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Effects of Various Drying Methods on Physicochemical Characteristics, Flavonoids and Polyphenol Content, and Antioxidant Activities of Different Extracts from *Morinda citrifolia* Fruit

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Introduction: *M. citrifolia* is known as a medical plant in Vietnam, named Noni, which contains numerous bioactive ingredients and applying good in functional food and pharmaceuticals. The notices on the change of physicochemical characteristics (color, pH, total solids, and titration acid), the content of flavonoids and polyphenol, and antioxidant activities (total, reducing power, and 2,2-diphenyl-1-picryl-hydrazyl-hydrate (DPPH) free radical scavenging) of different extracts from *Morinda citrifolia* fruit at various drying methods (solar energy, microwave, and heat pump), microwave power, and temperature have not been found. Therefore, the paper focused on these things.

Methods: *Morinda citrifolia* fruit were harvested in July 2020, dried by using different methods (solar energy, microwave, and heat pump), and soaked in 96% solvent (ethanol and aqueous) for evaluating physicochemical characteristics, flavonoids and polyphenol content, and antioxidant activities. Drying *M. citrifolia* was at the temperature (50, 60, and 70°C) and the microwave power (100, 200, 400, 600, and 800 W), corresponding to the heat pump method and the microwave method, respectively and evaluating the drying speed curve basing on the moisture of *M. citrifolia* according to the drying time.

Results: Physicochemical characteristics, flavonoids content, polyphenol content, and antioxidant activities (total, reducing power, and DPPH free radical scavenging) were affected by various drying methods, different extracting solvents (p<0.05) and changed the drying time, microwave power, and temperature according to the non-linear model of level 2. The stabilization of physicochemical characteristics, flavonoids content, polyphenol content, and antioxidant activities of *M. citrifolia* in the drying method of microwave power was the highest, followed by the heat pump and solar energy. Ethanol solvent was more effective than aqueous solvent as extracting bioactive substances (flavonoids content and polyphenol content).

Conclusion: The results will be useful for preparing the dried *M. citrifolia* to serve for the storage and the produce of *M. citrifolia* in functional food and pharmaceuticals.

Keywords: Antioxidant; drying; flavonoids; microwave; Morinda citrifolia; polyphenol.

1. INTRODUCTION

Morinda citrifolia is a commonly value medicinal plant in Australia, Asia Pacific, and South-East Asia, known as *M. citrifolia*. All different parts of *Morinda citrifolia* are useful in the treatment of other diseases because they possess other bioactivities such as antifungal, antioxidant, anti-inflammatory, antiarthritic, and anticancer [1]. *Morinda citrifolia* is also useful in numerous fields, for example, beverages, active powders, oil, natural preservatives in food, natural composition of medicine, and insecticide [2]. Different bioactivities and its application in life are because they contain numerous bioactivity substances, for example, triterpenoids, polyphenols, flavonoids, alkaloids, lignans, anthraquinones, carotenoids, esters, glycosides, nucleosides [3]. In traditional medicine, *M. citrifolia* is soaked in alcohol to drink or massage to reduce back pain, osteoarthritis pain, constipation, headache, anti-inflammatory, warts, dysentery, diarrhea, fever, insomnia, nervous breakdown, high blood pressure.

However, *Morinda citrifolia* is rich in nutrients and easily destroyed in a short time after harvesting. A manifestation of *M. citrifolia* cell destruction is evident in the color decrease (green and blue metabolism to white and black), softer fruit, the split water, and arising stench. Therefore, *M. citrifolia* fruit should be pre-treatment to dry or immediately be processed or soaked after harvest, and the thing is only suitable for small scale production. At the industrial scale of *M. citrifolia* processing, it is necessary for drying the *M. citrifolia* fruit for further research.

Nowadays, some notices are reported on *Morinda citrifolia* drying, for example, microwave, convection [4], hot-air oven [5]. These notices focused on phenolic content, antioxidant activities (DPPH free radical scavenging and ABTS), and color during the drying and the powder storage of *M. citrifolia*. Physicochemical characteristics such as color, pH, total solids, and titration acid, the content of flavonoids and polyphenol, and activities including total antioxidant, reducing power, and DPPH free radical scavenging of different extracts from *Morinda citrifolia* do not appear in the previous studies, specifical *Morinda citrifolia* commonly grown in Vietnam. Some studies showed some drying methods are useful for the maintenance of herb quality, for example, solar energy, microwave vacuum, infrared, fluidized bed, supercritical CO_2, radio-frequency, heat-pump, freeze, microwave, and cool drying [6].

Therefore, the current study focused on color, pH, total solids, titration acid, the content of flavonoids and polyphenol, and total antioxidant activity, reducing power activity, and DPPH free radical scavenging activity of different extracts (ethanol and aqueous) from *Morinda citrifolia* commonly grown in Vietnam under the effect of various drying methods according to the time, the temperature, and the microwave power.

2. MATERIALS AND METHODS

2.1 Sample Preparation

Morinda citrifolia was collected in July 2020 in the southeast region, Vietnam, and transported to the laboratory at a temperature under 10°C. At the laboratory, *Morinda citrifolia* was cleaned with the water tap, kept dry for 15 minutes, cut slices of 4 to 6 mm, and stored at 5 to 10°C for further studies.

2.2 Experience Design

2.2.1 Solar energy drying

Morinda citrifolia slices were spread evenly over the blister and placed in the sun until the moisture of 13% for further studies.

2.2.2 Heat pump drying

M. citrifolia slices were evenly spread in a heat pump drying machine and dried until getting 13% of moisture at different temperatures such as 50, 60, and 70°C for further studies.

2.2.3 Microwave drying

M. citrifolia slices were spread in a microwave oven and dried until getting the moisture of 13% at various microwave power such as 100, 200, 400, 600, and 800 W for further studies.

2.3 Extract Preparation

Dried *M. citrifolia* slices were grinned and separately soaked in 96% ethanol and aqueous for 24 hours at 50°C with the solvent-to-material ratio of 20/1 (v/w). After extraction, the filtrate was selected via the filter paper Whatman No4 and used for the evaluation of color, pH, total solids, titration acid, polyphenol content, flavonoids content, and antioxidant activities.

2.4 Evaluation of Color, pH, Total Soluble Solids, and Titration Acidity

Determination of titratable acidity, pH, and total soluble solids (°Brix) was according to the method of AOAC [7]. Color characteristics were measured using the machine Konica, Japan.

2.5 Content Quantification of Polyphenol and Flavonoids

2.5.1 Quantification of polyphenol content

Polyphenol content was quantified basing on Folin Ciocalteus reagent, described by Dang et al. [8].

2.5.2 Quantification of flavonoids content

Quantification of flavonoids content was according to the description of Evi et al. [9] with slight modification basing on the reaction between flavonoids and aluminum chloride with the standard of quercetin. 0.5 mL of extract was, in turn, vortexed to 2 mL of 96% ethanol, 0.1 mL of 10% aluminum chloride, 0.2 mL of 1 M potassium acetate, and 0.2 mL of distilled water and kept for 10 min at room temperature. Finally, the absorbance measurement of the mixture was at 376 nm [9].

2.6 Determination of Antioxidant Activity

2.6.1 Determination of total antioxidant activity

The determination of total antioxidant activity was according to the description of Cong et al. [10]. The activity base on the reaction between antioxidants and Mo^{6+} in the acid solution for forming Mo^{5+} that is a positive proportion to total antioxidant activity.

2.6.2 Determination of reducing power activity

Reducing power activity was determined based on the reaction between antioxidants and Fe^{3+} for forming Fe^{2+} that is a positive proportion to reducing power activity, described by Cong et al. [10].

2.6.3 Determination of DPPH free radical scavenging activity

Evaluation of DPPH free radical scavenging activity was based on the reaction between DPPH free radical and antioxidants for the metabolism of dark violet to light yellow or white, describe by Dang et al. [11]. The lighter the yellow or the white color, the stronger the free radical scavenging activity of the extract.

2.7 Drying Speed Curve Determination

The drying rate is calculated using:

$$DR = \frac{M_{t+dt} - M_t}{dt}$$

Wherein:
M_{t+dt} moisture content at time t+dt, g
Mt: moisture content at time t, g
t: drying time, minutes

2.8 Data Analysis

All experiments were triplication (n=3) and expressed as mean ± standard deviation. Analysis of statistics, ANOVA, and regression was by using the software MS. Excel 2016.

3. RESULTS AND DISCUSSION

3.1 Color, pH, Total Soluble Solids, and Titration Acidity

pH and titration acid of various extracts were non-significant differences ($p > 0.05$) for all three methods. The significant difference in total solids happened for other extract and drying methods ($p < 0.05$). *M. citrifolia* were dried by using various methods were the difference in the color ($p < 0.05$). The microwave method led the best color, followed by the heat pump, and continuously solar energy (Table 1). The best color was also found for ethanol extract in three methods, compared to aqueous extract. Total solids of aqueous extract were higher than ethanol extract. Total solids increased in the following order microwave, heat pump, and solar energy (Table 2). Fresh *M. citrifolia* possessed red color lower but green and blue color higher than dried *M. citrifolia* by using different methods. The color change of *M. citrifolia* was due to the metabolisms of chlorophyll and another pigment in *M. citrifolia* and mainly was chlorophyll.

Table 1. The color of *M. citrifolia* according to different drying methods

Drying method	Color		
	Red	Green	Blue
Solar energy	193	94	68
Heat pump	145	111	84
Microwave	143	140	105
The control sample (Fresh *M. citrifolia*)	137	158	179

3.2 Polyphenol Content

Polyphenol content ranged from 5.17 ± 0.24 to 7.64 ± 0.27 mg gallic acid equivalent/g DW as the change of the drying method and the drying condition. Various drying methods affected the polyphenol content of other extracts ($p < 0.05$). Polyphenol content got the highest value at microwave drying method, following to heat pump drying and finally solar energy drying. Aqueous extract possessed polyphenol content lower than ethanol extract for all three drying methods. Polyphenol content decreased gradually with the asymptotic trend of the horizontal axis according to the drying time until the constant weight for all drying methods. For the heat pump drying method, the drying temperature also impacted polyphenol content ($p < 0.05$). The decrease of polyphenol content following the drying time at 70°C was lower than 60 and 50°C (Table 3). *M. citrifolia* drying at 50°C led to the lowest polyphenol content in comparison to 60 and 70°C. For the microwave drying method, polyphenol content increased in the following order 800, 600, 400, 200, and 100 W that significantly affected polyphenol content ($p < 0.05$). The linear model and the non-linear model were found for polyphenol content when the temperature and the microwave power changed, corresponding to the heat pump and the microwave drying method. The microwave power of 100 W led to the highest polyphenol content, compared to other conditions for all three drying methods. The current results were different in comparison to the previous studies. There were many notices on the effect of various drying methods on polyphenol content of other medicinal plants, for example, microwave [12-14], infrared drying [12], microwave-assisted hot air drying [13], sun drying, and freeze-drying [14]. However, the presentation on *Morinda citrifolia* L. does not find, except for the notice of [4]. The difference in polyphenol content of various extracts was due to the polarity of the solvent. Different drying methods caused other degradation of *M. citrifolia* cell wall and polyphenol structure [15,16].

Table 2. pH, total soluble solids, and titration acidity of various extracts according to different drying methods

Extract	Drying method	pH	Total soluble solids (^{o}Brix)	Titration acidity (%)
96% ethanol	**Solar energy**			
	25 - 32°C	4.2	8.89 ± 0.33	0.56
	Heat pump			
	50°C	4.3	8.03 ± 0.29	0.59
	60°C	4.4	7.50 ± 0.21	0.61
	70°C	4.4	7.04 ± 0.22	0.61
	Microwave			
	100 W	4.5	6.87 ± 0.13	0.61
	200 W	4.5	6.56 ± 0.11	0.62
	400 W	4.4	6.03 ± 0.12	0.62
	600 W	4.4	5.72 ± 0.14	0.61
	800 W	4.6	5.11 ± 0.15	0.63
Aqueous	**Solar energy**			
	25 - 32°C	3.6	9.35 ± 0.24	0.50
	Heat pump			
	50°C	3.9	8.72 ± 0.24	0.50
	60°C	3.8	7.01 ± 0.20	0.49
	70°C	3.9	6.54 ± 0.19	0.50
	Microwave			
	100 W	4.0	7.18 ± 0.16	0.56
	200 W	4.1	6.84 ± 0.15	0.53
	400 W	4.1	6.47 ± 0.17	0.53
	600 W	4.2	6.13 ± 0.12	0.54
	800 W	4.2	5.57 ± 0.14	0.54
	The control sample			
96% ethanol	Fresh *M. citrifolia*	4.5	5.14 ± 0.25	0.60
Aqueous		4.4	6.13 ± 0.30	0.59

Values were expressed as mean ± standard deviation (SD) with the triplication and significant difference ($p < 0.05$)

Table 3. Polyphenol content under the different conditions and drying methods and various extracts

Different condition and drying method	Various extracts	
	96% ethanol	**Aqueous**
Solar energy		
25 - 32°C	5.17 ± 0.24	4.72 ± 0.20
Heat pump		
50°C	5.73 ± 0.16	5.45 ± 0.11
60°C	6.21 ± 0.17	5.88 ± 0.14
70°C	6.65 ± 0.15	6.17 ± 0.13
Microwave		
100 W	7.64 ± 0.27	7.03 ± 0.24
200 W	7.18 ± 0.16	6.49 ± 0.18
400 W	6.79 ± 0.22	6.05 ± 0.21
600 W	6.34 ± 0.20	5.63 ± 0.17
800 W	5.92 ± 0.19	5.18 ± 0.23
The control sample		
Fresh *M. citrifolia*	8.31 ± 0.32	8.26 ± 0.34

Data exhibited a significant difference ($p < 0.05$) by using Fisher analysis with the triplication. Polyphenol content was expressed as mg gallic acid equivalent/ g DW

3.3 Flavonoids Content

Flavonoids content of different extracts from *M. citrifolia* was strongly affected by drying methods ($p < 0.05$) and decreased in the following order of drying method: microwave, heat-pump, and solar energy. Flavonoids content got the highest value of 3.17 ± 0.14, 5.25 ± 0.16, and 4.87 ± 0.12 (mg quercetin equivalent/g DW) for aqueous extract and 3.65 ± 0.12, 5.56 ± 0.13, and 5.21 ± 0.17 (mg quercetin equivalent/g DW) for ethanol extract corresponding to the drying method of solar energy, microwave, and heat-pump. The difference in flavonoids content between aqueous and ethanol extract also occurs ($p < 0.05$). Flavonoids content in aqueous extract was lowest in comparison to ethanol extract for all drying methods. The drying temperature affected flavonoids content ($p < 0.05$), found in the heat pump drying method. Flavonoids content decreased following the drying time at various temperatures, got the value of 4.87 ± 0.12, 4.55 ± 0.19, and 4.12 ± 0.14 (mg quercetin equivalent/g DW) at 70, 60, and 50°C, respectively. Flavonoids content got 4.12 ±

0.14 and 4.62 ± 0.13 at 50°C for aqueous and ethanol extract, corresponded to 90.55 and 84.60 and 92.96 and 88.67 times in comparison to 60 and 70°C, respectively. Flavonoids content decreased as the increase of microwave power from 100, 200, 400 600, to 800 W, corresponding to 5.56 ± 0.13, 5.30 ± 0.11, 5.16 ± 0.14, 4.81 ± 0.10, and 4.55 ± 0.12 (mg quercetin equivalent/g DW), respectively (Table 4). Flavonoids content got the highest value at 70°C for the heat pump method and was 0.94 and 92.76 times of flavonoids content at 100 W for the microwave method, corresponding to the ethanol extract and the aqueous, respectively. Flavonoids content changed according to the non-linear model of level 2 ($R^2 > 0.95$) as the change of the drying temperature and the linear model ($R^2 > 0.95$) as the microwave power increase. The current results also were fully new in comparison to previous studies. Previous notices on flavonoids of Morinda mainly were the extraction, the purification, and the bioactivities of them [17]. The impact of the pretreatment and the drying condition on flavonoids was almost on other plants [15,18]. The change of flavonoids content at different conditions was due to the structure characteristics, the polarity, and the structural destroying of flavonoids during the drying process.

Table 4. Flavonoids content under the different conditions and drying methods and various extracts

Different condition and drying method	Various extracts	
	96% ethanol	Aqueous
Solar energy		
25 - 32°C	3.65 ± 0.12	3.17 ± 0.14
Heat pump		
50°C	4.62 ± 0.13	4.12 ± 0.14
60°C	4.97 ± 0.18	4.55 ± 0.19
70°C	5.21 ± 0.17	4.87 ± 0.12
Microwave		
100 W	5.56 ± 0.13	5.25 ± 0.16
200 W	5.30 ± 0.11	4.90 ± 0.19
400 W	5.16 ± 0.14	4.53 ± 0.17
600 W	4.81 ± 0.10	4.21 ± 0.14
800 W	4.55 ± 0.12	3.93 ± 0.13
The control sample		
Fresh *M. citrifolia*	5.98 ± 0.21	5.85 ± 0.22

A significant difference (p < 0.05) of data was tested by using Fisher analysis with the triplication. Flavonoids were calculated as mg quercetin equivalent/g DW

3.4 Total Antioxidant Activity

Total antioxidant activity is significantly affected by various drying methods ($p < 0.05$) and got the highest value of 26.37 ± 1.05, 22.68 ± 0.59, 17.51 ± 0.46 (mg ascorbic acid equivalent/g DW) for microwave drying method, following to heat pump method and solar energy, respectively. Total antioxidant activity was 16.38 ± 0.52 and 17.51 ± 0.46 mg ascorbic acid equivalent/g DW for aqueous and ethanol extract at the solar energy drying, corresponding to 0.67 and 0.66 times in comparison to the microwave drying method, respectively. The total antioxidant activity of the aqueous extract was lower than that of ethanol extract for all three drying methods.

For the heat pump drying method, total antioxidant activity was arranged from 18.25 ± 0.37 to 22.68 ± 0.59 mg ascorbic acid equivalent/g DW and changed to the trend of the linear model when the drying temperature increased from 50 to 70°C, respectively. The impact of the drying temperature on total antioxidant activity was significant ($p < 0.05$). The correlation between total antioxidant activity and the content of flavonoids ($R^2 > 0.9$) and polyphenol ($R^2 > 0.9$) was strong. The thing exhibited that polyphenol played a role better than flavonoids in total antioxidant activity. At the drying temperature of 50, 60, and 70°C, the total antioxidant activity of the aqueous extract was 18.25 ± 0.37, 19.97 ± 0.51, and 21.14 ± 0.62 mg ascorbic acid equivalent/g DW, corresponding to 94.46, 94.96, and 93.21% for ethanol extract, respectively (Table 5).

For the microwave drying method, the total antioxidant activity of different extracts was also strongly affected by the microwave power ($p < 0.05$). The increase of the microwave power led to a decrease in total antioxidant activity according to the negative correlation. Total antioxidant activity of aqueous and ethanol extract was in the range of 18.03 ± 0.52 to 26.37 ± 1.05 mg ascorbic acid equivalent/g DW. Total antioxidant activity of the aqueous extract was 24.50 ± 0.78, 23.14 ± 0.64, 21.63 ± 0.55, 19.07 ± 0.48, and 18.03 ± 0.52 mg ascorbic acid equivalent/g DW, corresponding to 92.91, 93.53, 94.95, 93.66, and 92.94% for ethanol extract as using the microwave power of 100, 200, 400, 600, and 800 W, respectively (Table 5).

Total antioxidant activity changed significantly at different conditions, was caused by the content change of polyphenol and flavonoids during the drying process. Simultaneously, the results of total antioxidant activity in the current study do not occur in previous studies. Total antioxidant activity of *Morinda citrifolia* only appear in the studies on the extraction [19], microencapsulation [20,21], and convective drying [4].

Table 5. Total antioxidant activity under the different conditions and drying methods and various extracts

Different condition and drying method	Various extracts	
	96% ethanol	**Aqueous**
Solar energy		
25 - 32°C	17.51 ± 0.46	16.38 ± 0.52
Heat pump		
50°C	19.32 ± 0.46	18.25 ± 0.37
60°C	21.03 ± 0.45	19.97 ± 0.51
70°C	22.68 ± 0.59	21.14 ± 0.62
Microwave		
100 W	26.37 ± 1.05	24.50 ± 0.78
200 W	24.74 ± 0.52	23.14 ± 0.64
400 W	22.78 ± 0.54	21.63 ± 0.55
600 W	20.36 ± 0.46	19.07 ± 0.48
800 W	19.40 ± 0.49	18.03 ± 0.52
The control sample		
Fresh *M. citrifolia*	26.37 ± 1.05	26.39 ± 1.07

Fisher analysis was used for evaluating a significant difference ($p < 0.05$) of data that were triplicated (n=3). Calculation of total antioxidant activity was mg ascorbic acid equivalent/g DW

3.5 Reducing Power Activity

Various drying methods such as microwave, heat pump, and solar energy impacted significantly reducing power activity, and the impact did not depend on the extracting solvent ($p < 0.05$). The reducing power activity of the aqueous extract was significantly different in comparison to ethanol extract ($p < 0.05$). Reducing power activity of various extracts got the lowest value at the solar energy method, compared to other methods, and the highest value at the microwave drying method.

Reducing power activity of the aqueous extract was 13.69 ± 0.44 mg $FeSO_4$ equivalent/g DW and corresponded to 0.93 times of ethanol extract at the solar energy drying method.

The results also showed that reducing power activity was affected by the drying temperature ($p < 0.05$) and changed according to the non-linear model with the trend of the proposition to the drying temperature. The strong correlation between reducing power activity and the drying temperature was also found as for total antioxidant activity and impacted by polyphenol content more than flavonoids. For ethanol extract, total antioxidant activity was 1.06, 1.05, and 1.07 times in comparison to aqueous extract, corresponding to 50, 60, and 70°C, respectively (Table 6).

The microwave power impacted reducing power activity ($p < 0.05$), exhibited via the change of the microwave power from 100 to 800 W. The non-linear model of level 2 presented the correlation between the microwave power and reducing power activity ($R^2 > 0.9$) was appeared when the increase of the microwave power from 100 to 800 W. Reducing power activity of the aqueous extract was 20.53 ± 0.79, 19.16 ± 0.44, 17.79 ± 0.38, 16.20 ± 0.41 and 15.18 ± 0.35, corresponding to 96.71, 95.32, 94.68, 93.80 and 94.70% of ethanol extract at the microwave power of 100, 200, 400, 600, and 800 W, respectively (Table 6). There are not any notices on reducing power activity of *Morinda citrifolia* at various drying conditions in previous studies, except for the publication on activity scavenging of *Morinda citrifolia* [22]. Various drying conditions showed the different reducing power activity of Morinda extracts because reducing power activity was controlled by polyphenol and flavonoids, proved by the analysis on over ANOVA.

Table 6. Reducing power activity under the different conditions and drying methods and various extracts

Different condition and drying method	Various extracts	
	96% ethanol	**Aqueous**
Solar energy		
25 - 32°C	14.72 ± 0.51	13.69 ± 0.44
Heat pump		
50°C	15.96 ± 0.49	15.02 ± 0.37
60°C	16.88 ± 0.33	16.14 ± 0.31
70°C	17.96 ± 0.65	16.83 ± 0.35
Microwave		
100 W	21.45 ± 0.84	20.53 ± 0.79
200 W	20.10 ± 0.49	19.16 ± 0.44
400 W	18.79 ± 0.56	17.79 ± 0.38
600 W	17.27 ± 0.61	16.20 ± 0.41
800 W	16.03 ± 0.60	15.18 ± 0.35
The control sample		
Fresh *M. citrifolia*	21.45 ± 0.84	21.17 ± 0.76

Data were triplicated (n=3) and evaluated a significant difference ($p < 0.05$) by using Fisher analysis. Reducing power activity was calculated corresponding to mg $FeSO_4$ equivalent/g DW

3.6 DPPH Free Radical Scavenging Activity

The change of drying method led to a significant difference in DPPH free radical scavenging activity of various extracts ($p < 0.05$). DPPH free radical scavenging activity got the highest value in the microwave drying method, following heat pump and solar energy for both extracts of ethanol and aqueous. DPPH free radical scavenging activity of the aqueous extract was usually lower and significantly different in comparison to that of ethanol extract ($p < 0.05$). DPPH free radical scavenging activity arranged from 58.07 ± 1.53 to 82.13 ± 2.05% as using various drying method and extracting solvents.

For the solar energy drying method, DPPH free radical scavenging activity was 58.07 ± 1.53 and 62.11 ± 2.03%, corresponding to the aqueous and ethanol extract.

For the heat pump method, the increase of the drying temperature significantly led to the decrease of the DPPH free radical scavenging activity ($p < 0.05$) that got 61.36 ± 1.51, 63.40 ± 1.56, and 69.88 ± 2.24% for aqueous extract and 66.36 ± 1.79, 70.18 ± 1.72, and 74.56 ± 2.38% for ethanol extract, corresponding to 50, 60, and 70°C, respectively. The linear model was found for the changing trend of DPPH free radical scavenging activity of both extracts with a strong correlation ($R^2 > 0.9$) when the change of the drying temperature was according to the increasing trend (Table 7).

For the microwave drying method, the microwave power impact strongly DPPH free radical scavenging activity ($p < 0.05$) that decreased according to the non-linear model of level 2 when the microwave power increased from 100 to 800 W. DPPH free radical scavenging activity got 78.06 ± 1.97, 74.15 ± 1.71, 69.42 ± 1.83, 62.08 ± 1.75, and 55.14 ± 1.37% for aqueous extract, corresponding to 95.04, 95.05, 94.78, 92.27, and 91.64% of ethanol extract, respectively (Table 7).

DPPH free radical scavenging activity of *Morinda citrifolia* at various conditions of drying and extract solvent was also no exception, compared to total antioxidant activity and reducing power activity. The change of DPPH free radical scavenging activity was caused by in charge of polyphenol and flavonoids during the drying process. DPPH free radical scavenging activity was also presented in previous studies [22] but not the impact of drying conditions.

Table 7. DPPH free radical scavenging activity under the different conditions and drying methods and various extracts

Different condition and drying method	Various extracts	
	96% ethanol	**Aqueous**
Solar energy		
25 - 32°C	62.11 ± 2.03	58.07 ± 1.53
Heat pump		
50°C	66.36 ± 1.79	61.36 ± 1.51
60°C	70.18 ± 1.72	63.40 ± 1.56
70°C	74.56 ± 2.38	69.88 ± 2.24
Microwave		
100 W	82.13 ± 2.05	78.06 ± 1.97
200 W	78.01 ± 2.12	74.15 ± 1.71
400 W	73.24 ± 1.95	69.42 ± 1.83
600 W	67.28 ± 2.64	62.08 ± 1.75
800 W	60.17 ± 2.94	55.14 ± 1.37
The control sample		
Fresh *M. citrifolia*	82.46 ± 2.31	81.93 ± 3.03

A significant level ($p < 0.05$) in Fisher analysis was used for evaluating the triplicated data. DPPH free radical scavenging activity was evaluated with the unit of %

3.7 Drying Speed Curve

The drying time of *M. citrifolia* was different when *M. citrifolia* drying was by using various drying methods, and the difference was significant ($p < 0.05$). The drying speed curve increased to the following arrange, microwave, heat pump, and solar energy. The drying time of *M. citrifolia* by using the solar energy method was 17 hours but only 8.5 hours at 50°C in the heat pump method. At 60 and 70°C, the drying time was 7.5 and 7.0 hours, respectively (Fig. 1). For the microwave method, the drying time was 45, 40, 30, 20, and 15 minutes, corresponded to 100, 200, 400, 600, and 800 W, respectively (Fig. 2). The thing meant the drying time was shortest in the microwave method and longest in the solar energy method. The slope of the drying speed curve occurred the highest at the microwave method, following heat pump and solar energy. The things exhibited the speed of moisture transfer from inside the material out of the material was highest in microwave drying, followed by the heat pump and finally solar drying. The microwave infiltrates inward *M. citrifolia*, reacted to water, fats, and organic substances, and transmits energy to the water for creating friction between the molecules and thereby producing heat that causes the *M. citrifolia* to heat up and quickly dry with better color than the other drying methods. Drying speed curve of *M. citrifolia* was presented by Ana et al. [4] as drying by the convective method

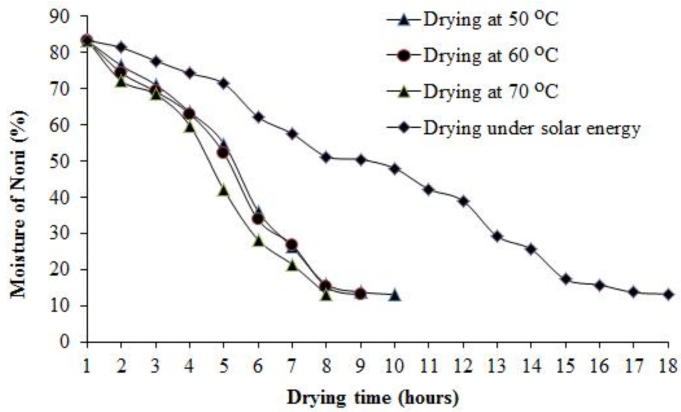

Fig. 1. Drying speed curve of *M. citrifolia* according to the method of solar energy and the heat pump

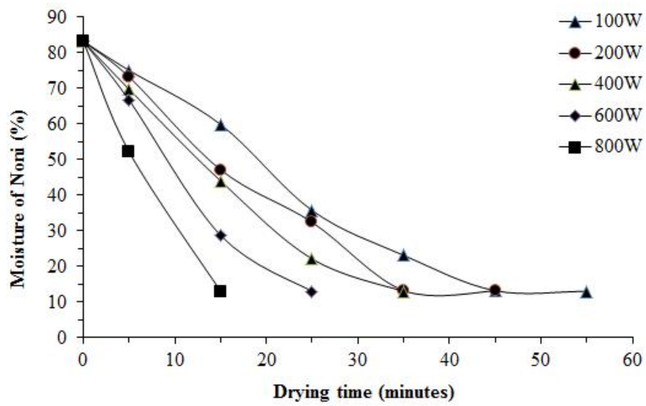

Fig. 2. Drying speed curve of *M. citrifolia* according to the microwave method

for *M. citrifolia*. The drying time in the notice of Ana was less than the current study. It could be the difference between machines and *Morinda citrifolia* that grown in various lands. The publication on drying time according to other drying methods for medicinal plants was very much [23-27].

4. CONCLUSION

Different drying methods such as the microwave, the heat pump, and solar energy strongly impacted the stabilization and the change of bioactive substances (polyphenol and flavonoids), antioxidant activities (total, reducing power, and DPPH free radical scavenging), and total soluble solids of *M. citrifolia* during the drying process. The microwave method was the most useful for drying *M. citrifolia* applicating into functional food and pharmaceuticals. Following was the heat pump method and finally solar energy. Ethanol extract possessed polyphenol, flavonoids, and antioxidant activities higher than aqueous extract for all drying methods. The drying condition of *Morinda citrifolia* was suitable at 100 W and 70°C for the microwave and the heat pump method, respectively. The suitable drying condition of *Morinda citrifolia* was 100 W and 70°C for the microwave and the heat pump method, respectively. Drying speed curves of *M. citrifolia* according to the mass always tends to asymptotically to the horizontal axis. The drying time was the shortest and longest as using the microwave and solar energy method, respectively. The current study will be useful for collecting the drying method and the extracting solvent during the production process of *M. citrifolia* into functional food and pharmaceuticals.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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