Erzincan Üniversitesi
Fen Bilimleri Enstitüsü Dergisi
2017, 10(1), 68-77
Araştırma Makalesi

Erzincan University
Journal of Science and Technology
2017, 10(1), 68-77
Research Article

Sun Drying of Cornelian Cherry Fruits (*Cornus mas* L.)

Bilgehan POLATOĞLU[1], Ayşe Vildan BEŞE[2*]

[1] Atatürk University, Erzurum Technical Vocational School, Erzurum, Turkey

[2] Atatürk University, Department of Chemical Engineering, Erzurum, Turkey

(Geliş Tarihi/Received: 31.01.2017, Kabul Tarihi/Accepted: 20.04.2017)

ABSTRACT

In this study, the sun drying behavior of cornelian cherry fruits was investigated. The drying rate curve of cornelian cherry was shown that the drying process took place in the falling rate period. Twelve thin-layer mathematical models were used for explaining the thin layer drying kinetics of cornelian cherry. The approximation of diffusion model was found to be the most appropriate model for the process. The Fick's diffusion model was used to calculate the effective moisture diffusion coefficients (D_{eff}) of cornelian cherry. The value of D_{eff} was obtained as 1.20x10^{-11} m^2/s. The vitamin C degradation of dried cornelian cherry was determined as about 51.1%.

Keywords: Cornelian cherry, Drying kinetics, Modeling, Effective diffusivity, Vitamin C

Kızılcık Meyvesinin (*Cornus mas* L.) Güneşte Kurutulması

ÖZ

Bu çalışmada, kızılcık meyvesinin güneşte kuruma davranışı incelenmiştir. Kızılcığın kuruma hız eğrisi, kuruma işleminin azalan hız periyodunda gerçekleştiğini göstermiştir. Kızılcığın ince tabaka kuruma davranışını açıklamak için on iki ince tabaka matematik modeli kullanılmıştır. Difüzyon yaklaşım modelinin işlem için en uygun model olduğu belirlenmiştir. Kızılcığın etkin nem difüzyon katsayısını (D_{eff}) hesaplamak için Fick'in difüzyon modeli kullanılmıştır. D_{eff} 'in değeri 1.20x10^{-11} m^2/s olarak hesaplanmıştır. Kurutulan kızılcığın C vitamin bozulması yaklaşık % 51.1 olarak belirlenmiştir.
Anahtar kelimeler: Kızılcık, Kuruma kinetiği, Modelleme, Etkin yayılma, C vitamini

1. Introduction

Cornus mas L. commonly known as cornelian cherry naturally grows in Southern Europe and southwest Asia. Cornelian cherry fruits have been used for food, cosmetic purposes and herbal medicine in Asia, Europe and China (Dinda et al., 2016). Cornelian cherry fruit contains antioxidant, flavonoid, melatonin and vitamin C. It has been reported that cornelian cherry juice is richer in various essential elements as Ca, Mn, Na, Zn, K and Fe than obtained juices from the plum, apple and pear (Cindrić et al., 2012).

Drying is a unit operation that the water is removed from the material by giving heat energy to the moisture material. The water inside the fruit is transferred to the surface through diffusion and is removed from the surface with evaporation. The vegetables and fruits are seasonal products and it is difficult to preserve them fresh for a long time due to high water content that causes microbial spoilage. The dried materials, however, have

ISSN: 1307-9085
e-ISSN: 2149-4584
*Correspondence to: vbese@atauni.edu.tr
DOI: 10.18185/erzifbed.289008

longer storage periods, therefore consumer and process industries can provide them all year round. Sun drying is one of the oldest methods used to preserve human's food as grain, fish, fruits, vegetables etc. Despite many disadvantages such as length of drying time, weather uncertainties, insect infestation and contamination of the product with dust, sun drying is still practiced in many places throughout the world as a traditional method (Sahdev, 2014). The thin- layer models are widely used to describe drying characteristics of the dried material to control the process, to determine the optimum process conditions for the equipment design and to minimize the total energy requirements. The thin- layer models can be classified into three groups as theoretical, semitheoretical and empirical. As the theoretical models have too many assumptions which lead to significant errors, their use is limited in equipment design. The semitheoretical models, derived from Fick's second law, are easier and they have fewer assumptions, so they are widely used. Although the empirical models are similar to the semitheoretical models, they provide limited information about drying characteristic of dried material strongly depend on experimental data (Kucuk et al., 2014).

Many studies have been reported the sun drying behavior of some fruits and vegetables such as corn kernels (Sahdev and Kumar, 2013), apricot (Togrul, 2005), ciku (Chong et al., 2009), mulberry (Doymaz 2004), fig (Doymaz, 2005), seedless and seeded grapes (Doymaz, 2012), aromatic plants (Akpınar, 2006), *Gundelia tournefortii* L. (Evin 2012), green bean and okra (Doymaz, 2011), cork planks (Costa and Pereria, 2013), and some leafy vegetables (Sob kola et al., 2007). No data on sun drying of cornelian cherry fruit have been reported yet in literature.

The main objectives of this research were to investigate the sun drying behavior of cornelian cherry, to predict the best thin-layer model for drying curve, to calculate effective diffusivity coefficient and to determine amount of vitamin C in dried cornelian cherry.

2. Materials and Methods

2.1. Raw Material

Fresh cornelian cherry fruits were obtained from the Coruh Valley, Erzurum, Turkey, in September, 2011. The oven method was used to determine initial moisture content of fresh cornelian cherry (AOAC, 1984). About 50 g of fresh cornelian cherry with five replicates were dried in an oven at 105 ^{o}C for 24 hours and the value of initial moisture was determined as about 75.4 % (w.b). The diameter of cornelian cherry was evaluated with a digital caliper (Powerfix) and its average value was found as 11.94 ± 0. 3 mm.

2.2. Drying process

The sun drying experiments were performed in September 2011 in Erzurum. Erzurum is located in the eastern region of Turkey and its geographic coordinates are 39^{o} 53′ North, 41^{o}16′ East. Fruits were distributed in a single layer on a stainless steel mesh tray (15x25 cm) and the tray was located on the open top floor of a four-floor building to benefit from the sky's direct radiation. The fruits (about 100 g) were exposed to sunlight between 8.00 a.m. and 18:00 p.m. hours. The measurements were made only during these periods. During the drying processes, the amount of water removed was periodically recorded at five hours using a digital balance (AND Electronic Balance FX 3000, Japan) accuracy of ±0.01. Experiments were completed when fruits reached constant weight.

3. Results and Discussion

3.1. Mathematical modelling of drying curves

The dimensionless moisture ratio (MR) is calculated by using following equation for drying samples at any time:

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad (1)$$

where M_o, M_e and M_t reflect initial moisture content (g H_2O/g dry matter), equilibrium moisture content (g H_2O/ g dry matter) and moisture content at any time (g H_2O/g dry matter), respectively.

As shown in Table 2, the experimental data obtained were applied to twelve thin-layer drying models which were widely used for food and biological materials. The correlation coefficient (R^2), the reduced chi-square(X^2) and the root mean square error (*RMSE*) were used to determine the ability of each model to the experimental data. The highest value of R^2 and the lowest values of X^2 and *RMSE* indicate the most appropriate of fit.

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{\text{pre},i}\right)^2}{N - z} \quad (2)$$

$$RMSE = \left[\frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{\text{pre},i}\right)^2}{N}\right]^{\frac{1}{2}} \quad (3)$$

where ,$MR_{pre,,i}$ is the *i*th predicted moisture ratio, $MR_{exp,i}$ is the *i*th experimentally observed moisture ratio, the *z* is number of constants in the model and *N* is the number of the data values. The drying rate (*R*) represents the variation of moisture ratio (*MR*) by time and Eq. (4) can be used to calculate drying rate.

$$R = \frac{dM_t}{dt} = \frac{M_{t+\Delta t} - M_t}{\Delta t} \quad (4)$$

where *R* is the drying rate (g H_2O/g dry matter. s), $M_{t+\Delta t}$ is the moisture content at $t+\Delta t$ (g H_2O/ g dry matter), M_t is also the moisture content at t (g H_2O/ g dry matter) and t is the drying time(min).

3.2. Determination of effective moisture diffusivity (D_{eff})

Fick's second law has been widely used to describe the transport of moisture from the material at unsteady state:

$$\frac{\partial M}{\partial t} = Deff\,\nabla^2 M \quad (5)$$

Eq. (6) is obtained from solution of Eq. (5) for only radial diffusion in a spherical body with the assumption of negligible external resistance and shrinkage, uniform initial moisture distribution, constant diffusivity and temperature (Crank, 1975).

$$MR = \frac{M_t - M_e}{M_o - M_e} = \frac{M_t}{M_0} = \frac{6}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{n^2}\exp\left(-\frac{n^2.\pi^2.D_{eff}}{r_0^2}t\right) \quad (6)$$

For long drying periods, Eq. (6) can be simplified by taking only the first term of the series then, following equation is obtained:

$$MR = \frac{6}{\pi^2} \exp\left(-\frac{\pi^2 . D_{eff}}{r_0^2} t \right) \quad (7)$$

Eq. (7) equation can be linearized as follows:

$$ln(MR) = ln\left(\frac{6}{\pi^2} \right) - \left(\frac{\pi^2 . D_{eff}}{r_0^2} t \right) \quad (8)$$

3.3. Determination of vitamin C

The vitamin C content was determined by the methods described by Jagato and Dani (1982) with little modification. Five grams of fresh and dried cornelian cherry samples blended were extracted with 100 mL distilled water and then filtered and centrifuged at 3000 rpm. 2 mL of supernatant was diluted with distilled water to 5 mL and then was transferred in to a polypropylene centrifuge tube. 2 mL of tri-chloro acetic acid (10%) was added in this solution and tube was placed for 5 minutes in an ice bath and then 2 mL Folin-Ciocalteu reagent was added onto the mixture. The mixture was homogenized and kept at dark for 10 min. The absorbance of the resulting solution was assayed at 750 nm by using UV spectrophotometer (Shimadzu, UV-160A, Japan). Results were expressed as milligrams of vitamin C per 100 g dry matter (mg vitamin C/100 g d.m.).

Table 1 shows the variation of ambient air temperature, relative humidity and wind velocity in time for a typical drying day. During the drying process, the mean values of ambient air temperature, relative humidity and wind velocity fluctuated about ± 2 ^oC, ± 4% and ± 0.5 m/s, respectively. This information was obtained from the Meteorology Unit in Erzurum.

Table 1. Variation of ambient air temperature, relative humidity and wind velocity during the sun drying of cornelian cheery on a typical day in September in Erzurum.

Day times	8^{00}	10^{00}	12^{00}	14^{00}	16^{00}	18^{00}
Temperature (^oC)	15	18	24	22	20	17
Relative humidity (%)	39	36	32	28	37	46
Wind Speed (m/s)	3	2	2	2	3	2

4.1. Drying curves of cornelian cherry

Figure 1 (a) shows the variation of moisture ratio with drying time of cornelian cherry fruit for the sun drying. The moisture ratio reduced exponentially with time. Figure 1 (b) shows the changes in drying rate as a function of drying time.

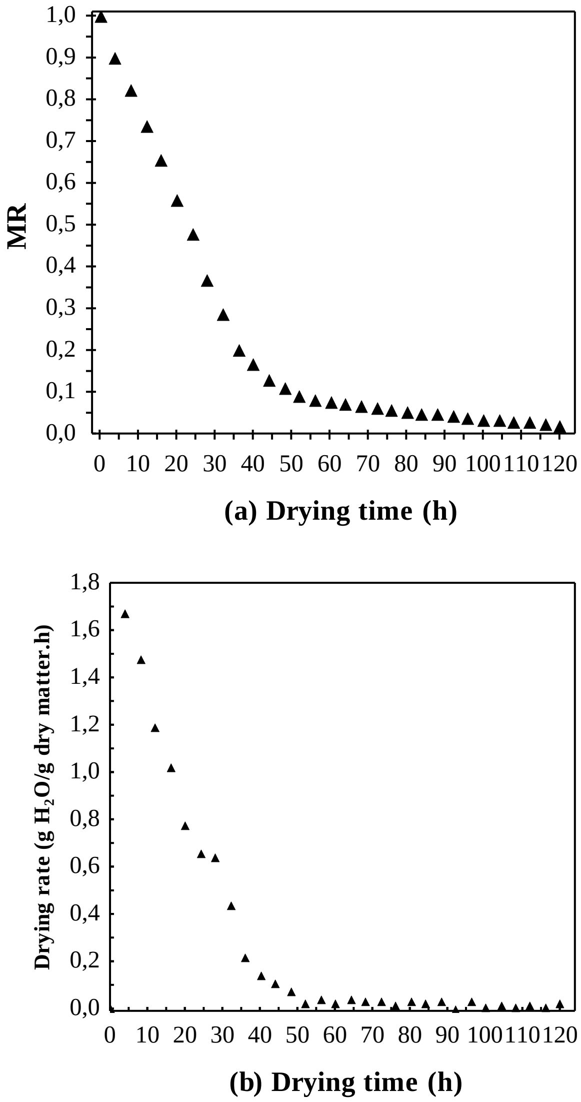

Figure 1. Drying curves of cornelian cherry (**a.** the variation of moisture ratio with drying time, **b.** the changes in drying rate as a function of drying time)

Drying rate decreased continuously with drying time. This behavior of curves shows that the drying process of cornelian cherry occurred in falling rate period and constant rate period was not present for the sun drying. The behavior represents that the mass transfer mechanism in the cornelian cherry is controlled by molecular diffusion. Similar results have been reported for as corn kernels (Sahdev and Kumar, 2013), apricot (Togrul, 2005), ciku (Chong et al., 2009), seedless and seeded grapes (Doymaz, 2012), green bean and okra (Doymaz, 2011) and hawthorn (Aral and Bese, 2016).

4.2. Evaluation of mathematical models

The experimental data were applied to twelve thin-layer models shown in Table 2.

The statistical analysis results of the models were calculated using non-linear regression analysis and they are summarized in Table 3. The approximation of diffusion model were found to be the most appropriate models for explaining the thin layer drying characteristic of cornelian cherry for the sun drying with the highest values of R^2 and the lowest values of X^2 and *RMSE*.

It is reported that the approximation of diffusion model is the best model describing the thin layer characteristics for green bean (Doymaz, 2011), tomato (Sacılık et al., 2006), and pumpkin (Yaldız and Ertekin, 2007).

4.3. Effective moisture diffusivity

The effective diffusivity was calculated using Eq. (8). *lnMR* versus time was plotted and the value of D_{eff} was determined as 1.20x10^{-11} m^2/s from the slope of straight line. This obtained value of D_{eff} for cornelian cherry was in general range of 10^{-11}-10^{-9} m^2/s for fruits and vegetables (Aral and Beşe, 2016). A comparison of D_{eff} values of some food materials in literature, and the obtained D_{eff} value in this study is shown in Table 4.

Table 2. Thin- layer models applied to drying curves of cornelian cherry (Kucuk et al., 2014).

Model No	Model Name	Model Equation
1	Page	MR= $\exp(-kt^n)$
2	Newton	MR= $\exp(-kt)$
3	Logistic	MR= $b/(1+a\exp(kt))$
4	Two-term	MR= $a\exp(-k_0t)+b\exp(-k_1t)$
5	Logarithmic	MR= $a\exp(-kt)+c$
6	Verma *et al.*	MR= $a\exp(-kt)+(1-a)\exp(-gt)$
7	Midilli *et al.*	MR= $a\exp(-kt^n)+bt$
8	Wang & Singh	MR= $1+at+bt^2$
9	Approximation of diffusion	MR= $a\exp(-kt)+(1-a)\exp(-kbt)$
10	Henderson & Pabis	MR= $a\exp(-kt)$
11	Two-term Exponential	MR= $a\exp(-kt)+(1-a)\exp(-kat)$
12	Modified Henderson & Pabis	MR= $a\exp(-kt)+b\exp(-gt)+c\exp(-ht)$

Table 3. Model constants and statistical results of applied mathematical models.

Model No	Model constants	R^2	X^2	RMSE
1	k=0.00036, n=1.001	0.996	0.0000	0.0025
2	k=0.00027	0.996	0.0000	0.0025
3	k=0.00036, a=1.636, b=2.654	0.997	0.0000	0.0031
4	k_0=0.00028, k_1=0.100, a=1.024, b=0.00	0.997	0.0000	0.0054
5	k=0.0003, a=1.017, c=0.011	0.997	0.0000	0.0053
6	k=0.00, a=-1030,34, g=0.00	0.996	0.0000	0.0030
7	k=188.16, a=1.00, b=0,00, n=0.00	0.995	0.0001	0.0106
8	a=-0.00014, b=0.00	0.905	0.0008	0.0293
9	**k=0.0017, a= - 0.163, b=0.178**	**0.999**	**0.0000**	**0.0024**
10	k=0.00028, a=1.025	0.997	0.0000	0.0051
11	k=6.438, a=0.0004	0.996	0.0000	0.0026
12	k=0.0003, a=0.394, b=0.236, c=0.394, g=0.0003, h=0.0004	0.997	0.0000	0.0059

Table 4. Effective diffusivity values dried some food materials under open sun.

Material	D_{eff} (m^2/s)	References
Cornelian cherry	$1.23x10^{-11}$	This study
Fig	$2.47x10^{-10}$	Doymaz (2005)
Okra	$1.52x10^{-11}$	Doymaz (2011)
G. tournefortii L.	$2.48x10^{-10}$	Evin (2012)
Seedless grapes	1.02×10^{-11}	Doymaz (2012)
Seeded grapes	1.66×10^{-11}	
Pineapple	$6.89x10^{-10}$	Olanipekun et al. (2015)

4.4. Vitamin C

Since the vitamin C is sensitive to light, heat, oxygen and pH, the processing and storage conditions significantly affect degradation of vitamin C. The fresh cornelian cherry had 296 ±0.12 mg/100 g dry matter value of vitamin C. After the drying processing, this value was determined as 145±0.06 mg /100 g dry matter. The degradation of vitamin C was approximately 51.1%. As the long drying period leads to more exposure to the atmospheric oxygen and the sun light of fruit, some quality aspects such as vitamin C are adversely affected (Arslan and Özcan, 2010).

4. Conclusion

Drying behavior of cornelian cherry fruit was investigated under open-sun in this study. Drying process of cornelian cherry occurred in the falling rate. The experimental data to twelve thin layer models and the approximation of diffusion model was found to be the best models for describing the thin layer drying characteristic of cornelian cherry for the sun drying. Effective moisture diffusion coefficients (D_{eff}) were calculated as $1.20x10^{-11}$ m^2/s. Approximately 51.1% of the vitamin C in the fruit was degraded during the drying.

Nomenclature

a, , b, k, n	model constants
D_{eff}	effective diffusivity coefficient (m^2/s)
M_t	moisture content of material at time t (g H_2O/ g dry matter)
M_e	equilibrium moisture content of material (g H_2O/ g dry matter)
M_o	initial moisture content of material (g H_2O/ g dry matter)
MR	moisture ratio
MR_{exp}	experimental moisture ratio
MR_{pre}	predicted moisture ratio
N	number of observations
R^2	regression coefficient
R	rate of drying (g H_2O /g dry matter.h)
r_o	radius (m)
RMSE	root mean square error
t	time (h)
z	number of constants in the model
χ^2	reduced khi-kare

5. References

Akpınar, E.K. 2006. Mathematical modelling of thin layer drying process under open sun of some aromatic plants. Journal of Food Engineering, 7, 864-870.

AOAC. 1984. Official Methods of Analysis, Washington, DC, Association of Official Analytical Chemistry Press.

Aral, S. and Beşe, A.V. 2016. Convective Drying of hawthorn fruit (*Crataegus* spp.): effect of experimental parameters on drying kinetics, color, shrinkage, and rehydration capacity. Food Chemistry, 210, 577-584.

Arslan, D. and Özcan, M.M. 2010. Study the effect of sun, oven and microwave drying on quality of onion slices. LWT-Food Science and Technology, 43(7), 1121–1127.

Chong, C.H., Law, C.L, Cloke, M., Abdullah, L.C., Daud, R.W. 2009. Drying models and quality analysis of sun dried ciku. Drying Technology, 27, 985-992.

Cindrić, I.J., Zeiner, M., Krpetić, M., Stingeder, G. 2012. ICP-AES determination of minor and major elements in Cornelian cherry (*Cornus mas* L.) after microwave assisted digestion. Microchemical Journal, 105, 72-76.

Costa, A. and Pereira, H. 2013. Drying kinetics of cork planks in a cork pile in the field. Food and Bioproducts Processing, 91(1), 14-22.

Crank, J. 1975. The Mathematics of diffusion, 2nd Ed., Oxford, Clarendon Press, Oxford, London.

Dinda, B., Kyriakopoulos, A.M., Dinda, S., Zoumpourlis, V., Thomaidis, N.S., Velegraki, A., Markopoulos, C., Dinda, M. 2016. *Cornus mas* L. (cornelian cherry), an important European and Asian traditional food and medicine: Ethnomedicine, phytochemistry and pharmacology for its commercial utilization in drug industry. Journal of Ethnopharmacology, 193, 670-690.

Doymaz, I. 2004. Pretreatment effect on sun drying of mulberry fruits (*Morus alba* L). Journal of Food Engineering, 65(2), 205–209.

Doymaz, I. 2005. Sun drying of figs: an experimental study. Journal of Food Engineering, 71(4), 403–407.

Doymaz, I. 2011. Drying of green bean and okra under solar energy. Chemical Industry & Chemical Engineering Quarterly, 17(2), 199–205.

Doymaz, I. 2012. Sun drying of seedless and seeded grapes. Journal of Food Science Technology, 49(2), 214-220.

Evin, D. 2012. Thin layer drying kinetics of *Gundelia tournefortii* L. Food and Bioproducts Processing, 90, 323-332.

Jagota, S.K. and Dani, H.M. 1982. A new colorimetric technique for the estimation of vitamin C using Folin phenol reagent. Analytical Biochemistry, 127, 178-182.

Kuçuk, H., Midilli, A., Kiliç, A., Dinçer, I. 2014. A Review on thin-layer drying-curve equations. Drying Technology, 32, 757-773.

Olanipekun, B.F., Tunde-Akintunde, T.Y., Oyelade, O.J., Adebisi, M.G., Adenaya, T.A. 2015. Mathematical modeling of thin-layer pineapple drying. Journal of Food Processing and Preservation, 39, 1431-1441.

Sacılık, K., Keskin, R., Elicin, A.K. 2006. Mathematical modeling of solar tunnel drying of thin layer organic tomato. Journal of Food Engineering, 73(3), 231-238.

Sahdev, R.K. and Kumar, S.M. 2013. An experimental study on open sun drying of corn kernels. International Journal of Engineering Research and Technology (IJERT), ISSN: 2278-0181, www.ijert.org.

Sahdev, R.K. 2014. Open sun and greenhouse drying of agricultural and food products: a review. International Journal of Engineering Research and Technology, 3(3), 1053-1066.

Sobukola, O.P., Dairo, O.U., Sanni, L.O., Odunevu, A.V., Fafiolu, B.O. 2007. Thin layer drying process of some leafy vegetables under open sun. Food Science and Technology International, 13(1), 35-40.

Togrul, I.T. 2005. Convective heat transfer coefficient of apricots under open sun drying conditions. Chemical Engineering Communications, 192(8), 1036-1045.

Yaldız, O. and Ertekin, C. 2007. Thin- layer solar drying of some vegetables. Drying Technology, 19 (3-4), 583-597.