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Research article

Enhancement of onion bulb drying with air dehumidification assisted dryer

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Abstract: Drying is an important process in onion bulb processing to preserve product quality and storage time. This paper discusses how to find an onion bulb with acceptable moisture content and high ingredient retention rate with minimized heat usage. As indicators, moisture content, riboflavin (Vitamin B_2) content, and heat efficiency are evaluated at different drying temperatures and air relative humidity. In doing so, the response surface method is employed to find the most favorable drying condition. Polynomial regression was found to be a good fit in predicting moisture content, while heat efficiency response is significantly fit after dehumidification is applied. Moreover, onion drying with air dehumidification has more advantages than that of without dehumidification. With low air relative and medium drying temperature, the heat efficiency of the onion bulb drying can be positively improved with an acceptable riboflavin retention. Analysis of variance revealed that air dehumidification and drying temperature have a significant impact on the drying time and heat efficiency. However, at high air temperatures, the effect of air dehumidification is limited.

Keywords: drying, dehumidification, efficiency, onion bulb, riboflavin

1. Introduction

Fresh-harvested onion bulb usually has a high amount of moisture content, approximately 88% [1,2]. The moisture also covers the surface of onion, which can drive germination. With this condition, the onions cannot be directly stored. Therefore, the moisture in the onion or shallot surface (outer layer) needs to be removed *via* a drying process. A convective dryer with hot air has been developed to dry onion. However, the introduction of heat can degrade the physicochemical quality of onion. By slicing, onion has a thinner size that can speed up moisture content reduction. As a result, the drying time can be shorter, and the onion quality can be retained [3]. However, the preference for onion slicing is limited. Most consumers prefer to get onion bulbs owing to their flexibility for processing, especially for seasoning food.

The drying temperature influences the degradation of the nutritional values of food, including onion or shallot [4]. Onion (*Allium cepa* L.) consists of several nutrients, such as protein, vitamins, minerals, and amino acids, which are sensitive to heat [5]. Onion bulb drying can be an option to retain ingredients as it removes water in the outer layer or surface of the onion. Microscopic observation of red onion bulbs revealed that there is a thin biofilm between the onion’s inner and outer layers that works as a selective permeable membrane [6]. When the outer layer can be kept dry, the inside layer can be covered to retain the ingredients and freshness.

Drying with air dehumidified by a desiccant can enhance the driving force for drying as well as retaining product quality. Djaeni and Perdanianti [7] have investigated red onion slice drying with a convective tray dryer using air dehumidified by several desiccants, such as silica, zeolite, and activated carbon. For all cases, the desiccants can increase the drying rate and speed up the drying time. The water transport in onion under drying was also studied using a validated model, as reported by Asiah et al. [6]. The study found that the favorable temperature for onion drying with desiccant was 60°C or below. Above 60°C, the effect of air dehumidification was found to be limited. Furthermore, the other studies also proved that at a higher temperature, the quality of onion is degraded [8,9]. Besides of quality, at a high temperature, the physical appearance of onion slices can be degraded. This observation convinced Roman et al. [10] who conducted the drying process at 60 and 70°C. These temperatures did not affect the total phenolic and flavonoid difference, significantly.

For comparison, in the case of onion curing, the process was conducted to remove moisture. Result indicated the water removal using dehumidified air at medium temperature was more superior than the direct sunlight heating and h air in terms of dehydration time [11]. It was also found that without air dehumidification, the drying process of onion was longer, especially at low temperatures [12]. Although sun drying and other long-process dryings only use low energy, long heat exposure has a higher impact on quality degradation than dehumidification drying [13].

This research investigated the effect of drying condition on the heat efficiency, moisture removal, and quality of onion bulb. Different from the previous research, this study involved the kinetics of drying rate, heat efficiency, and riboflavin analysis. In doing so, analysis of variance (ANOVA) and process optimization using the response surface methodology (RSM) were implemented to determine the significance level of the drying condition effect and the best condition for onion bulb drying. The logic diagram of this study is shown in Figure 1.

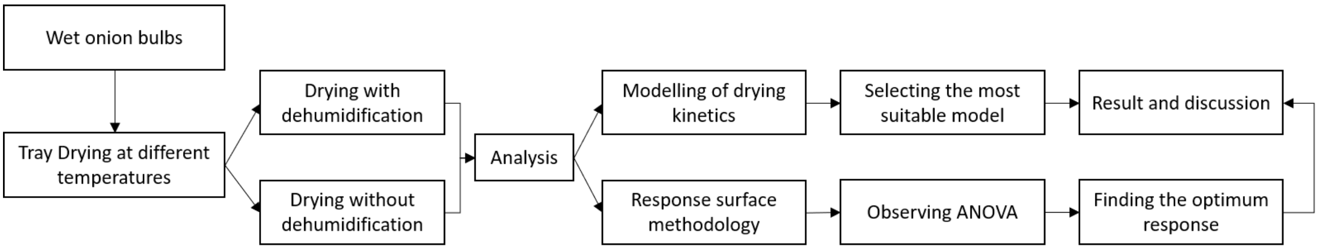

Figure 1. The logic diagram of this study.

2. Materials and methods

2.1. *Sample preparation*

Fresh onion bulbs were obtained from the Farmer Groups, Brebes, Central Java, Indonesia, and harvested in October 2020. The onion was taken rounding 2–3 days after harvested. Before drying, the bulbs were stored at room temperature for 1–2 days to make uniform moisture content.

2.2. *Initial moisture content*

The moisture content was measured using the gravimetric method. Onion bulbs (19.00 g) were sliced and then dried in the electric oven (Memmert UN110 Scwabach, Germany) at 110 ℃ until the weight was constant. The moisture content was calculated based on the different weights before and after drying. This procedure was repeated three times. The initial moisture content of onion was 83.58 ± 2.37 (w.b.).

2.3. *Drying procedure*

The drying procedure was performed in a tray dryer with length, height, and weight of 0.5, 0.2, and 0.7 m, respectively (Figure 2. The schematic of red onion drying with air dehumidification using zeolite in adsorberr. As a drying medium, ambient air was blown to the pipe with an inside diameter of 0.085 m at a linear velocity of 7.5 m/s (measured using an anemometer KW0600562, Krisbow®, Indonesia). Air was heated using electric heater until a certain temperature was reached (supposed 40 ℃). The moisture content in onion bulbs and the air relative humidity and temperature entering and exiting the dryer were determined every 60 min for 4 h. The procedures were repeated at drying temperatures of 50 ℃, 60 ℃, and 70 ℃. The processes were also performed with air dehumidification with local natural zeolite provide by Indrasari Chemical Store, Semarang, Central Java.

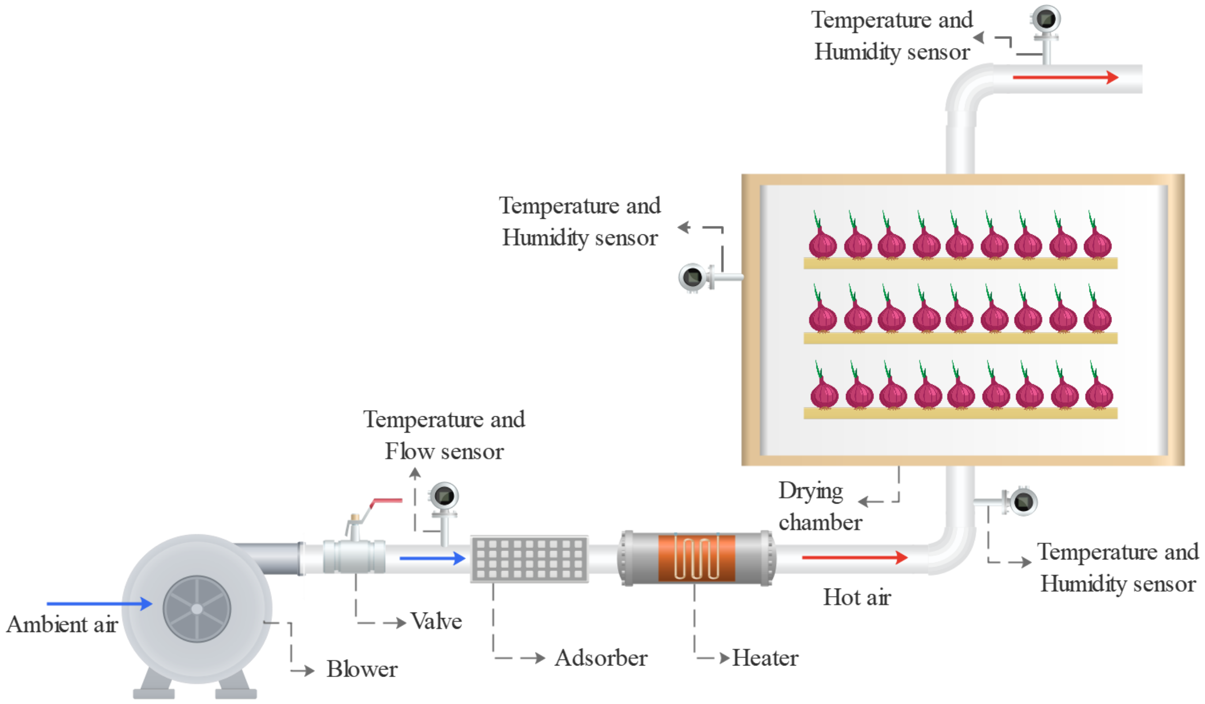

Figure 2. The schematic of red onion drying with air dehumidification using zeolite in adsorber.

2.4. Drying kinetics

The drying kinetics was estimated using Fick's law as follows [6]:

$$\ln(MR) = \frac{\ln(M_t - M_e)}{\ln(M_0 - M_e)} = \ln\left(\frac{6}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}}{r^2}\right) t \tag{1}$$

where *MR* denotes the moisture ratio (dimensionless); M_t and M_0, the moisture content at sampling and initial times, respectively; M_e, the moisture equilibrium calculated using the Henderson model [6]; *r*, the onion radius (*m*); and *t*, the drying time (*s*). As a result of the drying experiment, *MR* and *t* can be plotted to quantify the effective diffusivity, D_{eff}. The relationship between effective moisture diffusivity and the absolute temperature, *T* (*K*), is described by the Arrhenius correlation as follows [14]:

$$D_{eff} = D_0 \exp\left(-\frac{E_a}{RT}\right) \tag{2}$$

where D_0 denotes the Arrhenius factor; *R*, the ideal gas constant (J/K/mole); and E_a, the activation energy (J/mole). Meanwhile, the onion bulb drying time can be predicted using the Newton model expressed as follows:

$$MR = \exp(-kt) \tag{3}$$

Here, *k* denotes the drying constant (1/m).

2.5. Heat efficiency

The drying process was calculated to obtain the heat efficiency denoted by η. The calculation is expressed in Equation 4 as follows [15]:

$$\eta = \frac{M_d\left(X_{(t)} - X_{(t+1)}\right)\lambda}{FC_P(T_i - T_o)t_d} \tag{4}$$

where M_d denotes the mass of dry bulb (kg); $X_{(t)}$, the moisture ratio at a certain time; $X_{(t+1)}$, moisture ratio at a time after the previous certain time ($t+1$); λ, the latent heat of vaporization (2350 kJ/kg); F, the mass flow of air (kg/s); C_p, the specific heat of air (kJ/kg); T_i and T_o, the inlet and outlet temperatures of the drying column; and t_d, the observed time interval (3600 s).

2.6. Riboflavin content

The riboflavin (vitamin B2) content of onion bulb from different conditions was analyzed via high-performance liquid chromatography (LC-20AD, Shimadzu, Japan) at Agro-Based Industry Calibration and Analytical Laboratories, Bogor, West Java (accredited number LP-057-IDN). The observation of riboflavin was chosen since the nutrition is one of main ingredients in onion. Meanwhile, the observation of the others important components in onion such as thiamine (vitamin B1) and total of phenolic compounds under different drying condition has been previously studied [8,10,16]. In a brief, results showed that these compounds can be well retained on drying temperature below 80°C. ANOVA was used for the data analysis to determine the significance of different conditions.

2.7. Experiment optimization

Analysis of process optimization was conducted using the Response Surface Method (RSM) using Minitab® 19 (Minitab, LLC Pennsylvania, USA). The central composite design (CCD) was used to identify the effect of drying time (X_1) and temperature (X_2) on the moisture content of onion bulb (Y_1) and heat efficiency (Y_2). These two responses can be expressed as follows:

$$Y = A_0 + A_1X_1 + A_2X_2 + A_{12}X_1X_2 + A_{1,}X_1^2 + A_{22}X_2^2 \tag{5}$$

Where A_0 denotes the intercept constant; A_1 and A_2, the linear effects; A_{12}, the interaction effect; and A_{12} and A_{22}, the square effects. For the air dehumidification drying, the responses were denoted by $Y_{1,d}$ and $Y_{2,d}$ as moisture content and heat efficiency, respectively. The purpose of CCD application is to find the most favorable factors in order to obtain the optimum responses. This design consisted of 13 runs with coded factors as low to high values (−1, 0, +1) and α (1.41421). Table 1 presents the factor levels of two independent variables in this study.

Table 1. Factor levels of onion bulb drying.

Independent variables	Factor level				
	−α (−1.41421)	Low value (−1)	Center value (0)	High value (+1)	+α (+1.41421)
Drying time (min)	45.44	120	300	240	554.56
Temperature (°C)	45.86	50	60	70	74.14

3. Results

3.1. *Evaluation of moisture content*

This study observed the effect of temperature and dehumidification on moisture content. The data obtained from the experiment and the Newton model from bulb drying using a tray dryer under two conditions are plotted in Figure 3. The phenomenon demonstrates that air dehumidification using zeolite can speed up the reduction of the moisture content of onions. Air dehumidification reduces absolute humidity and relative humidity of air. It improves the mass transfer of moisture from onion surface to the air.

Meanwhile, for all cases, with the increase in air temperature, the moisture reduction in onion can be faster. In general, at a higher temperature, the relative humidity of air is also lower, which enhances the driving force for drying. Moreover, the moisture diffusivity or movement from the surface of onion to air also increases with the rising temperature [17]. As a result, moisture removal becomes faster [6,18,19].

The Newton model was also valid to express the moisture reduction in the onion bulb surface, as presented in Figure 3. Using the model, the drying time can be well estimated. In this study, drying was performed with the aim of reducing total moisture in onion by about 2% only. Thus, dried onion contained about 81% of the total moisture content (wet basis) or about 15% moisture in the outer layer/surface [6].

3.2. *Evaluation of drying kinetics (effective moisture diffusivity and activation energy)*

The effective moisture diffusivity of the drying process with and without air dehumidification was calculated using Equations 1 and 2. The model and experimental data are presented in Figure 4. The results indicated that the model using Fick's law correlation can fit the experimental data with R^2 value ranging from 0.866 to 0.998. Table 2 presents the result from the fitting and the effective moisture diffusivities. It demonstrates that the higher temperature, the higher the moisture diffusivity. This result is still comparable with that in previous studies conducted by Compaoré et al. [20] and Asiah et al. [6]. The data indicated that dehumidification-assisted drying has a better effect on the moisture diffusivity of onion drying compared to the drying without air dehumidification.

The activation energy (E_a) of the drying process is the minimum energy required for the drying process to occur [21]. The relationship between the moisture diffusivity and the drying temperature is depicted in Figure 5. The E_a values are 79.423 and 72.142 kJ/mol for onion drying without and with dehumidification, respectively. The higher the E_a value, the smaller the moisture diffusivity at the same drying temperature. Therefore, the moisture removal becomes slower. These two activation energies of onion drying used in this research are comparable with the food material activation energy ranging from 12.7 to 110 kJ/mol [22].

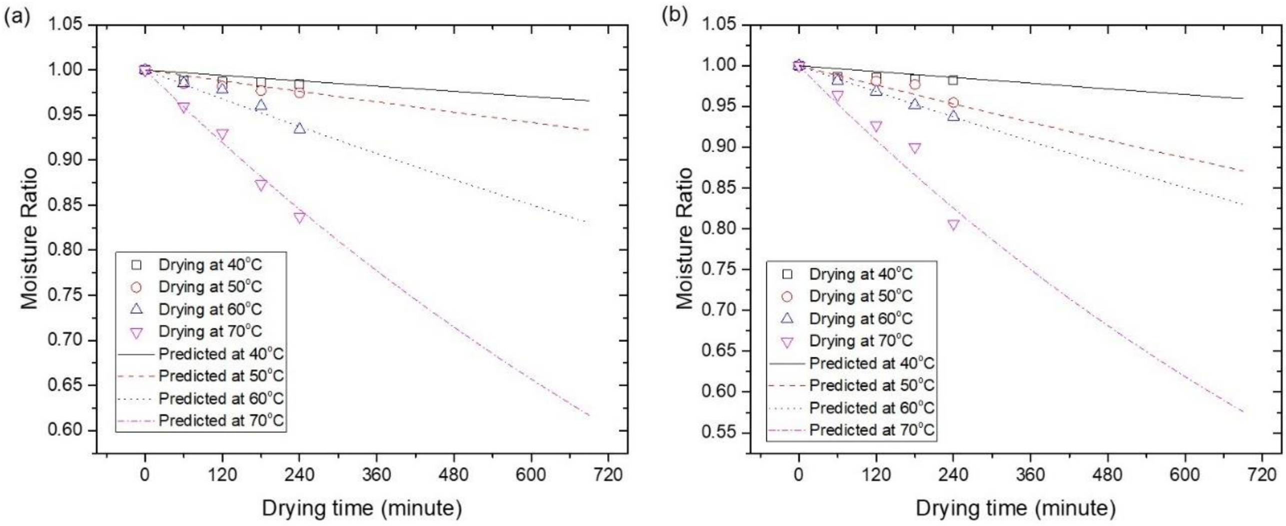

Figure 3. Moisture ratio analysis of drying (a) without dehumidification, and (b) with dehumidification at different temperatures.

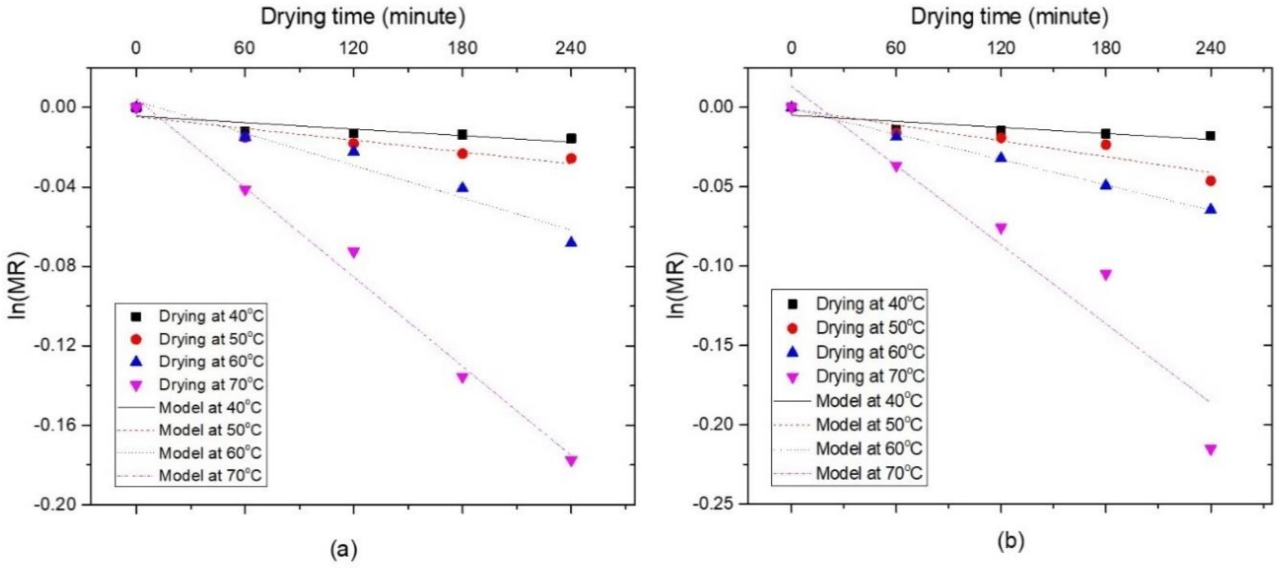

Figure 4. Natural logarithmic of Moisture Ratio (ln (MR)) against drying time at drying (a) without and (b) with dehumidification.

Table 2. Effective moisture diffusivities of onion bulb drying at different temperatures.

System	Drying Temperature (°C)	D_{eff} (10^{-10} m^2/s)	R^2
Without Dehumidification	50	0.676	0.866
	60	1.826	0.954
	70	4.733	0.989
With Dehumidification	50	1.352	0.896
	60	1.826	0.998
	70	5.409	0.922

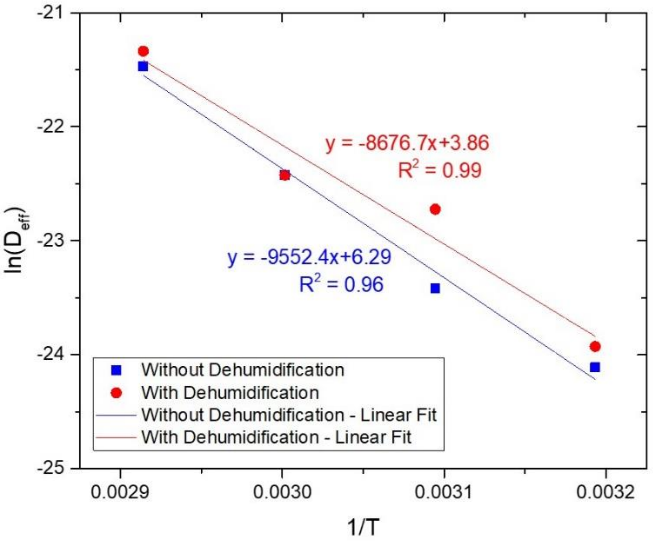

Figure 5. The relationship of ln (D_{eff}) and *1/T* at two conditions.

3.3. *Heat efficiency evaluation*

Heat efficiency was calculated using Equations 3–5, as presented in Figure 6. As can be seen from the figure, onion drying with zeolite exhibits higher efficiencies than that without zeolite. Meanwhile, for all cases, a high efficiency can be achieved at a high air temperature. These values are following the theory that a higher temperature increases the vapor pressure of moisture in which caused a faster moisture evaporation [23]. However, with natural zeolite, the heat efficiency at lower drying temperatures can be positively improved. In examples for seaweed and cassava drying, with air dehumidification, they exhibited a higher efficiency [24,25]. It seems that the tray dryer is more compatible with dry thin-layer products due to the easier water evaporation from the surface. Indeed, the onion bulb contains multiple layers, making the moisture transfer from the inner to the outer layer slow. The other ways to increase the heat efficiency of the drying process are by (a) optimizing the capacity of the dryer (air-to-wet product ratio), (b) extending the drying stage [26,27], (c) recycling the exhaust air [28], or (d) utilizing the exhaust air as a drying medium of the multistage dryer [29]. By extending the drying stage, the off-air can be totally reused in the next dryer. This procedure was repeated several times depending on the stage number.

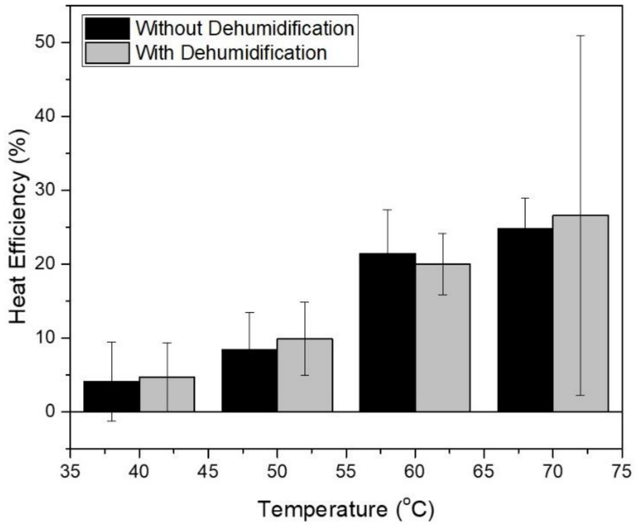

Figure 6. Heat Efficiency of onion bulb drying using a tray dryer.

3.4. Riboflavin Content

The riboflavin was analyzed after drying, as depicted in Figure 7. The introduction of heat to onion bulb affected riboflavin degradation. However, using air dehumidification drying, the drying time can be reduced that can inhibit riboflavin degradation. The result of ANOVA (Table 3) reveals that dehumidification has a significant effect on the riboflavin content after bulb drying process, showed by P-value < 0.05. In onion bulb drying, the preservation of vitamin and ingredients is still reasonable. As comparison, in the case of onion slice drying, the vitamin D degradation can reach up to 86% [2]. It implies that onion bulb drying can retain more vitamins and other nutrients.

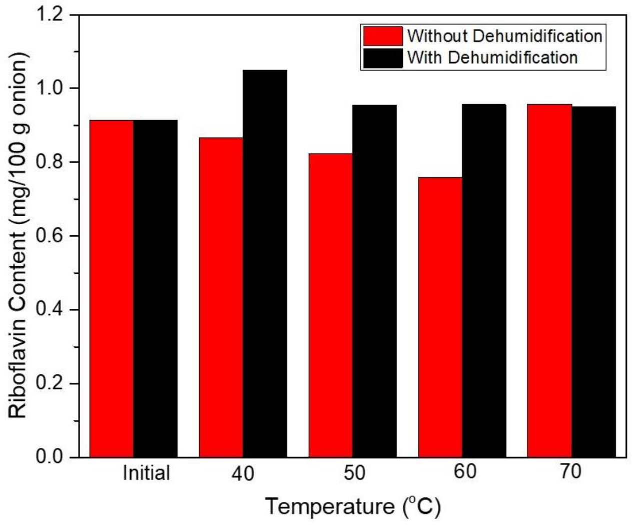

Figure 7. Riboflavin content of onion bulb before and after drying.

Table 3. ANOVA result for the effect of dehumidification on the onion bulb drying.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.025604	1	0.025604	5.980752	0.040214	5.317655
Within Groups	0.034248	8	0.004281			
Total	0.059852	9				

3.5. *Optimization of responses*

Table 4 presents the complete design of the experiment and responses. The moisture content and heat efficiency are fitted by the second-order polynomial model in terms of uncoded factors, as expressed by the following:

$$Y_1 = 0.64 + 0.0062X_1 + 0.1441X_2 + 0.00000X_1^2 - 0.001149X_2^2 - 0.000131X_1X_2$$
$$Y_2 = 126.4 + 0.0598X_1 - 4.23X_2 - 0.000034X_1^2 + 0.0365X_2^2 + 0.001614X_1X_2$$
$$Y_{1,d} = -1.19 + 0.0054X_1 + 0.2109X_2 + 0.00000X_1^2 - 0.001739X_2^2 - 0.000122X_1X_2$$
$$Y_{2,d} = -54.5 - 0.0381X_1 + 1.79X_2 - 0.000008X_1^2 - 0.0101X_2^2 + 0.00095X_1X_2$$

The response surface regression of the experimental and predicted data is displayed as a result of the use of ANOVA and correlation coefficients (R^2), which are presented in Table 5. The R^2 values of the moisture content regression under two conditions are close to 1, indicating a good fit between the experiment and the model. Furthermore, the variation of the drying times and temperatures has made a significant effect on the moisture content reduction of onion bulb (P-value < 0.005). The interaction between the drying time and the temperature under two drying conditions also demonstrates a significant effect on the moisture content of the product. It means that the predicted drying time is still reasonable. However, Table 5 also shows that the temperature has a significant effect on the heat efficiency of the process. In addition, the effect of dehumidification on heat efficiency was analyzed and summarized in Table 6, exhibiting a significant impact of dehumidification. Comparison of the experimental and predicted values of two responses is presented in Figure 8 and Figure 9.

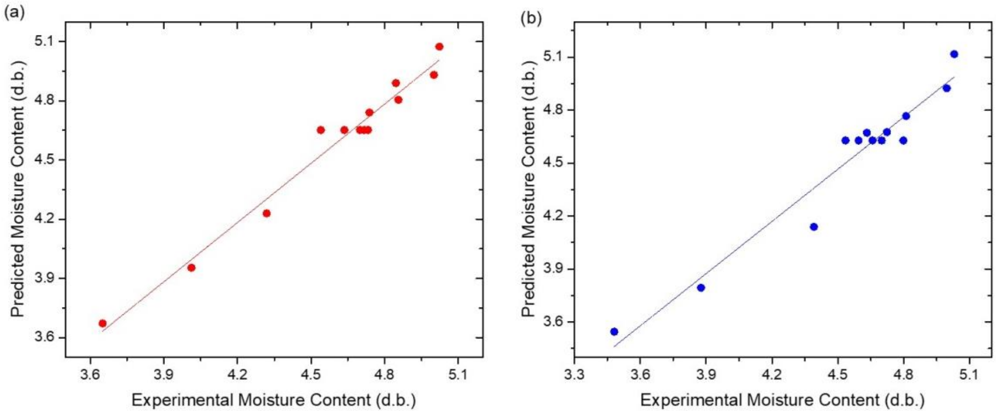

Figure 8. Comparison between the predicted and experimental moisture content.

Table 4. Design experiment and responses of red onion drying.

Run	Drying Time, X_1 (min)	Temperature, X_2 (°C)	Responses			
			Without Dehumidification		Dehumidification	
			Moisture Content (d.b.)	Heat Efficiency (%)	Moisture Content (d.b.)	Heat Efficiency (%)
1	480.00	50.00	4.856	7.90	4.631	6.18
2	300.00	60.00	4.699	12.64	4.798	18.20
3	300.00	45.86	4.846	7.91	4.811	11.30
4	480.00	70.00	3.651	24.19	3.480	28.98
5	45.44	60.00	5.023	1.01	5.030	16.35
6	300.00	60.00	4.716	15.12	4.699	24.32
7	300.00	74.14	4.012	28.99	3.876	32.64
8	300.00	60.00	4.732	11.58	4.658	26.90
9	120.00	70.00	4.738	17.79	4.723	25.60
10	554.56	60.00	4.319	16.83	4.390	30.56
11	300.00	60.00	4.636	10.48	4.535	19.94
12	300.00	60.00	4.540	11.11	4.594	17.81
13	120.00	50.00	5.001	13.12	4.996	9.63

Table 5. ANOVA second-order polynomial model for moisture content and heat.

Source	Without Dehumidification				Dehumidification			
	Moisture Content		Heat Efficiency		Moisture Content		Heat Efficiency	
	P-value		P-value		P-value		P-value	
X_1	0.001	S	0.051	NS	0.001	S	0.201	NS
X_2	0.001	S	0.001	S	0.001	S	0.002	S
X_1^2	0.843	NS	0.432	NS	0.851	NS	0.893	NS
X_2^2	0.006	S	0.030	S	0.009	S	0.612	NS
X_1X_2	0.001	S	0.145	NS	0.011	S	0.518	NS
Lack of Fit	0.495	NS	0.040	S	0.209	NS	0.215	NS
R^2	0.961		0.759		0.914		0.640	

*NS = Not Significant; S = Significant

Table 6. ANOVA of the effect of dehumidification in heat efficiency.

Source of Variation	SS	df	MS	F	P-value
Between Groups	309.7959	1	309.7959	5.08124	0.033589
Within Groups	1463.246	24	60.96857		
Total	1773.042	25			

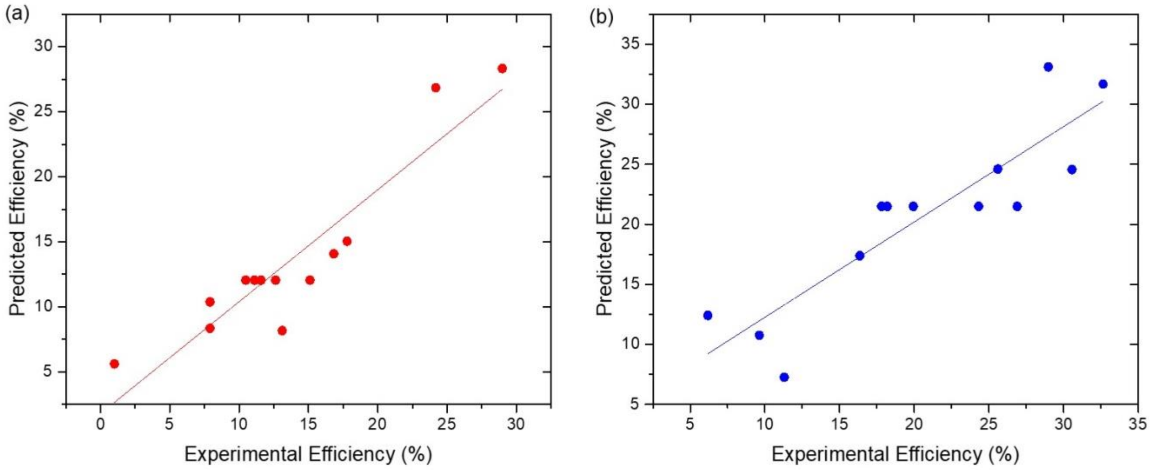

Figure 9. Comparison between the predicted and experimental heat efficiency.

Response optimization with the target of total moisture content of 4.263 d.b. (81% w.b.) and maximum heat efficiency was performed. The relationship between the drying time and temperature on these two responses is described as contour plot presented in Figure 10 and Figure 11. As can be seen from Figure 10, the drying time decreases with the increase in drying temperature. With a drying temperature of 70 ℃ without air dehumidification, the drying time requires about almost 5 h to dry the onion bulb, whereas after dehumidification, the drying time can be about 1 h shorter. In Figure 11, the highest efficiency is found at the highest temperature. The response optimizer estimates the favorable drying time and temperatures, as presented in Table 7. The optimization indicated that the heat efficiency of onion drying with air dehumidification is 10% higher than that without air dehumidification, with a shorter drying time.

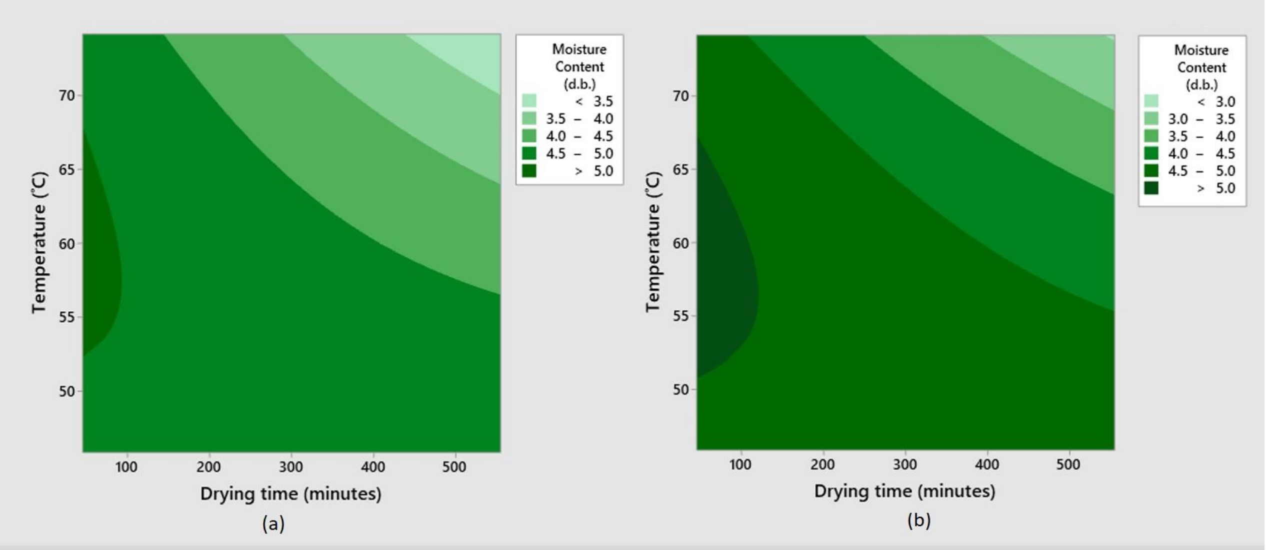

Figure 10. Contour plot of moisture content (a) without and (b) using dehumidification.

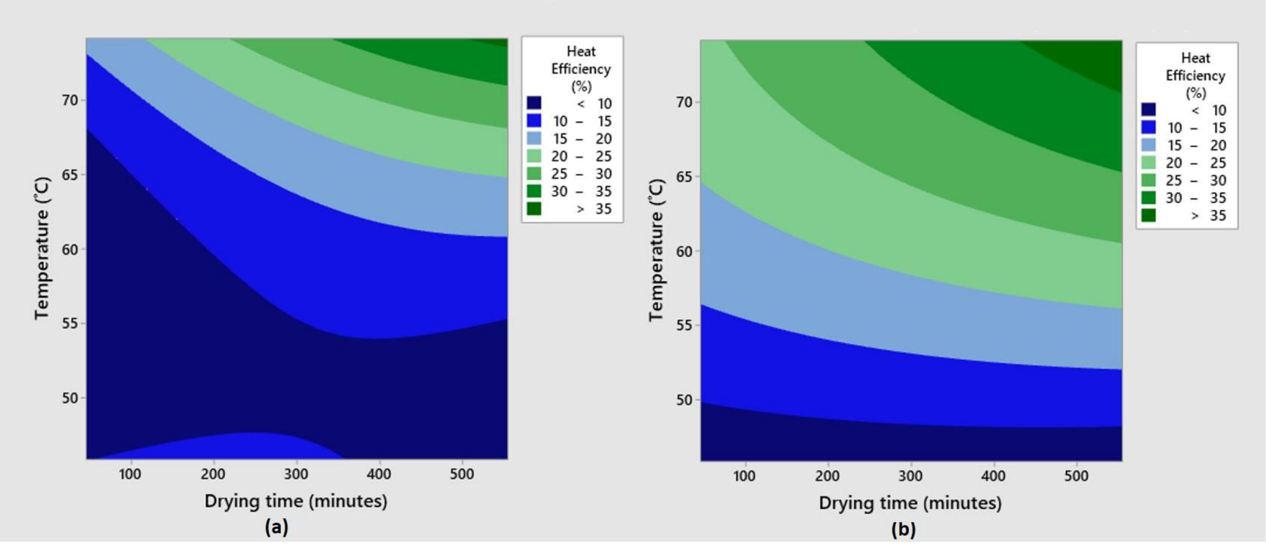

Figure 11. Contour plot of heat efficiency (a) without and (b) using dehumidification.

Table 7. Result of optimization at temperature of 60 °C.

System	Drying Time (min)	Temperature (°C)	Heat Efficiency (%) Fit	Moisture Content (d.b.) Fit	Composite Desirability
Without Dehumidification	554.558	60	14.1183	4.28302	0.675469
Dehumidification	534.838	60	24.2460	4.26311	0.826159

4. Conclusions

The effect of dehumidification and drying temperatures on the drying kinetics, efficiency, and riboflavin (vitamin B_2) degradation has been evaluated. Base on the results obtained, it can be concluded as follows:

a.) The ANOVA revealed that air dehumidification has a significant effect on the riboflavin retention and heat efficiency in onion bulb drying. In the case of the drying process, the application of dehumidification and high temperature shortened the drying time and led to a high drying efficiency.

b.) In the kinetics estimation, the Newton model was shown to be a good fit to the experimental values and can be used to predict the drying time of onion bulbs.

c.) Using air dehumidification, the drying time of onion can be positively reduced, and the quality of onion can be retained as expressed in the low riboflavin degradation.

d.) At different drying times and temperatures, optimization of the drying process was performed, in which an improvement was observed. The polynomial regression showed a good fit in the prediction of moisture content. Air dehumidification and drying temperature exhibited a significant impact on the drying time and heat efficiency.

e.) The result of optimization indicates that air dehumidification can shorten the drying time and enhance heat efficiency. However, at a temperature above 60 ℃, the effect of air dehumidification on the drying performances is limited.

In overall, this research is meaningful to determine the most favorable condition of onion drying for large scale or industrial application.

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Conflict of interest

All authors declare no conflicts of interest in this paper.

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