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Determination of the drying characteristics of cherry laurel (*Laurocerasus officinalis Roem.*) puree in a freeze-dryer

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This study aims at the determination of the effect of thickness on the freeze drying behavior of cherry laurel (*Laurocerasus officinalis Roem.*) puree, together with the determination of the physical, chemical, and powder properties of the obtained powders and the calculation of the energy efficiency of the drying process. The samples were dried at 3, 5, and 7 mm thicknesses. Among the twelve thin-layer drying models used, the Page (3 and 5 mm) and Logarithmic models (7 mm) were found to satisfactorily describe the drying behavior. The drying times were 8, 10, and 11 h with increasing the moisture extraction rate (MER) and specific moisture extraction rate (SMER), and decreasing specific energy consumption (SEC) values for the increasing thicknesses. The effective moisture diffusivity (D_{eff}) values were between 4.70-7.78E-08 m^2/s. The average total phenolic compounds and the vitamin C content values were 710 mg GAE/100g (db) and 23 mg/100g (db)), respectively. The bulk density values were between 99.75 and 113.88 kg/m^3, and the flowability and cohesiveness values were at fair-bad, and intermediate-high levels, respectively.

Keywords: Cherry laurel puree, Freeze drying, Thin layer modeling, Effective moisture diffusivity, Energy consumption, Powder properties.

INTRODUCTION

Cherry laurel (*Laurocerasus officinalis Roem.*) which belongs to the Rosaceae family is generally grown in the Black Sea Region in Turkey [1]. Cherry laurel contains high amounts of minerals (K (7938.7 ppm), Mg (1242.2 ppm), Ca (1158.9 ppm) etc.), vitamin C (3.7-6.8 mg/100 g wb), phenolic (3129.2 mg GAE/100 g db) and antioxidant compounds (2575 μmol Trolox/g wb) [2-4]. Besides being consumed fresh and in dried form, it is also used for making jams, molasses, marmalade, fruit juice, and pickle.

The consumption of cherry laurel is quite limited due to the short harvest time and the high perishability of the fruits. Considering the high nutritional properties of this fruit, freezing and drying might be suitable techniques for prolonging the consumption period, increasing the areas of utilization and increasing the post-harvest stability. Among these techniques drying constitutes an alternative way to increase the shelf life and consumption of cherry laurel. Freeze drying is a method in which drying takes place at very low temperatures and by this way a high quality product is provided. The water in the product (in solid phase) is removed by vacuum protecting the shape and texture and the volume loss of the product is prevented. In addition, the loss of minerals, vitamins, flavor, and aroma compounds of food is minimized [5].

Freeze drying has been used for several kinds of fruits such as strawberry [6], guava [7], pumpkin [8], mango [9], kiwi [10], watermelon [11], etc.

The aim of this study covers the determination of the effect of different thicknesses of cherry laurel puree on the freeze drying behavior, the determination of the physical, chemical, and powder properties of the obtained products and the calculation of the energy efficiency of the drying process.

MATERIAL AND METHOD

Material

Fully matured fresh fruits were obtained from a local supermarket in Kocaeli, Turkey. They were washed and grinded with a home-type blender (Tefal Smart, MB450141, Turkey) after the removal of the stones.

Drying Experiments

The experiments were performed in a pilot scale freeze dryer (Armfield, FT 33 vacuum freeze drier, England) at three thicknesses of 3, 5, and 7 mm in a vacuum (13.33 Pa absolute pressure), at a −48°C condenser temperature. The temperature of the heating plate was set to 10°C.

The weight of the samples was determined at 1 h intervals by using a digital balance with 0.01 precision (Ohaus AR2140, USA) until the weight of the sequent samples reached a constant value. The dried material was grinded for one minute in a home-type blender (Tefal Smart, MB450141, Turkey), then, the powders were stored in

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aluminum-laminated polyethylene (ALPE) packaging materials.

Physical and Chemical Analyses

The moisture content of the samples was determined according to AOAC [12]. The soluble solid contents (TSS), water activity, pH and color values of the samples were measured by using ATAGO 1T (England), Testo-AG 400 (Germany), Inolab WTW pH 720 (Germany), and Minolta CR-400 Colorimeter (Japan), respectively.

Total color changes (ΔE) of the powders with respect to cherry laurel puree were calculated by using Eq. (1) [13]:

$$\Delta E = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \quad (1)$$

In addition, Chroma value was calculated by using Eq. 2 [13]:

$$\text{Chroma} = (a^{*2} + b^{*2})^{1/2} \quad (2)$$

For the determination of the chemical properties of the samples; extracts were obtained according to the methods of Cemeroglu [14]. The obtained extracts were stored at -24°C in the dark until analysis.

The total phenolic content (TPC) of the samples was determined according to Franke *et al.* [15] and the results were given as gallic acid equivalents per 100 grams of dry sample.

The total antioxidant activities of the samples were determined using the method based on the principle of the activity of DPPH radicals. The % inhibition of samples was calculated by using Eq. (3):

$$\%\ \text{inhibition} = \frac{(A_{DPPH} - A_{extract})}{A_{DPPH}} * 100 \quad (3)$$

The total antioxidant activity was expressed as μmol Trolox equivalent per g sample (db) [14]. The vitamin C content of the samples was determined according to Hısıl [16] as mg vitamin C/100 g sample (db).

Mathematical Modeling of Drying Data

The moisture ratio (MR) values of the samples were calculated throughout the freeze drying operation by using Eq. (4):

$$\text{MR} = \frac{M_t - M_e}{M_o - M_e} \quad (4)$$

where, M_0, M_t and M_e represent the initial, any time and equilibrium moisture contents (kg water/kg dry matter), respectively.

Twelve thin layer drying models (Lewis, Page, Modified Page, Henderson and Pabis, Logarithmic, Midilli, Two Term, Two Term Exponential, Approximation of Diffusion, Wang and Singh, Verma, and Logistic), commonly used in drying processes, were employed [17,18].

The coefficient of determination (R^2), root mean square error (RMSE) and the reduced chi-square (χ^2) values were determined according to Ergun *et al.* [10]. The higher values of the coefficient of determination (R^2) and the lower values of root mean square error (RMSE), and reduced chi-square (χ^2) were chosen for assessing the goodness of fit.

For the determination of the effective moisture diffusivity (D_{eff}) values of the cherry laurel, Fick's diffusion model as given in Eq. (5) was used:

$$MR = \frac{8}{\pi}\sum_{i=1}^{\infty}\frac{1}{(2i-1)^2}\exp\left[-(2i-1)^2\pi^2\frac{D_{eff}}{4L^2}t\right] \quad (5)$$

where, t is the time (s), D_{eff} is the effective moisture diffusivity (m^2/s) and L (m) is the thickness of sample. For long drying times (MR<0.6) [19], a limiting case of Eq. (5) was obtained, and expressed in logarithmic form as given in Eq. (6):

$$lnMR = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}}{4L^2}\right)t \quad (6)$$

The effective diffusivity is typically calculated by plotting the experimental moisture ratio *versus* the drying time. From Eq. (6), a plot of ln MR *versus* the drying time gives a straight line with the slope given in Eq. (7):

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

Determination of Energy Efficiency of Freeze Drying Operation

The total energy consumption of the freeze-drying process was measured by a power measurement device (Makel M310.2218, Turkey). In order to determine the effectiveness of freeze drying, the moisture extraction rate (MER), specific energy consumption (SEC), and specific moisture extraction rate (SMER) values were calculated by the following equations (Eqs. 8-10) [20, 21]:

$$MER = \frac{\text{Amount of water removed during drying (kg)}}{\text{Drying time (h)}} \quad (8)$$

$$SEC = \frac{\text{Total energy supplied in drying process (MJ)}}{\text{Amount of water removed during drying (kg)}} \quad (9)$$

$$SMER = \frac{\text{Amount of water removed during drying (kg)}}{\text{Energy consumption (kWh)}} \quad (10)$$

Determination of the Powder Properties

The bulk and tapped density values, flowability (Carr Index) and cohesiveness (Hausner Ratio), the average wettability times, dispersibility, hygroscopicity (%) and caking degree of the powders were determined by using the methods of Chegini and Ghobadian [22], Jinapong *et al.* [23], Gong *et al.* [24], Pisecky [25], and Jaya and Das [26], respectively.

Determination of the Morphological Properties by Scanning Electron Microscopy (SEM)

The powder samples were placed on aluminum stubs using a double-sided adhesive tape. The samples were then coated with gold and were examined with a scanning electron microscope (Carl Zeiss 300 VP, Germany) operating at 3 kV accelerating voltage.

Determination of the Glass Transition temperature by Differential Scanning Calorimeter (DSC)

The glass transition temperature of the powder was determined by a differential scanning calorimeter (TA DSC Q2000, New Castle, DE USA) equipped with a thermal analysis station between -30°C to 100°C at 10°C/min for formation of glassy state in the powder and equilibrated for 10 min. DSC thermograms presenting the heat flow (W/g) and temperature relationship were used to analyze the thermal transitions in samples during heating and cooling. TA Instruments Universal analyses software was used to analyze the onset, mid and end points of the glass transition. The glass transition temperature (Tg) was calculated as the average of the onset and end point values [27].

Statistical Analyses

The data were analyzed using statistical software SPSS 16.0 (SPSS Inc., USA). The data were also subjected to analysis of variance (ANOVA) and Duncan's multiple range test ($\alpha=0.05$) to determine the difference between means. The drying experiments were replicated twice and all the analyses were triplicated.

RESULTS AND DISCUSSION

The experimental results showed that freeze-drying technique was effectively used in the drying of cherry laurel puree, as supported by the acceptable values for the analyzed properties. The efficiency of the process was calculated based on the solid content of puree (98.44-98.68%) and only slight losses due to handling were observed.

Some of the physical properties of cherry laurel powders are given in Table 1. Moisture content is the critical quality parameter for the powder products. The total soluble solid content (TSS) (°Bx) of cherry laurel puree was measured as 14.1°Bx, with a moisture content value of 81.15±0.28% (wb) which is similar to the value presented by Kolaylı *et al.* [2] (80.00±4.10% for cherry laurel). The moisture content values must be below 10% for the protection of the properties of powder products [28, 29] and suitable values of moisture content of the powders were obtained in this study. The final moisture content of the powders ranged between 7.05 and 9.42% (wb) and they could be classified as microbiologically safe for long-term storage. It was observed that the moisture content of the dried powders was affected by the drying thicknesses ($P<0.05$).

Table 1. Physical properties of the powders.

Properties	Cherry Laurel Powders Dried at Different Thicknesses		
	3 mm	5 mm	7 mm
Moisture Content (%wb)	7.70±0.86 ^{a}	7.05±0.19^{a}	9.42±0.17 ^{b}
Water activity	0.248±0.011 ^{a}	0.261±0.008 ^{a}	0.270±0.039 ^{a}
pH	4.527±0.022^{a}	4.509±0.022^{a}	4.499±0.022^{a}
Color			
L*	45.09±0.35^{c}	40.20±1.67^{b}	37.95±0.65^{a}
a*	20.54±0.66^{a}	23.14±0.96^{b}	24.27±0.53^{b}
b*	3.16±0.65 ^{a}	3.95±0.86^{a}	3.88±0.78^{a}
ΔE	17.77±0.11 ^{b}	14.71±0.48 ^{a}	13.69±0.74 ^{a}
Chroma	20.79±0.75^{a}	23.74±0.79^{b}	24.58±0.43^{b}

$^{a\text{-}c}$ Differences in the statistical evaluation are shown with different letters in the same row ($P<0.05$)

The water activity values of cherry laurel powders reached the range of 0.248 to 0.270 at the end of drying as in the acceptable limits for the safe storage of the powders. The measured water activity values were in the same range with freeze dried kiwi, pumpkin, quince and persimmon puree powders (between 0.225 and 0.273) [30, 31]. According to Table 1, it can be stated that the water activity values of the powders increased with the increasing drying thicknesses although no statistical difference was observed ($P>0.05$).

The pH value of the cherry laurel puree was measured as 4.424±0.001, similar to the pH values of 4.500±0.500 reported by Kolaylı *et al.* [2]. The pH values of the reconstituted powders (4.499-4.527) were found to be slightly higher compared to the puree and at 3 mm thickness it was observed to be the highest one. Considering the results in Table 1, the change in the drying thicknesses caused no significant effect on pH values ($P>0.05$). The increase in the pH values might be due to the loss of some acidic compounds in the structure during the drying process. In addition, since the powders were diluted to the initial moisture content before the measurements, the pH values might be affected by differences in the moisture content of the powders, hence, by the amount of water added.

The color values of the powders are given in Table 1 and it can be seen that significant differences were registered for L* and a* values between the powders ($P<0.05$) dried at different thicknesses. The color values (L*, a*, and b*) of the cherry laurel puree were measured as 28.38±0.17, 14.63±0.23, and 2.44±0.08, respectively. Kasım *et al.* [32] reported the color values of cherry laurel as 21.14-24.21, 5.63-17.72, and 0.22-3.97 for L*, a*, and b*, respectively, for 12 natural genotypes. These differences in the color values can be due to differences in the maturation degree and harvesting time. The color values were affected by the freeze drying process and higher values were observed for the powder products. The lightness values of the powders decreased depending on increasing drying thicknesses ($P<0.05$), which can be explained with the long drying times. The greenness/redness value of the sample dried at 3 mm thickness was statistically different from the other sample thicknesses ($P<0.05$) and there was no statistical difference in blueness/yellowness values of the powders depending on the increase of the drying thicknesses ($P>0.05$). The calculated values of ΔE for the powders with respect to the cherry laurel puree were significantly affected by the change of the drying thicknesses ($P<0.05$). The Chroma value of the cherry laurel puree was calculated as 14.83± 0.24. This value is similar to that reported by Kasım *et al.* [32] and Halilova and Ercisli [33] (5.35-18.15 and 8.39-19.07, respectively). The Chroma values of the powders significantly increased depending on the increasing drying thicknesses ($P<0.05$).

The results obtained from the chemical analysis of the powders are given in Table 2. According to Table 2 the total phenolic content values of cherry laurel puree and its powders were determined as 1083.11 and between 697.27 and 719.81 mg GAE/100g (db), respectively. The values of phenolic content of cherry laurel reported in the literature [4, 33, 34] ranged between 2436 and 7527 mg GAE/100 g (db) showing a large variation between the samples. No significant differences were observed in the phenolic content values of the powders for the change of the drying thicknesses ($P>0.05$). Dirim and Calıskan [8] reported a decrease of 3% (db) in total phenolic content of pumpkin puree in freeze drying. In another study, Chinese ginger was dried by five different drying methods (hot air, freeze, infrared, microwave, and intermittent microwave-convective drying). The phenolic content of fresh and dried Chinese ginger was found as 11.97, 9.69, 13.83, 11.35, 8.41, and 11.28 mg GAE/g (db), respectively. According to these values, the freeze drying method better preserved the phenolic content than the other methods [35].

The antioxidant activity of the cherry laurel puree and its powders was determined as 186.20 and 46.54-83.68 μmol Trolox/g (db), respectively. According to results, the antioxidant activity of the powders was affected by the change in drying thickness ($P<0.05$). The phenolic content affects the amount of antioxidant substances in foods, but color pigments are also a major parameter for the amount of antioxidant in foods. The values of the antioxidant activity of cherry laurel reported in the literature [36, 37] ranged between 21.20 and 35.9 μmol Trolox/g (wb). The degree of maturation, genotypes, and conditions of the growth area can be the reason for the different chemical properties of cherry laurel. In a study by Valadez-Carmona *et al.* [38], cacao pod husk was dried by convective, microwave, and freeze drying methods and the antioxidant activity of powders was found to be 35.8, 59.3, and 70.8 μmol Trolox/g (db), respectively, indicating better antioxidant activity preservation with freeze drying.

The vitamin C content of the cherry laurel puree was determined as 177.44 mg/100 g (db) and values ranging between 2.96 and 204.00 mg/100g (wb) for cherry laurel were reported in the literature [2, 37]. According to the results, the vitamin C values of the freeze dried cherry laurel powders decreased depending on increasing drying thickness ($P<0.05$). The vitamin C losses can be due not only to the freeze drying process, but to the operations before freeze drying such as handling, storage conditions, and mashing of cherry laurel. In general, vitamin C loss in freeze drying is lower when compared to other drying methods, since the process is performed at low temperatures with application of vacuum [39]. In their studies, Dirim and Calıskan [8] and Marques *et al.* [40] reported losses of vitamin C as 18% (db) for pumpkin and 13.0-69.3% (db) for acerola, respectively. However, in our study a considerable loss was observed.

The drying characteristics of the samples during the freeze drying process were determined from the mass loss in the samples of the known initial moisture content (81.15±0.28%, wb). The drying process was carried out by following the weight of the samples at one-hour intervals until constant weight. Most of the moisture in the samples was removed at the beginning of the drying process and at a slower rate until the end of the drying process. Moisture ratio with respect to drying time was calculated by using the moisture content data and fitted into the thin layer drying models. As a result of calculation of model parameters, five of the most suitable model equations and the statistical evaluations are given in Tables 3-5 for 3, 5 and 7 mm thicknesses, respectively.

The R^2 values of the different thin layer model equations were found to be above 0.9 for the three drying thicknesses (Tables 3-5). The experimental data and the model equations for the three most suitable drying curves of drying cherry laurel puree are given in Fig. 1.

The highest R^2 values were obtained for Page, Midilli and Two-Term Exponential model; Page, Midilli and Logistic model; and Logarithmic, Midilli, and Approximation of Diffusion model for 3, 5, and 7 mm, respectively. According to Tables 3-5, when RMSE and χ^2 values were examined, Page (3 and 5 mm thicknesses) and Logarithmic (7 mm thickness) models were chosen as the most suitable models for determining freeze drying characteristics of the samples.

Table 2. Chemical properties of the powders.

Properties	Cherry Laurel Powders Dried at Different Thicknesses 3mm	5mm	7mm
Total Phenolic Content (mg GAE/ 100g db)	715.30±14.24^{a}	697.27±19.37^{a}	719.81±8.72^{a}
Antioxidant Activity (μmol Trolox/g db)	63.31±1.00^{b}	83.68±1.25^{c}	46.54±0.80^{a}
Vitamin C (mg /100 g db)	28.26±1.24^{b}	22.84±1.45^{a}	20.01±1.55^{a}

$^{a\text{-}c}$ Differences in the statistical evaluation are shown with different letters in the same row ($P< 0.05$).

Table 3. Model equations and statistical results for the samples of 3 mm thickness (R^2, RMSE, and χ^2).

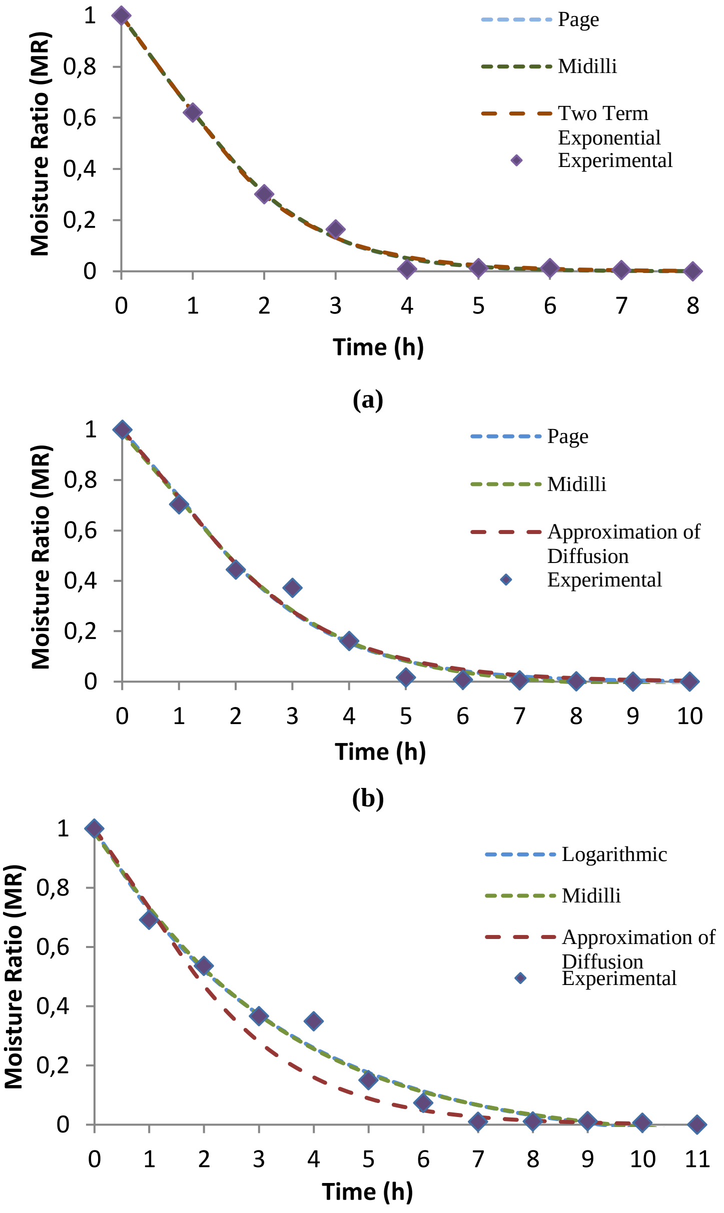
Models	Equations	R^2	RMSE	χ^2
Page	MR= $e^{-0.471\,t^{1.333}}$	0.997	0.0183	0.0004
Midilli	MR= $0.999e^{-0.470t^{1.329}} + 0.001t$	0.997	0.0183	0.0006
Two-Term Exponential	MR= $1.908e^{-0.876t} + (1-1.908)e^{-1.908(0.876)t}$	0.997	0.0197	0.0004
Approximation of Diffusion	MR= $29.885e^{-0.371t} + (1-29.885)e^{-0.371(0.984)t}$	0.992	0.0289	0.0125
Logistic	MR= $1.542/(1+0.543e^{1.000t})$	0.997	0.6064	0.5516

Table 4. Model equations and statistical results for the samples of 5 mm thickness (R^2, RMSE, and χ^2).

Models	Equations	R^2	RMSE	χ^2
Page	MR= $e^{-0.308t^{1.300}}$	0.987	0.0390	0.0019
Midilli	MR= $0.989e^{-0.304t^{1.275}} - 0.002t$	0.987	0.0374	0.0022
Approximation of Diffusion	MR= $-65.415e^{-0.751t} + (1 + 65.415)e^{-0.751(0.989)t}$	0.985	0.0399	0.0022
Verma	MR= $26.767e^{-0.240t} + (1-26.767)e^{-0.235t}$	0.985	0.4054	0.2260
Logistic	MR= $1.516/(1+0.537e^{0.701t})$	0.987	0.5882	0.4758

Table 5. Model equations and statistical results for the samples of 7 mm thickness (R^2, RMSE, and χ^2).

Models	Equations	R^2	RMSE	χ^2
Logarithmic	MR= $1.066e^{-0.293t} - 0.071$	0.986	0.0368	0.0018
Midilli	MR= $0.986e^{-0.291t^{1.073}} - 0.004t$	0.986	0.0374	0.0021
Approximation of Diffusion	MR= $-56.567e^{-0.536t} + (1 + 56.567)e^{-0.536(0.991)t}$	0.985	0.0406	0.0022
Verma	MR= $0.141e^{-17.605t} + (1 - 0.141)e^{-0.423t}$	0.984	0.3433	0.1620
Logistic	MR= $1.934/(1 + 0.984e^{0.485t})$	0.984	1.1675	1.8170



(a)

(b)

(c)

Fig. 1. Experimental data and computed moisture ratio values obtained by the selected models for different drying thicknesses: (a) 3 mm, (b) 5 mm, and (c) 7 mm.

Oztekin *et al.* [41] studied the drying of cherry laurel (250 g) using microwave and hot air and mathematical modeling of the drying behavior and found that Midilli and Verma models are the best models in describing the microwave (180-900W) and hot air (60-70°C) drying, respectively. Although there is no study in the literature about freeze drying of cherry laurel puree, there are lots of mathematical modeling studies for freeze drying of foods, e.g., Ergun *et al.* [10], Souza *et al.* [42], and Calıskan *et al.* [43] who reported the drying models as Two-term Exponential model for kiwi

(*Actinidia deliciosa*) slices, Page model for avocado (*Persea americana Mill.*) pulp, and Logarithmic model for kiwi (*Actinidia deliciosa*) puree as the best representative model, respectively. The moisture transfer during drying was modeled by using the Fick's law of diffusion model. Plots of natural logarithm of MR (lnMR) against drying time (s) for different drying thicknesses (3, 5, and 7 mm) yielded straight lines with relatively high correlation coefficients (0.983, 0.985, and 0.988, respectively) indicating goodness of fit (data and plots are not given here). The effective moisture diffusivity (D_{eff}) of the cherry laurel was calculated by using the equations 6 and 7 by taking into consideration that the MR values are lower than 0.6 for 80% of the total drying operation. The calculated values were 7.06E-08, 7.78E-08, and 4.70E-08 m^2/s, respectively for 3, 5, and 7 mm thicknesses. Kaya and Aydın [44] reported the effective diffusivity values of hot air-dried cherry laurel (35, 45, 55, and 65°C, 0.2-20.0 m/s air velocity and 10-95% relative humidity) as varying between 1.896E-10 and 3.252E-10 m^2/s indicating both higher D_{eff} results for freeze drying and difference in the genotypes. Calıskan and Dirim [31] reported the effective diffusivity value of persimmon puree as 7.302E−10m^2/s at freeze drying. Erbay and Icier [17] observed that the efficiency of moisture diffusivity in the drying of food materials was in the range of 10E-12 to 10E-06 m^2/s according to the literature. Also, 75% of the diffusivity values accumulated in the range of 10E−10 to 10E−08 m^2/s and the results of our study are in a good agreement with this fact.

The MER, SEC, and SMER values were used to determine the efficiency of the dryers and the results are given in Fig. 2 for different drying thicknesses.

As can be seen from Fig. 2 the MER and SMER values of the samples increased and SEC values of the samples decreased depending on increasing drying thickness related with amount. Oztekin *et al.* [41] reported that the energy consumption for drying of laurel berry samples was 0.92-1.44 kWh/kg sample for microwave dryer (0.2-1.1 h) and 6.12-9.26 kWh/kg sample for hot air dryer (12.0-28.0 h). In our study, the total energy consumptions of the equipment for drying were measured as 351.18- 457.67 kWh/kg sample for different dying thicknesses and these values were found to be higher than the values given by Oztekin *et al.* [47] due to the long operation time of freeze drying. Baysal *et al.* [45] studied the drying of apple slices (2 mm) at tray, heat pump and microwave freeze drying. In freeze drying, the researchers found lower SMER and MER, and higher SEC values than other drying methods. SMER, MER, and SEC values in freeze drying of apple slices were measured as 0.01 kg/kWh, 0.02 kg/h, and 259.2 MJ/kg, respectively. In cherry laurel puree drying, MER and SEC values were lower and SMER were higher than those given by Baysal *et al.* [45]. The energy consumption for drying foods depends on the used type of drying equipment, raw material, initial moisture content and thickness of the product.

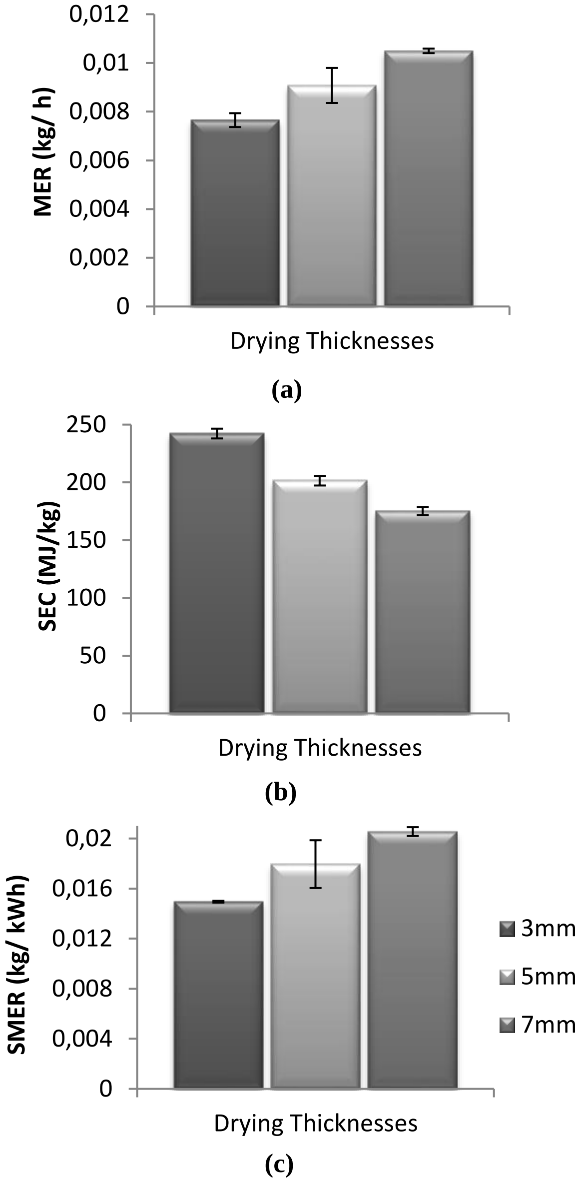


Fig. 2. Calculated values of MER (a), SEC (b), and SMER (c) for the different drying thicknesses.

The powder properties are very important for the storage, transportation and for industrial applications as dosing for powders. Some of the determined powder properties are given in Table 6. The bulk density is an important criterion for the transport and packaging of powdered foods which is influenced by the moisture content of the product, particle shape and particle size [46]. The bulk and tapped density values of the powders ranged between 99.75-113.88 kg/m^3 and, 136.20-182.40 kg/m^3, respectively, as given in Table 6. The change in the drying thickness caused significant effect on the bulk and tapped density values

The flowability and cohesiveness of the powders in terms of the Carr Index and Hausner ratio were evaluated. The classification of the powder flowability and cohesiveness based on the Carr index (CI) and Hausner ratio (HR) are very good (<15), good (15–20), fair (20–35), bad (35–45), and very bad (>45), and low (<1.2), intermediate (1.2–1.4), and high (>1.4), respectively [23]. The CI and HR values of the powders ranged between 26.75-39.24, and 1.37-1.65, respectively. Drying thickness was found to affect the CI and HR values of the powders ($P<0.05$). It may be due to high moisture content value of the powders. Depending on these results it can be stated that the powders showed fair and bad flowability and intermediate and high cohesiveness. As indicated by Koc *et al.* [48], flowability problems may occur in powder products which have high cohesiveness values.

Wettability is the ability for absorption of water on the surface of the powder particles which is affected by several properties of the products, as surface area, density, size, and surface activities of particle and hygroscopic material content of product [49]. The average wettability times of the powders are given in Table 6 as ranging between 2.37-3.25 s. The results showed that average wettability times of the powders significantly affected from the drying thicknesses ($P<0.05$). Freuding et al. [50] reported that low tapped density products have high wettability values. Dirim et al. [30], reported the wettability time and tapped density of freeze dried samples (pumpkin, quince and kiwi) as 77.33, 107.50, and 186.0s, and 250, 340 and 420 kg/m^3, respectively. However, in our study the wettability time values showed an inverse relationship with tapped density of the powder products.

Dispersibility is defined as the ability for the powder products to getting wet and dispersing without formation of dry lumps in water [49]. The average dispersibility values of the freeze dried powders were found to be 82.82, 75.71, and 62.52% for 3, 5, and 7mm, respectively (Table 6) and according to these results it can be stated that the average dispersibility values of the samples decreases depending on increasing drying thicknesses ($P<0.05$). The porous structure of the powder particles can affect the dispersibility property positively and the decrease of the pores with the increase in drying thicknesses supports this ($P<0.05$), mainly due to the differences in the moisture content values. Since bulk density, flow behavior, wettability and other properties are referred to as powder properties; they are influenced by moisture content of the powders [47]. fact. Erguney et al. [51] reported the dispersibility values of freeze dried cherry laurel powder (without carrier agent) as 81% and Jaya and Das [52] reported the dispersibility values of foods (instant coffee, tomato soup powder, mango powder etc.) are in the range of 68.19 to 99.98%. The results of our study are consistent with the reported values.

Hygroscopicity depends on the composition (low molecular weight sugar, organic acid, and moisture content, etc.) of the product [53]. As given in Table 6, the hygroscopicity values of the powders were affected by the change of drying thicknesses ($P<0.05$). The results are similar to the values reported in the literature as 7.68% for grugru palm [54], 7.20% for mango powder [52] and between 4.21-6.64% for tomato soup powder [52]. Erguney *et al.* [51] determined the hygroscopicity value of cherry laurel powder as 9.2% which can be explained by the lower moisture content (2.43%) of the powder product.

The values of caking degree for the powders are given in Table 6 as ranging between 42.04-49.95%. Depending on the changes in the drying thicknesses, significant differences were observed in the caking degree of the powders ($P<0.05$). The caking degree values of the powders are affected by the moisture content of the products and by differences in composition and product structure.

The selected images from the SEM microstructure analysis of the freeze-dried powders are given in Fig. 3 for different drying thicknesses.

The SEM images show that the appearance of the powder particles is in the form of a flake is similar to the SEM images of freeze-dried powders in the literature [45, 49]. Considering the SEM images of the powders at 100× magnification (pictures not given here) it was observed that particle sizes of the powders dried at 3 mm are higher than the others explaining the reason for high bulk and tapped densities of the powders dried at 5 and 7 mm thicknesses.

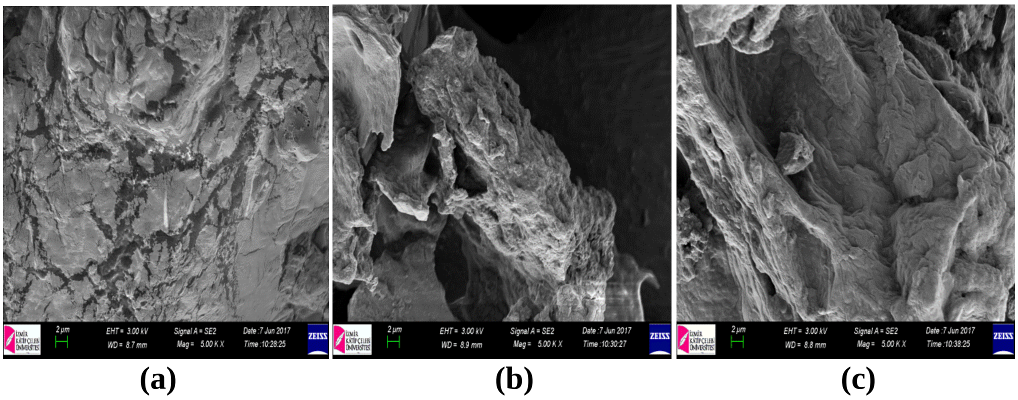
The results obtained from DSC analysis giving the glass transition temperature of the samples of the cherry laurel puree dried at the thickness of 5 mm are shown in Fig. 4.

According to the result of the DSC analysis, there are two transitions in the thermal flow thermogram. The glass transition temperature of the powder was calculated using the onset, mid and end points of the glass transition.

Table 6. Powder properties of the powders.

Properties	Cherry Laurel Powders Dried at Different Thicknesses		
	3mm	5mm	7mm
Bulk Density (kg/m^3)	99.75 ± 0.79^{a}	110.83 ± 0.62^{b}	113.88 ± 1.53^{c}
Tapped Density (kg/m^3)	136.20 ± 1.03^{a}	182.40 ± 1.32^{c}	166.35 ± 0.97^{b}
Flowability	26.75 ± 1.13^{a} (Fair)	39.24 ± 0.57^{c} (Bad)	31.53 ± 1.31^{b} (Fair)
Cohesiveness	1.37 ± 0.02^{a} (Intermediate)	1.65 ± 0.02^{c} (High)	1.46 ± 0.03^{b} (Intermediate)
Wettability time (s)	3.25 ± 0.25^{c}	2.83 ± 0.13^{b}	2.37 ± 0.04^{a}
Dispersibility (%)	82.82 ± 0.71^{c}	75.51 ± 0.69^{b}	62.52 ± 0.97^{a}
Hygroscopicity (%)	7.18 ± 0.06^{b}	6.36 ± 0.52^{a}	6.78 ± 0.12^{a}
Degree of Caking (%)	47.14 ± 0.23^{b}	42.04 ± 0.85^{a}	49.95 ± 0.68^{c}

$^{a-c}$ Different letters in the same row indicate significant difference between the drying thickness at $P<0.05$.



(a) **(b)** **(c)**

Fig. 3. Scanning electron micrographs of cherry laurel powders for the three drying thicknesses: (a) 3 mm, (b) 5mm, and (c) 7mm at 5000× magnification.

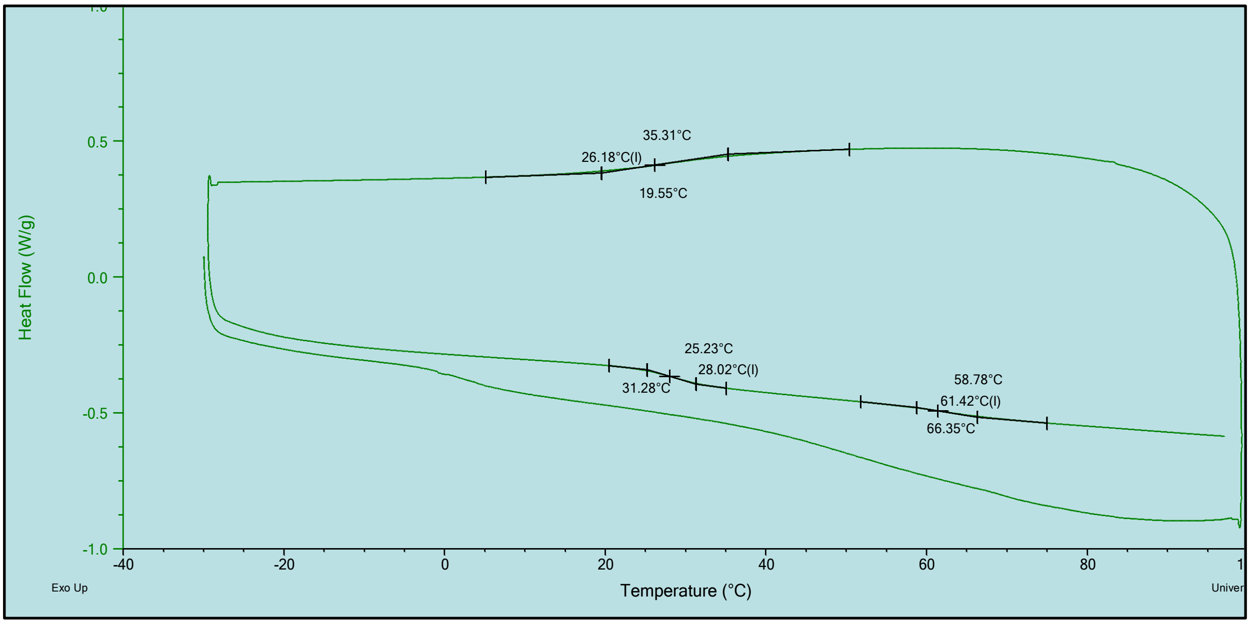


Fig. 4. Thermal flow thermogram of freeze-dried cherry laurel puree at 5 mm drying thickness

The first transition was measured as 28.18° and the second transition was at 62.19°C. To our knowledge, no study exists in the literature for the glass transition temperature measurement of cherry laurel powder. But Can-Karaca *et al*. [27] reported the glass transition of spray-dried sour cherry powders (a very similar fruit to cherry laurel) as between 7.7 ±1.0°C and 70.6±1.0°C with the addition of different amounts of carrier agents, carrier types and different inlet temperatures. Considering the glass transition temperature of 28.18°C it should be advised that the powders should be kept at temperatures lower than this value.

CONCLUSION

In this study, we observed that freeze drying can satisfactorily be applied for drying of cherry laurel puree to produce a powder and to provide prolonged consumption period. The present work describes the changes in some physicochemical and powder properties of powders dried at different thicknesses. Page and Logarithmic model which had the highest R^2 and lowest χ^2 and RMSE for all drying experiments were found to satisfactorily describe the drying behavior of cherry laurel puree. The calculated values of D_{eff} ranged between 4.700E-08 and 7.784E-08 m^2/s. The energy consumption was measured and it was observed that MER values and SMER of samples increased, and SEC values of samples decreased with increasing drying thickness. Moisture contents of the powders were found between 7.05 and 9.42% (wb). The measured water activity values of the powders are in acceptable limits for the safe storage of the products. The lightness value of cherry laurel puree was affected by the freeze-drying process and its value increased between 33.72% and 58.88%. ΔE values of the powders changed between 17.77±0.11, 14.71±0.48, and 13.69±0.74 for drying thickness of 3, 5, and 7 mm, respectively. The bulk density and tapped density values of the powders ranged between 99.75 and 113.88 kg/m^3, and 136.20-182.40 kg/m^3, respectively. Determination of flowability and cohesiveness in terms of Carr Index and Hausner ratio were evaluated as fair and bad, and intermediate and high levels, respectively. The determined average wettability times were less than 10 s. Caking degree of powders ranged between 42.04-49.95%. The results showed that average bulk and tapped density, wettability times, and caking degree of the powders significantly were affected by the drying thicknesses ($P<0.05$). Two transitions at 28.18°C and 62.19°C were observed with DSC analysis. The changes in tapped density, flowability, cohesiveness, hygroscopicity and caking degree followed the same tendency with moisture content values.

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REFERENCES

1. C. Alasalvar, M. Al-Farsi, F. Shahidi, *Journal of Food Science.* **70**, 1, 47 (2005).
2. S. Kolaylı, M. Kücük, C. Duran, F. Candan, B. Dincer, *Journal of Agricultural and Food Chemistry*, **51**, 7489 (2003).
3. S. Celik, I. Bakırcı, I.G. Sat, *International Journal of Food Properties*, **9**, 401 (2006).
4. E. Capanoglu, D. Boyacıoglu, R.C.H. de Vos, R.D. Hall, J. Beekwilder, *Journal of Berry Research*., **1**, 137 (2011).
5. C. Ratti, *Journal of Food Engineering*, **49**, 311 (2001).
6. F. Shishehgarha, J. Makhlouf, C. Ratti, *Drying Technology,* **20**, 1, 131 (2002).
7. T. Mahendran, *Tropical Agricultural Research & Extension*. **13**, 2, 48 (2010).
8. S.N. Dirim, G. Calıskan, *Gıda.* **37**, 4, 203 (2012).
9. O.A. Caparino, J. Tang, C.I. Nindo, S.S. Sablani, J.R. Powers, J.K. Fellman, *Journal of Food Engineering*,**111**, 135–148, (2012).
10. K. Ergun, G. Calıskan, S.N. Dirim, *Heat and Mass Transfer*, **52**, 2697 (2016).
11. A. Akyıldız, S. Polat, E. Agcam, *Gıda*, **42**, 2, 169-176, (2017) (in Turkish).
12. AOAC, Gaithersburg, MD, USA: Association of Official Analytical Chemists, 2000.
13. E. Demirhan, B. Ozbek, *Chem. Eng. Comm.*, **198**, 10, 1189 (2011).
14. B. Cemeroglu, Gıda Analizleri, **34,** 145, 168, (2007) (in Turkish).
15. S.I.R. Franke, K. Chless, J.D. Silveria, G. Robensam, *Food Chemistry*, **8,** 45 (2004).
16. Y. Hısıl, Ege University Engineering Department Academic Press. 41, 2007 (in Turkish).
17. Z. Erbay, F. Icier, *Cr. Reviews in Food Sci. and Nutrition.* **50**, 441–464 (2009).
18. I. Alibas, *J. Bıol. Envıron. Scı.*, **6**, 17, 161 (2012).
19. J. Crank, The Mathematics of Diffusion. 2nd ed. Oxford (UK), Clarendon Press, 1975.
20. K.J. Chua, S.K. Chou, J.C. Ho, M.N.A. Hawlader, *Drying Technology*, **20**, 8, 1580 (2002).
21. W. Jindarat, P. Rattanadecho, S. Vongpradubchai, *Experimental Thermal and Fluid Science***,** **35**, 728 (2011).
22. G.R. Chegini, B. Ghobadian, *Drying Technology*, **23**, 657 (2005).
23. N. Jinapong, M. Suphantharika, P. Jamnong, *Journal of Food Engineering*, **84**, 194 (2008).
24. Z. Gong, M. Zhang, A.S. Mujumdar, J. Sun, *Drying Technology,* **26**, 116 (2008).
25. J. Pisecky, Standards, specifications and test methods for dry milk products: in Concentration and

Drying of Foods, Elsevier Science Publishing. 203 (1985).

26. S. Jaya, H. Das, *Journal of Food Engineering,* **63**, 125 (2004).
27. A. Can-Karaca, O. Guzel, M.M. Ak, *J. Sci. Food Agric.* **96**, 449 (2016).
28. Y.S. Quek, N.K. Chok, P. Swedlund, *Chemical Engineering and Processing* **46**, 386 (2007).
29. L.T. Ng, P.H. Chong, Y.A. Yusof, N.L. Chin, R.A. Talib, T.S. Taip, M.G. Aziz, *Food Science Biotechnology,* **2**, 582 (2012).
30. S.N. Dirim, G. Calıskan, K. Ergun, *Gıda*, **40**, 2, 85 (2015) (in Turkish).
31. G. Calıskan, S.N. Dirim, *Gıda*, **40**, 1, 9 (2015).
32. R. Kasım, M. Sulusoglu, M.U. Kasım, *African Journal of Plant Science,* **5**, 5, 323 (2011).
33. H. Halilova, S. Ercisli, *Biotechnology & Biotechnological Equipment*, **24**, 3, 1970 (2010)
34. I.T. Karabegovic, S.S. Stojicevic, D.T. Velickovic, Z.B. Todorovic, N.C. Nikolic, M.I. Lazic, *Industrial Crops and Products*, **54**, 142 (2014).
35. K. An, D. Zhao, Z. Wang, J. Wu, Y. Xu, G. Xiao, *Food Chemistry,* **197**, 1292 (2016).
36. S. Ercisli, F. Celik, S.O. Yılmaz, A. Hegedus, *Hort. Science*, **46**, 6, 924 (2011)
37. H. Yıldız, S. Ercisli, H.K. Narmanlıoglu, S. Guclu, M. Akbulut, Z. Turkoglu, *Genetika,* **46**, 1, 129 (2014).
38. L. Valadez-Carmona, C.P. Plazola-Jacinto, M. Hermandez-Ortega, M.D. Hermandez-Navarro, F. Villarreal, H. Necoechea-Mondragon, A. Ortiz-Moreno, G. Ceballos-Reyes, *Innovative Food Science and Emerging Technologies*, **41**, 378 (2017).
39. L.G. Marques, J.T. Freire, *Drying Technology,* **23**, 2169 (2005).
40. L.G. Marques, M.C. Ferreira, J.T. Freire, *Chemical Engineering and Processing*, **46**, 451 (2007).
41. S. Oztekin, T. Erdem, S. Karaaslan, *Journal of Agricultural Machinery Science*, **6**, 2, 79 (2010).
42. D.S. Souza, L.G. Marques, E. de B. Gomes, N. Narain, *Drying Technology,* **33**, 194 (2015).
43. G. Calıskan, K. Ergun, S.N. Dirim, *Italian Journal Food Science*, **27**, 385 (2015).
44. A. Kaya, O. Aydın, *Journal of Food Process Engineering,* **31**, 398 (2008).
45. T. Baysal, N. Ozbalta, S. Gokbulut, B. Capar, O. Tastan, G. Gurlek, *J. of Thermal Science and Technology,* **35** (1), 135 (2015).
46. D.E. Walton, *Drying Technology,* **18**, 9, 1943 (2000).
47. A.M. Goula, K.G. Adamopoulos, *Drying Technology,* **26**, 6, 726 (2008).
48. M. Koç, B. Koç, F. Kaymak-Ertekin, *Akademik Gıda,* **9**, 4, 60 (2011) (in Turkish).
49. P. Schuck, Milk Powder: Physical and Functional Properties of Milk Powders, Elsevier Academic Press, London, UK, **2**, 117-124 (2011).
50. B. Freuding, S. Hogekamp, H. Schubert, *Chemical Engineering and Processing,* **38**, 525 (1999).
51. E. Erguney, Z. Gulsunoglu, E. Fıratgil-Durmus, M. Kılıc-Akyılmaz, *Akademik Gıda,* **13**, 2, 108 (2015) (in Turkish).
52. S. Jaya, H. Das, *Journal of Food Processing and Preservation,* **29**, 45 (2005).
53. C.C. Ferrari, S.P.M. Germer, I.D. Alvim, F.Z. Vissotto, J.M. de Aguirre, *International Journal of Food Science and Technology,* **47**, 1237 (2012).
54. D.M. Oliveria, E. Clemente, M.R.A. Aonso, J.M. Correia da Costa, *American Journal of Analytical Chemistry,* **4**, 1 (2013).

ОПРЕДЕЛЯНЕ НА ХАРАКТЕРИСТИКИТЕ НА СУШЕНЕ НА ПЮРЕ ОТ ЛАВРОВА ЧЕРЕША (*LAUROCERASUS OFFİCİNALİS ROEM.*) В СУШИЛНЯ-ФРИЗЕР

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(Резюме)

В статията се изследва влиянието на дебелината на слоя върху отнасянето на пюре от лаврова череша (*Laurocerasus officinalis Roem.*) при сушене чрез замразяване и са определени физичните, химичните и праховите свойства на получените прахове. Изчислена е енергийната ефективност на процеса на сушене. Пробите са сушени при дебелини на слоя от 3, 5 и 7 mm. Между дванайсетте модела на сушене на тънки слоеве, моделът на Page (3 и 5 mm) и логаритмичният модел (7 mm) описват задоволително отнасянето при сушене. Времето на сушене с повишаване на степента на изсушаване е 8, 10 и 11 ч. Специфичният разход на енергия намалява с увеличаване на дебелината. Стойностите на специфичната дифузивност на влагата (D_{eff}) са 4.70-7.78E-08 m^2/s. Съдържанието на тотални фенолни съединения и витамин C са съответно 710 mg GAE/100g (db) и 23 mg/100g (db)). Обемната плътност е между 99.75 и 113.88 kg/m^3, а течливостта и сцеплението са съответно на ниво средно-лошо и междинно-високо.