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Vacuum Application with Water Jet Technology in Drying Button Mushrooms (*Agaricus bisporus*)

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Abstract Button mushroom (*Agaricus bisporus*) is the most popular mushroom commodity in the world because of its deliciousness, texture, and nutritional value. However, the high water content in this product makes it perishable so that drying as a preservation method is needed. The present study aims to evaluate the vacuum drying method based on water jet technology by observing the physical quality and drying kinetics of slice button mushrooms. Drying was controlled with a constant pressure of 130 mbar with temperature variations of 50, 60, and 70 ^{o}C. The sample used was slice button mushroom with a thickness of 5 mm which was blanched in ascorbic acid solution. The results showed that vacuum drying can reduce water content up to 6.01-15.15 % (w.b.) with an average drying rate of 0.17-0.18 % (w.b.)/min. ANOVA test showed that the variation of drying temperature and blanching treatment had a significant effect on all observed physical parameters (moisture content, surface area, hardness, and color). At the end of drying, changes in physical parameters were observed, including surface area (19.98-38.45%), hardness (54.45-536.95 g), and color with indicators L* (25.45-71.01), a* (-2.52-15.44), and b* (5.63-29.38), whiteness (22.11-71.19%), and the best drying kinetics prediction models are the Two-term and Wang-Singh models.

Keywords Button Mushroom, Drying Kinetics, Vacuum Drying, Water Jet Technology

1. Introduction

Button mushroom (*Agaricus bisporus*) is a potential commodity that is considered in the agro-industry sector and as a vegetable with good nutrition, even cultivated in many countries [1]. Button mushrooms are popular because they have low calorific value but are rich in nutrients such as essential amino acids, vitamins (folate, niacin, and B2), as well as a number of minerals (phosphorus, zinc, potassium, and copper) [1, 2]. The high water content of button mushrooms makes this superior commodity easy to damage after harvest i.e., changes in size, color, moisture content, and texture [3]. Therefore, the drying method is the best solution in increasing shelf life and minimizing contamination that is harmful to health. Vacuum drying is one of the most widely used drying methods and has been shown to provide better results than other drying methods. Traditional methods cannot be applied to mushroom products because time and temperature that cannot be controlled make the final product undergo drastic physico-chemical changes [4]. The forced hot air drying method also cannot be applied to mushrooms, in this case the hot air released into the product will accelerate the oxidation process [5]. So that the selection of the vacuum method is one of the recommended drying methods because the drying time is relatively short, the temperature is controlled, and it avoids excessive oxidation. One of the innovative technologies is the water jet vacuum technology as a low-cost and energy-efficient system for lowering the pressure in the drying chamber. The vacuum process in the drying chamber is due to a nozzle system that is used to convert high-pressure fluid energy into fluid kinetic energy which can accelerate the flow at low pressure [6]. The resultant of high fluid flow velocity creates a low pressure area in the suction chamber which causes fluid to be drawn from within the drying chamber into this chamber [7].

Pre-treatment methods before drying should be considered to improve the quality of dry products. In addition, some pre-treatment methods can speed up the drying process. Such as hot water blanching treatment [4, 8], UV-B [3], pulsed electric field (PEF) and ultrasound (US) [8]. Ascorbic acid blanching treatment can be considered for mushroom farmers in various regions as a pre-treatment to extend shelf life and inhibit the development of microorganisms and prevent excessive phytochemical degradation. Transfer methods of final drying quality are fast, cheap, and easy to do are the primary considerations in this research has long been applied. Using ascorbic acid in the drying process generally produces a final product that is sometimes not optimal and can only be applied to certain agricultural products.

One important aspects of drying in the industrial sector is the modeling of the drying process [9]. Modeling aims to choose the appropriate drying method or process for the product conditions used and helps in understanding the heat and mass transfer processes in application [10]. The phenomenon of the drying process is also a very important factor in the design, simulation, and optimization of the drying process [9, 11, 12]. However, the result of the drying model also affects the physical changes such as shrinkage, product texture, and color attributes and can be linked with other parameters.

The limited availability of vacuum drying process data such as processing, packaging, and storage of button mushrooms in extending shelf life are necessary in this study. However, this study aims to compare the results of vacuum drying on dried button mushrooms without and with ascorbic acid blanching treatment in influencing drying and physical characteristics.

2. Materials and Methods

The button mushrooms used in this study were purchased from farmers of Agro Dejamuran, Malang City, Indonesia. The mushrooms were conditioned in a cooler (±20^{o}C) until the mushrooms were analyzed. Chemicals such as ascorbic acid and aquades were purchased at CV. Kimia Makmur Sejati, Malang City, Indonesia. All chemicals used are pro analysis.

2.1. Materials Preparation

Whole button mushrooms were cut into slices with a thickness of 5 mm uniformly. The samples in this study were control and hot water blanching with the addition of ascorbic acid (0.2 w/v). Blanching was carried out at a temperature of 97±2^{o}C under controlled heat conditions for 1 minute. The sample was put into a vacuum drying chamber with water jet technology to determine the drying kinetics. The temperatures were set at 50, 60, and 70^{o}C with a constant pressure of 130 mbar. Samples were measured every 30 minutes using an analytical balance (Fujitsu FRS-A-300, Japan) with an accuracy of ±0.001 g until the equilibrium moisture content was reached. Then, the dry matter of the sample was determined using the gravimetric method for 4-5 hours at a temperature of 105^{o}C [13].

2.2. Evaluation of Drying Characteristic

Measurement of moisture content in slice button mushrooms using the gravimetric method at a temperature of 105^{o}C, for 4-5 hours. Moisture content is displayed on a wet basis (w.b.) on each drying curve. The equation (1) for the moisture content in slice mushrooms can be determined as follows. M_i is the initial moisture content, m_d is the mass of dry material, and m_i is the mass of wet material [14].

$$M_i = \frac{m_i - m_d}{m_i} \quad (1)$$

The drying rate is a part of characteristic which is very important in determining the amount of water diffusion in foodstuffs. DR is drying rate, $M_{t+\Delta t}$ is moisture content at time t, and Δt is time difference. The calculation of the drying rate can be seen in the following equation (2) [4].

$$DR = \frac{M_{t+\Delta t} - M_i}{\Delta t} \quad (2)$$

2.3. Mathematical Model

There are 10 mathematical models used in this study as reported by [9] and can be seen the model equations in Table 1. The mathematical models are Modified Page, Henderson-Pabis, Logarithmic, Midilli et al., Two-term, Two-term Exp., Modified Henderson-Pabis, Wang-Singh, Verma et al., and Diffusion approach models. The fittest model will be selected and displayed based R^2, RMSE, and χ^2 value [4].

Table 1. The considered drying model

No	Model Name	Model Equations
1	Modified-Page	MR = exp[-(kt)n]
2	Henderson-Pabis	MR = a exp(-kt)
3	Logarithmic	MR = a exp(-kt) + c
4	Midili et al.	MR = a exp(-kt) + bt
5	Two-Term	$MR = a \exp(-k_0t) + b \exp(-k_1t)$
6	Two-Term Exp.	$MR = a\exp(-k_0t)+(1-a) \exp(-k_1at)$
7	Mod. Henderson-Pabis	MR = a exp(-kt) + b exp(-gt) + c exp(-ht)
8	Wang-Singh	$MR = 1 + at + bt^2$
9	Diffusion Approach	MR = a exp(-kt) + (1-a) exp(-kbt)
10	Verma et al.	MR = a exp(-kt) + (1-a) exp(-gt)

2.4. Surface Area

Determination of the final object shrinkage on the slice button mushroom is determined based on the surface area. Surface area analysis using ImageJ 1.8.0-172 software [14, 15]. The final large percentage of dried mushroom slices can be determined by the following equation (3), where Sa is the final object shrinkage and h_{t-i} is the t-th and 0-th data (initial). The determination of surface area was conducted once when moisture equilibrium was achieved.

$$\mathrm{Sa} = \frac{h_t}{h_i} \times 100\% \quad (3)$$

2.5. Hardness

Fresh and dried button mushrooms were analyzed for hardness using TexturePro CT V1.4 Build 17. Samples were analyzed with a test-return speed of 1.0 mm/s and a depth of 1.0 mm. The probe used in the test is the TA9 type and the load cell is 1000 g. The determination of hardness area was conducted once when moisture equilibrium was achieved.

2.6. Discoloration

Analysis of color changes used the image method approach. The light intensity of the box is kept constant at 26.99±0.89 W/m^2. The measured images were read the values of L*, a*, and b* with Matlab R2019a software. The L*, a*, b* data is then converted to whiteness attribute on button mushroom slice. The determination of discoloration area was conducted once when moisture equilibrium was achieved. Technical retrieval refers to Hawa et al. [17].

2.7. Statistical Analysis

Test parameters i.e., moisture content, surface area, hardness, color attributes using a Two-way ANOVA was performed with a 95% confidence level. The further test used was the Tukey test with a 95% confidence level. All experiments were repeated three times (n=3). For all statical analysis, $P<0.05$ (a significance level) was used. Drying modeling behavior of button mushrooms was analyzed coefficient of determination (R^2), Chi-squared, and root mean square error (RMSE) were used to express the goodness of fit models. Statistical analysis was performed using the MS-Excel.

3. Results and Discussion

3.1. Drying Kinetic Characteristics

The drying characteristics of slice button mushroom can be seen in Fig. 1. During the vacuum drying process, the sample experienced a decrease in moisture content with increasing time. An increase in temperature can accelerate the mass transfer process. The blanched samples reached equilibrium moisture content in 240–300 minutes and without blanching in 270–390 minutes. Based on the results of the data informs that the blanching treatment is able to speed up the drying process and save energy consumption costs. Blanching in ascorbate solution affects the impairment of cell walls and opens the pores of the material, making it easier for water to diffuse during drying [18]. This condition causes slice button mushrooms to reach equilibrium moisture content earlier.

Mass transfer characteristics can be identified through the drying rate per moisture content ratio. Fig. 2 provides information regarding the magnitude of the drying rate during vacuum drying. At the beginning of drying, the drying rate is still experiencing water transfer that is not large. The phenomenon of drying rate in button mushrooms is experiencing a peak of water transfer approaching the equilibrium moisture content which can be identified from the MR (0.2–0.5). However, the drying rate of the treatment without blanching was smaller than that of the blanching treatment. This happens because the surface evaporation rate is faster than the internal migration rate in mushrooms, as of it affects the drying moisture content and drying rate [5].

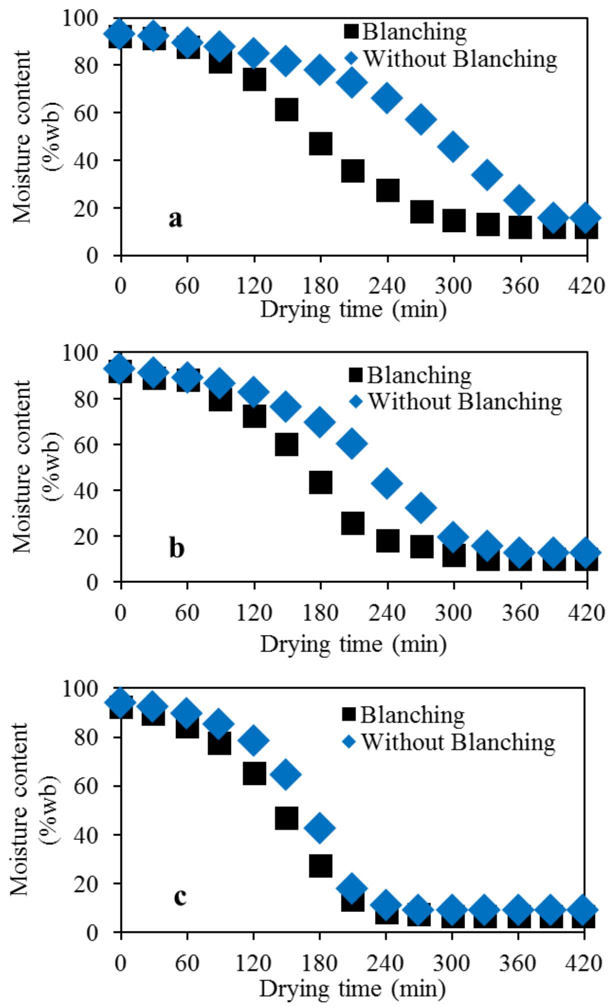

Figure 1. Experimentally measured moisture content with respect to drying time at temperature; (a) 50°C, (b) 60°C, (c) 70°C

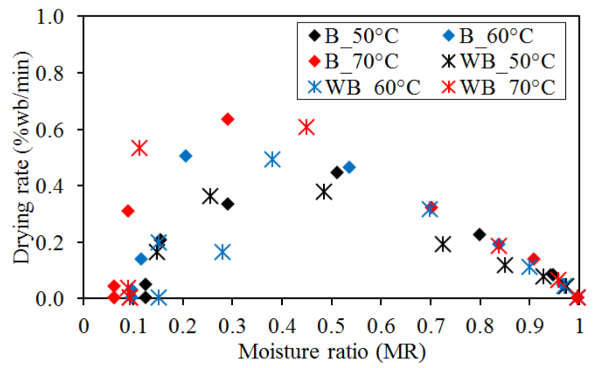

Figure 2. The variation of drying rate with respect to the moisture ratio, (B) blanching; (WB) without blanching

The ANOVA test (α=0.05) showed that the temperature treatment and blanching had an effect on the moisture content. Tukey's test on pre-treatment, blanching samples and control was significantly different to the final moisture content. The temperature factor shows that the temperature of 50°C is significantly different from that of 60°C, but the temperature of 60°C is not significantly different from 70°C.

3.2. Mathematical Modelling of Drying Curves

The mathematical models were evaluated based on R^2, χ^2 and RMSE. The summary of model constants and statistical parameter for sliced button mushroom can be seen at Table 2 (with blanching) and Table 3 (without blanching). The statistical parameters revealed that The Two-Term and Wang-Singh Model has the highest value of R^2, the lowest χ^2 and RMSE, as illustrated in Fig. 3. The value of the accuracy of the coefficient of determination is more than 0.9500, the chi square is less than 0.008, and the RMSE is less than 0.081. Two-term model is the best model because the experimental data shows the initial phase of the drying period which is represented by the initial curvature before the constant rate occurs.

Table 2. Best model constants and goodness analysis for button mushroom with blanching

No	Model Constant	R^2	χ^2	RMSE
Temp. 50 °C				
1	k=0.0381; n=0.1152	0.0939	0.0156	0.1163
2	a=1.1730; k=0.0050	0.9274	0.0103	0.0945

3	a=9.2144;
	k=0.0003;
	c= -8.1786
		0.9355	0.0095	0.0871

4	a=0.9345;
	k= -0.0918;
	n=0.5113;
	b= -0.0164
		0.9851	0.0024	0.0592

5	a=-7.0310;
	k_0=0.0123;
	b=8.0047;
	k_1=0.0102
		0.9884	0.0019	0.0369

6	a=0.0007; k=5.8621	0.9394	0.0157	0.1165

7	a=-.4257;
	k=0.0050;
	b=0.3216;
	c=0.04257;
	h=0.0050
		0.9274	0.0149	0.0946

8	a= -0.0030; b=0.0000	0.9497	0.0085	0.0857

9	a= -23.5484;
	k=0.0114;
	b=0.9452
		0.9881	0.0018	0.0376

10	a= -10.4120;
	k=0.0118;
	g=0.0104
		0.9881	0.0018	0.0376

Table 2 Continued

Temp. 60 °C				
1	k=0.04279; n=0.10862	0.9262	0.0192	0.1289
2	a=1.1839; k=0.0055	0.9135	0.0134	0.1079

3	a=-5.8539;
	k= -0.0004;
	c=6.8492
		0.8958	0.0167	0.1156

4	a=0.93553;
	k= -0.092;
	n=0.51109; b=-0.0172
		0.9787	0.0038	0.0741

5	a=9.6024; k_0=0.0114; b=-8.6377; k_1=0.0135	0.9809	0.0033	0.0495
6	a=0.0008; k=5.8643	0.9260	0.0192	0.1290

7	a=0.4292;
	k=0.0055;
	b=0.03254; g=0.0055; c=0.4292;
	h=0.0055
		0.9135	0.0194	0.1079

8	a= -0.0030; b=0.000			
9	a= -23.548; k=0.0126; b=0.9423	0.9804	0.0032	0.0504
10	a= -10.412, k=0.0131; g=0.0115	0.9803	0.0032	0.0504
Temp. 70 °C				
1	k=0.0504; n=0.11658	0.9222	0.0199	0.1314
2	a=1.1824; k=0.0068	0.9117	0.0149	0.1135
3	a=1.3814; k-0.00453; c= -0.2407	0.9279	0.0125	0.0998

4	a=0.93425; k=-.10283;
	n=0.5074;
	b= -0.01985
		0.9761	0.0045	0.0812

5	a=-7.0353; k_0=0.0168; b=8.0008 ; k_1=0.0138	0.9761	0.0045	0.0577
6	a= 0.0010; k=5.8505	0.9220	0.0200	0.1316

7	a=0.4284; k=0.0068;
	b=0.3254;
	g=0.0068;
	c-0.4284; h=0.0068
		0.9117	0.0215	0.1135

8	a= -0.0030; b=0.0000	0.8684	0.0220	0.1380
9	a= -23.548; k=0.0155; b=0.9412	0.9760	0.0040	0.0580
10	a= -10.4091; k=0.0160; g=0.0140	0.9756	0.0042	0.0583

Two-Term Model is one of the models that is able to provide a complete description of the drying process (phase) starting from the initial drying phase, constant rate, falling rate, and constant. While the Wang-Singh model can predict well for the drying phenomenon which tends to be sigmoid. The best model for drying button mushrooms on different types of drying methods found in several references i.e., the Page Model for the microwave drying method, the Logarithmic Model for the hot air drying method [19], the Page Model for the drying method for microwave vacuum [20], and the Henderson-Pabis model of the hot air method of UV-B treatment [3].

Table 3. Best model constants and goodness analysis for button mushroom without blanching

No	Model Constant	R^2	χ^2	RMSE
Temp. 50 °C				
1	k=0.0144; n=0.1593	0.8525	0.0246	0.1461
2	a=1.1667; k=0.0029	0.8285	0.0183	0.1259
3	a=9.2647; k=0.0003; c=-8.1243	0.9215	0.0088	0.0839
4	a=0.9546; k=-0.0474; n=0.4644; b=-0.0046	0.9708	0.0036	0.0724
5	a= -7.0647; k_0=0.0083; b=8.0024; k_1=0.0068	0.9476	0.0069	0.0710
6	a=0.0004; k=5.9377	0.8524	0.0247	0.1462
7	a=0.1003; k=0.0029; b=0.9660; g=0.0029; c=0.1003; h=0.0029	0.8285	0.0264	0.1259
8	a= -0.0001; b=0.0000	0.9857	0.0015	0.0358
9	a= -23.5449; k=0.0075; b=0.9424	0.9428	0.0067	0.0733
10	a= -10.4388; k=0.0077; g=0.0068	0.9433	0.0067	0.0734
Temp. 60 °C				
1	k=0.0212; n=0.1544	0.8898	0.0263	0.1510
2	a=1.1907; k=0.0040	0.8677	0.0190	0.1283
3	a=9.2580; k=0.0003; c= -8.1382	0.9433	0.0084	0.0820
4	a=0.9489; k= -0.0611; n=0.5319; b=-0.0102	0.9639	0.0058	0.0926
5	a=-7.0609; k_0=0.0107; b=8.0002 ; k_1=0.0087	0.9667	0.0057	0.0648
6	a=0.006; k=5.8919	0.8897	0.0263	0.1511
7	a=0.10034; k=0.00292; b=0.96603; g=0.00291; c=0.10034; h=0.00292	0.8992	0.0482	0.1701
8	a= -0.0001; b=0.0000	0.9055	0.0152	0.1147
9	a=-23.5454; k=0.0097; b=0.9405	0.9642	0.0056	0.0667
10	a= -10.4333; k=0.0100; g=0.0087	0.9644	0.0056	0.0669

Table 3 Continued

Temp. 70°C				
1	k=0.0458; n=0.1074	0.8865	0.0301	0.1616
2	a=1.2104; k=0.0059	0.8719	0.0227	0.1404
3	a=1.6204; k=0.0031; c= -0.4643	0.8977	0.0188	0.1228
4	a=0.9641; k= -0.1028; n=0.5031; b= -0.0194	0.9566	0.0087	0.1131
5	a= -7.0436; k_0=0.0153; b=7.9926 ; k_1=0.0123	0.9558	0.0089	0.0808
6	a=0.0008; k=5.8557	0.8863	0.0302	0.1671
7	a=0.4382; k=0.0059; b=0.3341; g=0.0059; c=0.4382; h=0.0059	0.8719	0.0829	0.1404
8	a= -0.0035; b=0.0000	0.8991	0.0206	0.1336
9	a= -23.5489; k=0.0139; b=0.9363	0.9550	0.0084	0.0818
10	a= -10.4120; k=0.0145; g=0.0125	0.9548	0.0084	0.0819

Table 4. Magnitude of change for button mushrooms

Time (min)	**Temp. (°C)**		
	50	**60**	**70**
Blanching			
0	100.0±0.00[a]	100.0±0.00[b]	100.0±0.00[b]
180	40.86±3.11[a]	33.25±4.54[b]	29.42±7.19[b]
300	34.49±3.54[a]	28.59±4.82[b]	20.17±2.97[b]
420	30.87±1.89[a]	23.87±3.02[b]	19.98±2.78[b]
Without Blanching			
0	100.0±0.00[a]	100.0±0.00[b]	100.0±0.00[b]
180	62.04±2.63[a]	38.58±3.31[b]	44.48±3.16[b]
300	46.51±1.68[a]	31.48±1.88[b]	29.60±3.80[b]
420	38.45±1.12[a]	29.16±1.87[b]	28.03±2.52[b]

*Mean value within a column followed by the different letters are significantly ($p<0.05$) according to Tukey's Test. Mean±SD (n=3)

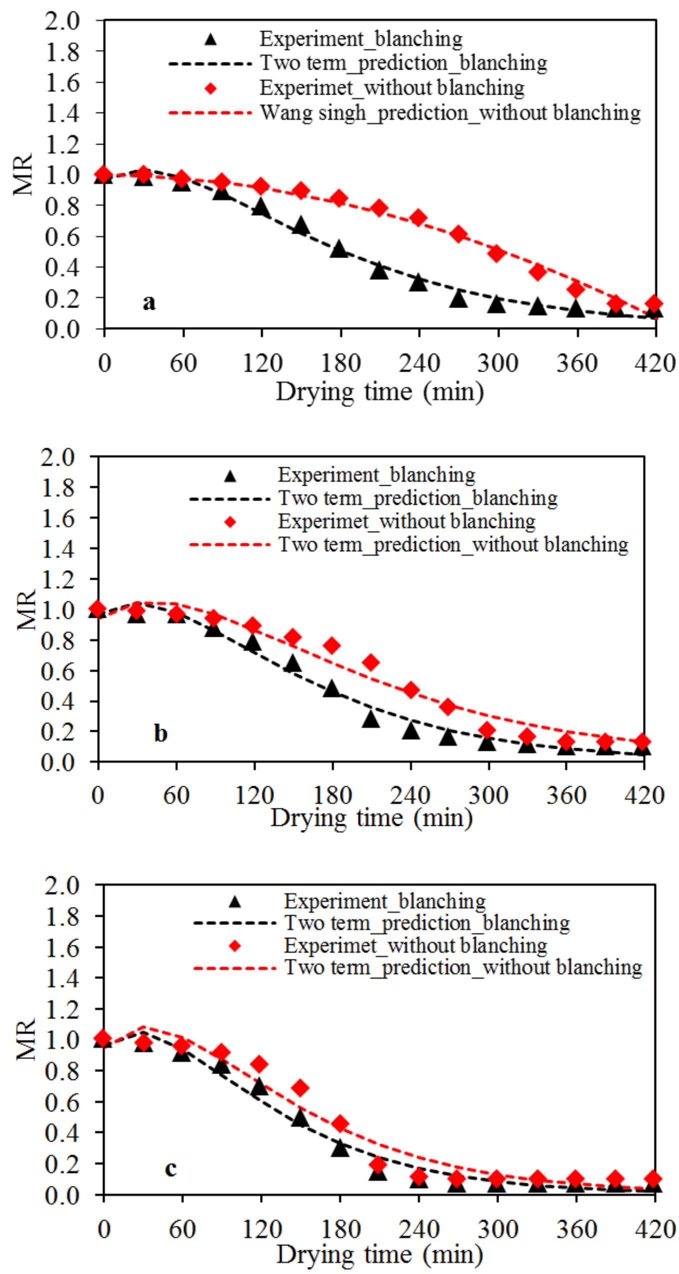

Figure 3. Measurement and predicted MR using Two-Term and Wang-Singh model, at drying temperatures; (a) 50°C, (b) 60°C, (c) 70°C

3.3. Surface Area

The effect of the blanching treatment affects differences in the final results of button mushroom drying. The magnitude of changes in the dry button mushrooms on the surface area of sliced button mushrooms can be seen in Table 4. The surface area shows a decrease with the duration of drying. The research data informs that the blanching treatment gives a larger shrinkage on the surface area. It is evident from the percentage of the surface area of the final object which is smaller than without blanching, which means that the shrinkage is very large in the blanching treatment. Loss of water during drying causes a very drastic shrinkage in physical parameters which is influenced by changes in the polymer of cell wall structure and loss of cell membrane integrity [21].

The ANOVA test (α=0.05) showed that the temperature treatment and blanching had an effect on the surface area. Tukey's test on pre-treatment, blanching samples and control was significantly different to the final surface area. The temperature factor shows that the temperature of 50 °C is significantly different from that of 60 °C, but the temperature of 60 °C is not significantly different from 70 °C. Higher temperatures cause higher shrinkage in this research. This result was observed by many reports that the shrinkage was related to the amount of removed moisture [22–26]. Heat and moisture loss can cause stress inside the cellular structure, leading to shrinkage in food material. Thus, the higher temperature causes higher shrinkage since the moisture content is lower [27].

3.4. Hardness

Table 5 shows information regarding the hardness changes of slice button mushrooms during vacuum drying. At the beginning of drying, the hardness of blanching button mushrooms was lower but increased until the end of drying. This was also confirmed by Pei et al. [5] and Zhang et al. [20] on button mushrooms. The blanching treatment was able to change the structure of the fungus to be more porous so that more water was transferred and the final structure was denser than that without blanching as reported by Jiang et al. [26]. The hardness values for blanching and non-blanching treatments were 427.65–536.95 g and 54.45–197.35 g, respectively. The hardness values in the blanching treatment have similarities as reported by Jiang et al. [26] ranged from 600 g. Zhang et al. [21] stated that the hardness will increase with the length of drying.

Table 5. Hardness for button mushroom

Time (min)	Temp. (°C)		
	50	**60**	**70**
Blanching			
0	7.05±0.25^a	7.05±0.25^b	7.05±0.25^b
180	24.15±1.45^a	20.40±0.00^b	19.35±0.15^b
300	156.10±0.00^a	132.05±24.9^b	124.35±0.05^b
420	536.95±31.1^a	454.10±0.00^b	427.65±0.75^b
Without Blanching			
0	14.65±0.15^a	14.65±0.15^b	14.65±0.15^b
180	34.70±0.00^a	17.50±0.00^b	16.60±0.00^b
300	45.30±2.80^a	26.60±0.00^b	25.20±1.40^b
420	197.35±6.45^a	116.10±4.90^b	54.45±5.85^b

*Mean value within a column followed by the different letters are significantly (p<0.05) according to Tukey's Test. Mean±SD (n=3)

The ANOVA test (α=0.05) showed that the blanching treatment and temperature had a significant effect on hardness. Tukey's test showed that the blanching treatment was significantly different to the hardness value. In addition, the vacuum drying temperature of 50°C was significantly different from that of 60°C. However, the temperatures of 60°C and70 °C were not significantly different. The results showed that the higher the drying temperature, the lower the hardness of the sample. Research by Pimpaporn et al. [28] and Guiné and Barroca [29] showed the same trend where the hardness of the samples decreased with increasing drying temperature applied. According to those reports, it can be concluded that the high drying temperature causes the softening of the tissue and changes in the more porous structure so that the hardness is lower.

3.5. Discoloration

The drying temperature and blanching treatment resulted in changes of color attributes. Table 6 informs that the blanching treatment or non-blanching can reduce the parameters L* and whiteness (%) and increase the parameters a* and b*. Dueik et al. [30] revealed a decrease in L* as an indication of darkening of the material and as a non-enzymatic browning reaction that occurs every time the process temperature increases. An increase in a* and a decrease in b* has also been reported by Salehi [31] which correlates with a decrease in brightness.

Based on the ANOVA test (α=0.05), the blanching treatment and temperature had a significant effect on changes in color attributes, which included L*, a*, b*, and whiteness. Tukey's further test also showed that the blanching treatment and temperature variations caused significant differences in all color attributes. The blanching treatment and high drying temperature resulted in a greater decrease in the percentage of whiteness and L*, which could be sensory observed as a darker color. The appearance of button mushroom during vacuum drying can be seen in Fig. 4. The darker color is mainly caused by high temperatures during blanching and during drying which can accelerate oxidation. In addition, non-enzymatic browning is also a common reaction during drying involving high temperatures, which occurs in all samples.

Table 6. Colour parameters of button mushroom post drying process

Drying Temperature (°C)	**Color Parameters**				
	L*	**a***	**b***	**Whiteness (%)**	**Representation**
Blanching					
Initial	67.38 ±0.59[a]	-2.52 ±0.09[a]	11.13 ±0.25[a]	65.44 ± 0.48[a]	
50	46.38 ±0.97[b]	4.95 ±0.09[b]	29.38 ±0.09[b]	38.66 ± 0.84[b]	
60	38.26 ±1.48[c]	14.25 ±1.48[c]	24.37 ±0.61[c]	32.10 ± 1.44[c]	
70	25.45 ±0.29[d]	15.44 ±0.24[d]	16.44 ±0.43[d]	22.11 ± 0.34[d]	
Without Blanching					
Initial	71.01 ±0.71[a]	-0.74 ±0.08[a]	5.63 ±0.24[a]	71.19 ± 0.65[a]	
50	54.43 ±2.03[b]	1.79 ±0.31[b]	20.50 ±0.05[b]	50.00 ± 1.86[b]	
60	43.58 ±1.03[c]	3.52 ±0.27[c]	21.44 ±0.29[c]	39.54 ± 0.91[c]	
70	41.43 ±1.39[d]	3.99 ±0.49[d]	21.31 ±0.17[d]	37.54 ± 1.27[d]	

*Mean value within a row followed by the different letters are significantly ($p<0.05$) according to Tukey's Test. Mean ±SD (n=3)

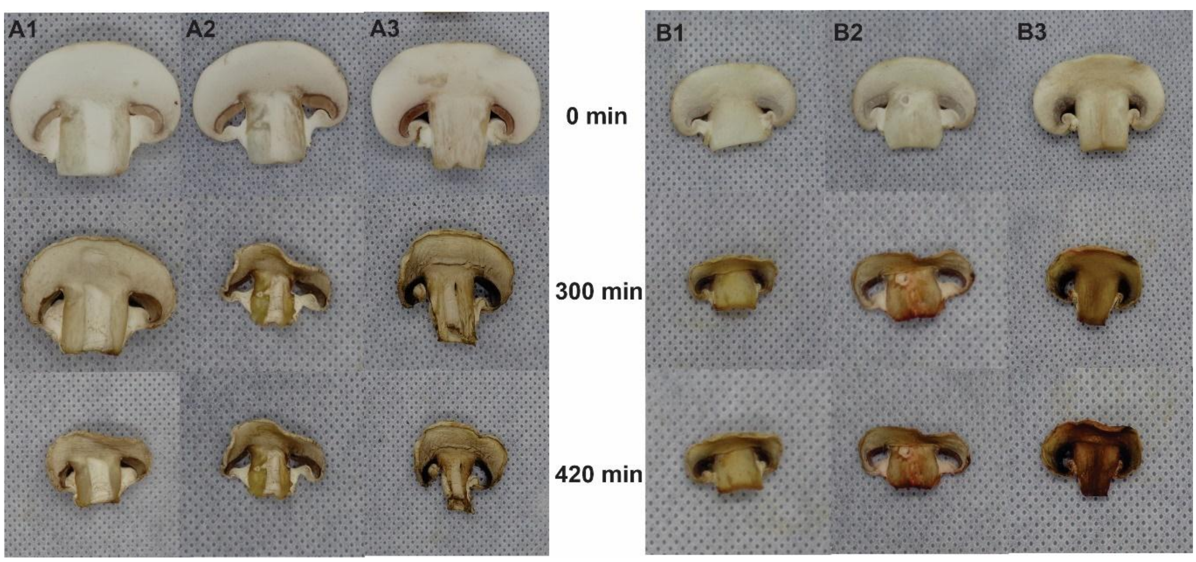

Figure 4. The result of drying for button mushroom slice, (A) without blanching; (B) blanching at drying temperatures; (1) 50°C; (2) 60°C; (3) 70°C

These two factors cannot be significantly prevented by the presence of ascorbic acid because fully oxidized ascorbic acid and melanin formation [32]. However, button mushrooms with blanching treatment are able to maintain their shape and provide a unique characteristic color. In contrast to without blanching which tends to have a shriveled mushroom slice shape that is different from its original shape.

4. Conclusions

Vacuum drying on slice button mushrooms has been evaluated in this study. Changes in drying characteristics (kinetics and drying rate), changes in final shrinkage, hardness, and color attribute were found during drying. The Two-Term and Wang-Singh model become the best mathematical models in predicting the drying characteristics based on the results of statistical analysis R^2, χ^2 and RMSE. The blanching treatment and drying temperature significantly affected the moisture content, drying rate, texture, shrinkage and color properties. Blanching can increase the drying rate, maintain the better shape of button mushrooms, but unfortunately causes greater shrinkage and browning. Although the final result of vacuum drying with ascorbic acid blanching treatment gave quite good physical characteristics, further investigation is needed.

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