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Assessment of the Applicability of Microwave Vacuum Drying Equipment based on the Change of Nutriental Components in Purple Potato

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Abstract
Vacuum microwave drying is one of the advanced drying techniques that has been widely studied and applied recently. In the vacuum microwave drying process, heat energy is supplied by electromagnetic energy to heat the material, under vacuum conditions. This paper presents the results of the study on the effects of vacuum microwave drying on drying time, total sugar content and protein content of purple sweet potatoes under different conditions of vacuum pressure (65, 75, 85 kPa) and microwave power (80, 240, 400 W); compared with the convection drying process using hot air when the product reaches the same humidity ≤ 5.0%. The results show that vacuum pressure and microwave power have an effect on the total sugar content and protein content of the sample after drying. The maximum total sugar and protein contents were 13.46 g /100 g of dry material and 3.27 g /100 g of dry material, respectively, under the conditions of 80 W microwave power, 85 kPa vacuum pressure and 20 min drying time. The total sugar and protein loss of the purple sweet potato sample dried by vacuum microwave was lower than that of the sample dried by forced convection with hot air with a significant difference ($p \leq 0.05$).

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Keywords: Vacuum microwave drying, hot air convection drying, total sugar content, protein, purple sweet potato

1. Introduction

Drying is a process of reducing the moisture content of raw materials based on the principle of the difference in partial vapor pressure of water on the surface of the raw material and the surrounding environment when using a heat agent [1, 12]. Vacuum microwave drying can be an alternative method to produce high-quality dried products, this method combines the benefits of drying with microwave energy and drying in a vacuum environment [2, 13]. One of the advantages of microwave drying is the very short drying time. The absorption of microwave energy by wet products depends on the moisture distribution, causing selective heating in the interior. Therefore, the low-moisture part of the wet material will be protected from overheating. Moreover, the shrinkage of food during microwave drying can be reduced due to the volume heating inside the product.

Vacuum drying allows the product to be dried at low temperatures, which is particularly suitable for heat-sensitive food products and fruits with high sugar content. Therefore, microwave vacuum drying allows the drying process to be carried out in a short time and at relatively low temperatures. This results in an efficient drying process, preserving nutritional value, color, texture and flavor [3, 14].

The advent of microwave drying in a vacuum environment marks the superiority in improving the existing disadvantages of previous drying methods for the food industry in particular and other industries in general, and also to produce high-quality products.

Microwave drying belongs to the high-frequency electric field group, does not affect the health of consumers, was recognized by the American Consumer Health Protection Association in 2009, and has been applied in many processing fields: Drying, blanching, vacuum drying, cooking in meat or vegetable production [4, 15].

Purple sweet potatoes originate from Japan, with the scientific name Okinawan. This is a food source containing many nutrients necessary for humans, including mainly starch (12.7 g), protein (1.6 g), and vitamin C, B vitamins and other minerals, the results are calculated per 100 g of raw materials [5, 6, 16]. Therefore, the objective of this study is to determine the influence of microwave vacuum drying conditions on this raw material, thereby determining the possibility of practical application for deep processing of local purple sweet potato sources.

2. Materials and Research Methods

2.1. Materials

Purple sweet potatoes used in the study were purchased in Binh Tan district, Vinh Long province. The raw materials were selected according to the standards of smooth skin, no scratches, no pests, no sprouts, and uniform in size. The raw materials were harvested in the winter-spring crop, after 78-80 days of planting. The raw materials had a moisture content of 70.56 %, a total sugar content of 14.28 ± 0.37 g /100 g of dry materials, and a protein content of 5.69 ± 0.39 g /100 g of dry materials. After being cleaned, peeled, and thinly sliced according to the diameter of the tubers with a thickness of 0.5 ± 0.01 mm, the raw materials were harvested in the winter-spring crop. Then blanch in boiling water at 100 °C for 15 seconds and cool by soaking in distilled water at room temperature for 1 minute.

2.2. Vacuum microwave drying equipment model

The vacuum microwave drying model is designed from a SHARP microwave oven, Model R- 20A1(S)VN with a volume of 22 L, a maximum microwave output power of 800 W, and a frequency of 2450 MHz. The vacuum chamber is designed by a glass bowl (placed inside the oven, heat-resistant up to 400 ºC) connected to a vacuum pump system with a Teflon plastic tube capable of achieving a maximum vacuum pressure of 90 kPa. A rotating system is used to allow the vacuum chamber to rotate with the turntable, reducing inhomogeneity due to microwave absorption of the samples during the drying process. The vacuum is controlled by a negative pressure sensor SPSA-TPC (Model V01). In addition, a condenser is installed in series between the vacuum chamber and the pump system to remove the water vapor released during the drying process, to protect the vacuum pump.

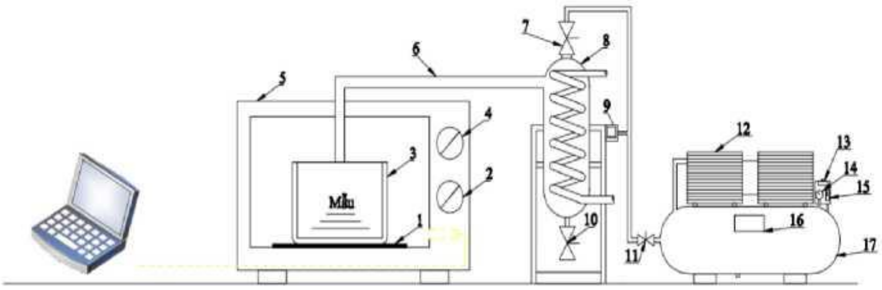

Fig 1: Model of microwave drying equipment in vacuum environment

1. Turntable
2. Timer
3. Drying chamber (vacuum chamber)
4. Power level control
5. Microwave oven
6. Teflon tube
7, 10,11. One-way valve
8. Microwave generator
9. Vacuum pressure control unit
12. Oil-free vacuum pump
13. Emergency switch
14. Vacuum pressure gauge
15. Vacuum pump switch
16. On/off relay
17. Accumulator

2.3. Experimental method

Purple sweet potatoes after treatment were placed in a vacuum chamber, weighing 40 ± 2 g (equivalent to 24 - 26 potato slices), and the drying experiment was conducted under the conditions set according to the experimental design: microwave power (80, 240, 400 W) and vacuum pressure (65, 75, 85 kPa) until the moisture content of the sweet potato sample was ≤ 5.0 %; the time required for a sample to dry under each condition was recorded. The moisture content was determined using an infrared moisture balance. The drying time was calculated using a timer integrated in the microwave oven. A control experiment was conducted using the hot air convection drying method, purple sweet potato samples were treated similarly to the vacuum microwave dried samples but were dried in an oven (Memmert, UN110) at 60 °C, recording the drying time until the sample reached a moisture content of ≤ 5.0 %.

2.4. Analytical method

Total sugar content is determined based on the color reaction between reducing sugar and dinitrosalicylic acid (DNS) reagent [7, 17]. The color intensity of the reaction mixture is proportional to the concentration of reducing sugar within a certain range, and the color is measured at a wavelength of

540 nm. Based on the standard curve of pure glucose with concentrations: 0, 100, 200, 300, 400, 500, 1000 ppm. 5 g of homogenized sample is added to 50 mL of ethanol, shaken well, boiled in a water bath for 30 minutes at 80 °C; then the solution is filtered with filter paper. Then add 10% HCl, boil in a water bath for another 5 minutes, cool, neutralize with NaOH and shake well. Pipette 1 mL of the filtrate into a test tube containing 0.5 mL of DNS reagent, and shake the test tubes well. Place the test tubes in a boiling water bath for exactly 10 minutes, cool, dilute with distilled water and then determine the absorbance at 540 nm.

Protein content is determined by the Kjeldahl method. The sample is mineralized with concentrated H_2SO_4 solution to obtain nitrogen in the form of NH_4+, NaOH is used to push ammonia out of the salt, and steam is used to pull ammonia out of the salt in the nitrogen distillation unit. Quantitatively release NH_3 by titration with 0.1N HCl with Tashiro indicator. Weigh 1 g of sample, 10 g of catalyst mixture $CuSO_4$:K_2SO_4 (1:10) and 15 mL of concentrated H_2SO_4 into the digestion tube. Perform mineralization of the sample in a suitable digestion system until a clear solution is obtained, and distill the nitrogen in a semi-automatic nitrogen distillation unit to transfer NH_3 into the absorption vessels. Titrate with 0.1N HCl standard solution with Tashiro indicator, the solution changes color from blue to purple, record the volume of 0.1N HCl consumed. Protein content is determined by multiplying total nitrogen content by the conversion factor 6.25.

2.5. Data processing method

Graphs are drawn using Microsoft Excel 2016 software with standard deviation (STD). Data are collected and processed using Minitab 19 software. Experiments are randomly arranged, repeated 3 times, one-way ANOVA and LSD (Least significant difference) are used to compare the results obtained between the levels of surveyed factors with $\alpha = 0.05$.

3. Results and Discussion

3.1. Effect of microwave power and vacuum pressure on drying time

In the drying process, time is a very important factor, but it is also affected by factors such as raw materials, equipment specifications, drying methods, etc. This study monitors the effect of microwave power and vacuum pressure on drying time.

The drying time showed a clear difference when changing the investigated factors as shown in Figure 2. The drying time decreased at the same vacuum pressure level when increasing the microwave power. The drying time required to bring the sample moisture content below 5.0 % at a vacuum pressure of 65 kPa decreased from 25 minutes to only 6 minutes when the power changed from 80 W to 400 W. At a microwave power of 400 W and a vacuum pressure of 85 kPa, the drying time was the shortest, only 5 minutes. The same trend was also found at the remaining microwave power levels and vacuum pressures. The moisture content of the sample decreased rapidly during microwave heating due to the heat generated inside the sample causing a large vapor pressure difference between the center and surface of the sample [8, 18]. The higher the microwave power, the more energy the sample receives, the more heat is generated, the faster the water vaporizes, so the drying time is shorter.

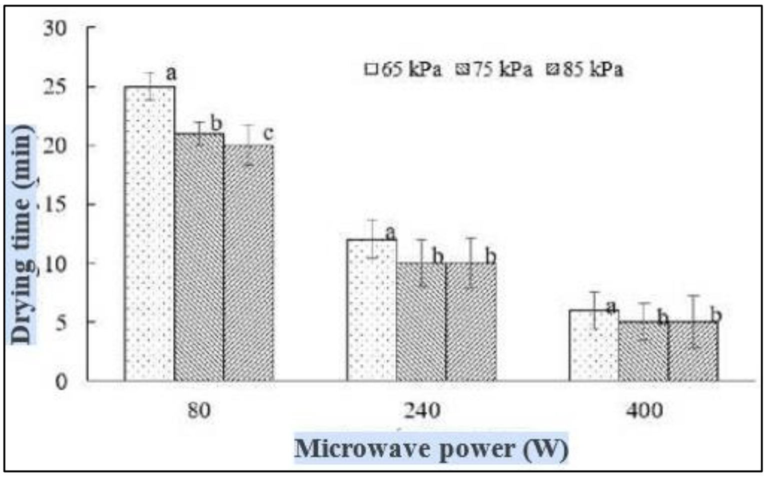

Fig 2: Effect of microwave power and vacuum pressure on drying time (Letters a, b, c represent significant differences (α = 5%) by LSD test)

Figure 2 shows the effect of vacuum pressure on drying time at different microwave power levels. When the vacuum pressure increases from 65 kPa to 85 kPa, the drying time decreases for all power levels, specifically at 80 W power, the drying time gradually decreases from 25 minutes to 20 minutes. Similarly, at 240 W power, the drying time decreases from 12 minutes to 10 minutes. At 400 W power, there is no difference in drying time because the large microwave power provides a lot of energy, making the vaporization speed faster and the drying time shorter. The increased vacuum pressure will reduce the drying time at microwave power levels because when the vacuum pressure is large, the heat of vaporization of water will decrease, so the water in the raw material is easier to escape than at low vacuum pressure.

3.2. Effect of microwave power and vacuum pressure on total sugar content

Microwaves when passed through the sample will heat them. Water, total sugar and substances in the food absorb microwave energy in a process called dielectric heating. Under vacuum conditions, microwave energy is provided at the molecular level causing changes in the nutritional composition of purple sweet potatoes.

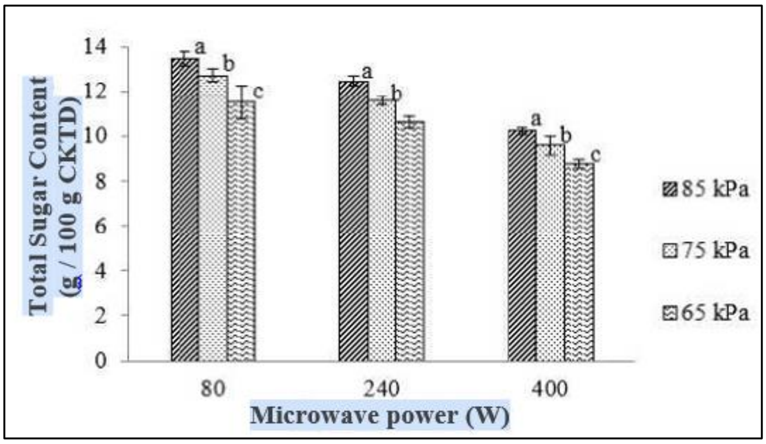

Fig 3: Total sugar content at different microwave power levels and vacuum pressures (Letters a, b, c represent significant differences (α = 5%) by LSD test)

The total sugar content of purple sweet potato under different drying conditions is shown in Figure 3. The results showed that microwave power had a significant effect on total sugar content ($p \leq 0.05$). Under the same vacuum pressure condition of 85 kPa, microwave power of 80 W achieved the highest total sugar content of 13.46 ± 0.33 g/100 g of dry material, then gradually decreased to 10.25 ± 0.77 g/100 g of dry material at 400 W. This trend also occurred similarly at the remaining vacuum pressures when microwave power increased. Thus, under the same vacuum pressure, the total sugar content will increase when microwave power gradually decreases. The main reason is that the Maillard reaction reduces the total sugar content during the drying process [9, 19]. The higher the microwave power, the longer the purple sweet potato sample is exposed to microwaves, receiving more energy in a cycle, the higher the temperature, the more Maillard reactions occur. At low microwave power, the microwave exposure time per cycle is shorter, so the sugar transformation is limited.

The effect of vacuum pressure on total sugar content in purple sweet potato samples at different power conditions is shown in Figure 3. When the vacuum pressure increases from 65 kPa to 85 kPa, the total sugar content increases from 8.78 ± 0.21 g/100 g of dry material to 10.25 ± 0.77 g/100 g of dry material (microwave power 400 W) this rule is also found at the remaining microwave powers. Vacuum pressure has a significant effect on the total sugar content of the product after drying. The higher the pressure, the lower the heat of vaporization of water, thus increasing the ability to retain total sugar in the dried sample [10, 20].

3.3. Effect of microwave power and vacuum pressure on protein content

Purple sweet potato is one of the potato varieties with the highest protein content, so the change in protein content during the drying process is very important.

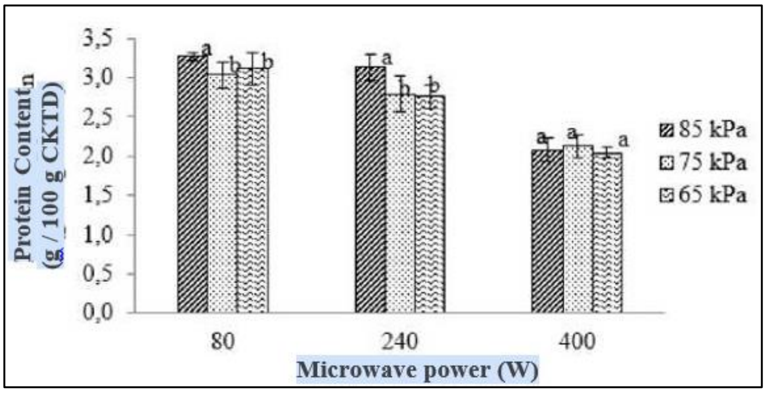

Fig 4: Protein content at different microwave power levels and vacuum pressures (Letters a, b, c represent significant differences (α = 5%) by LSD test)

The protein content of purple sweet potato samples dried under the same vacuum pressure condition of 85 kPa, respectively at the power level of 80 W was 3.27 ± 0.05 g/100 g of dry material, 240 W was 3.13 ± 0.17 g/100 g of dry material, 400 W was 2.08 ± 0.2 g/100 g of dry material. It was found that the protein content decreased gradually, inversely proportional to the microwave power; the lower the microwave power, the higher the protein content. Because the heat generated from microwave energy can destroy the protein structure, leading to changes in hydrogen bonds, hydrophobic interactions and disulfide bonds [10, 21]. At low microwave power levels, the microwave exposure time to the material is short, so the temperature of the sample will be lower than at higher microwave power levels. From this, it can be seen that the longer the microwave exposure time in a cycle of the sample, the lower the protein content.

When the vacuum pressure increased from 65 kPa to 75 kPa and 85 kPa, respectively, the microwave power was 400 W, the protein content had no obvious difference. This was repeated at two lower power levels of 80 W and 240 W. Thus, the vacuum pressure did not greatly affect the change in protein content of dried purple sweet potatoes.

3.4. Evaluation of drying time and changes in total sugar and protein content of vacuum microwave drying and convection drying

Up to now, hot air convection drying is the most popular method used to dry food, however, this method has many disadvantages such as long drying time and significant loss of nutrients.

To evaluate the superiority of drying purple sweet potatoes by vacuum microwave drying, a comparison was made with samples dried by hot air convection at 60 °C. The values of time, total sugar content and protein content are shown in Table 1. In the vacuum microwave drying experiment at 80 W power, 85 kPa pressure obtained the highest total sugar and protein content, so this result was used to compare with the value from the sample dried by convection at 60 °C.

Based on Table 1, the total drying time of the vacuum microwave drying method (85 kPa, 80 W) until the sample reaches a moisture content of ≤ 5.0% is only 20 minutes while the convection drying time takes up to 360 minutes (6 hours) with the same initial mass of raw materials. The reason why vacuum microwave drying gives a very short drying time is because during the drying process, microwaves pass through the purple sweet potato slices and heat them.

Table 1: Comparison of drying time, total sugar content, protein content when the moisture content of purple sweet potato is ≤ 5.0% between vacuum microwave drying and hot air convection drying (The letters a, b, c represent differences at the significance level (α = 5%) by LSD test)

Method	Drying time (min)	Total sugar content (g/100 g dry material)	Protein content (g/100 g dry material)
Vacuum microwave drying (85 kPa, 80 W)	20	$13,46 \pm 0,33^a$	$3,27 \pm 0,05^a$
Hot air convection drying (60 °C)	360	$8,94 \pm 0,15^b$	$2,10 \pm 0,03^b$

Microwave energy is supplied directly at the molecular level through interaction with the electromagnetic field, in particular, through molecular friction, which is the result of the rotation of the electric dipole in the molecules according to the electromagnetic field oscillation. The main mechanism of microwave heating is the rotation of the electric dipole and ion polarization (Dipolar polarization mechanism). Thus, only materials with sufficiently large polarization can have the expected results of microwave heating. Water in food is the main component with electric dipoles, which plays a very important role in dielectric heating. With the electric dipole structure, there are positive and negative charges at both ends, so the water molecules will rotate in a direction parallel to the external electric field.

The alternating electric field oscillation reverses the rotation of the molecules, collides with other molecules and forces them to move, leading to the conversion of this dispersed energy into heat energy. At ultra-high frequencies, molecules continuously reverse, creating high energy conversion, leading to very rapid heating, so the drying time will be short [2, 12]. With the hot air convection drying method, heat is transferred indirectly through the medium, which is air. The air only contacts the surface of the sample, and depends a lot on the moisture transfer process inside the drying sample, so the drying time is very long. In addition, hot air convection drying under normal pressure conditions causes the Maillard reaction and other reactions to occur more, so the total sugar and protein content is significantly lower than the vacuum microwave drying method [11, 13].

4. Conclusion

Initial studies on the effects of microwave vacuum drying showed that microwave power and vacuum pressure had a significant effect on the total sugar content and protein content of purple sweet potato samples after drying. Using higher microwave power and lower vacuum pressure reduced total sugar content and protein content. In the drying condition with 80 W microwave power, 85 kPa vacuum pressure gave the product with the highest total sugar and protein content. Comparing the purple sweet potato sample dried in microwave vacuum under 80 W microwave power, 85 kPa vacuum pressure and the sample dried in hot air convection at 60 °C showed that the time of microwave vacuum drying was 18 times faster thanks to the special mechanism of microwave action. The results obtained when vacuum microwave drying only needed 20 minutes while the hot air convection drying time required more than 360 minutes (6 hours) to achieve the relative humidity at the vacuum microwave drying level (≤ 5.0%). In addition, the total sugar and protein content were also 1.50 and 1.55 times higher, respectively, than when using hot air convection drying. The research results evaluated the impact of microwave power as well as vacuum pressure on purple sweet potato tubers as well as evaluated the superiority compared to the hot air convection drying method.

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