Drying characteristics and quality evaluation in convective drying of *Cissus quadrangularis* Linn.

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Abstract. This study aimed to investigate the effect of drying temperature (40, 60, 80, and 100˚C) on drying characteristics of *Cissus quadrangularis* Linn. (CQ) undergoing convective drying. Physical properties and phytochemicals of the dried CQ were also evaluated. CQ with the thickness of 5 mm was dried from about 10 to 0.1 g water/g dry matter. The results showed that increasing drying temperature increased drying rate (DR) and effective moisture diffusivity (D_{eff}) and consequently decreased drying time. The drying time, maximum DR, and D_{eff} were in the ranges of 85-1920 min, 0.0059-0.0248 g water/g dry matter·min, and 0.7302-9.1281×10^{-9} m^2/s, respectively. Lower drying temperature could preserve quality of the dried CQ. Decreasing drying temperature resulted in greener and lower bulk density and shrinkage. The greatest total phenolic content (TPC) and quercetin content were obtained by drying the CQ at 60˚C.

1 Introduction

CQ, a conventional medicinal plant, is used for treatment of various conditions such as hemorrhoid and irregular menstruation [1]. Normally, fresh CQ cannot be consumed as it contains calcium oxalate which leads to throat irritation. As same as most herbal plants, it must be dried, ground and capsulated for consumption [2]. Convective drying has been the most common way to produce the dried CQ.

Drying temperature is a crucial parameter required for dryer operation. This parameter can affect the moisture transport phenomena and stability of phytochemicals in material. Evaluation of the moisture diffusion mechanism and quality degradation as affected by different drying temperatures can help making decision in drying process design of convective drying of CQ and hence optimizing quality of the dried CQ.

However, little information is available in the literature on drying characteristics and product quality of CQ undergoing convective drying. Therefore, the aim of this study was to investigate the effect of drying temperatures on drying characteristics and moisture transport property of CQ during drying in a convective dryer. Quality of the dried CQ (greenness, shrinkage, bulk density, total phenolic content (TPC), and quercetin content) affected by drying temperature was evaluated.

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2 Materials and methods

2.1 Sample and sample preparation

Fresh CQ was purchased from a herbal farm in Prachin Buri Province, Thailand. It was washed and cut at the thickness of 5 mm, of which the top and bottom portions were excluded. The initial moisture content was 10.10±0.15 g water/g dry matter.

2.2 Architecture of experimental apparatus

The convective drying system was designed and fabricated at the Agricultural Engineering Workshop, King Mongkut's Institute of Technology Ladkrabang, Thailand. A schematic diagram of the overall experimental setup is illustrated in Fig. 1. The dryer consisted of three main components, including heaters, a drying chamber, and a control system. A double-walled stainless steel drying chamber was cylindrical with a diameter and length of 30 and 60 cm. The perforated stainless steel drying tray (0.20×0.40×0.05 m^3) was fitted in the chamber. Fin heaters of 4 kW and a blower of 0.5 HP were used for producing hot air. The hot air temperature was measured by thermocouples (type K, Lega model AK-01, Lega Coperation Co., Ltd., Bangkok, Thailand) and controlled by PID (Proportional–Integral–Derivative Controller) with an accuracy of ±1˚C.

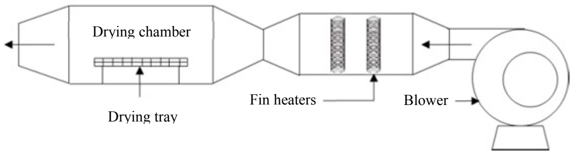

Fig. 1 Schematic view of the convective dryer.

2.3 Experimental Procedure

The experiments of convective drying of CQ were performed at the temperatures of 40, 60, 80, and 100˚C. A fixed air velocity of 1 m/s was used. CQ (260 g) was placed on the drying tray in single layer. During the process of drying, the sample was weighed at each predetermined interval for determination of drying characteristics and D_{eff} as shown in 2.4 and 2.5. Drying was performed until the moisture content of QC reached 0.10 g water/g dry matter. Quality of the dried CQ was evaluated as listed in 2.6.

2.4 Drying characteristic determination

Moisture content was determined in a hot air oven at 105˚C for 24 h [3]. The equation for calculation of the moisture content in dry basis is as follows:

$$M = \frac{W_w - W_d}{W_d} \quad (1)$$

where M, W_w, and W_d are moisture content (g water/g dry matter), wet weight of the material (g), and dry weight of the material (g), respectively.

Moisture ratio (MR) and DR were calculated as below:

$$MR = \frac{M_t - M_e}{M_i - M_e} \quad (2)$$

$$DR = \frac{M_{t+dt} - M_t}{dt} \quad (3)$$

where M_i, M_t, M_e, and M_{t+dt} are moisture content (g water/g dry matter) at initial, specific time, equilibrium, and t+dt, respectively; and t is drying time (min).

2.5 Calculation of effective moisture diffusivity

To evaluate the moisture transport property, that is, diffusion mechanism of CQ during drying in a convective dryer, values of D_{eff} at different drying temperatures were determined. The diffusion mechanism can be explained by the Fick´s second law. The solution of this equation developed by Crank [4], and the form of Eq. (4) is applicable for material with slab geometry by assuming uniform initial moisture distribution:

$$\mathrm{MR} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left(-\frac{(2n+1)^2 \pi^2 D_{eff} t}{4L^2} \right) \quad (4)$$

where D_{eff} is the effective diffusivity (m^2/s), L is the half-thickness of slab (m), and n is the number of terms taken into consideration.

2.6 Quality evaluation

2.6.1 Greenness (negative a∗)

Color in CIE L*, a*, and b* system of the dried CQ was measured by a spectrocolorimeter (ColorFlex, Hunter Associates Laboratory, Inc., Virginia, USA). As CQ is a plant, its main color was expressed by CIE $a*$ (redness/greenness) coordinate.

2.6.2 Shrinkage

Calculation of shrinkage was based on the concept of fluid replacement. In this work, *n* heptane was used as a fluid. Shrinkage was expressed in terms of the percentage of change in the volume of the dried CQ over the fresh CQ.

$$\%\, Shrinkage = \left(\frac{V_i - V}{V_i} \right) \times 100 \quad (5)$$

where V_i and V are respectively the volumes of material at the beginning and dried product.

2.6.3 Bulk Density

A 25-mL cylinder was filled with the dried CQ and tapped 5 times. Weight of the CQ inside the cylinder was measured. Bulk density was computed by dividing the weight of CQ by its volume.

2.6.4 Total phenolic content

TPC of the dried CQ was determined by Folin-Ciocalteu method [5]. Dried CQ was ground and sieved through a 180 mesh screen. Five millimeters of 70% methanol was used to extract a sample of 0.2 g. The mixture was extracted under reflux condenser at 70˚C for 2 h. The extract was vigorously agitated using a vortex mixer for 5 min and centrifuged at 3500 rpm for 10 min. UV-vis spectrophotometer (UV-1800, Shimadzu, Kyoto, Japan) was used for TPC analysis with an absorbance of 765 nm. A calibrating agent was pure ethanol. The content was expressed as gallic acid equivalents.

2.5.5 Quercetin content

The quantitative HPLC method for determining quercetin in the dried CQ was modified from Thiangtham [6]. The HPLC system (SPD-10A, Shimadzu Co., Kyoto, Japan) with C-18 reverse phase was used in this analysis. A mobile phase was 65:35 v/v of 0.05% ortho-phosphoric acid: acetonitrile. A standard agent was trans-resveratrol. The retention time of quercetin was 8.78.

2.6 Statistical analysis

The experimental data were analyzed using one-way ANOVA with the experimental design of a completely randomized design. Mean and standard deviation were used to present the experimental data. Duncan's multiple range test was used to determine the significance of differences between treatments at 95% confidence level.

3 Results and discussion

3.1 Drying characteristics

Drying curves of convective drying of CQ are shown in Fig. 2. It can be observed that the MR decreased with drying time following an exponential decay. The drying results showed that increasing drying temperature led to increase in DR and consequently decrease in drying time. It took only 85 min to dry CQ at 100˚C while the drying times were 1920, 230 and 130 min when drying at 40, 60 and 80˚C, respectively.

As can be seen from Fig. 3, the constant rate drying period was not observed in convective drying of CQ; the drying process took place in the falling rate period except a very short accelerating period at the beginning. The moisture loss rate of CQ was faster at the beginning than at the end. This observation is in agreement with previous results on thin-layer drying of biological products [7]. The maximum DR obtained from each drying condition was determined. It was found that the maximum drying rates were 0.0059, 0.0107, 0.0173, and 0.0248 g water/g dry matter·min when drying CQ at 40, 60, 80 and 100˚C, respectively. As compared to the lowest drying temperature of 40˚C, the maximum drying rate increased by 81, 193 and 320% when drying at 60, 80, 100˚C, respectively.

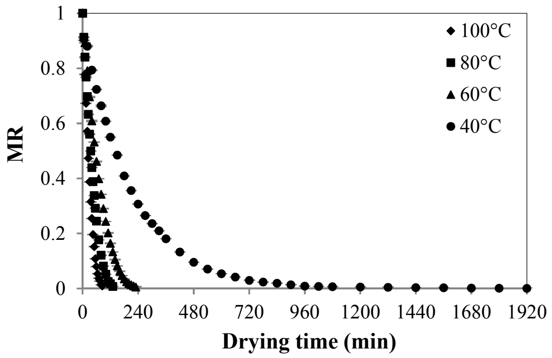

Fig. 2 Drying curves of convective drying of CQ at different drying temperatures.

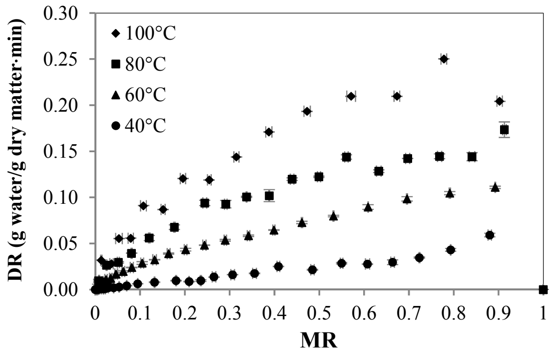

Fig. 3. DR curves of convective drying of CQ at different drying temperatures.

3.2 Effective moisture diffusivity

Values of D_{eff} of CQ dried at different drying temperatures were determined by plotting experimental data in terms of ln MR versus drying time. It is clear that increasing drying temperature resulted in higher D_{eff} (Table 2). These values met the standard range of D_{eff} of food and agricultural products subjected to drying (from 10^{-10} to 10^{-9} m^2/s) [8].

Table 1. D_{eff} $\times 10^{-9}$ (m^2/s) of convective drying of CQ at different drying temperatures.

Temperature (˚C)	D_{eff} $\times 10^{-9}$ (m^2/s)	R^2
40	0.7302	0.9780
60	3.6918	0.9630
80	6.0043	0.9582
100	9.1281	0.9591

3.3 Quality of the dried CQ

Table 2 shows the results of physical property determination of the CQ subjected to convective drying at different drying temperatures. Significant differences of the dried CQ were observed for their greenness (a*), bulk density, and shrinkage ($P < 0.05$). When drying temperature increased, greenness value decreased. This could be due to a non-enzymatic browning reaction occurring at high drying temperature [9]. On the other hand, increasing drying temperature resulted in increased bulk density and shrinkage of the dried CQ. High drying temperature can cause high stress development in material during drying and result in shrinkage of the material [10]. From these properties, it could be concluded that better physical properties was provided by lower drying temperature.

Significant differences in TPC and quercetin content of the dried CQ were also observed ($p < 0.05$) as shown in Fig. 4. It is interesting that the peak of TPC and quercetin content were given by convective drying of CQ at the drying temperature of 60˚C. Chan et al. [11] reported that browning reaction products formed during drying have higher antioxidant activity. This should be the reason of the lowest values of TPC and quercetin content in the CQ dried at 40˚C. However, cell walls of CQ may be disrupted at high drying temperature. As a result, its oxidative and hydrolytic enzymes are released and its phytochemicals are degraded [5].

Table 2. Physical properties of the dried CQ.

Temp. (˚C)	Greenness (a*)	Bulk density (g/cm^3)	Shrinkage (%)
40	-2.26 ± 0.13^{d}	0.182 ± 0.002^{c}	88.47 ± 0.51^{c}
60	-1.12 ± 0.01^{c}	0.184 ± 0.010^{c}	89.62 ± 2.94^{b}
80	4.49 ± 0.08^{b}	0.211 ± 0.001^{b}	89.63 ± 0.55^{b}
100	4.75 ± 0.08^{a}	0.233 ± 0.002^{a}	92.47 ± 0.32^{a}

The same letter in the same column is not significantly different at $p<0.05$.

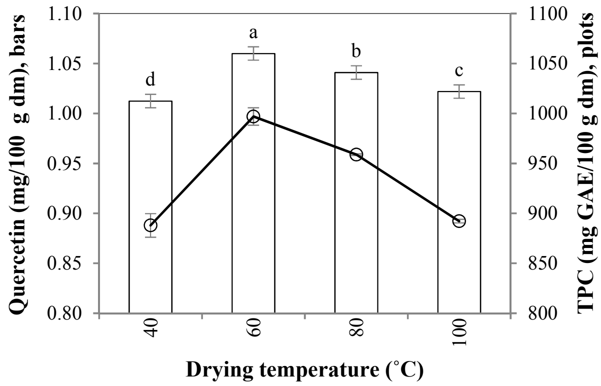

Fig. 4. Quercetin contents (bars) and TPC (plots) of the dried CQ.

4 Conclusions

The effect of drying temperatures on convective drying of CQ was analysed in the present work. Increased drying temperature resulted in increases in DR and D_{eff} and decrease in drying time. The highest values of maximum DR of 0.0248 g water/g dry matter·min and D_{eff} of 9.1281×10^{-9} m^2/s and the lowest value of drying time of 85 min were obtained by drying CQ at the highest temperature of 100˚C. However, lower drying temperature trended to provide better quality of the dried CQ. The highest TPC and quercetin content were provided by convective drying of CQ at the drying temperature of 60˚C.

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