumin content in ginger powder. This is supported by the statement from Prasetyowati & Syarifah (2019) that curcumin content increases at temperatures of 45 °C, 60 °C, and 75 °C.

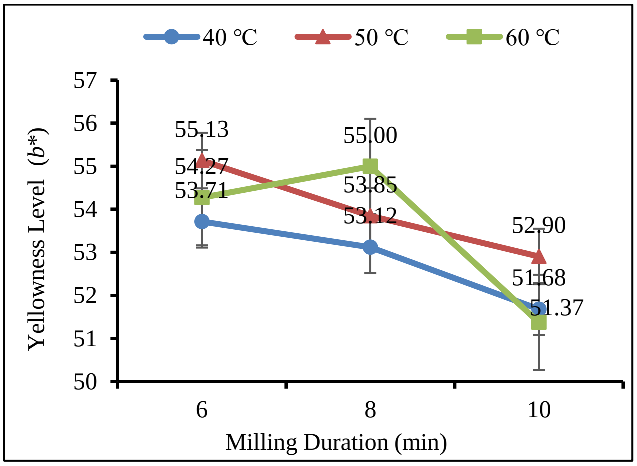

Figure 7. Relationship between yellowness level (b^*) and drying temperature at various milling durations

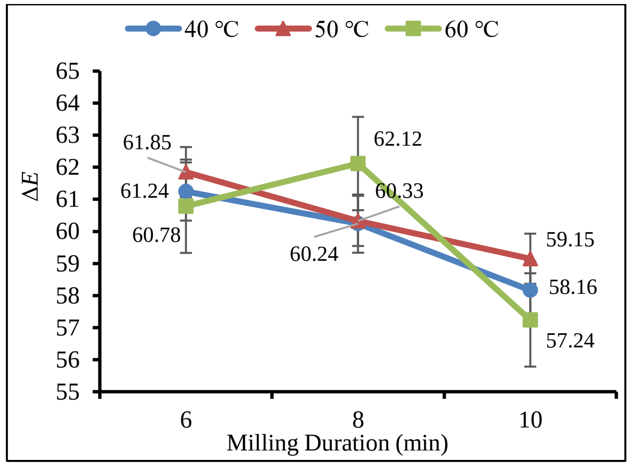

Figure 8. Relationship between color change (ΔE) of ginger powder and drying temperature at various milling durations

d. Color Change (ΔE)

The ΔE value indicates the color change of a product. The ΔE value is obtained from the calculation of *L*, *a*, and *b* values. The graph illustrating the relationship between the color changes (ΔE) of ginger powder and drying temperature at various milling durations is presented in Figure 8. It can be seen that the highest color change value occurs at a drying temperature of 60 °C and a milling duration of 8 min, which is 62.12, while the lowest value occurs at a drying temperature of 60 °C and a milling duration of 10 min, which is 57.24. The ΔE value increases at 50 °C and decreases again at 60 °C. Meanwhile, the ΔE value tends to decrease with longer milling durations. At a temperature of 60 °C and a duration of 8 min, the ΔE value increases due to the increased yellowness level resulting from the higher curcumin content at that temperature. Heating can break the bonds between nitrogen and magnesium compounds present in color pigments. When magnesium (Mg) is released, it will be replaced by two hydrogen molecules, forming a new formation called pheophytin, which has a brownish color (Muchtadi *et al*., 2010).

3.2. Statistical Analysis

Table 1 summarizes the results of two-way ANOVA about the effect of treatments on the engineering properties of curcuma flour. It is known that there is a significant difference in the treatment variable values to the observation variable. Determination of significant difference is based on the significance value and indicated by the asterisk symbol (*). If the calculated F > F table, then there is a significant difference in the observation variable values to the treatment variable. If the calculated F < F table, then there is no significant difference in the observation variable values to the treatment variable. There was a significant difference in the milling duration treatment on the brightness level (*L*), yellowness level (b), and ΔE variables. The drying temperature treatment showed a significant difference in the moisture content, brightness level (*L*), redness level (*a*), water absorption, and angle of repose variables.

Observational variables indicating significant engineering properties differences were then subjected to Duncan's test to determine significant differences in each variation of drying temperature or milling duration. The results of the Duncan's test for the engineering properties of curcuma flour under different drying temperature treatments can be seen in Table 2. It is known that in the drying temperature treatments (40 °C, 50 °C, and 60 °C), there are significant differences in the engineering property variables including moisture content, color (*L* and *a*), water absorption, and angle of repose. This is indicated by the different letter notations on the resulting observation variable values. The test results showed a decrease in moisture content values, while an increase occurred in the brightness level (*L*), water absorption, and angle of repose variables at temperatures of 40 ℃, 50 ℃, and 60 ℃. In the redness level (*a*) testing, there were fluctuating data, namely 8.72 at 40 ℃, then a decrease to 7.87 at 50 ℃ and an increase to 8.19 at 60 ℃.

Table 1. Results of ANOVA on the engineering properties of curcuma powder

Observation Variable	Source of Variation	Sum of Squares (SS)	Degrees of Freedom (DF)	Mean Square	F Value	F Critical
Final Moisture Content	Milling Duration	0.000005	2	0.000002	0.051	3.555
	Drying Temperature	0.005	2	0.002	50.129*	3.555
	Interaction	0.0002	4	0.00005	1.086	2.928
	Error	0.001	18	0.00005		
	Total	0.006	26			
Brightness Level (L)	Milling Duration	21.424	2	10.712	8.223*	3.555
	Drying Temperature	23.022	2	11.511	8.837*	3.555
	Interaction	0.701	4	0.175	0.134	2.928
	Error	23.447	18	1.303		
	Total	68.594	26			
Redness Level (a)	Milling Duration	0.039	2	0.020	0.053	3.555
	Drying Temperature	3.397	2	1.698	4.565*	3.555
	Interaction	1.733	4	0.433	1.165	2.928
	Error	6.696	18	0.372		
	Total	11.865	26			
Yellowness Level (b)	Milling Duration	29.545	2	14.773	4.486*	3.555
	Drying Temperature	5.808	2	2.904	0.882	3.555
	Interaction	6.570	4	1.642	0.499	2.928
	Error	59.279	18	3.293		
	Total	101.203	26			
ΔE	Milling Duration	51.553	2	25.777	7.145*	3.555
	Drying Temperature	1.481	2	0.741	0.205	3.555
	Interaction	12.417	4	3.104	0.861	2.928
	Error	64.935	18	3.607		
	Total	130.386	26			
Bulk Density	Milling Duration	0.0002	2	0.0001	0.057	3.555
	Drying Temperature	0.0004	2	0.0002	0.123	3.555
	Interaction	0.002	4	0.0005	0.292	2.928
	Error	0.028	18	0.0016		
	Total	0.031	26			
Water Absorption Capacity	Milling Duration	0.487	2	0.244	0.852	3.555
	Drying Temperature	3.153	2	1.577	5.514*	3.555
	Interaction	0.097	4	0.024	0.085	2.928
	Error	5.147	18	0.286		
	Total	8.885	26			
Angle of Repose	Milling Duration	1.089	2	0.544	1.864	3.555
	Drying Temperature	5.700	2	2.850	9.758*	3.555
	Interaction	8.906	4	2.226	7.623*	2.928
	Error	5.257	18	0.292		
	Total	20.951	26			

Table 2. Duncan's test results for different drying temperature treatments

Temperature	Moisture Content	Brightness Level (*L*)	Redness Level (*a*)	Water Absorption Capacity	Angle of Repose
40 ℃	11.48 ± 0.40[c]	68.32 ± 1.31[a]	8.72 ± 0.62[b]	2.88 ± 0.57[a]	28.54 ± 0.82[a]
50 ℃	10.04 ± 0.55[b]	69.49 ± 0.77[ab]	7.87 ± 0.63[a]	3.57 ± 0.43[b]	29.65 ± 0.88[b]
60 ℃	8.24 ± 0.93[a]	70.58 ± 1.84[b]	8.19 ± 0.53[ab]	3.64 ± 0.46[b]	28.90 ± 0.68[a]

Note: Different letters in the same column indicate significant differences in statistics α = 0.05

The results of Duncan's test for the engineering properties of curcuma flour under different milling duration treatments can be seen in Table 3. It is known that in the milling duration treatments (6, 8, and 10 min), there are significant differences in the engineering property variables including color (L and b) as indicated by different letter notations on the resulting observation variable values. The test results showed an increase in the brightness level values for milling durations of 6, 8, and 10 min. Meanwhile, there was a decrease in yellowness level and ΔE values at durations of 6, 8, and 10 min.

Table 3. Duncan's test results for different milling duration treatments

Duration	Brightness Level (*L*)	Yellowness Level (*b*)	ΔE
6 min	68.38 ± 1.31[a]	54.37 ± 1.67[b]	61.29 ± 2.00[b]
8 min	69.45 ± 0.77[ab]	53.99 ± 2.15[b]	60.90 ± 1.80[b]
10 min	70.56 ± 1.84[b]	51.99 ± 2.13[a]	58.18 ± 2.00[a]

Note: Different letters in the same column indicate significant differences in statistics α = 0.05

The results of the interaction test for the angle of repose of curcuma flour under different drying temperature and milling duration treatments can be seen in Table 4. It can be seen that the regression coefficient of the drying temperature is 0.017 with a significance value of 0.420 > 0.05 and the regression coefficient of the milling duration is -0.086 with a significance value of 0.432 > 0.05, then the temperature and milling duration variables have no effect on the angle of repose. Meanwhile, the interaction regression coefficient is -0.035 with a significance value of 0.005 < 0.05, indicating a negative and significant interaction effect on the angle of repose.

Table 4. Interaction test results of treatment factors on the observation variable of angle of repose

Observation Variable	Variability Source	Value	Significance
Angle of Repose	Temperature	0.017	0.420
	Duration	-0.086	0.431
	Interaction	-0.035	0.005

The test of the strength of the relationship between the drying temperature and milling duration treatment variables with the engineering properties observation variable of curcuma flour in this study was conducted through correlation tests using the Pearson method. The correlation test results can be seen in Table 5. Based on the correlation test results in Table 5, it is known that there are observation variables of the engineering properties of curcuma flour that have a relationship with the treatment variables of drying temperature and milling duration. The determination of correlation values is indicated by asterisks () and double asterisks (**). Asterisk () indicates a significant correlation at the α ≤ 0.05 level, while (**) indicates a significant correlation at the α ≤ 0.01 level. Correlation values that result in negative (-) values have an inverse relationship, while values with positive (+) results have a direct relationship. The temperature treatment has a positive correlation value on the color brightness (*L*), color redness (*b*), bulk density, water absorption, and angle of repose variables, while it has a negative correlation value on the moisture content and color (*a*) variables. The duration treatment has a positive correlation value on the moisture content, color brightness (*L*), and water absorption variables, while it has a negative correlation value on the color redness (*a*), color yellowness (*b*), bulk density, and angle of repose variables.

Table 5. Correlation test results of treatment variables on observation variables

Observation Variable	Range			Variable Treatment		Correlation Level	
	Minimum	Maximum	Mean	Temperature	Duration	Temperature	Duration
Moisture Content	6.83	12.08	9.92	-0.902**	0.019	Very Strong	Very Weak
Brightness, *L*	66.32	72.48	69.46	0.579**	0.559**	Moderate	Moderate
Redness, *a*	6.93	9.67	8.26	-0.332	-0.038	Weak	Very Weak
Yellowness, *b*	49.46	56.60	53.45	0.149	-0.503**	Very Weak	Moderate
Color change, ΔE	55.60	64.00	60.12	0.071	0.030	Very Weak	Very Weak
Bulk Density	0.32	0.43	0.37	0.041	-0.014	Very Weak	Very Weak
Water Absorption Capacity	2.20	4.33	3.36	0.541**	0.188	Moderate	Very Weak
Angle of Repose	27.06	30.85	29.03	0.163	-0.159	Very Weak	Very Weak

Note: * significant correlation at $\alpha \leq 0.05$ level; ** significant correlation at $\alpha \leq 0.01$ level

4. CONCLUSION

1. The engineering properties results of curcuma flour on the observation variable of moisture content range from 7.97% to 11.77%; color brightness (*L*) ranges from 67.07 to 71.78; color redness (*a*) ranges from 7.67 to 8.92; yellowness color (*b*) ranges from 51.37 to 55.13; bulk density ranges from 0.35 g/ml to 0.38 g/ml; water absorption ranges from 2.78 to 3.79 ml/g; and angle of repose ranges from 27.99° to 30.44°.
2. Drying temperature and milling duration treatments have an influence on the engineering properties of curcuma flour. Drying temperature has an inverse effect on the moisture content variable, a direct effect on the color brightness (*L*) and water absorption variables, and a fluctuating effect on the color redness (*a*) and angle of repose variables. Meanwhile, milling duration has a direct effect on the color brightness (*L*) variable and an inverse effect on the yellowness color (*b*) and color change ΔE variables.

RECOMMENDATION

Further studies are needed on curcuma drying with different drying temperature and milling duration treatments to obtain the best quality curcuma flour.

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