Acta Sci. Pol. Technol. Aliment. 21(4) 2022, 379–387

www.food.actapol.net pISSN 1644-0730 eISSN 1898-9594 http://dx.doi.org/10.17306/J.AFS.2022.1061

ORIGINAL PAPER

Received: 30.05.2022
Accepted: 22.07.2022

IMPACT OF DRYING TEMPERATURES ON DRYING BEHAVIOURS, ENERGY CONSUMPTION AND QUALITY OF PURPLE SWEET POTATO FLOUR

Nguyen Minh Thuy[1]✉, Le Huy Hiep[1], Ngo Van Tai[2], Huynh Thi Thu Huong[3], Vo Quang Minh[3]

[1]Institute of Food and Biotechnology, Can Tho University
Can Tho 900000, **Vietnam**
[2]School of Food Industry, King Mongkut's Institute of Technology
Ladkrabang, Bangkok 10520, **Thailand**
[3]College of Environment and Natural Resources, Can Tho University
Can Tho 900000, **Vietnam**

ABSTRACT

Background. Purple sweet potatoes were produced with a high yield annually. Applying the drying process to purple sweet potatoes could enhance the economic value of this material. Furthermore, energy consumption, as well as the change in the quality of the product, are the important characteristics that determine the product's quality and effect on the environment.

Material and methods. This research examined the impact of various drying temperatures on kinetic behaviour, effective moisture diffusivity coefficient (D_{eff}), activation energy (E_a), specific energy consumption (SEC), color, shrinkage and physicochemical characteristics of purple sweet potatoes. The final quality of the sample was also evaluated.

Results. Seven models were applied and fitted to actual data of the drying process. The two-term model showed the best fit with high R^2, and low RMSE and Chi-square. The calculated D_{eff} and E_a values were 1.58–2.67 m^2/s and 17.95 kJ/mol, respectively. The energy consumption of drying purple sweet potatoes ranged from 107.92 to 119.01 kWh/kg. The quality of the product was maintained when a sample was dried at 60°C.

Conclusion. Temperature strongly affected the quality of dried purple sweet potatoes and energy consumption. The first report about the value of energy used during the drying process of sweet potatoes also provides more information about the effect of the drying process on carbon emissions to the environment. Therefore, research aimed at improving product quality and minimizing environmental impacts should be implemented in the future and concerned with ensuring sustainable agricultural production.

Keywords: sweet potato, drying process, energy consumption, modeling, kinetic behaviours

INTRODUCTION

Sweet potato (*Ipomoea batatas* L.) is an important crop providing food for humans and raw materials for industrial processing plants to create high economy products. According to the restructuring of the agriculture sector in Vinh Long province, each year there is an attempt to stabilize the sweet potato growing area from 10,500 to 11,000 hectares, with an output of 300,000–400,000 tons, which is home to a large sweet potato

✉nmthuy@ctu.edu.vn, https://orcid.org/0000-0003-3927-9099, phone 00918391270

growing area. Binh Tan District of Vinh Long Province in the Mekong Delta is often referred to by locals as their "Kingdom of Sweet Potatoes" since this tropical tuber has been identified by Vinh Long authorities as one of the province's three key plants. However, due to the COVID-19 epidemic, purple sweet potato (PSP) exports are facing many difficulties, the price of sweet potatoes is meager, many farmers are suffering heavy losses, and work to "rescue" Binh Tan sweet potatoes has been carried out every year. Purple sweet potato is a high-quality food with many benefits for human health, but most of them are used or sold fresh, and annual post-harvest losses are still very high. Therefore, research to protect these materials for a longer time will solve the sizeable annual output, provide good food for the people and ensure income for household production. PSP contains many essential nutrients for the body, such as vitamin C, group B vitamins, and minerals (Mohanraj and Sivasankar, 2014). In addition, they also contain many biological compounds such as polyphenols, and anthocyanins, which have antioxidant, cancer-preventing, and anti-aging properties (Alam, 2021). However, the price and quality fluctuations of PSP during postharvest storage are influenced by storage conditions and time, while purple sweet potato can be used to prepare a wide variety of quality foods. Because of its high starch content and beautiful color, PSP powder can also partially replace wheat flour in some food processing technologies such as bread, noodles, and folk cakes, etc.

Drying is one of the methods widely used to preserve agricultural products, and thin-layer drying is a commonly used method for determining their drying kinetics (Akpinar et al., 2003; Tai et al., 2021; Thuy et al., 2021). Drying significantly reduces volume and weight and minimizes packaging, storage, and transport costs. It allows dried products to be stored easily in ambient conditions. Thus, selecting the most suitable thin layer drying model is also an essential tool in describing the drying behaviours of fresh materials. Furthermore, global warming because of fossil fuel use has become a global problem. Fossil fuels, which are used in power plants to create electricity, contribute the most to global greenhouse gas emissions. Given the importance of the agriculture industry in terms of power consumption, the processing and drying sectors consume the most energy in this sector (Kaveh et al., 2020b). Farm practices are linked to the formation and release of greenhouse gasses. Because the drying process necessitates massive energy, these emissions are particularly significant (Kaveh et al., 2020a). However, there are still limited studies that have been done on the drying kinetics and calculation of energy consumption of Vietnamese purple sweet potatoes.

This study is aimed at determining the effect of different air temperatures on the drying characteristics of PSP, fitting the drying curves with proposed mathematical models and testing the goodness of fit. The change in product quality and energy consumption was also investigated and calculated to select the appropriate temperature for dried PSP. This result could help improve the value of Vietnamese PSP, help solve the problem of PSP falling in price, create product diversity, and provide more information about effects on the environment by using energy.

MATERIALS AND METHODS

Sample preparation

PSP were harvested from Binh Tan district, Vinh Long province (Vietnam) [10°08'42.9"N 105°46'40.1"E]. Before drying, the sample was washed, peeled, and sliced (2 mm thickness). The mass of each treatment was approximately 1 kg. The initial moisture content of these samples was 284.76 % dry basis (db). Then, the sliced PSP was steamed at 100°C for 3 mins (Thuy et al., 2020a). The blanched slices were dried as the drying process mentioned below. Subsequently, the dried sliced purple sweet potatoes were ground, sieved (flour should pass through a 100 μm sieve – US Standard Mesh No. 70), and packaged inside a plastic container for further analysis.

Drying procedure

The drying process of purple sweet potatoes was conducted in an oven dryer (Memmert UN30, Germany) at 0.5 m/s of air velocity. The sample was put in a single layer on the stainless-steel tray. During the process, the weight loss was periodically recorded by taking out the tray and weighing it on an electronic balance with the accuracy of ±0.01 g. The drying was stopped until the weight was almost unchanged. All the drying experiments were conducted in triplicates. The moisture ratio (MR) was calculated as the Equation 1.

$$\text{MR} = \frac{M_t - M_e}{M_o - M_e} \tag{1}$$

where M_t, M_o, and M_e are moisture content at each measurement time, initial moisture content, and equilibrium moisture content (kg water/kg dry matter), respectively. However, the drying varied continuously during the drying experiments, and the relative moisture content of drying air is simplified into Equation 2 (Akpinar et al., 2003).

$$\text{MR} = \frac{M_t}{M_o} \tag{2}$$

Seven thin layer drying models(Akpinar et al., 2003), including Henderson and Pabis, Modified Henderson and Pabis, Logarithmic, Newton, Page, Two-term, Two-term exponential, were fitted to the drying data to select the best model suitable for describing the drying process of purple sweet potato. The Stagraphics Centurion XV.I and MATLAB were used to determine the model constants. The best fit of the model was based on the root mean square error (RMSE, Equation 3), coefficient of determination (R^2, Equation 4), and chi-square (χ^2, Equation 5).

$$R^2 = \frac{N\sum_{i=1}^{N}\text{MR}_{\text{pre},i}\text{MR}_{\text{exp},i} - \sum_{i=1}^{N}\text{MR}_{\text{pre},i}\sum_{i=1}^{N}\text{MR}_{\text{exp},i}}{\sqrt{\left(N\sum_{i=1}^{N}\text{MR}_{\text{pre},i}^2 - \left(\sum_{i=1}^{N}\text{MR}_{\text{pre},i}\right)^2\right)}} \tag{3}$$

$$\text{RMSE}\left[\tfrac{1}{N}\sum_{i=1}^{N}\left(\text{MR}_{\text{pre},i} - \text{MR}_{\text{exp},i}\right)^2\right]^{1/2} \tag{4}$$

$$^2 = \frac{\sum_{i=1}^{N}\left(\text{MR}_{\text{pre},i} - \text{MR}_{\text{exp},i}\right)^2}{N - n} \tag{5}$$

where:

$\text{MR}_{\exp,i}$ and $\text{MR}_{\text{pre},i}$ – the experimental and predicted moisture ratio at observation *i*,

N – the number of the experimental data points,

n – the number of constants in the model.

Calculation of D_{eff} (effective moisture diffusion) and E_a (activation energy)

There are two important parameters, including D_{eff} and E_a, to consider when modeling and developing the drying and mass transfer processes (Abasi et al., 2017). Diffusion is the main process of drying wet materials which controls the moisture's movement and involves liquid diffusion, vapor diffusion, and hydrodynamic flow. By plotting the ln(MR) data obtained from the experiments, there will be a line with a slope against the time, and the equality between this slope and coefficient in Equation 6 leads to the possibility of calculating D_{eff} by using Equation 7 (Dibagar and Amiri Chayjan, 2019).

$$\ln\left(\text{MR}\right) = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2}{4L^2}D_{\text{eff}}t\right) \tag{6}$$

$$\text{Slope} = \frac{\pi^2 D_{\text{eff}}}{4L^2} \tag{7}$$

where:

t – the time, s,

D_{eff} – the effective diffusivity, m^2/s,

L – the thickness of samples, m.

The relationship between effective diffusivity and drying temperature can be predicted appropriately using the Arrhenius equation (Akpinar et al., 2003). The activation (E_a) can be determined using Equation 8.

$$D_{\text{eff}} = D_o \exp\left(\frac{-E_a}{RT}\right) \tag{8}$$

where:

D_o – the pre-exponential factor of the Arrhenius equation, m^2/s,

E_a – the activation energy, KJ/mol,

T – the absolute drying air temperature, K,

R – the universal gas constant (8.314 J/mol·K).

Specific energy consumption (SEC)

The required energy to extract 1 kg of purple sweet potatoes by means of a hot air dryer with different temperatures is expressed as SEC. The SEC was calculated as described by Kaveh et al. (2020a).

Shrinkage

Shrinkage (S_b) is considered as the ratio of the final volume of the dried (V) to the initial volume (V_o) of the undried products. The sample's shrinkage was determined in specific mass experiments by means of toluene and represented as Equation 9 (Udomkun and Innawong, 2018).

$$S_b = \frac{V_0 - V}{V_0} \times 100 \qquad (9)$$

Physico-chemical characteristics of purple sweet potato flour

To measure color, the data were collected and calculated as described by Kaveh et al. (2020a). Color and ΔE indexes were obtained from the average values, including 15 points from each repetition. Total anthocyanin content of purple sweet potato was determined by pH differential method with slight modification as described by Thuy et al. (2021). The moisture content of the sample was analyzed based on the AOAC method (AOAC, 2005). The water activity of the samples was measured by Water Activity Measurement Instruments (NOVASINA, Sweden). After selecting the appropriate temperature, the proximate composition of flour was determined based on AOAC method (AOAC, 2005). The water absorption index, water solubility index, and swelling capacity of the product were also investigated (Ahmed et al., 2010).

RESULTS AND DISCUSSION

Kinetic characteristics of purple sweet potatoes' drying process

The drying temperature used for the drying process of PSP dramatically influences the change in moisture ratio (MR) and the percentage of moisture in the raw materials. Moisture content and MR decreased continuously as temperature and time increased. The final moisture content of PSP reached 12–16% db after 12, 10, 8, and 7 hours of drying, respectively, at the drying temperature of 50, 60, 70, and 80°C. The water loss was higher at high temperatures (Fig. 1). Due to the higher temperature, it was observed that the faster the material's moisture loss rate, the shorter the drying time (Azizpour et al., 2014). Recent studies showed that the drying process of fruits and vegetables followed several of the kinetic models described and is greatly influenced by the equipment as well as the type of raw materials (Azizpour et al., 2014; Tai et al., 2021; Thuy et al., 2021; Thuy et al., 2020b). The actual moisture data in the different experimental modes were converted into a more helpful moisture ratio expression. Curve fitting calculations with drying time were performed with seven drying models. The analysis results performed on these drying models were given in Table 1.

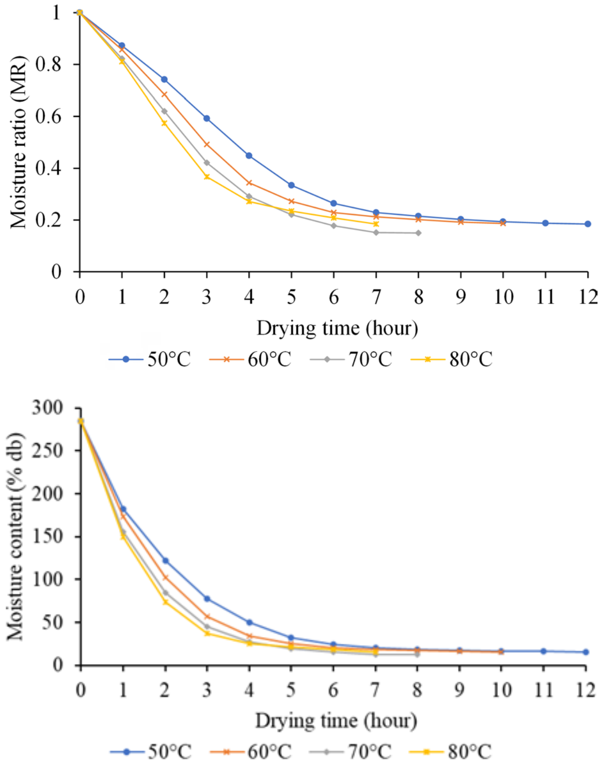

Fig. 1. Change of moisture content and moisture ratio during drying process at different temperatures

The selection models were evaluated based on root mean square error (RMSE), coefficient of determination (R^2), and Chi-squared (χ^2). All models gave high R^2 values in the range of 97.13 to 99.21%, indicating that all equations could adequately describe the drying process of purple sweet potatoes. RMSE ranged from 0.0249 to 0.0590, χ^2 ranged from 0.0009 to 0.0444. The two-term model exhibited higher compatibility than the other models, based on the higher R^2 and lower RMSE and Chi-square. In addition, comparing the prediction values of the Two-term model with the experimental data showed a good agreement. The actual and predicted data were highly correlated with an R^2 value of 0.995 (Fig. 2). The two-term model also effectively described the drying kinetics of figs (Babalis et al., 2006) and kenaf core (Misha et al., 2013).

Table 1. Calculation results of parameters of drying curve models for PSP dried at different temperatures

Model	Temperature °C	Model constants	RSME	R^2 %	χ^2
Henderson and Pabis: MR = ae^{-kt}					
	50	a = 1.0192, k = 0.1898	0.0484	97.41	0.0028
	60	a = 1.0165, k = 0.2260	0.0520	97.18	0.0033
	70	a = 1.0310, k = 0.2841	0.0362	98.85	0.0017
	80	a = 1.0172, k = 0.2924	0.0447	98.19	0.0027
Modified Henderson and Pabis: MR = $ae^{-kt} + be^{-} + ce^{-ht}$					
	50	a = 0.4993, k = 0.2197 b = 0.4974, g = 0.2576 c = 0.0544, h = 0.0510	0.0476	98.40	0.0042
	60	a = 0.3404, k = 0.3622 b = 0.0340, g = 0.0841 c = 0.6719, h = 0.2373	0.0550	98.25	0.0067
	70	a = 0.3436, k = 0.2844 b = 0.3436, g = 0.2841 c = 0.3437, h = 0.2836	0.0553	98.85	0.0092
	80	a = 0.4045, k = 0.3755 b = 0.2207, g = 0.1148 c = 0.4057, h = 0.3922	0.0725	98.41	0.0210
Logarithmic: MR = $ae^{-kt} + c$					
	50	a = 0.9503, k = 0.2470, c = –0.0997	0.0416	98.26	0.0023
	60	a = 0.9403, k = 0.3003, c = –0.1070	0.0444	98.17	0.0444
	70	a = 1.017, k = 0.2950, c = –0.0164	0.0388	98.87	0.0023
	80	a = 0.9547, k = 0.3516, c = –0.0777	0.0443	98.52	0.0031
Newton: MR= e^{-kt}					
	50	k = 0.1857	0.0469	97.35	0.0024
	60	k = 0.2218	0.0498	97.13	0.0027
	70	k = 0.2749	0.0363	98.68	0.0015
	80	k = 0.2868	0.0421	98.13	0.0020
Page: MR = e^{-kt^n}					
	50	k = 0.1887, n = 0.990	0.0514	95.82	0.0032
	60	k = 0.2300, n = 0.9763	0.0523	97.15	0.0033
	70	k = 0.2381, n = 1.1075	0.0342	98.97	0.0015
	80	k = 0.2801, n = 1.0190	0.0453	98.14	0.0027
Two-term: MR = $ae^{-kt} + be^{-k_ot}$					
	50	a = 0.0066, k = 0.2509, b = 1.1411, k_o = 0.2452	0.0249	99.21	0.0009
	60	a = 0.5082, k = 0.2260, b = 0.5082, k_o = 0.2260	0.0590	97.18	0.0055
	70	a = 0.5155, k = 0.2841, b = 0.5155, k_o = 0.2841	0.0428	98.85	0.0033
	80	a = 0.5086, k = 0.2924, b = 0.5086, k_o = 0.2924	0.0547	98.19	0.0060
Two-term exponential: MR = $ae^{-kt} + (1 - a)e^{-kat}$					
	50	a = 0.4931, k = 0.2685	0.0470	97.56	0.0026
	60	a = 0.4660, k = 0.3378	0.0497	97.42	0.0030
	70	a = 0.5947, k = 0.3415	0.0404	98.57	0.0021
	80	a = 0.5537, k = 0.3754	0.0446	98.20	0.0027

a, b, c, g, h, n, k, k_o, L – model constants.

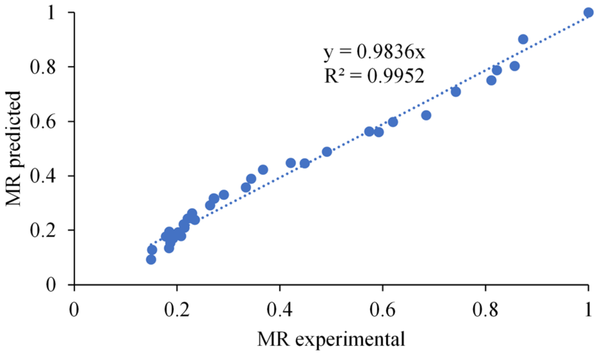

Fig. 2. Correlation between MR (experimental) and MR (predicted from Two-term model) at drying temperature range from 50°C to 80°C

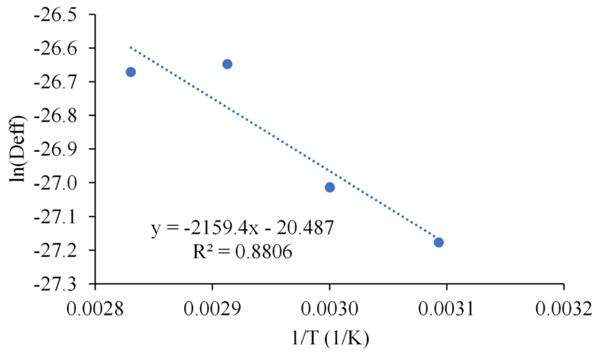

Fig. 3. Influence of air temperature on effective moisture diffusivity

The effective moisture diffusion values of PSP at 50°C to 80°C ranged from 1.575 × 10^{-12} to 2.672 × 10^{-12} m^2/s. It was observed that the values of D_{eff} increased significantly with increasing temperature, consistent with recent research (Misha et al., 2013; Tai et al., 2021; Thuy et al., 2021; 2022). D_{eff} value is the key drying parameter representing the conductive term of all moisture transfer mechanisms (Srikiatden and Roberts, 2006). The activation energy is another important drying parameter representing water molecules' energy level for moisture diffusion and evaporation. To obtain the effect of temperature on the effective diffusivity, the values of ln(D_{eff}) versus 1/T (1/K) determined the activation energy, as shown in Figure 3. E_a value was found to be 17.95 kJ/mol. The value of activation energy for most agro-food products is 12.7–110 kJ/mol (Akpinar et al., 2003). Lower activation energy showed less sensitivity to drying temperature.

Specific energy consumption

One of the critical characteristics of evaluation during process activities, such as drying and distillation, is energy consumption. Energy prices continue to rise and fluctuate due to a lack of fossil fuels and environmental issues (greenhouse gas emissions), necessitating the development of innovative ways to reduce energy use in industry (Mierzwa et al., 2019). Before drying, the blanching process also consumed 3.78 kWh/kg, measured by a power meter. In addition, Table 2 presents the effect of different temperatures on the hot air dryer's specific energy consumption (SEC). As expected, the drying time and the SEC were reduced by increasing the temperature because the thermal gradient and accelerating moisture extraction were enhanced. Drying at higher temperatures caused larger mass transfer and thus a shorter drying time that reduced SEC (Filippin et al., 2018).

Table 2. Effect of drying temperature on the SEC, shrinkage, and physicochemical characteristics of dried purple sweet potatoes

Temperature °C	SEC kW·h/kg	Shrinkage %	Moisture %	a_w	TAC mg/g	ΔE
50	119.01^d	53.56^a	6.60^a	0.437^a	0.71^a	34.2^c
60	115.07^c	54.36^a	6.55^a	0.440^a	0.85^b	29.7^b
70	111.38^b	59.56^b	6.56^a	0.449^b	0.73^{ba}	27.8^a
80	107.92^a	62.34^c	6.59^a	0.457^c	0.70^a	27.6^a

Data are mean of three replicates. Values having different superscripts in columns differ significantly ($p < 0.05$).
TAC – total anthocyanin content.

The highest SEC (119.01 kWh/kg) occurred at 50°C; however, the lowest amount (107.92 kWh/kg) was reported at 80°C. These findings agree with the documented values of 51.12 to 106.7 kWh for cornelian cherry (Ozgen, 2015) and 26.90 to 111.05 kWh/kg for soybeans (Soponronnarit et al., 2001). Based on greenhouse gas (GHG) emissions of power plants using natural gas and heavy oil to produce 1 kW of electricity (Nazari et al., 2010), the lowest emissions were seen when purple sweet potatoes were dried at 80°C and 0.5 m/s of air velocity. By increasing the inlet air temperature, their emission levels started to decline. The increase in GHG emissions can be explained by the higher SEC during drying at a high air velocity and a low temperature (Motevali and Tabatabaee Koloor, 2017).

Shrinkage

The technique and degree of product drying impact the amount of shrinkage. Shrinkage occurs when water is withdrawn from the cell space and replaced with air (Tsuruta et al., 2015). Physical parameters like porosity, density, and product shape are all affected by shrinkage. Shrinkage increases as the amount of water removed increases (Parthasarathi and Anandharamakrishnan, 2014). Drying of PSP by means of different drying temperatures leads to the shrinkage from 53.56% to 62.34% (Table 2). The water steam pressure was created during drying, causing cell expansion, known as the puffy effect. This phenomenon and heating can reduce shrinkage (Aydogdu et al., 2015). This is due to faster moisture transfer to the samples' outer layer after applying different temperatures.

Physical characteristics

Product colour is one of the essential criteria in the process of evaluating the quality of dried products. The colour change during drying can assess the drying conditions' impact on consumers' sensory value. The results showed that the product colour correlated with the drying temperature; when increasing the drying temperature, the ΔE value decreased gradually. The colour change was most significant when purple sweet potatoes were dried at 50°C, while a minor colour change was found in products dried at 70°C and 80°C. The higher the drying temperature, the shorter the drying time of the product, thereby limiting the browning processes caused by air and other reactions. It is thought that the colour change during sweet potato drying happens because of various factors, including thermal destruction of carotenoids, oxidation, enzymatic reactions, and non-enzymatic browning reactions (Chen et al., 2016). However, too high a drying temperature can produce browning pigment by the caramel reaction. It was reported that during the drying process of foods, temperature and moisture content strongly affected the browning reaction (Chen et al., 2016). The final moisture content and product's water activity ranged from 6.55–6.60% and 0.437–0.457, respectively. With this range of humidity and water activity, the product can be stored for a long time and still maintain its quality (Tapia et al., 2020).

Anthocyanin content

The drying temperatures greatly influenced the anthocyanin of the product. It was observed that the highest anthocyanin was found in the sample which was dried at 60°C. The decreasing trend of anthocyanin was observed when the drying temperature increased. Anthocyanin is a heat-sensitive compound easily degraded at high temperatures (Rehman et al., 2017; Thuy et al., 2021). Product properties are strongly influenced by drying temperature. The appropriate drying temperature for purple sweet potato is 60°C, which will bring short drying time, save time and energy and maintain anthocyanin content in the product.

The final quality of the product

After drying, purple sweet potatoes were ground into a powder (Fig. 4) and analyzed for essential components. The crude protein, ash, fat, and fiber contents were 4.48, 2.71, 0.83, and 3.8% (w/w), respectively.

Fig. 4. Purple sweet potatoes powder

At the same time, water absorption index (g/g dry solids), water solubility index (g/100 g dry solids), and swelling capacity (g/g dry solids) were also analyzed as 1.19, 38.24, 1.98, respectively. The analysis results provided essential information for further applications of purple sweet potato powder in the food processing industry.

CONCLUSION

The application of the drying model showed that it is effective in describing the moisture change with the drying time of purple sweet potatoes. Among the seven applied models, the two-term model is highly compatible with the experimental value. At the same time, the change in drying temperature strongly affects the product's quality and energy consumption. The results show that drying purple sweet potatoes at 60°C was the most suitable. However, to optimize the production process, process parameters must be studied more deeply to maintain product quality and save energy to help reduce environmental pollution.

ACKNOWLEDGMENT

This study is funded in part by the Can Tho University, Code: TĐH2022-08.

REFERENCES

Abasi, S., Minaei, S., Khoshtaghaza, M. H. (2017). Effect of desiccant system on thin layer drying kinetics of corn. J. Food Sci. Technol., 54(13), 4397–4404. https://doi.org/10.1007/s13197-017-2914-z

Ahmed, M., Akter, M. S., Lee, J.-C., Eun, J.-B. (2010). Encapsulation by spray drying of bioactive components, physicochemical and morphological properties from purple sweet potato. LWT – Food Sci. Technol., 43(9), 1307–1312. https://doi.org/10.1016/j.lwt.2010.05.014

Akpinar, E., Midilli, A., Bicer, Y. (2003). Single layer drying behaviour of potato slices in a convective cyclone dryer and mathematical modeling. Energy Conv. Manag., 44(10), 1689–1705. https://doi.org/10.1016/S0196-8904(02)00171-1

Alam, M. K. (2021). A comprehensive review of sweet potato (*Ipomoea batatas* [L.] Lam): Revisiting the associated health benefits. Trends Food Sci. Technol., 115, 512–529. https://doi.org/10.1016/j.tifs.2021.07.001

AOAC (2005). Official methods of analysis (18th ed.). Arlington, VA, USA: Association of Official Analytical Chemists.

Aydogdu, A., Sumnu, G., Sahin, S. (2015). Effects of microwave-infrared combination drying on quality of eggplants. Food Bioproc. Technol., 8(6), 1198–1210. https://doi.org/10.1007/s11947-015-1484-1

Azizpour, M., Mohebbi, M., Hossein Haddad Khodaparast, M., Varidi, M. (2014). Optimization of Foaming parameters and investigating the effects of drying temperature on the foam-mat drying of shrimp (*Penaeus indicus*). Drying Technol., 32(4), 374–384. https://doi.org/10.1080/07373937.2013.794829

Babalis, S. J., Papanicolaou, E., Kyriakis, N., Belessiotis, V. G. (2006). Evaluation of thin-layer drying models for describing drying kinetics of figs (*Ficus carica*). J. Food Eng., 75(2), 205–214. https://doi.org/10.1016/j.jfoodeng.2005.04.008

Chen, Z.-G., Guo, X.-Y., Wu, T. (2016). A novel dehydration technique for carrot slices implementing ultrasound and vacuum drying methods. Ultrason. Sonochem., 30, 28–34. https://doi.org/10.1016/j.ultsonch.2015.11.026

Dibagar, N., Amiri Chayjan, R. (2019). Rough rice convective drying enhancement by intervention of airborne ultrasound – A response surface strategy for experimental design and optimization. Drying Technol., 37(9), 1097–1112. https://doi.org/10.1080/07373937.2018.1485693

Filippin, A. P., Molina Filho, L., Fadel, V., Mauro, M. A. (2018). Thermal intermittent drying of apples and its effects on energy consumption. Drying Technol., 36(14), 1662–1677. https://doi.org/10.1080/07373937.2017.1421549

Kaveh, M., Amiri Chayjan, R., Taghinezhad, E., Rasooli Sharabiani, V., Motevali, A. (2020a). Evaluation of specific energy consumption and GHG emissions for different drying methods (Case study: Pistacia Atlantica). J. Cleaner Prod., 259, 120963. https://doi.org/10.1016/j.jclepro.2020.120963

Kaveh, M., Taghinezhad, E., Aziz, M. (2020b). Effects of physical and chemical pretreatments on drying and quality properties of blackberry (*Rubus* spp.) in hot air dryer. Food Sci. Nutr., 8(7), 3843–3856. https://doi.org/10.1002/fsn3.1678

Mierzwa, D., Szadzińska, J., Pawłowski, A., Pashminehazar, R., Kharaghani, A. (2019). Nonstationary convective drying of raspberries, assisted by microwaves and ultrasound. Drying Technol., 37(8), 988–1001. https://doi.org/10.1080/07373937.2018.1481087

Misha, S., Mat, A. S., Ruslan, M. H., Sopian, K., Salleh, E. (2013). The effect of drying air temperature and humidity on the drying kinetic of kenaf core. Appl. Mech. Mat., 315, 710–714.

Mohanraj, R., Sivasankar, S. (2014). Sweet potato (*Ipomoea batatas* [L.] Lam). A valuable medicinal food: A review. J. Med. Food, 17(7), 733–741.

Motevali, A., Tabatabaee Koloor, R. (2017). A comparison between pollutants and greenhouse gas emissions from operation of different dryers based on energy consumption of power plants. J. Clean. Prod., 154, 445–461. https://doi.org/10.1016/j.jclepro.2017.03.219

Nazari, S., Shahhoseini, O., Sohrabi-Kashani, A., Davari, S., Paydar, R., Delavar-Moghadam, Z. (2010). Experimental determination and analysis of CO_2, SO_2 and NO_x emission factors in Iran's thermal power plants. Energy, 35(7), 2992–2998. https://doi.org/10.1016/j.energy.2010.03.035

Ozgen, F. (2015). Experimental investigation of drying characteristics of cornelian cherry fruits (*Cornus mas* L.). Heat Mass Trans., 51, 343–352. https://doi.org/10.1007/s00231-014-1397-y

Parthasarathi, S., Anandharamakrishnan, C. (2014). Modeling of shrinkage, rehydration and textural changes for food structural analysis: A review. J. Food Proc. Eng., 37(2), 199–210. https://doi.org/10.1111/jfpe.12073

Rehman, R. N. U., You, Y., Zhang, L., Goudia, B. D., Khan, A. R., ..., Ma, F. (2017). High temperature induced anthocyanin inhibition and active degradation in malus profusion [Original research]. Front. Plant Sci., 8. https://doi.org/10.3389/fpls.2017.01401

Soponronnarit, S., Swasdisevi, T., Wetchacama, S., Wutiwiwatchai, W. (2001). Fluidised bed drying of soybeans. J. Stored Prod. Res., 37(2), 133–151. https://doi.org/10.1016/s0022-474x(00)00015-1

Srikiatden, J., Roberts, J. S. (2006). Measuring moisture diffusivity of potato and carrot (core and cortex) during convective hot air and isothermal drying. J. Food Eng., 74(1), 143–152. https://doi.org/10.1016/j.jfoodeng.2005.02.026

Tai, N. V., Linh, M. N., Thuy, N. M. (2021). Modeling of thin layer drying characteristics of "Xiem" banana peel cultivated at U Minh district, Ca Mau province, Vietnam. Food Res., 5(5), 244–249. https://doi.org/10.26656/fr.2017.5(5).180

Tapia, M. S., Alzamora, S. M., Chirife, J. (2020). Effects of water activity (a_w) on microbial stability as a hurdle in food preservation. In G. V. Barbosa-Cánovas, A. J. Fontana Jr., S. J. Schmidt, T. P. Labuza (Eds.), Water activity in foods: Fundamentals and applications (pp. 323–355). John Wiley.

Thuy, N. M., Chi, N. T. D., Huyen, T. H. B., Tai, N. V. (2020a). Orange-fleshed sweet potato grown in Viet Nam as a potential source for making noodles. Food Res., 4(3), 712–721. https://doi.org/10.26656/fr.2017.4(3).390

Thuy, N. M., Tuyen, N. T. M., Thanh, N. V., Tai, N. V. (2020b). Evaluation of freeze-drying conditions on the process kinetics and physicochemical properties of purple shallot. Food Res., 4(5), 1630–1636. https://doi.org/10.26656/fr.2017.4(5).246

Thuy, N. M., Minh, V. Q., Ben, T. C., Ha, H. T. N., Tai, N. V. (2021). Impact of different thin layer drying temperatures on the drying time and quality of butterfly pea flowers. Food Res., 5(6), 197–203. https://doi.org/10.26656/fr.2017.5(6).328

Thuy, N. M., Tien, V.Q., Van Tai, N., Minh, V. Q. (2022). Effect of foaming conditions on foam properties and drying behavior of powder from magenta (*Peristrophe roxburghiana*) leaves extracts. Horticulturae, 8(6), 546. https://doi.org/10.3390/horticulturae8060546

Tsuruta, T., Tanigawa, H., Sashi, H. (2015). Study on shrinkage deformation of food in microwave-vacuum drying. Drying Technol., 33(15–16), 1830–1836. https://doi.org/10.1080/07373937.2015.1036286

Udomkun, P., Innawong, B. (2018). Effect of pre-treatment processes on physicochemical aspects of vacuum-fried banana chips. J. Food Proc. Preserv., 42(8), e13687. https://doi.org/10.1111/jfpp.13687