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FULL PAPER

A study of drying parameters on drying time and colour quality of grated coconut using tumbling mechanism in convective dryer

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Abstract

A small scale convective dryer with tumbling mechanism was specially constructed for drying grated coconut. This new drying mechanism was evaluated in term of drying behaviour and colour quality of the final product. Three main factors that involved were hot air temperature, rotational speed (rpm) and air velocity. Every combined parameter of a sample was compared to each other and also with freshly grated coconut. It was found that the combination of 60°C, 6 rpm and 4.31 ms^{-1} had the shortest drying time as well as the highest drying rate among other combinations. In contrast, combination factors of 50°C, 3 rpm and 2.06 ms^{-1} had the lowest drying rate. Three main factors; temperature, rotational speed and air velocity were significantly contributed to the response of drying time as ($p<0.05$). Drying rate also increased with increase in temperature, rotational speed and air velocity. In term of colour analysis (L*, a*, b*), there was a significant difference among dried grated coconut samples. Nevertheless, sample 60˚C, 3 rpm and 4.31 ms^{-1} and 50˚C, 3 rpm and 4.31 ms^{-1} showed no significant different ($p>0.05$) in lightness when compared to freshly grated coconut hence excellent in retaining its original appearance. On top of that, sample (60˚C, 3 rpm and 4.31 ms^{-1}) also achieved considerable drying rate with an acceptable drying time of 135 mins.

1. Introduction

Drying of agricultural products has always been of great importance for the preservation of food. Many food products are dried at least once at some point in their preparation (Madamba *et al*., 1996). Drying of fruits and vegetables is a complicated process involving simultaneous, coupled heat and mass transfer, under transient conditions (Diamante *et al.,* 2010). The introduction of dryers in developing countries can reduce crop losses and improve the quality of a dried product significantly when compared to traditional methods. The major objective of drying food products is the reduction of moisture content to a level which allows safe storage over an extended period (Doymaz *et al.,* 2003). Drying consists of a critical step by reducing the water activity of the products being dried. A high amount of energy is required in drying due to the high latent heat of the water. Although drying is an energy driven unit operation, its efficiency can be improved if the drying rate that determines the drying period is increased. In the coconut industry, drying coconut meat reduces its moisture content that inhibits the growth of bacteria and the action of enzymes that causes spoilage (Lola Domnina *et al.,* 2016).

According to FAO, the coconut is grown, or it occurs naturally in 94 out of 284 countries and territories of the world (FAO STAT, 2018). Coconuts are Malaysia's fourth-largest industrial crop behind oil palm, rubber and rice with most of the plantations found in Sabah and Sarawak. It is also considered one of the oldest agro-based industries. In Malaysia, the domestic demand for coconut products is in the form of fresh coconut, tender coconut, coconut oil and processed cream powders. Desiccated coconut has a great nutritional value containing 68.99% carbohydrates, 25.59% fat and 0.85% protein (Khuwijitjaru *et al.,* 2012). In term of exports, an increasing trend has been seen in the export product such as desiccated coconut, coconut milk powder and activated carbon (Sivaprasangam, 2008). Desiccated coconut is the dried, white, particulate or shredded food product manufactured from freshly peeled coconut kernels. According to (Sangamithra *et al.,* 2013), desiccated coconut is obtained from drying of shredded, ground coconut after separating from the brown testa.

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Matured coconuts are dehusked and de-shelled whereby both processes can be done by using machines available in a market. In order to reduce the microbial count, the grated coconuts or coconut flakes are steamed blanched for about 20 mins. The grated coconut is then dried in the hot air dryer at a temperature of 80-90°C for about 10 hrs to reduce the moisture content up to 3%. The previous study done by (Madhiyanon *et al.,* 2009) found that 60-120°C temperature of air with a velocity of 2.5 ms^{-1} could reduce the moisture level from 105% d.b to 3% d.b. Nevertheless, enzymatic browning can be a significant problem limiting the shelf life of the much-dried product.

Previous studies have also emphasized in drying kinetics and thin layer drying for shredded coconut, which most of them used heated air dryer or convective type dryer. Agarry and Aworanti (2012) reported that the drying regime of coconuts had a falling rate period characteristics. The constant rate period was obviously not observed in the coconut samples because of the complex nature of the internal moisture movement mechanisms. Nonetheless, preceding drying studies provided no attempt or data of using alternative conductive drying technique for desiccated coconut. Desiccated coconut is hygienically dried to about 3-4% moisture and is the main flavouring ingredient in chocolate bars, filler in nut-based product and as decoration for ice-cream and other frozen food products (Madamba, 2003). In fresh dry process of getting virgin coconut oil (VCO), the dried grated coconut or desiccated coconut was pressed mechanically to obtain oil (Mansor *et al.,* 2012).

In this study, therefore, the attention is attracted to the drying behaviour of grated coconut using a convective dryer with a tumbling mechanism. In addition to that, the colour changes between fresh and dried grated coconut are also being investigated. The optimum samples will be chosen based on rapid drying time, as well as fewer color changes.

2. Materials and methods

2.1 Sample preparation and experimental procedure

Grated coconuts used in the drying experiments were bought from Pasar Borong Serdang. The grated coconut was taken from the same supplier with the same grating size. This drying study was conducted at Postharvest Laboratory, Engineering Research Centre MARDI, Serdang. Figure 1 shows the schematic diagram of a laboratory convective cabinet dryer unit which was used for studying the drying behaviour of grated coconut. The dryer was specially designed and fabricated to undergo experiments. The dryer (54 x 61 x 63 cm) consists of an axial blower, 1 kW heater, a temperature controller and an additional motor to run the tumbler. The tumbler has a volume of 0.0297 m^3 with 0.42 m and 0.30 m of length and diameter respectively. The experiments were performed to determine the effect of air temperatures (50 and 60˚C), airflow rates (2.06 and 4.13 ms^{-1}) and rotational speed (3 and 6 rpm) on drying time and colour differences between fresh and dried grated coconut. About 3 kg of wet grated coconut was placed on a single inside a tumbler. Moisture content reduction and colour changes of grated coconuts during drying were measured at interval time manually. Colour was measured by Konica Minolta Chromameter (CR-400); Minolta Co. Ltd, Japan. Each reading was the average of triplicates flashes which shows L (lightness), a* (greenness to redness) and b* (yellowness to blueness). The moisture content of grated coconut was measured using Mettler Toledo HX 204 throughout the drying process. Drying time was recorded as well as the colour changes between fresh and dried grated coconut. Drying of grated coconut was stopped when the moisture content reached to 3-4%, wet basis.

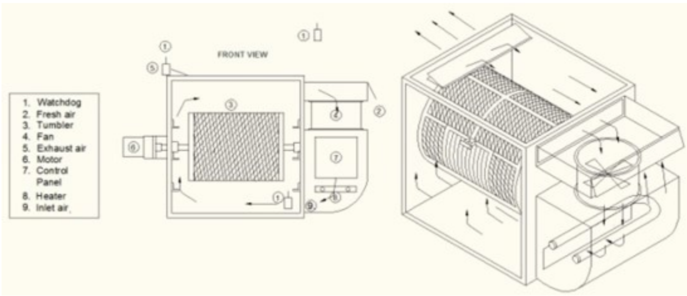

Figure 1. Schematic diagram of a convective dryer equipped with a tumbler.

2.2 Drying rate analysis

The drying rate of grated coconut was calculated using the following equation:

$$DR = \frac{M_t - M_{t+\Delta t}}{\Delta t}$$

where M_t is the moisture content at any time, is the $M_{t+\Delta t}$ moisture content at $t + \Delta t$ (kg water/kg dry matter) and t is time (min).

2.3 Experimental design: factors, level and response

To determine a mathematical model between response and factors, one response was identified; drying rate. In order to investigate, the experimental design was carried out choosing three factors, namely temperature, rotational speed and air velocity. These three factors were named A, B and C, respectively. Each of this factor was corresponded to low and high levels of treatment and coded as (-1) and (+1) respectively. Factors and levels were given in Table 1. A 2^3 full factorial design was undergoing to set the mathematical relationships and

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to represent how drying rate and colour depends on the temperature, rotational speed and air velocity. The data resulted from the experiments were analyzed by using Design Expert 12.0 software in order to determine main effects, interaction as well as p-value, standard error, the sum of squares errors, F statistics and contour and surface plots.

Table 1. Experimental factors and levels

Factors		Parameter Values	
		Low level (-1)	High level (+1)
Temperature (˚C)	A	50	60
Rotational speed (rpm)	B	3	6
Air velocity (ms^{-1})	C	2.06	4.13

2.4 Colour analysis

The different in lightness value (L*) between dried grated coconut and freshly grated coconut for every sample with varies combination drying parameters were analyzed using simple two sample T-test. Analysis of variance (ANOVA) was also used to determine statistically significant differences amongst samples of fresh and dried grated coconut ($p<0.05$) in term of colour using Minitab 19 package software. The average colour changes of each sample were calculated using the following equation:

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

Where ΔL = L dried sample – L fresh sample; Δa = a dried sample – a fresh sample; and Δb = b dried sample – b fresh sample;

3. Results and discussion

3.1 Drying rate analysis

Figures 2 and 3 illustrated the drying curve moisture reduction and drying rate of grated coconut, respectively. Initially, a higher drying rate was obtained followed by slower moisture removal rate. It was clearly stated that the parameter factors (60°C, 6 rpm and 4.31 ms^{-1}) resulted in the shortest drying time as well as the highest drying rate compared to others. Using an experimental factorial design, a mathematical model was set to analyze the effects of drying parameters to determine the drying time as a response. Factors were represented as A, B and C in the model, and they were temperature, rotational speed and air velocity, respectively. The design matrix for the experiments was illustrated in Table 2, while the result of ANOVA for drying time measurements was given in Table 3. ANOVA results indicated that those three factors (temperature, rotational speed and air velocity) were significant at $p<0.05$ in a 95% confidence interval.

Actual equation model:

Drying time = -2.25*temperature – 8.33*rotational speed – 33.33*air velocity + 428.67

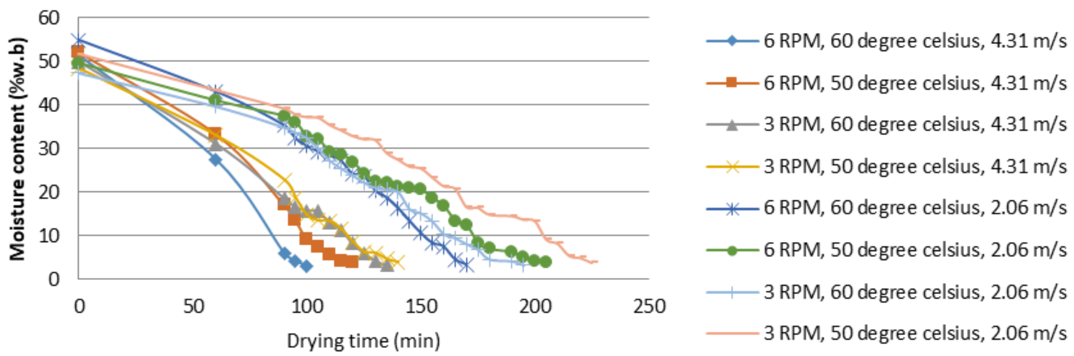

Figure 2. Drying curve of moisture reduction

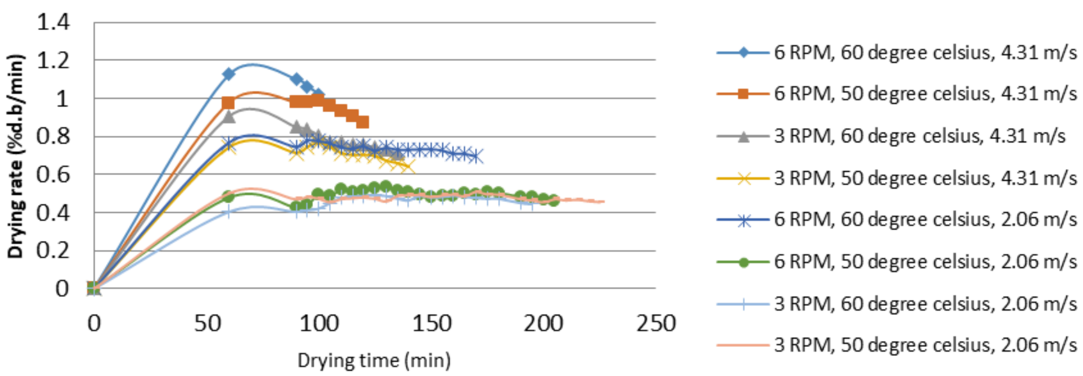

Figure 3. Drying rate of every combination of drying factors

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Table 2. Design matrix for the experiments

Std	Run	Factor 1 A: Temperature (°C)	Factor 2 B: Rotational speed (rpm)	Factor 3 C: Air velocity (ms^{-1})	Response Drying time (min)
3	1	50	6	2.06	205
2	2	60	3	2.06	195
1	3	50	3	2.06	225
7	4	50	6	4.31	120
6	5	60	3	4.31	135
8	6	60	6	4.31	100
4	7	60	6	2.06	170
5	8	50	3	4.31	140

According to (Muhammad Haniff *et al.,* 2014), logarithmic model at 60˚C for the grated coconut is considered to be the most precise model for drying kinetics of grated coconut. Based on the ANOVA result in Table 3, the actual model was significantly achieved by considering these three factors. Nevertheless, the equation model can only be used to make drying time predictions about the response for given levels of each factor. Figure 4 and 5 also showed that the three factors were significantly influenced the drying time. Perturbation plot revealed that air velocity difference played a major role in determining drying time followed by rotational speed and temperature. This can be seen when a low level of code for every factor contributed to the prolong drying time. It can be said that the tumbling effect had assisted in higher drying rate, hence reduced drying time significantly.

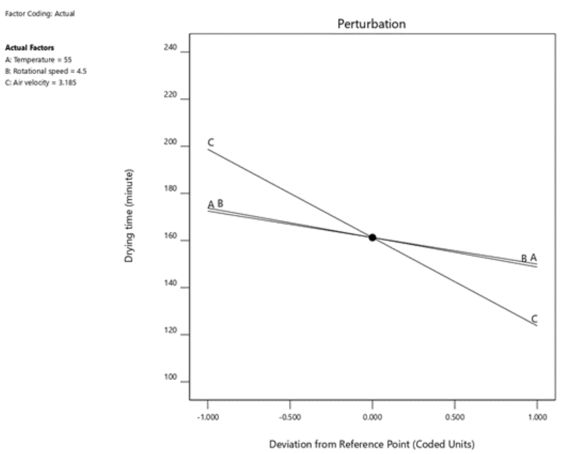

Figure 4. Pertubation plot for the factor effects on the response

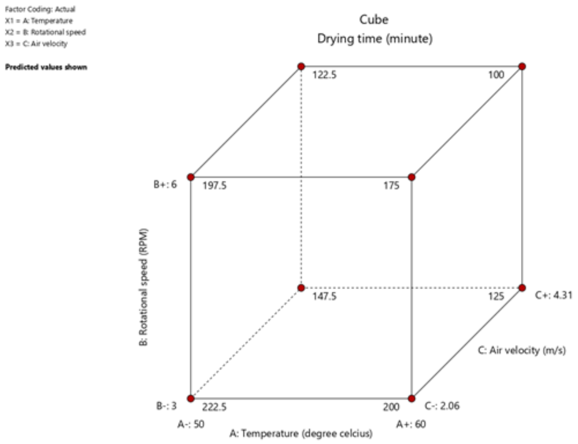

Figure 5. 3D Cube graph

3.2 Colour analysis

Based on the color analysis result in Table 4, colour characteristics of freshly grated coconut in terms of L*, a*, b* were in the range of 66.52 to 78.81, -3.42 to -5.02 and 6.09 to 8.14 respectively. Nevertheless, the lightness value of freshly grated coconut samples was not significant, except sample taken from 60/3/4.31. In contrast, a* and b* value of each fresh sample was significant prior to drying. Once drying completed, the range value of the dried sample in terms of L*, a*, b* were from 64.62 to 74.56, -3.45 to 4.70, 7.83 to 10.16 respectively. It can be said that the drying process had decreased the range pattern for L* and a* value while the b* value was increased. Moreover, it seems that samples from different combination of drying parameters were significant to each other as illustrated by Table 5. Therefore, T-test analysis for lightness (L*) was conducted in order to identify the difference between fresh and dried samples. Based on the p-value in Table 6, it was clearly shown that only samples from 50/3/4.31 and 60/3/4.31 were not significant in lightness as compared to others. In other words, no distinct changes in lightness were detected for those two samples. Even though sample 60/6/4.31 had the shortest drying time, the lightness value was depleted significantly. The colour changes were further analyzed using ΔE and a*/b*. According to Doymaz *et al.,* (2006), higher L* and lower a*/b* value is required for dried stuff. Table 7 shows that ΔE was between 2.64 to 7.05, while a*/b* value was in the range -0.34 to 0.51. The least chroma or colour changes based on ΔE and a*/b* value was from a sample (50/3/2.06), (50/3/4.31) and (60/3/4.31). Figure 6

Table 3. Analyses of variance for the factorial model (Response: drying time)

Source	Sum of Squares	DF	Mean of Squares	F-value	P-value
Model	13512.50	3	4504.17	65.52	0.0007
Temperarute	1012.50	1	1012.5	14.73	0.0185
Rotational Speed	1250.00	1	1250	18.18	0.013
Air velocity	11250.00	1	11250	163.64	0.0002
Residual	275.00	4	68.75		
Cor Total	13787.50	7			

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Table 4. Colour (L*, a*, b*) value of freshly grated coconut with samples from different combination of drying parameters.

Drying Parameters (°C/rpm/ms^{-1})	L*	a*	b*
(50/3/4.31)	76.97±1.65^{a}	-4.62±0.14^{bcd}	8.01±0.43^{ab}
(60/3/4.31)	66.52±0.82^{b}	-4.78±0.20^{cd}	7.27±0.30^{abc}
(50/6/4.31)	75.70±1.33^{a}	-5.02±0.34^{d}	8.14±0.05^{a}
(60/6/4.31)	77.60±1.02^{a}	-4.88±0.14^{cd}	7.34±0.14^{abc}
(50/3/2.06)	77.35±0.56^{a}	-3.42±0.21^{a}	7.05±0.44^{c}
(60/3/2.06)	78.81±0.80^{a}	-4.40±0.20^{bc}	6.09±0.44^{d}
(50/6/2.06)	76.31±0.59^{a}	-3.47±0.30^{a}	6.82±0.25^{cd}
(60/6/2.06)	77.64±1.29^{a}	-4.14±0.05^{b}	7.25±0.18^{bc}

Mean±standard deviation values followed by superscript letters within the same column are significantly different (p<0.05) by Tukey's multiple range tests

Table 6. T-test for L* (lightness) value between fresh and dried grated coconut

Drying Parameters (°C/rpm/ms^{-1})	T-value	P-value
(50/3/4.31)	2.34	0.079
(60/3/4.31)	1.84	0.139
(50/6/4.31)	5.31	0.006
(60/6/4.31)	8.04	0.001
(50/3/2.06)	17.23	0.000
(60/3/2.06)	9.18	0.001
(50/6/2.06)	11.37	0.000
(60/6/2.06)	5.33	0.006

Two sample T-test at 95% CI; (p<0.05) are significantly different

Table 5. Colour (L*, a*, b*) value of dried grated coconut with different combination drying parameters

Drying Parameters (°C/rpm/ms^{-1})	L*	a*	b*
(50/3/4.31)	74.56±0.66^{a}	-4.34±0.10^{c}	10.12±0.03^{ab}
(60/3/4.31)	64.62±1.60^{a}	-4.44±0.12^{cd}	8.90±0.54^{c}
(50/6/4.31)	69.62±1.13^{ab}	-4.70±0.18^{d}	9.25±0.12^{c}
(60/6/4.31)	71.78±0.73^{bc}	-4.25±0.09^{c}	8.95±0.09^{c}
(50/3/2.06)	71.48±0.19^{bc}	-3.64±0.12^{ab}	8.96±0.26^{c}
(60/3/2.06)	74.50±0.13^{c}	-3.90±0.02^{b}	7.83±0.06^{d}
(50/6/2.06)	70.38±0.68^{c}	-3.45±0.03^{a}	10.16±0.19^{a}
(60/6/2.06)	72.99±0.78^{d}	-3.60±0.15^{ab}	9.46±0.21^{bc}

Mean±standard deviation values followed by superscript letters within the same column are significantly different (p<0.05) by Tukey's multiple range tests

Table 7. Colour quality of dried grated coconut

Drying Parameters (°C/rpm/ms^{-1})	ΔE	a*/b* (dried)
(50/3/4.31)	3.13±0.40^{cd}	-0.43±0.01b^{c}
(60/3/4.31)	4.54±1.01^{d}	-0.50±0.03^{d}
(50/6/4.31)	2.64±0.44^{d}	-0.41±0.03^{b}
(60/6/4.31)	4.67±0.09^{bc}	-0.50±0.01^{d}
(50/3/2.06)	6.20±1.11^{ab}	-0.51±0.01^{d}
(60/3/2.06)	6.08±0.72^{ab}	-0.47±0.01^{cd}
(50/6/2.06)	7.05±0.63^{a}	-0.34±0.01^{ab}
(60/6/2.06)	5.19±0.66^{ab}	-0.38±0.02^{a}

Mean±standard deviation values followed by superscript letters within the same column are significantly different (p<0.05) by Tukey's multiple range tests

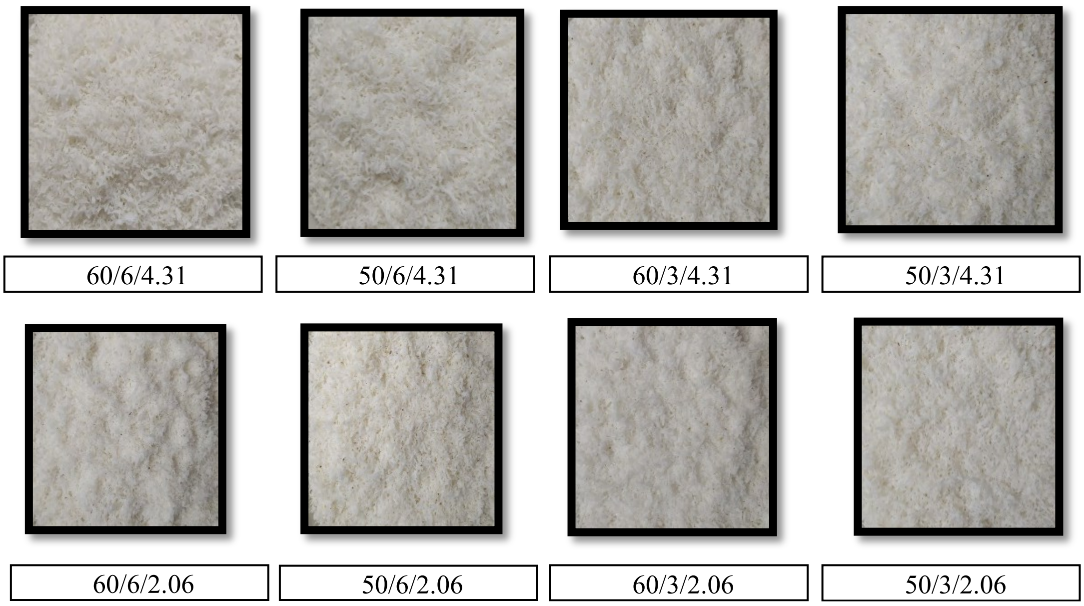

Figure 6. The final color of dried grated coconut samples according to combination drying parameters

illustrates the final colour of dried grated coconut.

4. Conclusion

Drying behaviour of grated coconut was explored using a special designed convective dryer with varies combination of drying parameters. The moisture substance of the grated coconut decreased from 50-54% (w.b) to final moisture content of 3-4% (w.b). Throughout this study, it was proven that three factors

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temperature, rotational speed and air velocity played a significant role in drying time as well as drying rate. The final actual equation was produced to predict drying time as affected by three main factors. It was found that samples of 50˚C/3 rpm/4.31 ms^{-1} and 60˚C/3 rpm/4.31 ms^{-1} were superior in retaining its original lightness and also had a quite short drying time. In contrast, sample of 50˚C/ 6 rpm/ 2.06 ms^{-1} and 60˚C/ 6 rpm/ 2.06 ms^{-1} were among the best in achieving a lower value of a*/b* with considerably higher drying time. In a nutshell, sample 60˚C/3 rpm/4.31 ms^{-1} can be choosen as the best combination parameters to achieve a higher drying rate as well as the acceptable colour quality of dried grated coconut.

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