Effects of drying methods on color retention and chlorophyll of celery (*Apium graveolens* L.), spinach (*Spinacia oleracea* L.), Malabar spinach (*Basella alba* L.)

Dat Q. Tran, Hai V. Luong, Ha T. T. Do, Hanh H. Nguyen, Thao T. T. Nguyen*, & Dat T. Huynh

Faculty of Food Science and Technology, Nong Lam University, Ho Chi Minh City, Vietnam

ARTICLE INFO

Research Paper

Received: September 15, 2020
Revised: October 22, 2020
Accepted: November 18, 2020

Keywords

Celery
Foam-mat drying
Malabar spinach
Microwave drying
Spinach

***Corresponding author**

Nguyen Thi Thanh Thao
Email: ngtthanhthao@hcmuaf.edu.vn

ABSTRACT

Dried vegetables are considered convenient for storage, transportation and preservation. The different drying techniques could influence the quality of resulting products. This study aimed to evaluate the effects of three distinguish drying methods as hot-air drying, foam-mat drying and microwave drying on the color retention and chlorophyll of green vegetables powder. Fresh spinach (*Spinacia oleracea* L.), celery (*Apium graveolens* L.), Malabar spinach (*Basella alba* L.) were dried by different methods: hot-air at 60°C, foam-mat at 60°C and microwave at 270 W until the samples reached approximately 9% of moisture content (wb). The drying time of the dried samples by microwave, foam-mat and hot-air method were 60, 210 and 240 min, respectively. Foam-mat dried vegetables were found to have the best quality in terms of color and the residual chlorophyll content. The findings suggest that foam-mat drying is promising in dried vegetable processing.

Cited as: Tran, D. Q., Luong, H. V., Do, H. T. T., Nguyen, H. H., Nguyen, T. T. T., & Huynh, D. T. (2020). Effects of drying methods on color retention and chlorophyll of celery (*Apium graveolens* L.), spinach (*Spinacia oleracea* L.), Malabar spinach (*Basella alba* L.). *The Journal of Agriculture and Development* 19(6), 53-61.

1. Introduction

Drying is a traditional method of food preservation and has been widely used in the food industry. This process causes a reduction in weight and volume, leading to the minimized packaging, storage, transportation costs, and improving the shelf life of the product (Baysal et al., 2003). Hot-air drying is the process that the convection of air flow is used to dry raw materials (Ratti, 2001). During hot-air drying, water is removed by the heat transferred from the hot air to the product by convection and evaporated water is transported to the air also by convection. Microwave drying is based on the conversion of alternating electromagnetic field energy into heat by the effect of the polar molecules (Vadivambal & Jayas, 2007). Foam-mat drying is used to dry liquid-solid foods (e.g. juice, milk, fruits, beverages and jams), in which the foams undergo air drying temperatures from 50 to 80°C. The foam is produced by mixing the stabilizing agent and or foaming agent (e.g. glycerol monostearate, carboxymethyl cellulose, trichlorophosphate) (Widyastuti & Srianta, 2011; Febrianto et al., 2012; Kandasamy et al., 2012). Color changes are undesirable since the loss of color during drying most likely links to the lower nutritive value of those components building the color (Cui et al., 2004; Konopacka, 2006). Green vegetables are an important source of car-

Table 1. Proximate composition of vegetable samples per 100 g of edible part

Component	Vegetable samples		
	Spinach	Celery	Malabar spinach
Dry matter (g)	7.20	4.70	5.90
Carbohydrates (g)	2.29	2.38	2.79
Protein (g)	2.62	1.34	1.59
Lipid (g)	< 0.30	< 0.30	< 0.30
Fibre (g)	2.11	1.82	2.07
Ash (g)	2.04	0.83	1.29
Calories (kcal)	22.00	16.00	20.00

Samples were analyzed by Eurofins Sac Ky Hai Dang Company Limited.

bohydrates, minerals, and vitamins, particularly fiber. According to Nguyen et al. (2007) and USDA (2019), celery (*Apium graveolens* L.) has a remarkable content of calcium and potassium (325 mg/100 g) while spinach (*Spinacia oleracea* L.) is rich in beta carotene (2147 µg/100 g), fiber (2.4 g/100 g), and Malabar spinach (*Basella alba* L.) contains a high amount of vitamin C (102 mg/100 g). However, because of the limitation of storage time, the use of green vegetables is quite disadvantageous due to the loss in quality. The drying technique is considered as one of the solutions for this problem. This study was aimed to evaluate the effects of three different drying methods on the quality of green vegetable powder.

2. Materials and Methods

2.1. Materials

Spinach, celery and Malabar spinach were bought at the local supermarket (Figure 1). The vegetable samples chosen for the experiment were fresh and carefully packaged. The sample qualities were evaluated by shape, size, color, smell, texture, and especially nutritional value which was shown in Table 1.

2.2. Methods

2.2.1. Sample preparation

The non-edible part of the samples was removed and then the samples were washed with water and drained. Each sample was chopped and ground for 120 seconds by using a multipurpose blender (capacity: 750 W). The moisture and chlorophyll contents were measured. The ground samples were subjected to different drying methods.

2.2.2. Drying methods

In the hot air drying method, 150 g of each sample was spread evenly on the tray (25 x 30 cm) then dried by a hot air dryer at 60°C.

In the foam-mat drying process, a total of 150 g of sample including 1.5% soy protein (SP), 0.5% methyl cellulose (MC) and the vegetable puree was whipped (by using hand mixer HR3705, Philips, Netherlands). For celery and Malabar spinach, the whipping was done in 10 min while the spinach sample was whipped for 15 min to achieve the optimum foam density in the range 0.2 - 0.6 g/cm^3 as described in a study by Hart et al. (1963). The semi-solid foams were spread evenly on the tray (25 x 30 cm) then dried at 60°C.

In terms of microwave drying, 150 g of each ground sample was spread evenly on the tray (25 x 30 cm) before being placed on the microwave (NN-9853, Panasonic, Japan) at the microwave power of 270 W was used in this method.

The moisture was determined every thirty minutes until the moisture content was reached lower than 9% (wet bulk) (Larrauri, 1999). Consequently, dried samples were ground to a fine powder and screened to achieve 0.3 mm diameter particles using a grinder (HR2221/00, Philips, Netherlands). The final powder samples were evaluated for color retention and chlorophyll content.

2.2.3. Moisture content determination

Moisture content was determined using the oven drying method. The samples were dried in the oven at 105°C for 24 h. The dried samples

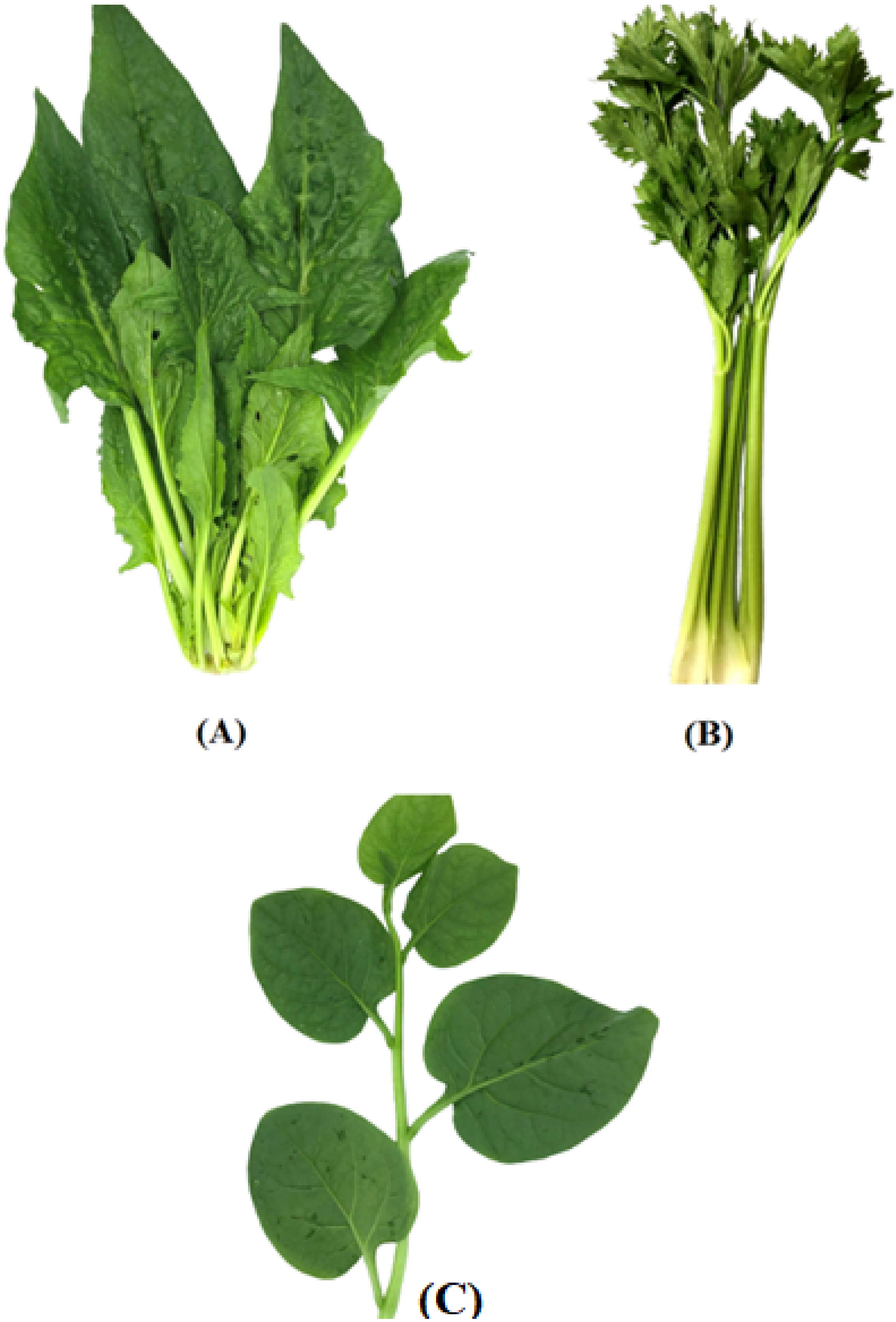

Figure 1. Fresh samples of spinach (A), celery (B), Malabar spinach (C).

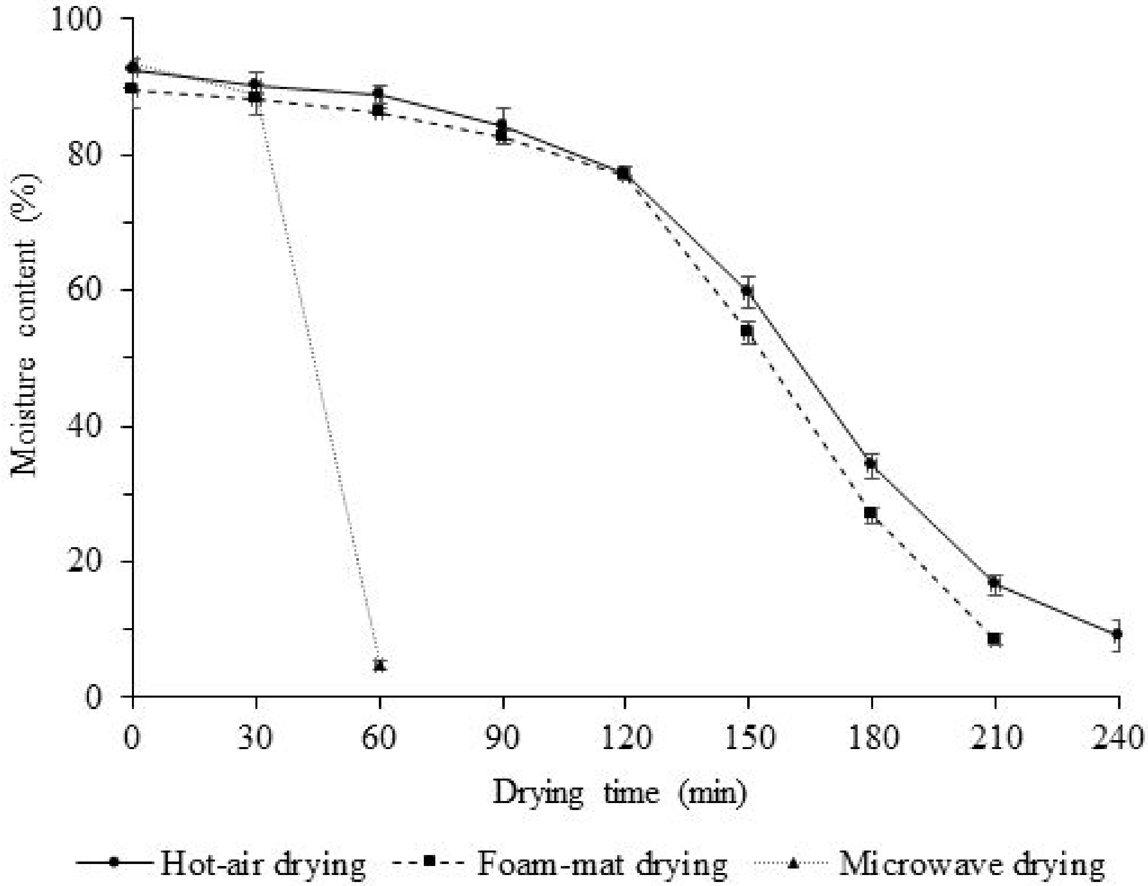

Figure 2. The changes in the moisture content of ground spinach during drying processes.

were cooled in a desiccator for 30 min and the weight was measured (± 0.01 g error). Moisture content was calculated by Formula 1:

$$X = \frac{W_1 - W_2}{W_1} \times 100 \quad (1)$$

Where:

X: moisture of samples (%)

W_1: the weight of samples before drying (g)

W_2: the weight of samples after drying (g)

2.2.4. Color analyses

The color was measured by using a colorimeter (CR-400, Konica-Minolta, Japan). The color was expressed in CIELAB color value (L^*, a^*, b^*) whereby L^* stands for the lightness from black (0) to white (100), a^* is from green (-) to red (+) color, b^* is from blue (-) to yellow (+) color. Measurements were done in triplicates. The Browning Index (BI) was calculated using the following expression of (Mohapatra et al., 2010) (Formula 2):

$$BI = \frac{100(X - 0.31)}{0.17} \quad (2)$$

$$\text{With: } X = \frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^*}$$

2.2.5. Chlorophyll content determination

Chlorophyll content was measured by using a colorimetric method described by Sumanta et al. (2014). An appropriate amount of sample (0.5 g for the fresh ground sample and 0.1 g for the powdered sample) was taken and transferred into a 50 mL centrifuge tube then 20 mL of 90% ethanol was added. The sample mixture was centrifuged at 6000 rpm for 10 min. The supernatant was separated and 1 mL of the supernatant was aliquoted and mixed with 4 mL of 90% ethanol. The solution mixture was analyzed for Chlorophyll-a, Chlorophyll-b by using a spec-

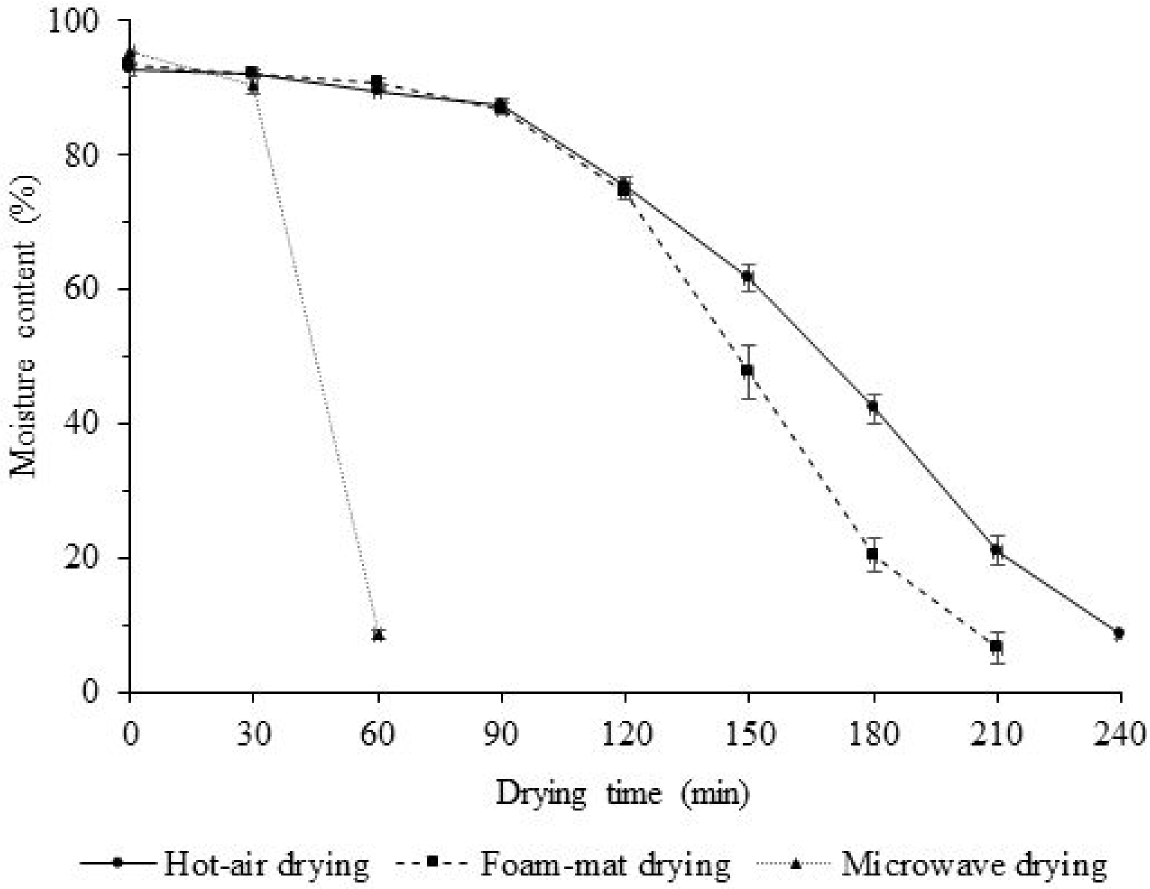

Figure 3. The changes in the moisture content of ground celery during drying processes.

trophotometer (SPECTRO-UV 11, MRC, UK) and was calculated by Formula 3 and 4:

$$\text{Chl-a} = 13.36A_{664} – 5.19A_{649} \quad (3)$$

$$\text{Chl-b} = 27.43A_{649} – 8.12A_{664} \quad (4)$$

Where:

Chl-a: Chlorophyll-a content (µg/mL)

Chl-b: Chlorophyll-b content (µg/mL)

A_{664}: Absorbance at 664 nm

A_{649}: Absorbance at 649 nm

2.2.6. Statistical and data analysis

The data are presented as the mean of three determinations ± standard deviation. The data were analyzed by ANOVA and LSD using JMP statistics software (Version 10.0). Statistical significance for differences was tested at 5% probability level ($P < 0.05$).

3. Results and Discussion

3.1. Changes in moisture content during the drying process

The initial moisture contents of fresh vegetables were measured about 89-95%. The moisture content of the raw material decreased during the drying time. In microwave drying, the shortest drying time (around 60 min) was required to achieve a moisture content of 9% (wb). This trend was observed in all three vegetable samples (Figures 2, 3 and 4). The obtained results in this study were in good agreement with the findings reported by Maskan (2001). The drying time of microwave drying was significantly reduced by up to 89% compared to hot air drying. In a microwave drying system, the microwave can easily penetrate the dry outer layer and be absorbed by the water inside the raw material. The water molecules absorbed microwave energy so they fluctuated at very high frequencies, created great

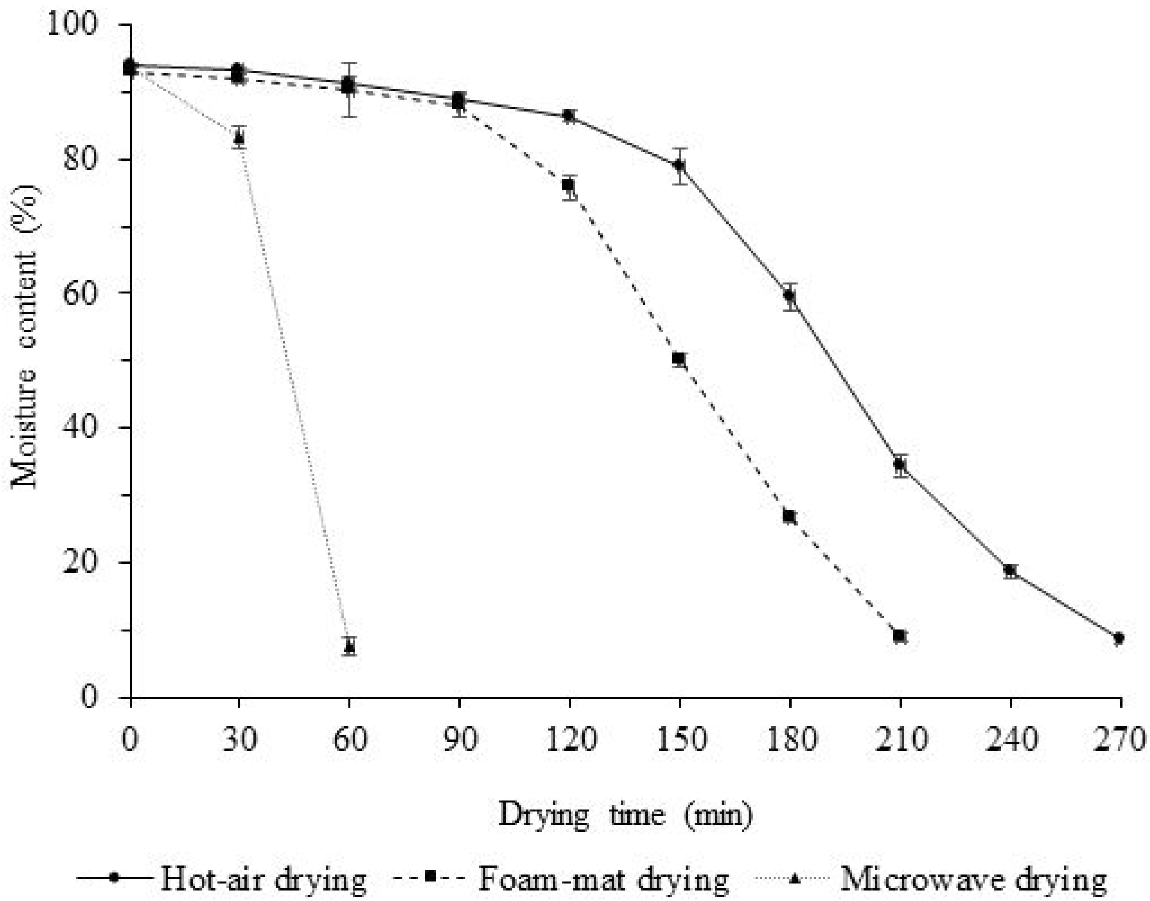

Figure 4. The changes in the moisture content of ground Malabar spinach during drying processes.

friction so the material was heated quickly. The quick energy absorption causes rapid evaporation of water creating an outward flux of rapidly escaping vapor (Lyons et al., 1972). Three vegetable materials in this study seem to obey this hypothesis.

From the drying curves in Figures 2, 3 and 4, it can be observed that the rate of water removal was initially constant for the hot-air method and foam-mat method due to the high moisture content. The moisture contents of hot-air and foam-mat dried samples were dramatically decreased after 90-minute of processing. Compared to conventional hot-air drying, foam-mat drying had at least 30 min shorter drying time (210 vs. 240 min). The moisture reduction rate of foam-mat drying was faster than that of hot air drying could be due to larger the contact surface area. According to (Sangamithra et al., 2015a), the foam generated from whipping has a high surface area that accelerates the dehydration process. Hot-air drying had the longest time of 240 - 270 min, and foam-mat drying was last about 210 min. Longer drying time is unfavorable since it leads to higher energy consumption and possible reduction in product quality (Chua et al., 2002).

3.2. Color analyses

Color is an important attribute of dried leafy vegetables that reflects customer acceptance. Limited changes in color are favorable in the drying process of vegetables. The dried leafy vegetable is expected to have a bright green color. L* value indicates the brightness of the samples, was measured and the results are presented in Table 2. The L* values were significantly different between samples obtained from different drying methods ($P < 0.05$).

In comparison, the foam-mat drying method consistently resulted in the brightest color products compared to microwave and hot-air drying

Table 2. Color of vegetable powder using different drying methods

Drying method	Vegetable samples								
	Spinach			Celery			Malabar spinach		
	L*	a*	BI	L*	a*	BI	L*	a*	BI
Hot air drying	$52.6^{b} \pm 0.6$	$-11.2^{b} \pm 0.3$	$22.5a \pm 0.4$	$54.6^{c} \pm 0.5$	$-8.0^{b} \pm 0.2$	$20.5^{c} \pm 0.5$	$54.2^{c} \pm 0.3$	$-9.8^{b} \pm 0.1$	$26.1^{b} \pm 0.6$
Foam-mat drying	$54.6^{a} \pm 0.9$	$-12.7^{c} \pm 0.2$	$22.8^{a} \pm 0.4$	$59.2^{a} \pm 0.1$	$-10.4^{c} \pm 0.2$	$22.3^{b} \pm 0.5$	$58.5^{a} \pm 1.0$	$-11.0^{c} \pm 0.3$	$20.9^{c} \pm 0.7$
Microwave drying	$51.5^{c} \pm 0.2$	$-9.8^{a} \pm 0.3$	$22.4^{a} \pm 0.4$	$57.8^{b} \pm 0.4$	$-6.1^{a} \pm 0.2$	$27.5^{a} \pm 0.7$	$56.3^{b} \pm 0.5$	$-6.0^{a} \pm 0.1$	$27.7^{a} \pm 0.6$

Different letters within the same column denote significant differences at $P < 0.05$, BI: browning index.

methods. The highest value of L* was found in celery product (L* = 59.2) resulted from foam-mat drying. The results in this study are in agreement with previous studies since foam-mat drying generates the appreciable brightness of okra (Falade & Omojola, 2010), yam flour (Falade & Onyeoziri, 2012), and muskmelon (Sangamithra et al., 2015b). The negative value of a* reflects the greenness of the samples which was found lowest ($P < 0.05$) in the foam-mat drying method, regardless of the type of vegetables (Table 2). Within the foam-mat drying method, the lowest value was recorded in spinach (a* = -12.7). This finding implies a high ability to retain the color of leafy vegetables of foam-mat drying method. In contrast, dried vegetables obtained from microwave drying had high a* values. The highest a* value was found in Malabar spinach (a* = -6.0). The microwave drying method, thus, would cause the most serious color changes of dried vegetables. The a* values of products resulted from the conventional hot-air drying were in between compared to that obtained from foam-mat and microwave drying methods. In terms of the green color retention, microwave drying was not superior to the conventional methods. One of the major drawbacks of microwave drying of plant material is the inhomogeneity of heat delivery that leads to overheating of certain local regions of plant tissues (Holtz et al., 2010; Wojdyło et al., 2014). It is possible that the overheating in vegetable tissues in this study occurred which led to the change of sensitive components such as color as observed. The browning during drying is an important factor causing the color change. The browning index (BI) values were calculated (Table 2) to compare the ability of browning during drying. Microwave drying method resulted in high values of BI that seen in celery and Malabar spinach samples. The BI values calculated for microwave drying were significantly higher ($P < 0.05$) than that of foam-mat drying and hot-air drying process. This result conforms to the disadvantage of microwave drying as stated in a study by Lenaerts et al. (2018) since the method can lead to a significant browning.

3.3. Chlorophyll

The favorable green color of vegetables is due to the availability of chlorophyll. The chlorophyll contents of dried vegetables obtained from different drying methods were measured to clarify

Table 3. The remained chlorophyll content of vegetable powders

Drying method	Vegetable samples		
	Spinach	Celery	Malabar spinach
Hot-air drying	$85.82^{a} \pm 0.60$	$81.99^{a} \pm 1.75$	$83.45^{a} \pm 1.08$
Foam-mat drying	$86.65^{a} \pm 0.66$	$81.87^{a} \pm 1.47$	$84.42^{a} \pm 0.38$
Microwave drying	$60.01^{b} \pm 0.42$	$41.16^{b} \pm 1.49$	$48.97^{b} \pm 0.88$

Different letters within the same column denote significant differences at $P < 0.05$

the color changes (the greenness, in particular). The results are presented in Table 3. The remained chlorophyll contents of samples obtained from foam-mat drying were significantly higher ($P < 0.05$) than that obtained from the microwave drying method. Compare to hot-air drying, foam-mat drying retained a higher content of chlorophyll (though statistically insignificant). Generally, the remained chlorophyll contents of the samples dried by hot-air and foam-mat techniques were highest (> 80%) while that of those dried by microwave oven had the lowest content (< 60%). The reduction of greenness color of vegetables during heat processing is involved in conversion of chlorophyll to pheophytin and pyropheophytin (Falade & Omojola, 2010). Chlorophyll was also previously documented to be sensitive to heat (Koca et al., 2007). The result of chlorophyll analysis confirms the previous hypothesis that the microwave drying process, although the drying time is shorter than the others, caused overheating of some vegetable regions that can lead to a significant change in the color building by chlorophyll. Foam-mat drying seems to be the most appropriate drying method to retain the dried leafy vegetables' color.

4. Conclusions

In the present study, the hot-air, foam-mat and microwave drying methods were used to clarify the effects on color and chlorophyll retentions of dried spinach, celery and Malabar spinach. The microwave drying method had the shortest drying time but caused the most unfavorable color change and a significant reduction in chlorophyll content in all vegetables. Conventional hot-air drying had the longest drying time and caused a relative loss in the greenness of vegetables. The foam-mat drying method had a significantly shorter drying time compared to the hot-air drying. The foam-mat drying products were characterised with the highest lightness, greenness and chlorophyll retention. Foam-mat drying resulted in products with the lowest browning index. The foam-mat drying method would be the most suitable for preparing dried vegetables. Nutritional composition retention and other sensory attributes should be compared to further elucidate the potentials of the foam-mat drying method.

Acknowledgement

This research was funded by Nong Lam University, Ho Chi Minh City under the internal research scheme (research code: CS-SV19-CNTP-02).

References

Baysal, T., Icier, F., Ersus, S., & Yıldız, H. (2003). Effects of microwave and infrared drying on the quality of carrot and garlic. *European Food Research and Technology* 218(1), 68-73.

Chua, K., Hawlader, M., Chou, S., & Ho, J. (2002). On the study of time-varying temperature drying-Effect on drying kinetics and product quality. *Drying Technology* 20(8), 1559-1577.

Cui, Z. W., Xu, S. Y., & Sun, D. W. (2004). Effect of microwave-vacuum drying on the carotenoids retention of carrot slices and chlorophyll retention of Chinese chive leaves. *Drying Technology* 22(3), 563-575.

Falade, K. O., & Omojola, B. S. (2010). Effect of processing methods on physical, chemical, rheological, and sensory properties of okra (*Abelmoschus esculentus*). *Food and Bioprocess Technology* 3(3), 387-394.

Falade, K. O., & Onyeoziri, N. F. (2012). Effects of cultivar and drying method on color, pasting and sensory attributes of instant yam (*Dioscorea rotundata*) flours. *Food and Bioprocess Technology* 5(3), 879-887.

Febrianto, A., Kumalaningsih, S., & Aswari, A. W. (2012). Process engineering of drying milk powder with foam mat drying method. *A Study on the Effect of the Concentration and Types of Filler* 2, 3588-3592.

Hart, M., Ginnette, L., Morgan, A., & Graham, R. (1963). Foams for foam-mat drying. *Food Technology* 17(10), 1302-1304.

Holtz, E., Ahrné, L., Rittenauer, M., & Rasmuson, A. (2010). Influence of dielectric and sorption properties on drying behaviour and energy efficiency during microwave convective drying of selected food and nonfood inorganic materials. *Journal of Food Engineering* 97(2), 144-153.

Kandasamy, P., Varadharaju, N., Kalemullah, S., & Ranabir, M. (2012). Production of papaya powder under foam-mat drying using methyl cellulose as foaming agent. *Asian Journal of Food and Agro-Industry* 5(5), 374-387.

Koca, N., Karadeniz, F., & Burdurlu, H. S. (2007). Effect of pH on chlorophyll degradation and colour loss in blanched green peas. *Food Chemistry* 100(2), 609-615.

Konopacka, D. (2006). The effect of enzymatic treatment on dried vegetable color. *Drying Technology* 24(9), 1173-1178.

Larrauri, J. (1999). New approaches in the preparation of high dietary fibre powders from fruit by-products. *Trends in Food Science & Technology* 10(1), 3-8.

Lenaerts, S., Van Der Borght, M., Callens, A., & Van Campenhout, L. (2018). Suitability of microwave drying for mealworms (*Tenebrio molitor*) as alternative to freeze drying: Impact on nutritional quality and colour. *Food Chemistry* 254, 129-136.

Lyons, D. W., Hatcher, J. D., & Sunderland, J. E. (1972). Drying of a porous medium with internal heat generation. *International Journal of Heat and Mass Transfer* 15(5), 897-905.

Maskan, M. (2001). Kinetics of colour change of kiwifruits during hot air and microwave drying. *Journal of Food Engineering* 48(2), 169-175.

Mohapatra, D., Bira, Z. M., Kerry, J. P., Frías, J. M., & Rodrigues, F. A. (2010). Postharvest hardness and color evolution of white button mushrooms (*Agaricus bisporus*). *Journal of Food Science* 75(3), E146-E152.

Nguyen, C. K., Dao, H. T. A., Dung, L., Lam, N., Mai, L., & Sy, N. (2007). Vietnamese food composition table. Ha Noi, Vietnam: Medical Publishing House.

Ratti, C. (2001). Hot air and freeze-drying of high-value foods: a review. *Journal of Food Engineering* 49(4), 311-319.

Sangamithra, A., Sivakumar, V., John, S. G., & Kannan, K. (2015a). Foam mat drying of food materials: A review. *Journal of Food Processing and Preservation* 39(6), 3165-3174.

Sangamithra, A., Sivakumar, V., Kannan, K., & John, S. G. (2015b). Foam-mat drying of muskmelon. *International Journal of Food Engineering* 11(1), 127-137.

Sumanta, N., Haque, C. I., Nishika, J., & Suprakash, R. (2014). Spectrophotometric analysis of chlorophylls and carotenoids from commonly grown fern species by using various extracting solvents. *Research Journal Chemical Sciences* 4(9), 63-69.

USDA (United Stated Department of Agriculture). (2019). *Vegetables and vegetable products-Vinespinach, (basella), raw.* Retrieved April 01, 2019, from https://fdc.nal.usda.gov/fdc-app.html#/food-details/170474/nutrients.

Vadivambal, R., & Jayas, D. (2007). Changes in quality of microwave-treated agricultural products—a review. *Biosystems Engineering* 98(1), 1-16.

Widyastuti, T. E. W., & Srianta, I. (2011). Development of functional drink based on foam-mat dried papaya (Carica papaya L.): Optimisation of foam-mat drying process and its formulation. *International Journal of Food, Nutrition and Public Health* 4(2), 167-176.

Wojdyło, A., Figiel, A., Lech, K., Nowicka, P., & Oszmiański, J. (2014). Effect of convective and vacuum–microwave drying on the bioactive compounds, color, and antioxidant capacity of sour cherries. *Food and Bioprocess Technology* 7(3), 829-841.