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EFFECT OF DRYING METHODS ON DRYING CHARACTERISTIC, ENERGY CONSUMPTION AND COLOR OF NECTARINE

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ABSTRACT

The effect of drying methods on drying characteristic, energy consumption and color has been investigated for nectarine in this study. Sun, hot air, microwave and infrared drying techniques were applied as drying methods. The drying temperature was determined as 50 ºC for hot air drying of nectarine, as the applied powers were 90W and 83W for microwave and infrared dryings, respectively.

The results obtained from the experiments indicate that the **microwave** drying method is the most effective method for drying of nectarine. The higher "L" value and lower "-a/b" ratio values were obtained in hot-air dried nectarine slices. The results have been modelled with six different models in the literature to determine the drying kinetics for nectarine. Comparing the high R^2, low RMSE and $\chi 2$ values for all drying methods; it is presented that "Midilli et al." model is the most convenient model for drying of nectarine.

INTRODUCTION

Nectarines (*var. nucipersica* or *var. nectarina*) and peaches (*Prunus persica*) belongs to Rosaceae family. The nectarine is a peach with recessive genes and referred as a "shaved peach" or "fuzzless peach", due to its lack of fuzz or short hairs. There are also some differences including fruit size, shape, firmness, external color, aroma and flavor. Nectarine fruit, which can be yellow or white fleshed, have smooth skin, a distinctive flavor and texture, and are usually smaller [1-3]. The nectarine is loaded with health benefits, such as antioxidants, Vitamins A and B, and Potassium. To keep nectarine for longer time, it must be stored in refrigerator or controlled atmosphere condition. Drying is an alternative method for long storage and an ancient process used to preserve food and extend the shelf life of food. Drying not only affects water content of the plants but also inhibits microorganism growth and prevents degradation because of bio-chemical reactions.

The objectives of this study are to evaluate and compare the drying kinetics, product quality and specific energy consumption during the drying of nectarine slices by four drying methods: (1) hot-air drying, (2) sun drying (3) IR drying and (4) microwave drying.

In addition to this to obtain the best model for the drying kinetics of nectarine slices; Lewis, Henderson & Pabis, Page, Aghbashlo et al., Verma et al. and Midilli et al. models were fitted to the experimental data.

EXPERIMENTAL

Materials and Methods

The experiments were carried out using nectarine (Prunus persica var. nucipersica eller var. nectarina) purchased from a local market. The selected nectarine samples were cleaned with tap water to make samples free from foreign materials. Surface water was removed by blotting with absorbent paper. In order to preserve its original quality, they were stored in a refrigerator at 4 ± 1 °C until drying experiments.

Dry matter and moisture content of the fresh samples were determined prior to drying process. The moisture contents of the samples were obtained by the Association of Official Analytical Chemists [4]. To determine the initial moisture content, 30 g of sample was dried in an oven (Memmert UM-400) at 105 ºC for 24 h and this experiment was repeated four times. The average initial moisture content of nectarine slices was found as 84 % w.b.

Drying experiments were carried out with a moisture analyzer with one 250 W halogen lamp (Snijders Moisture Balance, Snijders b.v., Tilburg, Holland) for the infrared drying process, a Robert Bosch Hausgerate GmbH (Germany) model microwave oven with a maximum output of 800 W working at 2450MHz for microwave drying, a cabinet type dryer (APV & PASILAC Limited of Carlisle, Cumbria, UK) for hot air drying. In all experiments, 50 g nectarine slices were selected from the uniform and healthy parts.

Also before the drying process samples cut as flat slabs (0.03x0.02x0.005m). The experiments were respectively performed at 83 W and 90 W for infrared and microwave dryings till the moisture contents of the samples reduced to 0.06 g water/g dry matter with infrared drying and 0.18 g water/g dry matter for microwave drying. Hot air drying process was performed at 50 ºC temperature with a constant air velocity of 1.0 ms^{-1}. The process was continued till the moisture content of the samples decreased the value of 0.07 water/g dry matter. Open-air sun drying experiments were carried out between 36 and 49 °C in August 2014 (08.00 AM- 20.00 PM) in Greece. When the moisture level of the sample decreased to 11% (w.b.), the process was finished. All experiments were repeated for three times and the average data was calculated by following equation.

Moisture content on dry basis (% d.b.):

$$M_{initial} = \frac{W_w - W_d}{W_d} \tag{1}$$

where, $M_{initial}$ is the initial moisture content of nectarine on d.b.%, Ww is the wet weight and W_d is the dry weight of nectarine in g.

Mathematical Modeling

In order to determine the moisture ratio as a function of drying time, six different thin-layer drying models, namely Lewis, Henderson & Pabis, Page, Aghbashlo et al., Verma et al., and Midilli et al., were investigated (Table 1). The moisture ratio and drying rate of nectarines were calculated using the following equations (Eq. 2 and 3):

$$MR = \frac{M_t - M_e}{M_o - M_e} \tag{2}$$

where, MR is the moisture ratio, M_t, M_o and M_e are the moisture content (g water /g dry matter) on dry basis at any time, initial and equilibrium, respectively. The equilibrium moisture content (M_e) was assumed to be zero for microwave and infrared drying and the MR equation (Equation 2) was simplified as Equation 3 [5, 6]:

$$MR = \frac{M_t}{M_o} \tag{3}$$

Table 1. Thin layer drying curve models

Model name	Model	Reference
Lewis	$MR = \exp(-kt)$	[7]
Henderson and Pabis	$MR = a\exp(-kt)$	[8]
Page	$MR = exp(-kt^n)$	[9]
Aghbashlo et al.	$MR = \exp\left(-\frac{k_1 t}{1 + k_2 t}\right)$	[10]
Verma et al.	$MR = a\exp(-kt) + (1-a)\exp(-gt)$	[11]
Midilli *et al.*	$MR = a\exp(-kt^n) + bt$	[12]

Statistical Analysis

The statistical analysis of experimental data was determined using Statistica 8.0.550 (StatSoft, Inc., Tulsa, OK) software package, which is based on the Levenberg–Marquardt algorithm. The three criteria of statistical analysis have been used to evaluate the adjustment of the experimental data to the different models: the coefficient of determination (R^2), reduced chi-square (χ^2) and root-mean-square error (RMSE). These parameters can be calculated as:

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N - z} \tag{4}$$

where, $MR_{exp,i}$ and $MR_{pre,i}$ are the experimental and predicted dimensionless MR, respectively, N is the number of data values, and z is the number of constants of the models.

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{\exp,i}\right)^2\right]^{1/2} \tag{5}$$

Color Measurements

Color analysis for fresh, microwave dried, infrared-dried, hot-air dried and sun-dried nectarine sample was done with Chromameter CR-400 (Minolta, Japan) on three randomly selected slices at 5 different locations. Color test of the nectarine samples were replicated for five times and the average values were calculated. Three parameters (lightness, redness and yellowness) for the fresh and dried samples were investigated. L, a and b respectively present darkness-lightness, greenness-redness and blueness-yellowness. The lightness or darkness of the sample was represented on the scale of 0–100; where, white = 100 and dark = 0. Hunter represents redness and yellowness as positive (+), and greenness and blueness as negative (−) [13]. The R were determined using the following equation [14].

$$R = \frac{a}{b} \quad (6)$$

Energy Consumption

E_t is the total energy consumption for infrared drying is calculated using following equation:

$$E_t = P * t \quad (7)$$

where; E_t is total energy consumption (kW h), P is infrared power level (kW), t drying time (h).

The energy consumption value in the microwave drying of nectarine slices was calculated with Equation 8 [15].

$$E_t = P * t \quad (8)$$

where; P is microwave output power (kW).

In hot air drying, the electricity requirement for both drying of the samples and blowing of the air are considered in the total energy consumption and given by Equation 9 [16]:

$$E_t = \rho_a A v c_a \Delta T * D_t \quad (9)$$

where; E_t is total energy consumption (kWh), ρ_a is air density (kg/m^3), A is cross sectional area of container in which sample is placed, (m^2), υ is air velocity (m/sec), c_a is specific heat (kJ/kg °C), ΔT is a temperature difference between inlet and outlet air (°C), D_t is total drying time of each sample (h).

RESULTS AND DISCUSSION

Figures 1 demonstrates the drying curves of nectarine for different drying methods. It is seen that moisture ratios decrease continuously with drying time. As seen in these curves, no constant rate period was observed in drying of nectarine, while a falling rate period was occurred. The moisture ratio decreases to 0.18 in 56 minutes with microwave drying, to 0.06 in 390 minutes with infrared drying, to 0.07 in 660 minutes with hot-air drying and to 0.11 in 1380 minutes with sun drying.

Figure 2 and 3 show the effect of drying method on the drying rate as a function of moisture content for nectarine. Due to the drying time is significantly shorter in microwave drying than the other drying methods; the microwave drying rate is given in separate graphs (Fig. 3). A rising drying rate period was seen in hot air and microwave dryings, while a constant drying rate was obtained with infrared drying. Sun drying method showed two different drying rate period which can be attributed the temperature differences over the drying progress. Similar findings were reported in previous studies [17-19].

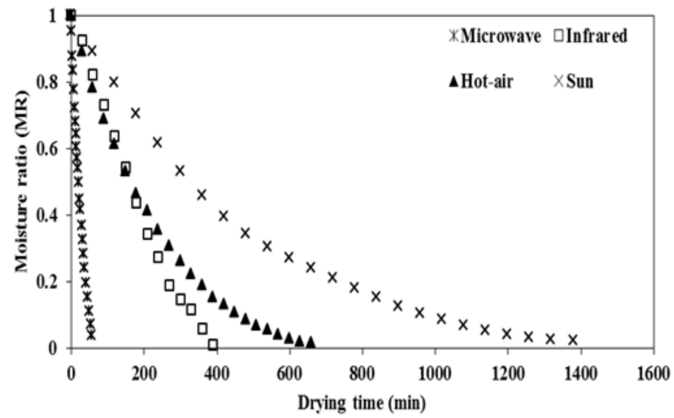

Figure. 1. Moisture ratios versus drying time for microwave, infrared, hot air and sun dryings

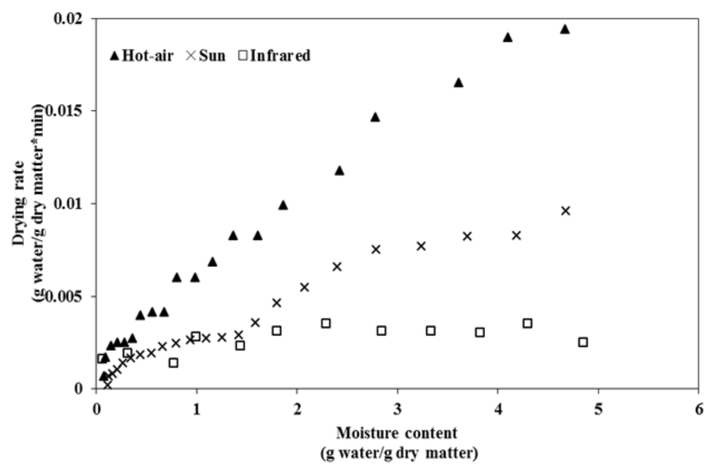

Figure 2. Drying rate versus moisture content of nectarine with different drying methods

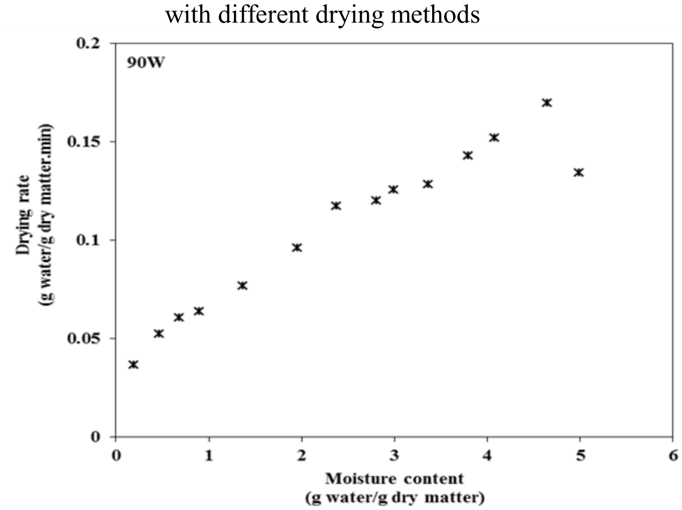

Figure 3. Drying rate versus moisture content of nectarine with microwave drying

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. The values of L (lightness), a (greenness) and b (yellowness) were measured for all dried nectarine samples and are given in Table 1.

Table 1. Color parameters of fresh and dried nectarine slices

Drying methods	Drying conditions	Color parameters			R
		L	a	b	
	Fresh	65.10	6.00	21.56	0.28
Infrared	83 W	63.86	14.22	34.45	0.41
Microwave	90 W	53.85	11.10	19.47	0.57
Hot-air	50 ºC	**69.91**	11.39	30.64	**0.35**
Sun	36 to 49 °C	53.14	13.84	17.85	0.77

As shown in Table 1, the best color parameters were obtained as L=69.91 and a/b=0.35 in hot air drying. Similar results are also available in the literature [20, 21].

Thin-layer drying models, namely, the Lewis, Henderson and Pabis, Page, Aghbashlo et al., Verma et al. and Midilli et al. were used to describe the drying process during drying of nectarine slices. In order to describe the moisture ratio as a function of drying time at the various drying methods, six drying models were fitted to experimental data and their coefficient of determination (R^2), reduced chi-square (χ^2) and root-mean-square error (RMSE) were calculated. The calculated R^2, RMSE and χ2 values are given in Table 2. The quality of fitting was determined by the lowest χ2 and RMSE values and the highest R^2 values.

As seen in Table 2, six different models were applied for all drying methods and removable moisture ratio with the lowest degree of error was obtained with Midilli et al. model. Applying this model to all drying methods, RMSE value varied between 0.004252 and 0.009452, χ2 value between 0.000070 and 0.000113, and R^2 value between 0.9991 and 0.9997. Several authors have reported good results from the application of the Midilli at al., model to the drying kinetics of foods [22-24].

The energy consumption values obtained with microwave, infrared and hot-air drying of nectarine slices is given in Figure 4.

Comparing three drying methods, it was seen that the lowest energy consumption was occurred in microwave drying method and this was followed by infrared and hot-air drying methods. Energy consumption was calculated as 0.092 kWh for microwave drying. The highest energy consumption was obtained as 1.78 kWh with hot-air drying. As there was no energy consumption in sun drying method, it was not given in the Figure 4. These results are in agreement with the observations of earlier researchers [25, 26].

Table 2. Statistical results obtained with the selected models

Drying methods	Drying cond.	Model	R^2	χ2	RMSE
Microwave	90 W	Lewis	0.9779	0.001816	0.04168
		Henderson and Pabis	0.9864	0.001147	0.03256
		Page	0.9969	0.000254	0.06922
		Aghbashlo et al	0.9988	0.000098	0.99880
		Verma et al	0.9758	0.002956	0.04987
		Midilli et al	0.9992	0.000073	0.00499
Infrared	83 W	Lewis	0.9632	0.00459	0.16236
		Henderson and Pabis	0.9699	0.004292	0.15708
		Page	0.9969	0.000439	0.04123
		Aghbashlo et al	0.9990	0.000138	0.02546
		Verma et al	0.9583	0.004685	0.06466
		Midilli et al	0.9994	0.000070	0.00775
Hot-air	50 ºC	Lewis	0.9929	0.000638	0.02467
		Henderson and Pabis	0.9943	0.000533	0.02203
		Page	0.9982	0.000169	0.01240
		Aghbashlo et al	0.9996	0.000029	0.00512
		Verma et al	0.9866	0.001510	0.03525
		Midilli et al	0.9997	0.000022	0.00425
Sun	36 to 49°C	Lewis	0.9864	0.001048	0.03155
		Henderson and Pabis	0.9876	0.001007	0.03010
		Page	0.9904	0.000780	0.02649
		Aghbashlo et al	0.9903	0.000785	0.02658
		Verma et al	0.9890	0.000944	0.02832
		Midilli et al	0.9991	0.000113	0.00945

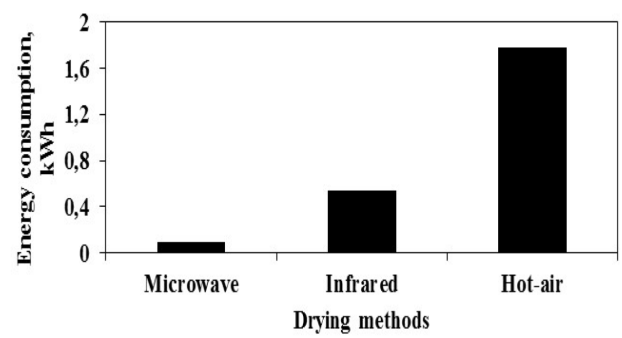

Figure 4. Energy consumption versus drying methods

CONCLUSION

The effect of drying methods, (sun, hot air, microwave and infrared drying) on drying characteristic, energy consumption and color has been studied for nectarine.

Comparing the drying time and energy consumption, the microwave drying was determined as the most efficient process for drying of nectarine. Drying time was obtained as 56 minutes and energy consumption as 0.092 kWh. The best color parameters were obtained as L=69.91 and a/b=0.35 in hot air drying.

All experimental results were fitted to six different models which show the change in the moisture content of nectarine. The Midilli et al. model showed the closest result to the experimental results and was assumed as the best model to be used in drying of nectarine.

NOMENCLATURE

M_{in}	Initial moisture content (g water /g dry matter)
W_w	Wet weight (g)
W_d	Dry weight (g)
MR	Moisture ratio (dimensionless)
M_e	Equilibrium moisture content (g water/ g dry matter)
M_t	Moisture content at any time during drying (g water/g dry matter)
M_o	Initial moisture content (g water /g dry matter)
χ^2	Chi-square
$RMSE$	Root mean square error
N	Number of observations
z	Number of constants
$MRexp$	Experimental moisture ratio
$MRpre$	Predicted moisture ratio
R^2	Determination of coefficient
k, n, a, b, g, k_1, k_2	Constants in models
t	Drying time (min)
E_t	Total energy consumption (kW h)
P	Infrared or microwave power level (kW)
ρ_a	Air density(kg/m^3)
A	Cross sectional area (m^2)
υ	Air velocity (m/sec)
c_a	Specific heat (kJ/kg °C)
T	Temperature (°C)
a	Greenness
b	Yellowness
L	Lightness

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