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Effects of steaming and drying on quality and antioxidant activity of white-fleshed sweet potato powder (*Ipomoea batatas*)

Efectos de la cocción al vapor y el secado sobre la calidad y la actividad antioxidante del polvo de batata de pulpa blanca (*Ipomoea batatas*)

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Abstract

White-fleshed sweet potatoes (WFSP) are rich sources of polyphenols. The flesh of PFSP contains total polyphenol content (TPC) at 1.52 mgGAE/g fresh weight. The raw material's total free radical scavenging capacity was estimated (at 42.4% DPPH). The inactivation of peroxidase (POD) and polyphenol oxidase (PPO), the breakdown of total phenolic compounds, antioxidant activity, and the whiteness of WFSP were evaluated during steam blanching from 0 to 9 minutes. Steam blanching time from 7 to 9 minutes at boiling temperature (100ºC) inactivated most of the POD and PPO enzymes (71.2% and 70.5%, respectively), thus TPC and antioxidant activity remains high, resulting in a bright white product. After 7 minutes of blanching, drying experiments of WFSP slices were conducted at air temperatures of 50 to 80ºC. The best alternative for describing and understanding the drying of WFSP slices was the Page model. In the temperature's ranges, the values of the moisture diffusivity (D_{eff}) and activation energy are obtained from 3.059×10^{-12} to 5.095×10^{-12} m^2/s and 14.93 kJ/mol, respectively. The drying temperature of 70ºC for 10 hours was suitable for producing WFSP powder with low water activity (0.5) and moisture content (6.5%), high TPC and antioxidant activity, and low specific energy consumption. These results suggested that the WFSP powder exhibited potential as a nutraceutical ingredient product.

Keywords: White flesh sweet potatoes, blanching, drying, quality, antioxidant activity, modeling.

Resumen

Las batatas de pulpa blanca (WFSP) son fuentes ricas en polifenoles. La pulpa de PFSP contiene un contenido total de polifenoles (TPC) de 1.52 mgGAE/g de peso fresco. Se estimó la capacidad total de eliminación de radicales libres de la materia prima (42.4% DPPH). La inactivación de la peroxidasa (POD) y la polifenol oxidasa (PPO), la descomposición de los compuestos fenólicos totales, la actividad antioxidante y la blancura del WFSP se evaluaron durante el escaldado con vapor de 0 a 9 minutos. El tiempo de escaldado con vapor de 7 a 9 minutos a temperatura de ebullición (100ºC) inactivó la mayoría de las enzimas POD y PPO (71.2% y 70.5%, respectivamente), por lo que el TPC y la actividad antioxidante permanecen altos, dando como resultado un producto blanco brillante. Después de 7 minutos de escaldado, se realizaron experimentos de secado de rodajas de WFSP a temperaturas del aire de 50 a 80°C. La mejor alternativa para describir y comprender el secado de rebanadas de WFSP fue el modelo de Page. En los rangos de temperatura, los valores de difusividad de la humedad (D_{eff}) y energía de activación se obtienen desde 3.059×10^{-12} hasta 5.095×10^{-12} m^2/s y 14.93 kJ/mol, respectivamente. La temperatura de secado de 70oC durante 10 horas fue adecuada para producir polvo de WFSP con baja actividad de agua (0.5) y contenido de humedad (6.5%), alto TPC y actividad antioxidante, y bajo consumo de energía específica. Estos resultados sugirieron que el polvo WFSP exhibía potencial como producto ingrediente nutracéutico.

Palabras clave: batatas de pulpa blanca, escaldado, secado, calidad, actividad antioxidante, modelado.

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1 Introduction

A variety of sweet potatoes is called *Ipomoea batatas* (L.), a gamopetalous dicot in the family *Convolvulaceae*. Depending on the variety, the flesh of sweet potatoes can be beige, white, red, pink, purple, yellow, orange, or purple (Mu and Singh, 2019). The sweet potato plant has a short, adaptable growing season, good pest and disease resistance, year-round planting and harvesting, and a tolerable yield (Iese *et al*., 2018). They can also grow in moderately fertile soil or deficient in fertility. Vietnam's Mekong Delta region, namely the Binh Tan district of Vinh Long province, is where the white flesh sweet potato (WFSP) started. Locals call it the "Kingdom of sweet potatoes," with a harvest area of 3,300 hectares. The crop is the area's most important fresh agricultural crop, produced significantly (Nguyen *et al*., 2019). However, sweet potato is classified as highly perishable and is included in the scope of significant global challenges to reduce postharvest losses and improve the poor distribution of food (Zhang *et al*., 2017).

Due to sprouting and chilling injury at low temperatures, sweet potatoes's postharvest behavior is susceptible to storage at ambient temperature. Therefore, it is advised to use an efficient postharvest preservation technique, such as drying, to increase sweet potatoes' shelf life (Rashid *et al*., 2022). Sweet potatoes contain phenolic compounds that have been shown to prevent leukemia, inhibit the growth of stomach and colon cancer cells, and control blood sugar levels (Franková *et al*., 2022); it is also related to their antioxidant activity (Jung *et al*., 2011). Consuming foods high in antioxidants is favorably linked to a lower risk of chronic disease development and reducing glycemic index (Zujko and Witkowska, 2023; Ngo *et al*., 2022; Ngo *et al*., 2023). Natural antioxidant ingredients from plant foods are popular in the industry (Nanasombat *et al*., 2015). According to several studies, the phenolic composition of food products affects most antioxidant activity (Dibanda *et al*., 2020).

However, after peeling, sweet potatoes quickly turn brown due to the action of enzymes on polyphenols, a process that is accelerated when exposed to oxygen. It is essential to inactivate the enzyme since browning can impact the final product's sensory quality. Vegetables can be blanched by submerging in hot water or steam containing acid and salt (Fellows, 2022). Hot steam has been regarded as an effective heat source for blanching, especially in large quantities. Blanching inactivates enzymes and lessens the microorganisms on the food's surface. The most commonly used additive to prevent browning is sulfite, which is inexpensive and very effective. However, this substance can cause off-flavors, health risks (e.g., bronchial asthma), and commercial problems (Lien *et al*., 2016). This study used steam blanching before drying WFSP slices to inactivate the enzyme and improve the product's appearance.

Drying can be considered a preservation technology because it can remove water from materials, including heat and mass transfer processes, helping to preserve materials during storage. Hot air drying is the most commonly used technique due to its high drying efficiency. However, heat treatment should also be performed at mild temperatures for the minimum time necessary (El Broudi *et al*., 2022). Drying kinetics and mathematical models for the drying process of some vegetables and fruits have been studied (Krokida *et al*., 2003; Thuy *et al*., 2022; Thuy *et al*., 2023; Loan and Tai, 2023), allowing simulation and process optimization as well as sizing and determining the commercial application of the drying system. Our research has applied eight popular mathematical models in the drying process of white-fleshed sweet potatoes. The effective moisture diffusion coefficient and activation energy of the drying process were estimated. These results provide a theoretical basis and predictive guidance on controlling the hot air drying process and obtaining white sweet potato powder with short drying time and optimal quality.

2 Materials and methods

2.1 *Preparation of the materials and the sample*

White-fleshed sweet potato varieties are harvested at Binh Tan District Farm, Vinh Long, Vietnam. After harvest, the tubers were sorted, washed, peeled and sliced using a Food Slicer (Mandoline, Zhejiang, China) with a slice thickness of about 2 mm. After slicing, they are quickly blanched with steam to avoid enzymatic browning.

2.2 *Blanching process*

WFSP slices (about 300 gr) were subjected to steam blanching at 100ºC and different times (3 to 9 mins). Every 2 minutes, the sweet potato slices are removed and cooled immediately by dipping them in cold water (about 1.5 min). Unblanched WFSP was taken as a control sample. The samples' whiteness, TPC, residual POD and PPO enzyme activity, as well as antioxidant activity, were also assessed.

2.3 *Drying procedure*

White sweet potato slices were blanched for the appropriate time (selected from the previous experiment), followed by drying in a hot air dryer (Memmert UN30 from Germany) at temperatures of 50, 60, 70 and 80ºC, the air flow rate was 1 m/s and the air humidity was adjusted to ≈ 25%. Sweet potato slices were arranged in layers on a stainless steel tray (300 g per batch). Sample weight loss during this process was recorded by periodically removing each tray and weighing it on an electronic scale with an accuracy of 0.01g. The drying process was completed when the moisture content of the sample reached about final 5-6%. Each drying experiment was conducted three times.

2.4 *Physicochemical analysis*

2.4.1 *Whiteness*

The L*, a*, and b* values of powder were determined using a Hunter Lab Colorimeter (Color Flex, USA). Equation 1 was used to determine the whiteness value (Wang *et al*., 2013).

$$Whiteness = 100 - [(100 - L)^2 + a^2 + b^2]^{1/2} \tag{1}$$

2.4.2 *Total polyphenol content (TPC)*

The total phenolics were determined using the Folin-Ciocalteau assay. Results were expressed as mg gallic acid equivalent/100g (mg GAE/100g) using gallic acid as the standard (Teixeira *et al*., 2013).

2.4.3 *Moisture content*

The AOAC method (AOAC, 2005) determined the moisture content. Water activity (a_w) using a RotronicHygroPalm HP23-AW-A-SET-40 (USA) measurement device.

2.4.4 *DPPH (%)*

The antioxidant activity of the product was assessed using the approach described by Brand-Williams *et al.* (1995), based on the scavenging capacity of the stable 1,1-diphenyl-2-picrylhydrazyl (DPPH) free radical.

2.4.5 *PPO and POD residual activity analysis*

POD and PPO tests were carried out qualitatively and quantitatively following the techniques used by Hultin *et al.* (1966) and Teisson (1979), respectively. For peroxidase and polyphenol oxidase, the absorbance increase of 0.001 units per minute response at 470 and 395 nm, respectively, was used to define one unit of enzyme activity (Unit). The ratio of enzyme activities between blanched and unblanched samples was then used to compute the percentage of residual enzyme activity (Equation 2).

$$\text{Residual activities} = \frac{E}{E_o} \times 100 \tag{2}$$

Where: E and E_o are the activities of blanched and unblanched samples, respectively.

2.5 *Mathematical modelling*

Throughout the drying studies, the drying changed continuously; Equation 3 identifies the relative moisture content of the drying air (Akpinar *et al.*, 2003).

$$MR = \frac{M_t}{M_0} \tag{3}$$

Eight thin-layer drying models were fitted to the drying data to determine which model best explained the drying process of WFSP (Table 1).

Which model best fit the data was determined using the root mean square error (RMSE, Equation 4), coefficient of determination (R^2, Equation 5), and chi-square (χ^2, Equation 6).

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

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

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{pre,i} - MR._{exp,i})^2}{N - n} \tag{6}$$

Table 1. Mathematical models applied to study the drying kinetics.

No.	Model name	Model	References
1	Approximation of diffusion	MR= aexp(-kt)+(1-a)exp(-kbt)	Mulinacci (1996)
2	Henderson and Pabis	MR= aexp(-kt)	Rosa *et al.* (2015)
3	Modified Henderson and Pabis	MR= aexp(-kt)+bexp(-gt)+cexp(-ht)	Akpinar and Bicer (2008)
4	Logarithmic	MR= aexp(-kt)+c	Akpinar and Bicer (2008)
5	Newton	MR= exp(-kt)	Sobukola *et al.* (2007)
6	Page	MR= exp(-kt^{n})	Akpinar and Bicer (2008)
7	Two-term	MR= aexp(k$_{o}$t)+bexp(-k$_{1}$t)	Sobukola *et al.* (2007)
8	Two-term exponential	MR= aexp(-kt)+(1-a)exp(-kat)	Sobukola *et al.* (2007)

Table 2. Effect of blanching time on color, TPC, antioxidant activity, and residual POD and PPO activity.

Blanching time (min)	Whiteness	TPC (mgGAE/g)	DPPH%	Residual POD activity	Residual PPO activity
0	64.9 ± 0.1^{a}	1.52 ± 0.09^{ab}	45.4 ± 0.4^{b}	100 ± 0.0^{d}	100 ± 0.0^{d}
3	67.8 ± 0.3^{b}	1.75 ± 0.04^{c}	52.6 ± 0.3^{d}	38.2 ± 0.23^{c}	65.5 ± 1.22^{c}
5	68.4 ± 0.3^{bc}	1.75 ± 0.02^{c}	52.2 ± 0.4^{d}	31.4 ± 0.12^{b}	48.2 ± 1.12^{b}
7	69.5 ± 0.2^{c}	1.62 ± 0.02^{b}	49.5 ± 0.2^{c}	30.5 ± 0.21^{ab}	32.6 ± 1.53^{a}
9	69.4 ± 0.2^{c}	1.45 ± 0.08^{a}	42.9 ± 0.2^{a}	28.8 ± 0.12^{a}	30.5 ± 1.83^{a}

Data are expressed as means±SD of triplicate experiments; Mean values in column with different letters are significantly different at $p \leq 0.05$

where $MR_{exp,i}$ and $MR_{pre,i}$ are the moisture ratio at observation i, experimental, and anticipated moisture ratios. N is the number of experimental data points.

2.6 Calculation of D_{eff} (effective moisture diffusion), E_a (activation energy) and specific energy consumption (SEC)

According to our prior work, the effective moisture diffusivity (D_{eff}) was estimated. A relationship of the Arrhenius type between the D_{eff} and temperature was used to derive the activation energy (E_a) (Thuy *et al.*, 2021; Thuy *et al.*, 2023). The energy needed (SEC = Et/mw) to remove 1 kilogram of water from the sample was defined as the specific energy consumption (SEC) (kW), where MW is the mass of water removed (kg) (Thuy *et al.*, 2022).

2.7 Statistical analysis

The statistical software Stratigraphic Centurion XVI (USA) was used for data analysis. The significant difference in the obtained data was analyzed by the variance (ANOVA) method at $p \leq 0.05$.

3 Results and discussion

3.1 Effect of blanching on quality of WFSP and enzyme deactivation

3.1.1 Total polyphenol content

With antioxidant properties, polyphenols can eliminate free radicals and prevent some oxidation reactions. Blanching is one of the valuable heat treatment techniques used in food processing to deactivate enzymes that adversely influence the polyphenol content of sweet potatoes, preserving this chemical and enhancing food quality. The TPC of raw white sweet potato (unblanched) was determined to be 1.52 mgGAE/g. An increase (about 15.13%) in TPC was observed when the blanching time was 3 min (Table 2). It was comparable to the values listed in the findings of a prior study using water blanching of African green vegetables by Managa *et al.* (2020). Saini *et al.* (2023) studied water blanching of purple and Lady Rosetta potatoes, showing that TPC increased by 7.8% and 10.41%, respectively. It might be because the extraction of polyphenols was aided by the disassembly of polyphenol-protein complexes caused by heat. However, when the blanching time is prolonged (3 to 7 minutes), this content decreases (about 7.43%). Then, it continued to reduce to 17.14% when blanching sweet potatoes for 9 minutes (compared to the value obtained at 3 minutes of blanching). Leaching and/or the phenolic chemicals' susceptibility to temperature were likely to blame for this alteration.

3.1.2 *DPPH-radical-scavenging activity*

A similar pattern for DPPH-radical-scavenging activity was observed, where 3 to 5 minutes of blanched samples achieved higher values than samples treated with other times (p<0.05). Steam-blanched WFSP samples could increase or retain bioactive compounds, thus enhancing antioxidant activity. By DPPH, WFSP's initial antioxidant activity was 45.4%, which tended to increase and gradually decrease with blanching time (Table 2). In plants, the TPC contributes to the antioxidant activity (Dibacto *et al*., 2021), so these values also increase and decrease, corresponding to the TPC in WFSP slices at different blanching times.

3.1.3 *The whiteness*

One of a product's fundamental qualities is its whiteness, which denotes whether browning is an enzymatic or non-enzymatic process. The whiteness of white sweet potato samples at different blanching times showed a significant difference compared to non-blanched samples. The sample with a longer blanching time increased the L* value; therefore, n comparison to the control sample, the whiteness value increased and was substantially different ($p \leq 0.05$). A significant increase in whiteness was seen after 3 mins of blanching (67.8) compared to the control (64.9). The blanching process improved the color of dried sweet potatoes (Oke and Workneh, 2013). In this study, the increase in whiteness of WFSP with blanching time was due to PPO and POD enzymes being inactivated, as they are the leading cause of the browning reaction (Nascimento and Canteri, 2018).

3.1.4 *The residual enzyme activities*

The activities of two enzymes, POD and PPO of WFSP, decreased over time by steamed blanching. At the first 3 min of blanching, the remaining activity rates of POD and PPO enzymes were reduced by 61.8% and 34.5%, respectively. Then, the inactivation rate gradually decreased until the blanching time was 9 minutes. It can also be seen that the thermal stability of these two enzymes is slightly different; the POD enzyme was inactivated faster than PPO after 3 minutes of blanching. PPO was shown to be more heat resistant than POD in slices of blanched garlic, according to Fante and Norea (2012). The remaining POD and PPO were heat resistant, so they were not wholly inactivated during the 9 min blanching; the residual enzyme activities of 28.8% and 30.5%, respectively, were found.

3.2 *Mathematical modelling*

Expressions for moisture ratios were created from numerous tests' data on moisture content. Eight drying models were used to perform curve fitting calculations with drying time. Table 3 displays the statistical analysis findings performed on these eight drying models. The models were assessed and selected using the coefficient of determination (R^2), root mean square error (RMSE), and chi-square (χ^2) values. High R^2 values (97.19% to 99.72%) in the analytical findings for each equation suggest that each equation can adequately represent the thin layer drying of WFSP. The χ^2 values ranged from 0.0004 to 0.0211, and the RMSE values were in the 0.0193 to 0.0650 range. Since the Page model had the highest R^2 value (99.45-99.72%), the lowest χ^2 (0.0004-0.0006) and RMSE values (0.019-0.0225) out of the eight models used, it had the most remarkable match to the WFSP drying process. The final moisture content of WFSP powder reached 6 to 7% after 14, 12, 10, and 8 hours, respectively, at temperatures between 50 and 80ºC. When comparing the Page model's predicted values to the experimental values, it was found to be a good fit (Figure 3).

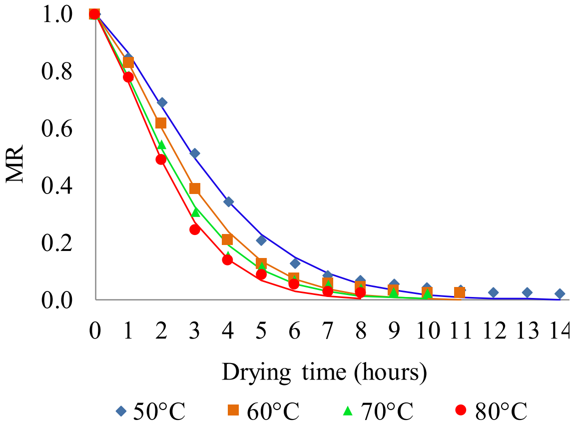

Figure 3. Modeling of drying curves using the Page model for WFSP.

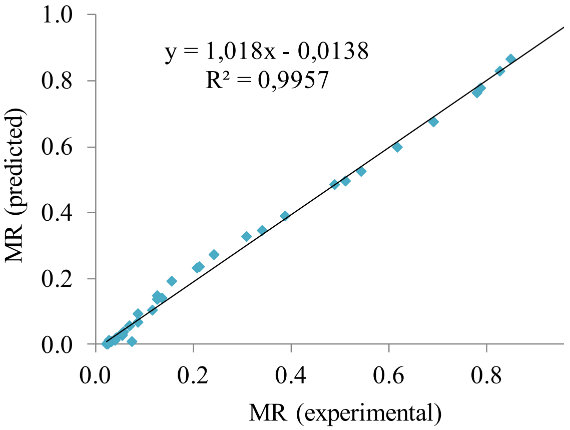

Figure 4. Experimental moisture ratio versus predicted moisture ratio using Page model.

Table 3. Modeling of WFSP thin-layer drying at various temperatures.

Model	Temp. (ºC)	Model constants	RMSE	R^2	χ^2
Approximation of diffusion	50	a=0.4892; k=0.2728; b=0.9982	0.058	97.39	0.0042
	60	a=0.7298; k=0.3338; b=0.9904	0.064	97.19	0.0055
	70	a=0.8040; k=0.3755; b=0.9903	0.054	98.01	0.004
	80	a=0.8181; k=0.4154; b=1.0125	0.0648	97.57	0.0063
Henderson and Pabis	50	a=1.0776; k=0.2913	0.0488	97.99	0.0028
	60	a=1.0732; k=0.3554	0.0542	97.76	0.0035
	70	a=1.0554; k=0.3940	0.0463	98.35	0.0026
	80	a=1.0571; k=0.4372	0.0549	97.97	0.0039
Modified Henderson and Pabis	50	a=0.4178; k=0.3343; b=0.4178; g=0.3349; c=0.4178; h=0.3349	0.0389	98.76	0.0026
	60	a=0.3578; k=0.3557; b=0.3578; g=0.3557; c=0.3576; h=0.3548	0.07	97.76	0.0098
	70	a=0.4306; k=0.4734; b=0.4306; g=0.4732; c=0.4306; h=0.4736	0.0325	99.3	0.0026
	80	a=0.3524; k=0.4370; b=0.3524; g=0.4370; c=0.3524; h=0.4376	0.0839	97.97	0.0211
Logarithmic	50	a=1.1042; k=0.2632; c=0.0393	0.0471	98.28	0.0028
	60	a=1.1085; k=0.3152; c=0.0482	0.0522	98.13	0.0036
	70	a=1.0784; k=0.3632; c=0.0313	0.0465	98.52	0.003
	80	a=1.1080; k=0.3755; c=0.0640	0.0521	98.44	0.0041
Newton	50	k=0.2726	0.0537	97.39	0.0031
	60	k=0.3341	0.0579	97.19	0.0037
	70	k=0.3756	0.0483	98.01	0.0026
	80	k=0.4166	0.0562	97.57	0.0035
Page	50	k=0.1451; n=1.4361	0.0195	99.68	0.0004
	60	k=0.1850; n=1.4784	0.0193	99.72	0.0004
	70	k=0.2494; n=1.3649	0.0225	99.61	0.0006
	80	k=0.2692; n=1.4299	0.0216	99.45	0.0006
Two-term	50	a=0.5388; k=0.2912; b=0.5388; k_0=0.2915	0.0531	97.99	0.0038
	60	a=0.5366; k=0.3549; b=0.5366; k_0=0.3559	0.0606	97.76	0.0055
	70	a=0.5277; k=0.3940; b=0.5277; k_0=0.3940	0.0525	98.35	0.0043
	80	a=0.5286; k=0.4372; b=0.5286; k_0=0.4371	0.065	97.97	0.0076
Two-term exponential	50	a=0.9931; k=0.2728	0.0557	97.39	0.0036
	60	a=0.9906; k=0.3344	0.0607	97.19	0.0044
	70	a=0.9891; k=0.3759	0.0509	98.01	0.0032
	80	a=0.9913; k=0.4169	0.06	97.57	0.0046

The experimentally and the predicted MR were satisfactorily correlated (R^2=0.9957) (Figure 4). Additionally, the Page model gives the most precise account of the kinetics of red chili drying (Najla and Bawatharani, 2019), butterfly pea flowers (Thuy *et al.*, 2021), and chili peppers (Ajuebor *et al.*, 2022).

3.3 D_{eff}, E_a, and specific energy consumption

The effective moisture diffusion coefficient D_{eff} is a coefficient that includes many different phenomena related to water loss in food (Tlatelpa-Becerro *et al.*, 2022). At the studied drying temperature range, effective moisture diffusivity (D_{eff}) values were obtained (Table 4), which showed good correlation with drying temperature and ranged from 3.059×10^{-12} to $5,095\times10^{-12}$ m^2/s. This result is mainly due to increased temperature leading to higher water diffusion in sweet potato slices and greater evaporation. Similar outcomes were found in earlier research on Vernonia amygdalina leaves (Alara *et al.*, 2019), where the D_{eff} ranged from 4.55×10^{-12} to 5.48×10^{-12} m^2/s at three different air temperatures (40, 50, and 60ºC), and butterfly pea flowers drying at 55 to 70ºC with D_{eff} varying from 2.392×10^{-12} to 7.756×10^{-12} m^2/s (Thuy *et al.*, 2021).

Table 4. The variation in the WFSP's effective moisture diffusivity (D_{eff}).

Temperatures (ºC)	D_{eff} (m^2/s)
50	$3.059 \pm 0.032 \times 10^{-12}$
60	$3.859 \pm 0.045 \times 10^{-12}$
70	$4.029 \pm 0.067 \times 10^{-12}$
80	$5.095 \pm 0.098 \times 10^{-12}$

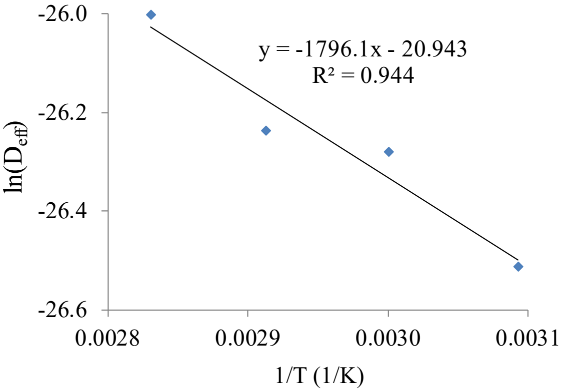

Figure 5. The linear relationship between $\ln(D_{eff})$ and 1/T (K^{-1}) at the temperature specified by the Arrhenius-type relationship.

The association between $\ln(D_{eff})$ and the temperature's reciprocal (1/(T+273.15)) showed a linear trend with best-fit quality (R^2=0.94) (Figure 5). The straight line over the temperature ranges in this graphic demonstrated the reliance on Arrhenius. Based on the computed activation energy from the straight line slope (14.93 kJ/mol), 1 mol of water in the WFSP requires 14.93 kJ of energy to dry. This result was remarkably similar to the water yam's (Okeleye *et al.*, 2021). Selvi (2020) reported that most agricultural products have E_a values ranging from 14.42 to 43.26 kJ/mol due to various drying procedures.

As expected, a rise in temperature decreased drying time and specific energy consumption (SEC). This is due to the increased moisture extraction and enhanced temperature gradient. Thuy *et al.* (2022) found that greater drying temperatures accelerated mass transfer, shortened drying times, and decreased specific energy consumption (SEC). At a temperature of 50°C, the highest specific energy capacity (104.01 kWh/kg) was noted. The minimum value of 65.92 kWh/kg was recorded at a temperature of 80°C. However, there is no significant difference in SEC value when the sample dried at 70 and 80ºC. The lower energy consumption could lead to a reduction in carbon gas emissions (Thuy *et al.*, 2022).

3.4 The quality of white sweet potato powder

3.4.1 The moisture content (MC) and water activity

The MC of WFSP ranged from 6.5 to 6.6%, as depicted in Table 5. These values were lower than the moisture content of five different sweet potato varieties (ranging from 7.9 to 9.7%) reported by Amajor *et al.* (2011). These values were also lower than the recommended moisture level for wheat powder of 15.5% (Tortoe *et al.*, 2017). The MC of sweet potato powder dried in hot air in our investigation ranged from 4.41 to 4.71%, making it somewhat higher than the published results of Ruttarattanamongkol *et al.* (2016).

Sweet potato powder with the lowest moisture content is predicted to have a longer shelf life and preservation time, while also maintaining good quality of the powder due to limited microbial activity and chemical reactions (Li *et al.*, 2017). Therefore, the moisture value achieved for WFSP powder samples dried at temperatures of 70 and 80ºC in this study (6.5-6.6%) can ensure good preservation of product. In addition, the water activity (a_w) of the powder measured from 0.5 to 0.6 is a good sign that the product has stable quality and long-term use.

3.4.2 The whiteness

The whiteness values ranged from 82.11 to 88.74 (Table 5). The highest value was obtained for the sample dried at 70ºC for 10 hrs, and lower at other temperatures and drying times. The longer drying time (14 hours at 50ºC) or high temperature (80ºC) also adversely affected the color of the powders (Figure 6).

Table 5. Results of moisture content and water activity, color, TPC, and antioxidant activity of WFSP powder.

Drying temperature (ºC)	Drying time (h)	Moisture content (%)	Water activity	Whiteness	TPC (mgGAE/g)	DPPH%
50	14±0.15	6.6 ± 0.1^a	0.63 ± 0.07^a	65.8 ± 0.2^a	1.23 ± 0.56^a	52.5 ± 0.52^a
60	12±0.1	6.6 ± 0.2^a	0.62 ± 0.08^a	67.4 ± 0.4^b	1.29 ± 0.34^a	53.5 ± 0.72^a
70	10±0 .1	6.5 ± 0.2^a	0.60 ± 0.06^a	70.2 ± 0.2^d	1.40 ± 0.23^b	56.8 ± 0.23^c
80	8±0.1	6.5 ± 0.2^a	0.60 ± 0.08^a	68.5 ± 0.3^c	1.37 ± 0.34^a	56.7 ± 0.34^b

Data are expressed as means±SD of triplicate experiments; Mean values in column with different letters are significantly different at $p \leq 0.05$.


Control sample 50ºC – 14 hrs 60ºC – 12 hrs 70ºC – 10 hrs 80ºC – 8 hrs

Figure 6. WFSP powder samples were blanched and dried at different temperatures and times compared to the control sample.

3.4.3 TPC and antioxidant activity

TPC is susceptible to temperature changes and prolonged heat treatment durations, as was mentioned. According to our research, samples with higher TPC content also had stronger antioxidant activity. Our results are consistent with those of several earlier research (Fu *et al*., 2016; Makori *et al*., 2020; de Albuquerque *et al*., 2019), which they reported. They showed that phenolics were the main factor affecting the antioxidant activity of sweet potatoes. Natural phenolic compounds have received increasing attention recently and can be found in many plant products. Consuming products containing high levels of this compound may reduce the risk of developing the disease, increasing their antioxidant activity and other health-promoting factors. Thus, the investigation revealed that the best and most suitable temperature for drying white sweet potatoes appears to be 70ºC. At this temperature and within 10 hours of drying, the final product has the brightest white color, high TPC content and antioxidation activity, and lowest moisture content and water activity.

Conclusions

The findings showed that the quality of WFSP was significantly influenced by changes that took place in the first three minutes after blanching. The time to blanch white potato slices with steam is about 7 minutes for the best quality of ingredients, preparing for the subsequent drying process. Among the eight applied drying models, the Page equation relating moisture loss over time at different temperatures performed well across all statistical parameters. As a result, this model can be used to forecast WFSP's drying properties. A drying temperature of 70ºC for 10 hrs appears superior for creating powder from white sweet potatoes. White sweet potato powder can be used in food processing, especially for formulating foods. This activity will also take full advantage of the vast sweet potato output currently in surplus in local production; the farmers' income will be improved accordingly.

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