Sigma J Eng & Nat Sci 34 (2), 2016, 141-151

Sigma Journal Engineering and Natural Sciences
Sigma Mühendislik ve Fen Bilimleri Dergisi

Research Article / Araştırma Makalesi

OPEN-AIR SUN DRYING:THE EFFECT OF PRETREATMENT ON DRYING KINETIC OF CHERRY TOMATO

Osman İSMAİL*, Emel AKYOL

Yildiz Technical University, Chemical-Metallurgical Faculty, Chemical Engineering Department, Davutpasa, Esenler-ISTANBUL

Received/Geliş: 26.01.2016 Revised/Düzeltme: 07.03.2016 Accepted/Kabul: 10.03.2016

ABSTRACT

In this study, the effects of open-air sun drying and pretreatment on drying characteristic of cherry tomato (*Lycopersicum esculentum*) were investigated. Drying times were determined as 26 and 22 h for natural and pretreated, respectively. The pretreated samples were dried in slightly shorter time than the natural samples.
The drying process took place in the falling rate period. Different seven theoretical drying models were applied to experimental data of falling rate periods. All the models were compared according to statistical parameters; i.e. model efficiency (R^2), chi-square (χ^2) and root mean square error (*RMSE*). It was observed that Verma et al. model among the models used is best mathematical model represented the open-air sun drying behavior of cherry tomatoes. The best chroma (*C**) value were obtained in pre-treatment dried cherry tomatoes.
Keywords: Cherry tomatoes, open-sun drying, pretreatment, chroma, modelling.

AÇIK-HAVA GÜNEŞ KURUTMA: KİRAZ DOMATESİN KURUMA KİNETİĞİ ÜZERİNE ÖN İŞLEMLERİN ETKİSİ

ÖZ

Bu çalışmada, kiraz domatesin (*Lycopersicum esculentum*) kuruma özellikleri üzerine açık hava güneş kurutma ve ön işlemlerin etkisi incelenmiştir. Kuruma süreleri, naturel ve ön işlemli için sırasıyla 26 ve 22 saat olarak tespit edilmiştir. Ön işlemli örnekler, doğal örneklere göre daha kısa sürede kurutulmuştur. Kuruma işlemi azalan hız periyodunda gerçekleşmiştir. Azalan hız periyodundaki deneysel veriler yedi farklı teorik kurutma modeline uygulanmıştır. Modeller arasındaki kıyaslama R^2, χ^2 ve *RMSE* istatistiki parametreleri kullanılarak yapıldı. Kullanılan modeller arasında Verma ve ark. modelinin kiraz domatesinin açık hava güneş altında kuruma davranışını temsil eden en iyi model olduğu görüldü. En iyi renk değeri (*C**) ön işlemli olarak kurutulmuş kiraz domateste elde edilmiştir.
Anahtar Sözcükler: Kiraz domates, açık-güneş kurutma, önişlem, renk, modelleme.

[*] Corresponding Author/Sorumlu Yazar: e-mail/e-ileti: ismail@yildiz.edu.tr, tel: (212) 383 47 74

1. INTRODUCTION

Food security is one of the most important global problems of the 21st century. Climate change also has a profound impact on food production. In other words, the demand for sustainable fruit and vegetables is expected to rise as the population becomes more aware of the importance of consuming healthy and sustainable food. There is a continuing and expanding demand to the agricultural products. This situation has added new dimensions to conventional manufacturing in vegetable and fruit sectors [1].

Dehydration is one of the oldest methods of food preservation and it represents a very important aspect of food processing. Longer shelf life, product diversity and substantial volume reduction are the main reasons for popularity of dried fruits and vegetables. Drying of heat-sensitive biomaterials such as fruits, vegetables, and the so-called wellness, or functional foods, requires special techniques to avoid product degradation due to thermal decomposition, oxidation, or enzymatic browning. Many approaches having been tried in order to improve the quality of vegetables products [2, 3].

Open-air sun drying process which is a gentle drying process is a commonly used method for the reason that the biological value of the material, structure, flavor, aroma, and color are retained in the product. Seasonal drying by using solar energy allows the production of high quality without requiring a high energy costs in the regions where the climatic conditions are very convenient.

In recent years, several investigations have been carried out to develop open sun drying mainly for preserving various agricultural products, such as red peppers [4, 5], green pepper [6], chilli pepper [7], mint leaves [8], onion slices [9], Gundelia tournefortii L. [10] and roasted green wheat [11].

Some pretreatments used before drying in order to improve the drying efficiency for fruits and vegetables. Various solutions such as alkaline ethyl oleate [12], calcium chloride [13], sodium chloride [14], sodium metabisulfite [15] are oftenn used for pretreatmets of tomatoes and then can be dried in different shapes [16-18]. Akanbi et al., (2006) declared that immersing the tomatoes in a solution of sodium metabisulfite have a positive impact on the protection of color. Davoodi et al., (2007) compared the application of calcium chloride, potassium metabisulfite, calcium chloride+potassium metabisulfite and sodium chloride as a pretreatment application on product quality. They found that combination of calcium chloride+ potassium metabisulfite give the best protective effect [19].

Simulation models are benefit tools for prediction of performance of open sun and solar drying. In order to explain drying behaviour of food, several thin layer equations were used before [20, 21]. However, no published work seems to have been found detailing the effects of oleic-acid- potassium carbonate solution on open-sun drying of cherry tomatoes in the literature.

The goal of the current study was to investigate the effect of pretreatment solution and open-sun drying procedure on drying characteristic and colour of cherry tomatoes. The drying data were modeled with seven theoretical drying models present in the literature to determine the change in the moisture content of the cherry tomatoes samples as a function of drying time.

2. EXPERIMENTAL

2.1. Materials

Fresh cherry tomatoes (*Lycopersicum esculentum*) were gathered from the garden in Thrace region of Turkey. The selected samples were cleaned with tap water to make samples free from dust and foreign materials. Freshly samples were selected by colour and size (average diameter and weight of 2.7 ± 0.2 cm, 26.9 ± 2 g) and cut into halves with a knife.

2.2. Pretreatment

For pretreatment, tomatoes samples were immersed in solution of 2% oleic acid and 2% potassium carbonate at room temperature for 1 min.

Natural: No pre-treatments were applied.

Chemicals used for dipping were technical grade.

2.3. Drying Process

Before drying trial, the cherry tomatoes samples were taken out and kept at room temperature for about 12 h over night for thermal equilibrium. Dry matter and moisture contents of the cherry tomatoes samples were determined prior to drying experiments. The moisture contents of the samples were obtained by the Association of Official Analytical Chemists [22]. To determine the initial moisture content of the samples, five samples, about 5g, were dried in an oven (Memmert UM-400: Technical specifications: 220 V, 50 Hz, 6,1 A, 1400 W. Nominal temperature: 220ºC) at 105 ºC for 24 h. At least three replicates of experiments were performed. The average initial moisture content of cherry tomatoes samples was found to be 93.4± 0.2% (wet basis**).**

Pre-treated and natural cherry tomatoes were distributed uniformly in a single layer tray separately (about 58±2g), and then sun dried by direct exposure to solar radiation in July 2012 in theThrace region in Turkey.

The cherry tomatoes samples were exposed to sunlight for 12 h daily. During dehydration, the weight loss and the temperature of the ambient air were measured and recorded at each hour from 8:30 am to 20:30 pm. Due to the dehydration process was completed in two and three days; the samples were kept in a sealed glass jar over the night. The weight loss and the temperature of the ambient air were measured at 1-hour intervals during drying by a portable digital balance (Alfais, I2000-1), which has a 0-300 g measurement range with an accuracy of ±0.1 g. Ambient air temperatures were measured by thermometer (Isolab, 059.01.007), with a reading accuracy of ±0.1 °C. Each drying experiment was replicated at least two times and the average kinetic data for the two trials along with the standard error has been reported.

2.4. Mathematical Modeling

To determine the moisture ratio as a function of drying time, seven different theoretical drying models were used (Table 1).

Table 1. List of theoretical models [23-29].

Model name	**Equation**	**References**
Newton	$MR = exp(-kt)$	(Ayensu, 1997)
Henderson and Pabis	$MR = A_o\, exp(-kt)$	Henderson and Pabis (1961)
Logarithmic	$MR = aexp(-kt)+c$	Vega-Gálvez et al. (2008)
Aghbashlo et al.	$MR = exp((-k_1t)/(1+k_2t))$	Aghbashlo et al., (2009)
Wang and Singh	$MR = 1+at+bt^2$	Wang and Singh (1978)
Verma et al.	$MR = aexp(-kt)+(1-a)exp(-gt)$	Verma et al., (1985)
Alibaş	$MR = a\ exp((-ktn) + (bt))+g$	Alibas (2012)

The moisture ratio and drying rate of cherry tomatoes during drying experiments were calculated using the following equations [30,31]:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \tag{1}$$

where; *MR* is the moisture ratio (dimensionless), M_t is the moisture content at a specific time (g water/g dry matter), M_o is the initial moisture content (g water /g dry matter), M_e is the equilibrium moisture content (g water/g dry matter), respectively.

The equilibrium moisture content (M_e) was assumed to be zero for sun drying and the MR equation (Eq.(1)) was simplified as Eq.(2) [32]:

$$MR = \frac{M_t}{M_0} \quad (2)$$

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

where; *DR* is the drying rate (g water/g dry matter*min), M_{t+dt} is the moisture content at t + dt (g water/g dry matter), and tm is the drying time (min).

The regression analysis was performed using Statistica Computer Program (version 10). The determination of coefficient (R^2), reduced chi-square (χ^2) and root mean square error (RMSE) were used in this study to evaluate the goodness of fit. These parameters can be calculated by using the following equations:

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

(4)

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N - z} \quad (5)$$

where; N is the number of observations, z is the number of constants, MR_{exp} and MR_{pre} are the experimental and predicted moisture ratios, respectively. The higher R^2 values and the lower χ^2 and RMSE values are the goodness of fit [33].

2.5. Calculation of Effective Moisture Diffusivity

The effective moisture diffusivity (D_{eff}) were calculated according to the following Eq.(6) for cherry tomatoes [34].

$$MR = \frac{M_t - M_e}{M_0 - M_e} = \frac{8}{\pi^2}\exp\left[-\frac{\pi^2 D_{eff} t}{4L^2}\right] \quad (6)$$

where, D_{eff} is the effective moisture diffusivity (m^2/s); *L* is the halfthickness of the slab in sample (m) and *t* is drying time (s).

From Eq. (6), a plot of ln MR versus drying time should give a straight line with a slope (K):

$$k_o = \frac{\pi^2 D_{eff}}{4L^2} \quad (7)$$

Using the slope value, the effective moisture diffusivity could be determined.

2.6. Colour Measurement

Color is one of the most important quality criteria for food. An unfavorable color change of food can decrease its quality level and market opportunity. Color measurements of fresh and dried cherry tomatoes were done with Minolta CR-200 Chroma Meter (Minolta Co., Osaka, Japan). L*, a* and b* values were determined according to the CIE L*a*b* colour coordinate system. The CIELAB color system describes the color of an object in terms of its position in three-dimensional space where the three axes are brightness (L*), red–green axis (a*) and yellow–blue axis (b*) [35]**.**

Chroma (C*) and color difference (ΔE) were calculated by Eq.(8) and Eq. (9) [36].

$$C^* = \sqrt{a^2 + b^2} \tag{8}$$

$$\Delta E = \sqrt{\left((L_o - L)^2 + (a_0 - a)^2 + (b_0 - b)^2\right)} \tag{9}$$

3. RESULTS AND DISCUSSION

3.1. The Effect of Pretreatment on Drying Time

The effect of the pretreatment on changes in the moisture ratio of cherry tomatoes samples with drying time are presented in Figure 1.

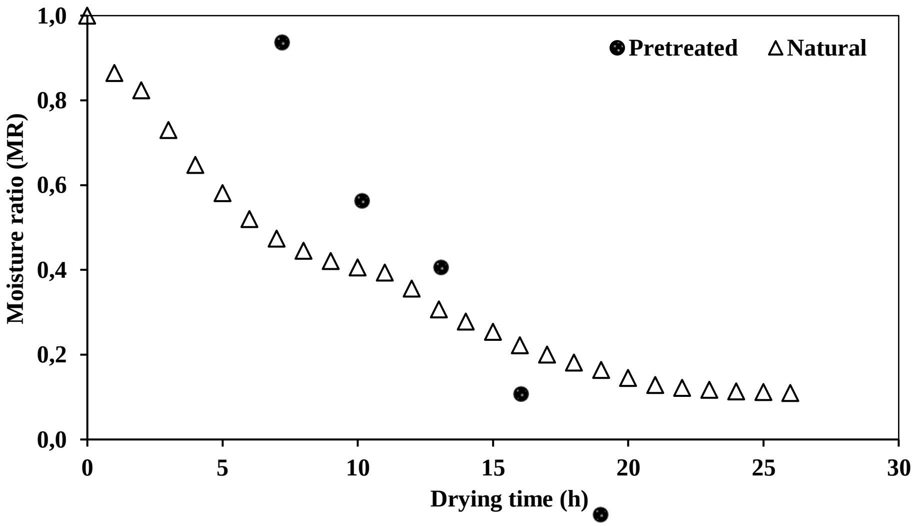

Figure 1. Open-air sun drying curves of cherry tomatoes for pretreated and natural

It is clear that the moisture ratio decrease continuously with the drying time. As shown in Figure 1, pre-treatment is a very factor for the cherry tomatoes drying because it affects the drying time. In other words, the pretreated cherry tomatoes dried slightly faster than the natural cherry tomatoes, thus confirming the fact that pretreatment reduces the resistance to the movement of moisture, thereby increasing the drying rate. Drying was continued until the moisture ratio of the samples reached 0.10 ± 0.01 and drying times were determined as 26 and 22 h for natural and pretreated, respectively. Pretreatment solution caused a decrease in the drying times by 15%. The equilibrium moisture content was zero for all the experimental runs. In addition, the experiment had good repeatability as indicated by the low values of standard error in Figure 1. As a result, shows that pretreatment was more effective methods in cherry tomatoes open air sun drying. Similar results have been reported in the literature for various tomatoes such as by Muratore et al. (2008) for cherry tomato, Sacilik et al. (2006) for organic tomato and Gürlek et al. (2009) for tomato [35, 37-38].

The values of the drying rate of cherry tomatoes samples were calculated using Eq. (3). Drying rate is defined as the amount of water removed. The changes in drying rates versus moisture content are shown in Figure 2.

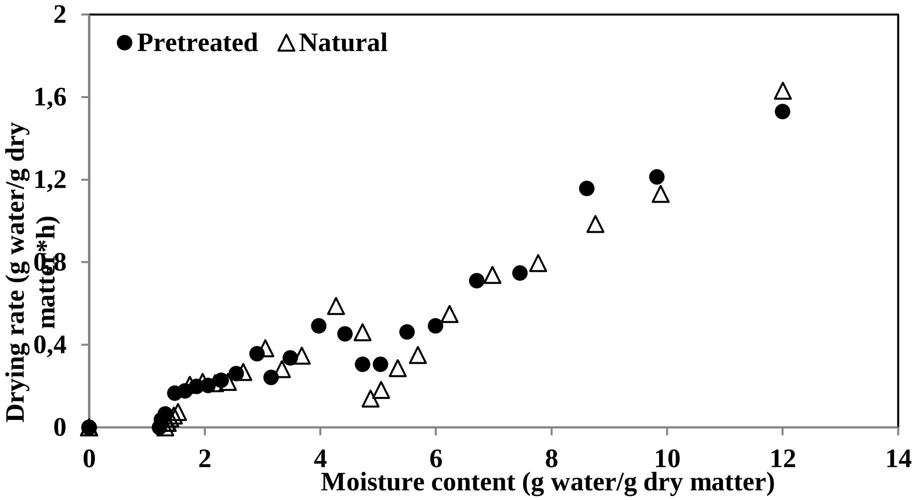

Figure 2. Variation of drying rate with moisture ratio for cherry tomatoes

The drying curves show that drying rate decreased continuously with decreasing moisture ratio. According to the results in Figure 2, the pre-treatment had a significant effect on the moisture content of the cherry tomatoes samples as expected. Also, during the falling rate period, the drying rate decreased continuously with decreasing moisture content. As seen in Figure 2, the drying curve has two stages. The drying rate was rapid during the first stage and then became very slow in the last stage. Open air sun drying experiments showed falling drying period; no constant rate period was observed. During the falling drying rate period, the material surface is no longer saturated with water and drying rate is controlled by diffusion of moisture from the interior of solid to the surface. The standard errors in Figure 2 are relatively small indicating good repeatability of the experiments. Similar results have been reported by Muratore et al. (2008), Demir and Sacilik (2010) and Kostoglou et al. (2013). [35, 39-40].

3.3. Evaluation of the Models

The moisture contents of cherry tomatoes samples were transformed into dimensionless moisture ratio to perform modeling studies easily. The values of the moisture ratio of cherry tomatoes samples were calculated using Eq. (2). The moisture ratio values were fitted to seven theoretical drying models listed in Table 1. The acceptability of the model is based on correlation coefficient, mean squared deviation and root mean square error. To observe the accuracy of the models, coefficient of determination (R^2), reduced mean squared deviation or chi-square (χ^2) and the root mean square error (*RMSE*) values are calculated and are given in Figures 3-5.

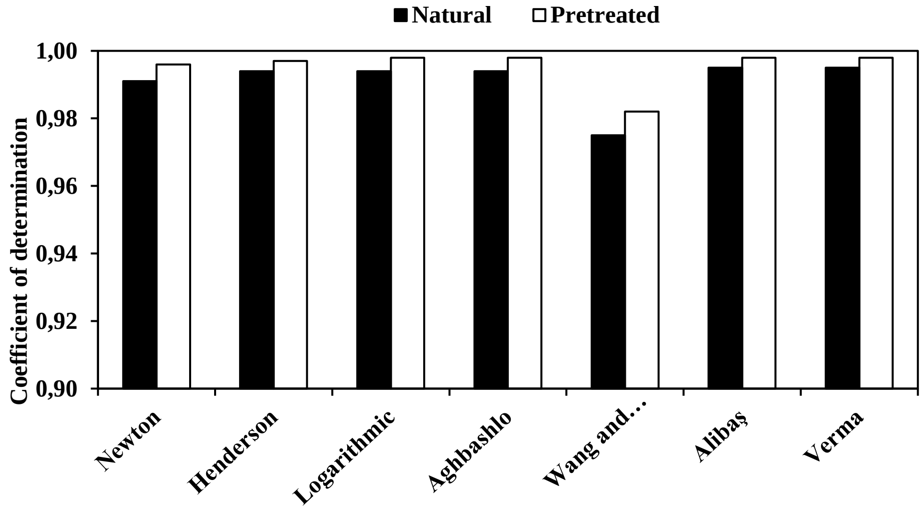

Figure 3. Comprasion of correlation coefficient (R^2) values for seven theoretical models

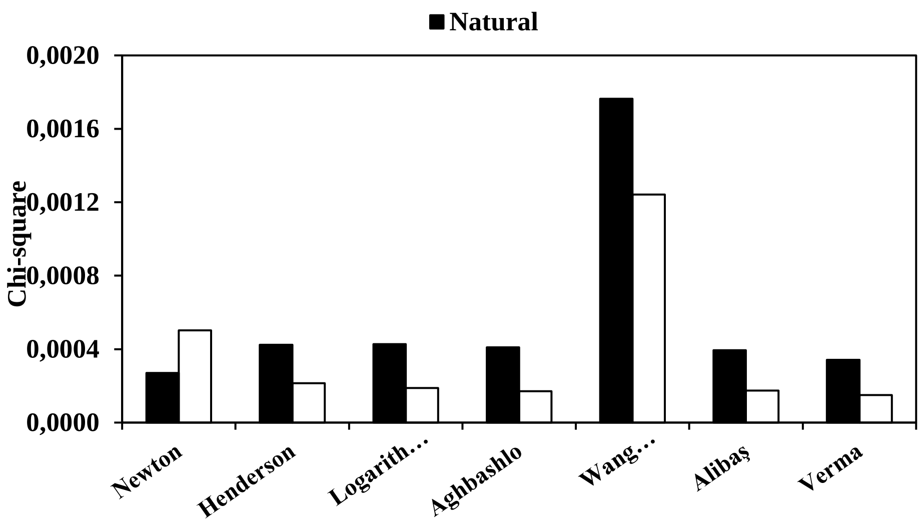

Figure 4. Comprasion of chi-square (χ^2) values for seven theoretical models

Figure 3 is examined, show that the R^2 values for all models are above 0.975. Since R^2 value was found to close to unity, the model implies a good fit to the data. This means that all established models successfully described the relation between time and moisture ratio.

The statistical parameter estimations showed that R^2, RMSE and χ^2 values ranged from 0.975 to 0.998, from 0.011444 to 0.040468, and from 0.000149 to 0.001242, respectively. The statistical data from the models were investigated and the model of Verma et al. presented the removable moisture rate, with the lowest error rate at all two trials. Thus, the Verma et al. model was considered the best model to represent the open air sun drying behaviour of cherry tomatoes samples. Doymaz [41] reported that the Verma et al. model was found successfully applied to sun drying of figs. The Verma et al. model have also been suggested by other authors to describe sun and solar drying of cocoa bean [42], and mint by products [43].

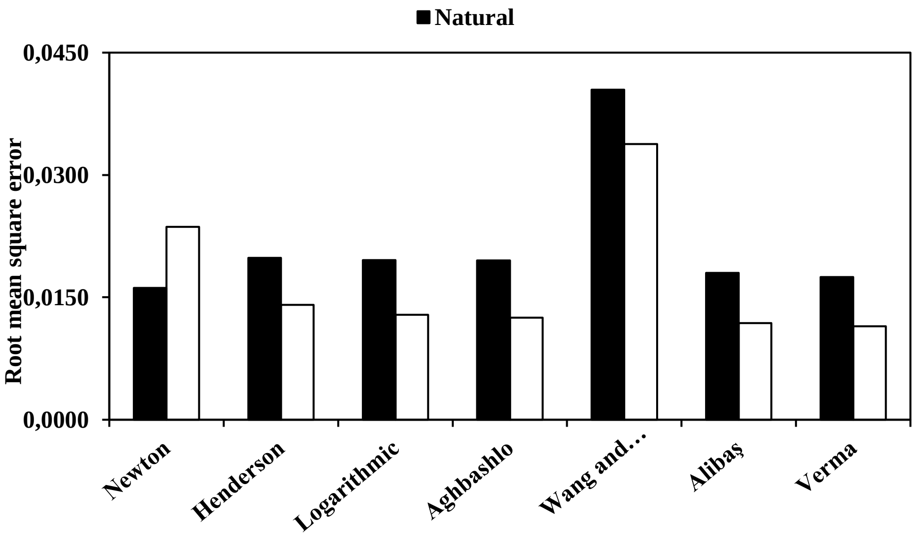

Figure 5. Comparison of *RMSE* values for seven theoretical models for pre-treated and natural samples

3.4. Determination of Effective Diffusion Coefficient

Based on Fick's second law, effective moisture diffusivity was calculated from Eq. (7). The values of effective diffusion coefficient for treated and natural cherry tomatoes samples are found as 4.76×10^{-10} and 4.42×10^{-10} m^2/s s, respectively. It can be seen that effective diffusion coefficient (*Deff*) in cherry tomatoes samples values was increasing with pretreatment. In other words, the diffusion coefficients of cherry tomatoes dipped in solution were higher than natural (untreated) samples. When samples were dried at pretreated, increased heating energy would increase the activity of water molecules leading to higher effective moisture diffusivity. In the study by Abano et al. (2011) the effective moisture diffusivity were reported 5.13×10^{-10} to 10.26×10^{-10} m^2/s for tomato slices at air temperatures of 50 to 80°C [44].

Bagheri et al (2013) [21] reported (tomato slices) effective diffusion coefficient for laboratory solar dryer, open sun drying and shadow process were found to be $5.248\text{-}13.66\times10^{-9}$, $3.42\text{-}8.69\times10^{-9}$ and $2.05\text{-}6.21\times10^{-9}$ m^2/s respectively. The effective diffusion coefficient values reported are within the general range of $10^{-12} - 10^{-8}$ m^2/s for drying of food materials [45-46].

3.5. Color Analysis

The colour is one of the important quality parameters in determining of dehydrated agricultural product. Too much color change of food can decrease its quality level and market opportunity. The values of L^*, a^*, b^* were measured and C^*, ΔE values calculated before and after drying cherry tomato samples as given in Table 2.

Table 2. Color values of dried cherry tomatoes samples at pretreated and natural

Applications	L^*	a^*	b^*	C^*	ΔE
Fresh	46.2 ± 0.9	38.7 ± 0.8	32.9 ± 0.6	50.79	-
Treated	33.8 ± 0.7	20.4 ± 0.9	21.8 ± 0.4	29.85	24.73
Natural	32.9± 0.8	17.2± 0.5	19.4± 0.5	25.92	28.66

The results show that L^*, a^* and b^* values of dried pretreatment and natural cherry tomato samples are lower than fresh samples. Hence, a darker lightness, an increase in greenness and a decrease in yellowness were seen in the colors of the dried cherry tomato samples. There are many diverse factors influencing the colour parameters of dried product. Some chemical reactions such as lipid oxidation and browning reactions might alter the final colour [34].
When evaluated values of total colour difference (ΔE) which is increasingly used in the determination of food quality changes, it is seen that colour loss in natural dried cherry tomatoes has been more. Higher C^*, a^* and b^* values were found for pretreated cherry tomatoes compered with natural drying. It can be concluded pretreatment method which were applied in this research were found effective in maintaining the color.

4. CONCLUSION

In this study, the effect of pretreatment and open-air sun drying method on drying characteristics of cherry tomatoes were investigated. The results show that pretreatment affect the dehydration of the cherry tomatoes. It was seen that pretreated cherry tomato resulted at shorter drying times than untreated samples. Drying rate curves of cherry tomato samples, the drying rate was rapid during the first stage and then became very slow in the last stage. The effective diffusion coefficients were determined as 4.76×10^{-10} and 4.42×10^{-10} m^2/s for pretreated and natural cherry tomato samples, respectively. Pre-treatment yielded good results in terms of drying time and colour. The moisture content data observed during the experiments are converted into the moisture ratio and fitted to the seven empirical drying models. The Verma et al. model model showed the closest result to the experimental results and was assumed as the best model to be used in drying of cherry tomato samples. As a final conclusion, considering the energy cost and drying time, open-sun drying method for cherry tomatoes can be recommended.

REFERENCES / KAYNAKLAR

[1] Hawkesworth S., Dangour A.D., Johnston D., Lock K., Poole N., Rushton J., Uauy R., Waage J., (2010) Feeding the world healthily: The challenge of measuring the effects of agriculture on health, *Philosophical Transactions B* 365, 3083–3097.

[2] Akpinar E.K., Midilli A., Biçer Y., (2003) Single layer drying behaviour of potato slices in a convective cyclone dryer and mathematical modeling, *Energy Conversion and Manegement* 44, 1689-1705.

[3] Marques L.G., Freire J.T., (2005) Analysis of Freeze-Drying of Tropical Fruits, *Drying Technology* 23, 2169-2184.

[4] Ergüneş G., Tarhan S., (2006) Color Retention of Red Peppers by Chemical Pretreatments during Greenhouse and Open Sun Drying, *Journal of Food Engineering* 76, 446-452.

[5] Kooli S., Fadhel A., Farhat A., Belghith A., (2007) Drying of Red Pepper in Open Sun and Greenhouse Conditions: Mathematical Modelling and Experimental Validation, *Journal of Food Engineering* 55, 1094-1103.

[6] Akpinar E. K., Bicer Y., (2008) Mathematical Modelling of Thin Layer Drying Process of Long Green Pepper in Solar Dryer and Under Open Sun, *Energy Conversionand Management* 49, 1367–1375.

[7] Tunde-Akintunde T.Y., (2011) Mathematical Modeling of Sun and Solar Drying of Chilli Pepper, *Renewable Energy* 36, 2139-2145.

[8] Akpinar E.K., (2010) Drying of Mint Leaves in A Solar Dryer and under Open Sun: Modelling, Performance Analyses, *Energy Conversion and Management* 51(12), 2407-2418.

[9] Arslan D., Özcan 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.

[10] Evin D., (2012) Thin layer drying kinetics of Gundelia tournefortii L., *Food and Bioproducts Processing* 90(2), 323–332.

[11] Al-Mahasneh M.A., Rababah T.M., Bani-Amer M.M., Al-Omari N.M., Mahasneh M.K., 2013 Fuzzy and Conventional Modeling of Open Sun Drying Kinetics for Roasted Green Wheat, *International Journal of Food Properties* 16, 70-80.

[12] Doymaz I., (2004) Drying Kinetics of White Mulberry, *Journal of Food Engineering* 61(3), 341–346.

[13] Lewicki P.P., Michaluk E., (2004) Drying of Tomato Pre-Treated with Calcium, *Drying Technology: An International Journal* 22(8), 1813-1827.

[14] Movagharnejad K., Nikzad M., (2007) Modeling of Tomato Drying Using Artificial Neural Network, *Computers and Electronics in Agriculture* 59, 78–85.

[15] Akanbi C.T., Adeyemi R.S., Ojo A., (2006) Drying Characteristics and Sorption Isotherm of Tomato Slices, *Journal of Food Engineering* 73(2), 157–163.

[16] Sacilik K., Keskin R., Elicin A.K., (2006) Mathematical Modelling of Solar Tunnel Drying of Thin Layer Organic Tomato, *Journal of Food Engineering* 73(3), 231–238.

[17] Corrêa P.C., de Oliveira G.H.H., Baptestini F.M., et al., Diniz M.D.D.S., da Paixão A.A., (2012) Tomato İnfrared Drying: Modeling and Some Coefficients of the Dehydration Process, *Chilean Journal of Agricultural Research* 72(2), 262-267.

[18] Abano E.E., Haile M.A., Owusu J., Engmann F.N., (2013) Microwave-Vacuum Drying Effect on Drying Kinetics, Lycopene and Ascorbic Acid Content of Tomato Slices, *Journal of Stored Products and Postharvest Research* 4(1), 11 – 22.

[19] Davoodi M.G., Vijayanand P., Kulkarni S.G., Ramana K.V.R., (2007) Effect of Different Pre-Treatments and Dehydration Methods on Quality Characteristics and Storage Stability of Tomato Powder, *LWT-Food Science and Technology* 40(10), 1832-1840.

[20] Panchariya P.C., Popovic D., Sharma A.L., (2002) Thin-layer Modelling of Black Tea Drying Process, *Journal of Food Engineering* 52(4), 349–357.

[21] Bagheri H., Arabhosseini A., Kianmehr M.H., Chegini G.R., (2013) Mathematical Modeling of Thin Layer Solar Drying of Tomato Slices, *Agricultural Engineering International: CIGR Journal* 15(1), 146-153.

[22] AOAC., (1990) Official Method of Analysis, *Association of Official Analytical Chemists*, Arlington, USA.

[23] Ayensu A., (1997) Dehydration of Food Crops Using A Solar Dryer with Convective Heat Flow, *Solar Energy* 59(4-6), 121-126.

[24] Henderson S.M., Pabis S., (1961) Grain Drying Theory I. Temperature Effect on Drying Coefficient, *Journal of Agricultural Engineering Research* 6, 169-174.

[25] Vega-Gálvez, A., Ayala-Aponte A., Notte E., De La Fuente L., Lemus-Mondaca R., (2008) Mathematical Modeling of Mass Transfer During Convective Dehydration of Brown Algae Macrocystis Pyrifera, *Drying Technology* 26(12), 1610-1616.

[26] Aghbashlo M., Kianmehr M.H., Khani S., Ghasemi M., (2009) Mathematical Modeling of Carrot Thin-layer Drying Using New Model, *International Agrophysics* 23(4), 313-317.

[27] Wang C.Y., Singh R.P., (1978) Use of Variable Equilibrium Moisture Content in Modelling Rice Drying, *ASAE Meeting paper* No. 78-6505, St.Joseph.

[28] Verma L.R., Bucklin R.A., Endan J.B., Wratten F.T., (1985) Effects of Drying Air Parameters on Rice Drying Models, *Transactions of the ASAE*, 28, 296-301.

[29] Alibas I., (2012) Microwave Drying of Grapevine (Vitis vinifera L.) Leaves and Determination of Some Quality Parameters, *Tarım Bilimleri Dergisi-Journal of Agricultural Sciences* 18, 43-53.

[30] Akpınar E.K., Biçer Y., Midilli A., (2003) Modeling and Experimental Study on Drying of Apple Slices in A Convective Cyclone Dryer, *Journal of Food Process Engineering* 26(6), 515-541.

[31] Lee J.H., Kim H.J., (2008) Drying Kinetics of Onion Slices in A Hot-Air Dryer, *Journal of Food Science and Nutrition* 13, 225-230.

[32] Özbek B., Dadali G., (2007) Thin-layer Drying Characteristics and Modelling of Mint Leaves Undergoing Microwave Treatment, *Journal of Food Engineering* 83(4), 541-549.

[33] Darvishi H., Asghari A., Najafi G., Gazori, H.A., (2013) Mathematical Modeling, Moisture Diffusion, Energy consumption and Efficiency of Thin Layer Drying of Potato Slices, *Journal of Food Processing & Technology* 4(215), doi.org/10.4172/21577110.1000215.

[34] Okos M.R., Campanella O., Narsimhan G., Singh R.K., Weitnauer A.C., (2007) Food dehydration. *In:Handbook of Food Engineering*. Heldman DR, Lund DB (eds), CRC Press, Florida, USA, pp. 601-744.

[35] Muratore G., Rizzo V., Licciardello F., Maccarone E., (2008) Partial Dehydration of Cherry Tomato at Different Temperature and Nutritional Quality of the Products, *Food Chemistry* 111(4), 887-891.

[36] Jarad F.D., Moss, B.W., Youngson C.C., Russell M.D., (2007) The Effect of Enamel Porcelain Thickness on Color and the Ability of A Shade Guide to Prescribe Chroma, *Dental Materials* 23(4), 454-460.

[37] Sacilik K., Keskin, R., Elicin A.K., (2006) Mathematical modelling of solar tunnel drying of thin layer organic tomato, *Journal of Food Engineering* 73(3), 231-238.

[38] Gürlek G., Özbalta N., Güngör A., (2009) Solar Tunnel Drying Characteristics and Mathematical Modelling of Tomato, *Isı Bilimi ve Tekniği Dergisi* 29(1), 15-23.

[39] Demir K., Sacilik K., (2010) Solar Drying of Ayas Tomato Using A Natural Convection Solar Tunnel Dryer, *Journal of Food Agriculture and Environment* 8(1), 7-12.

[40] Kostoglou M., Chrysafis N., Andritsos N., (2013) Modelling Tomato Dehydration in a Tunnel Dryer Using Geothermal Energy, *Drying Technology: An International Journal* 31(1), 5-16.

[41] Doymaz I., (2005) Sun drying of figs: an experimental study, *Journal of Food Engineering* 71(4), 403-407.

[42] Hii C.L., Law C.L., Cloke M., (2008) Modelling of Thin Layer Drying Kinetics of Cocoa Beans During Artificial and Natural Drying, Journal of Engineering Science and Technology 3(1), 1–10.

[43] Sallam Y.I., Aly M.H., Nassar A.F., Mohamed E.A., (2015) Solar drying of whole mint plant under natural and forced convection, Journal of Advanced Research 6(2), 171–178.

[44] Abano E.E., Ma H., Qu, W., (2011) Influence of Air Temperature on the Drying Kinetics and Quality of Tomato Slices, *Journal of Food Processing & Technology* 2, 123, doi:10.4172/2157-7110.1000123.

[45] Madamba P.S., Driscoll R.H., Buckle K.A., (1996) The Thin-Layer Drying Characteristics of Garlic Slices, *Journal of Food Engineering* 29(1), 75-97.

[46] Erbay Z., Icier F., (2010) A Review of Thin Layer Drying of Foods: Theory, Modeling and Experimental Results, *Critical Reviews in Food Science and Nutrition* 50(5), 441-464.