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INVESTIGATION ON DRYING BEHAVIOR OF ISPARTA ROSE FLOWERS (*ROSA DAMASCENA* MILL.) UNDER NATURAL SHADE CONDITIONS

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Abstract

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The present study was carried out to determine drying characteristics of Isparta Rose (*Rosa damascena* Mill.) under natural shade conditions. Four experiments were conducted during the rose flower harvest session.

Fresh rose flowers, harvested between 13th May and 11th June 2010. A naturally ventilated storage building was modified into an ideal ambience for shaded natural drying and designed trays with shelves were used for drying. For the drying process 1000±1 g samples were laid onto each shelf.

During the experiments, indoor and outside climate conditions such as temperature, humidity and weight loss and drying time were continuously recorded. The moisture content (MC), moisture ratio (MR) and drying rate were calculated. Those data correlated with 13 different drying rate kinetic models. The initial average moisture content of the rose flowers was 79.6±2.32% w.b. After drying, the product with an average weight of 214.1±24.6 g and with a final average moisture content of 7.11±0.83% w.b. was obtained. Drying time varied between 72-162 h (3-7 day) depending on the climatic conditions.

Models developed by Bala (1998) and Verma et al. (1985) were found to be the most suitable for describing the drying curve of the Isparta Rose with r^2 of 1.00 and 0.99, χ^2 of 0.000023 and 0.001813 and RMSE of 4.6×10^{-12} and 0.038388, respectively. As a result, during the natural shaded drying process it is seen that rose flower has hygroscopic characteristics. Rose flower is highly affected by air temperature and humidity during drying. For this reason, the drying process must be conducted properly in a short period.

Key words: drying model, drying rate, isparta rose (*rose damascena* mill.), moisture ratio, natural drying

Introduction

Rosa damascena Mill. with the commercial name Isparta Rose is a cultured valuable plant and oil is produced from the flowers (Ercisli, 2005; Franz and Novak, 2010). The Isparta Rose, also as known as oil rose and oil pink rose, is registered geographical location and produced in Isparta, Burdur, Afyonkarahisar and Denizli provinces of Turkey (Resmi Gazete, 2006).

Isparta is located at 37°46′N and 30°33′E and 1035 m above sea level in the West Mediterranean Region. Turkey produces almost 53% of the world's rose oil production (Gülcicegi Raporu, 2011) while the other producers are Bulgaria and China, production is only in a trace amounts. Rose cultivation in Turkey is concentrated within the Isparta with a share of 90% total production. The most important end products are rose oil, rose oil solid (rose concrete), rose absolute and rose water (Baydar et al., 2005).

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Baydar et al. (2008) propose that drying rose petals would introduce new utilization opportunities such as decorative, herbal, aromatic, hydrotherapeutic and cosmetic uses.

In recent years, usage of roses in health and aroma therapy applications has caused an increasing demand. Preservation of color, flavor and essential oils is of great importance during the drying process of medical and aromatic plants. Therefore, the relationships between temperature and humidity levels of drying air, drying speed and drying duration should be optimized (Bayhan et al., 2011).

In recent years, a number of studies have been carried out developing alternative products of rose flowers. The drying technique is one of the primary methods for product preservation and protection. Drying technique is a process used after the harvest for medicinal and aromatic plants in order to lower humidity from ~ 85% wb to ~% 8-12 wb for appropriate storage conditions. The drying process should be successfully completed in a short period in order to prevent roses from decomposing should use minimum energy for commercial concerns (Brennan, 2003; Polatci, 2008).

The drying process must be conducted in the production fields because of the restricted production of the Isparta Rose within the region (Baydar et al., 2005; Baydar, 2007). Harvest periods is very short approximately 40 days (from the second half of May to the end of June), (Loghmani-Khouzani, et al., 2007; Okan, 1962 in Demirozer, 2008; Saribas and Aslancan, 2011) and transportation and storage of harvest is difficult when it is fresh (Baydar et al., 2008). However, studies on this topic are limited and insufficient (Oztekin and Soysal, 2000a; Oztekin, 2001; Ozguven et al., 2006).

According to the study conducted by Oztekin and Soysal (2000a), drying 160 kg rose flowers in a tray type drying process at a 40°C drying air temperature, took 5 hours to reduce moisture content from 80% w.b. to 29% w.b.. In another project, the same drying system was applied with different drying air temperatures varying between 46.8-53.3°C. In the experiments, different weights of rose flowers were laid onto shelves. In only one experiment, before the rose flowers were laid into the dryer, 4 hours wilting was applied. During the wilting process, the rose flowers lost their moisture content from 84.93% w.b. to 78.50% w.b. in a 35°C ambient temperature (Oztekin, 2001).

The objectives of this study were to investigate the drying characteristics of the Isparta Rose under natural shade conditions, to fit the drying curves with mathematical models and to calculate the diffusivity coefficients for Isparta Rose.

Experimental Design

Fresh rose flowers were harvested between 13th May and 11th June 2010, and were supplied by Gülbirlik (The Agriculture Sales Cooperatives for Rose, Rose oil and Oil-Bearing Seeds), Isparta-Turkey. After harvest, rose flowers were transported to the drying area within sacks. Fresh flowers (1000 g) were laid onto shelves as a thin layer after measuring their weight with an assay balance (Table 1). Every day between 2:00-4:00 pm when the relative humidity is at its lowest, 35 selected shelves -7 shelves from 5 trays- were weighed in order to determine weight loss. Fresh and dry rose flower examples were sampled to determine initial and final moisture content. Harvest moisture of rose flowers used in the trials ranged between 76.3-81.7% w.b. (Figure 1).

A ventilated storage building (10 x 20 x 8 m) was modified into an ideal ambience for shaded natural drying and specially designed trays with shelves were used to determine drying characteristics of Isparta Rose (Figure 1a).

12 experimental large tray dryers were designed to dry aromatic and medicinal plants for large-scale industrial purposes. Every tray has seven two-sided layers, making a total of 14 shelves. The tray dryers were designed with wheels to ease transportation. Every shelf has a 1 m^2 drying area with a sliding loading and uploading mechanism (Figure 1b).

Five microdatalogger were placed on trays to record continuously temperature and humidity during the drying process. One microdatalogger was placed outside of the building in order to record the outside climatic conditions. Moreover, to measure weight loss directly related with thin layer drying, an assay balance was used to measure the shelves every day at 2:00 pm (Figure 1a, Table 1).

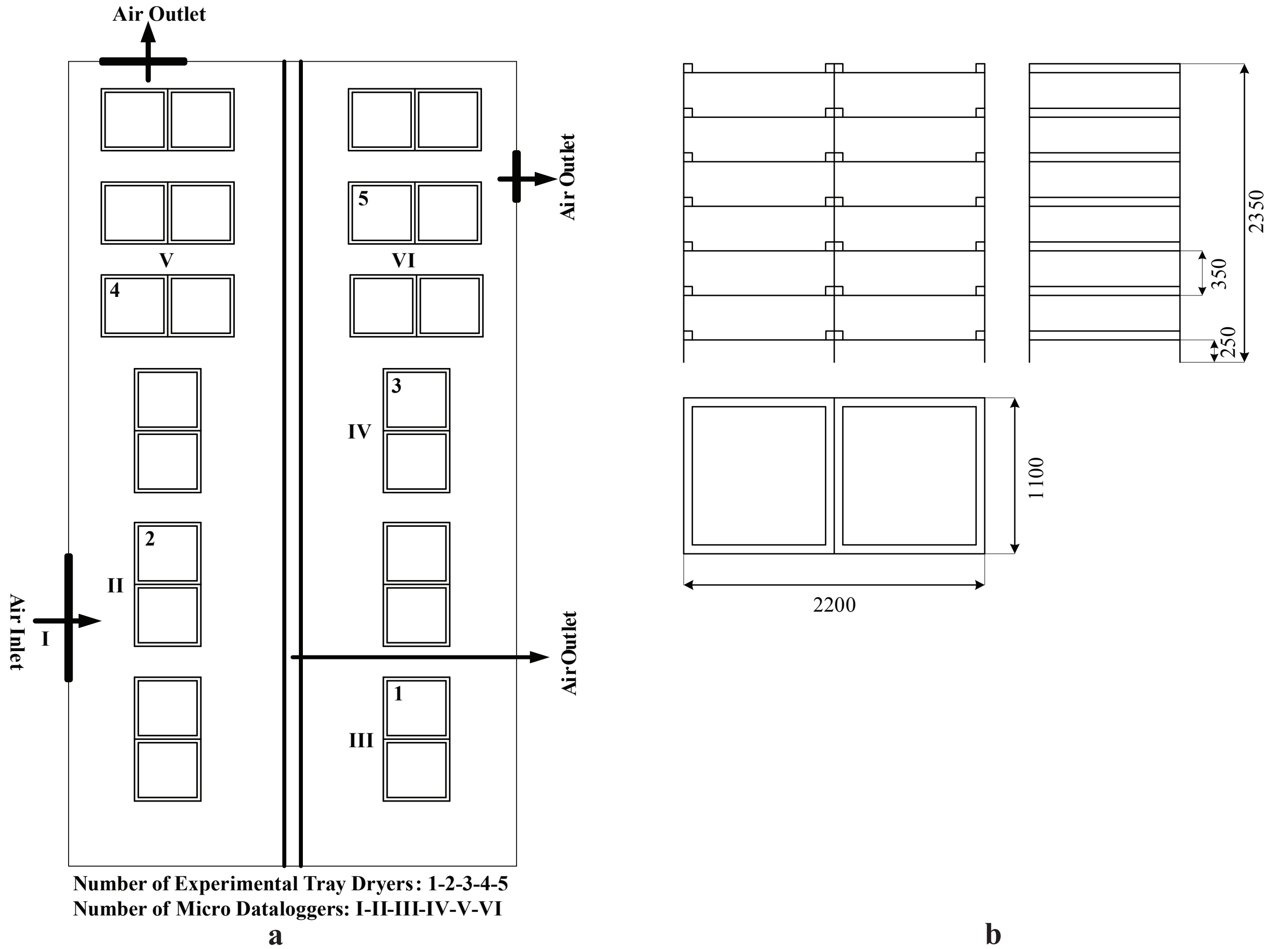

Fig. 1. Placement (a) and technical drawing (b) of tray dryers

Table 1
Specifications of instruments including their rated accuracy

Instrument	Model	Range & Accuracy	Made by
Micro Datalogger (Temperature/RH/Light/External)	H8 Pro	-20 to 70°C, e=±0.6°C 25-85%RH (15 to 45°C), e=±3,5%RH	Hobo, USA
Balance (Weight)	UX6200H	0.5-6200 g, e=±0.1	Shimadzu, JAPAN

Determination of Moisture Content (MC)

MC is commonly defined either as mass of water (m_w) per total mass (m_w+m_{DM}) noted as $MC_{w.b.}$ (w.b. for wet basis) in percentage (Müller and Heindl, 2006):

$$MC_{w.b.} = \left(\frac{m_w}{m_w + m_{DM}}\right).100$$

or as mass of water (m_w) per dry mass (m_{DM}) noted as $MC_{d.b.}$ (d.b. for dry basis) frequently as a percentage, but better given as a ratio:

$$MC_{d.b.} = \left(\frac{m_w}{m_{DM}}\right)$$

The initial (from 500 g fresh sample) and final (from 100 g dried sample) moisture content of the samples were determined (in triplicate) using the hot-air oven (Nuve EN 055, Turkey) method at 70°C for 48 h.

Mathematical Modeling of Drying Curves as Moisture Ratio and Drying Rate

The moisture ratios (MR) of the Isparta Rose flowers were calculated using the following equation:

$$MR = \frac{M - M_e}{M_o - M_e}$$

where MR is the dimensionless moisture ratio, M is the moisture content at any specific time in % w.b., M_e is the equilibrium moisture content in % w.b and M_o is the initial moisture content in % w.b. However, MR was simplified to M/M_o since the relative humidity of the drying air fluctuated continuously under natural drying conditions (Diamente and Munro, 1993). To determine the moisture ratio as a function of drying time, not only three popular thin layer-drying models were used but also many others that may be suited. For the mathematical modeling, the equations were tested to select the best model for describing the drying curve equation for Isparta Rose during natural shade drying. The thin layer drying curves were obtained fitted to the drying models in (Table 2).

Microsoft Excel 2010 was used in numerical calculations. The parameters were evaluated by the non-linear least squares method of the Marquardt-Levenberg procedure. Reduced chisquare (χ^2), root mean square error (RMSE) and the coefficient of determination (R^2) were used as the primary criteria to select the best equation to account for variation in the drying curves of the dried samples which are described as follows:

$$R^2 = \frac{\sum_{i=1}^{n}(MR_i - MR_{pre,i}) . \sum_{i=1}^{n}(MR_i - MR_{exp,i})}{\sqrt{\left[\sum_{i=1}^{n}(MR_i - MR_{pre,i})^2\right] . \left[\sum_{i=1}^{n}(MR_i - MR_{exp,i})^2\right]}}$$

$$\chi^2 = \frac{\sum_{i=1}^{n}(MR_{exp,i} - MR_{pre,i})^2}{N - n}$$

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

where $MR_{exp,i}$ is the i^{th} experimentally observed moisture ratio, $MR_{pre,i}$ is the i^{th} predicted moisture ratio, N is the number of observations and n is the number of constants in the drying model. Based on the criteria of the lowest reduced chi-square and RMSE and the highest R^2, the best model to describe the thin layer drying characteristics was chosen (Rayaguru and Routray, 2011; Vega-Gálvez et al., 2010).

In the statistical modeling procedure, a nonlinear regression procedure using the MATLAB computer

Table 2
Selected thin layer mathematical drying models for describing drying curves (MR)

Model no.	Equation	Model name	References
1	MR = exp(-kt)	Newton (Lewis or Exponential)	O'Callaghan et al.,1971
2	MR = a exp(-kt)	Henderson and Pabis	Henderson &Pabis, 1961
3	MR = a exp(-kt)+b exp(-gt)+c exp(-ht)	Modified Henderson and Pabis	Karathanos, 1999
4	MR = exp(-kt^n)	Page	Page, 1949
5	MR = a exp(-kt) + c	Logarithmic	Yağcıoğlu, 1999
6	MR = a exp(-k$_0$t) + b exp(-k$_1$t)	Two-Term	Henderson, 1974
7	MR = 1 + at + bt^2	Two-Term Exponential	Sharaf-Elden et al., 1980
8	MR = a exp(-kt) + (1-a) exp(-kbt)	Diffusion Approximation	Yaldiz and Ertekin, 2001
9	MR = a exp(-kt) + (1-a) exp(-gt)	Verma et al.	Verma et al., 1985
10	MR = 1+at+bt^2	Wang and Singh	Wang and Singh, 1978
11	MR = a exp(-kt^n) + b^t	Midilli et al.	Midilli et al., 2002
12	MR = exp(-(kt)^n)	Modified Page	Overhults et al., 1973
13	MR = A exp^{-Bt} A=(a$_0$+a$_1$ rh+a$_2$ T+a$_3$ rh^2+a$_4$ T^2) B=(b$_0$+b$_1$ rh+b$_2$ T+b$_3$ rh^2+b$_4$ T^2) RH: Relative humidity of the drying air. T: Temperature of the drying air. t: Time of drying	Bala	Bala, 1998 in Smitabhindu, 2008

program was performed for the proposed models for model evaluation and for the fitting of the curves into the models.

Reduced chisquare RMSE and r^2 were calculated in order to evaluate the goodness of fit of the models. The lower the $\chi 2$ and RMSE values and the higher the r^2 values indicate the high fit of the model (Doymaz, 2003).

The equations below are used for the mathematical modeling MR of Isparta Rose flowers under natural shade drying conditions according to thin layer drying theory (Table 2).

The drying rate of the Isparta Rose flowers was calculated as follows: (Doymaz, 2006)

$$\frac{\Delta M}{\Delta t} = \lim_{\Delta t \to 0} \frac{M_{t+\Delta t} - M_t}{\Delta t}$$

where;

$\Delta M/\Delta t$: Drying rate (kg water /kg dry matter.hour)

M_t : Moisture content at the time of t (kg water /kg dry matter)

$M_{t+\Delta t}$: Moisture content at the time of $t+\Delta t$ (kg water /kg dry matter)

t, Δt : Time (hour)

Using the following equation to calculate the drying rate is more common (Yelmen, 2010):

$$Drying\ Rate = \frac{(M_{t+dt} - M_t)}{dt}$$

Sensory Evaluation

Eight panelists, trained in the discriminative evaluation of dried Isparta Rose flowers, conducted the sensory analysis. The visual appearance and odor of dried flowers were evaluated on a nine-point scale (9: Like extremely, 7: Like moderately, 5: Neither like nor dislike 3: Dislike moderately, 1: Dislike extremely). Scores under 4 points are considered to be unmarketable (Kramer and Twigg, 1984; Altug, 1993).

Results and Discussion

Shaded natural drying experiments were conducted during the harvest period of Isparta Rose flowers between May and June 2010 in Isparta Region. Humid and rainy climate conditions at harvest time make it hard to dry Isparta Rose flowers naturally. It is also observed that day and night temperatures and humidity differences affect Isparta Rose flowers.

The average initial and final moisture contents in % (w.b.) of the fresh and dry Isparta Rose flowers samples for the 4 trials were respectively 81.7±4.10, 80.1±2.80, 80.4±0.30, and 76.3±1.20 and 7.23±1.45, 5.93±0.35, 7.90±0.20, and 7.37±0.21 as determined by the outside and inside (ambient) weather conditions during shaded natural drying of Isparta Rose flowers, as shown in Table 3. More suitable climatic drying conditions in shade were in Exp III, Exp I, Exp IV and Exp II respectively

Table 3
Drying parameters under natural shade conditions for Isparta rose flowers

Drying parameters	Experiments			
	I	II	III	IV
Mean Inside Air Temperature, °C	19.3±3.52	17.4±3.97	20.0±3.39	18.5±3.48
Mean Outside Air Temperature, °C	20.0±6.75	17.7±5.39	20.4±4.91	18.7±4.30
Mean Inside Relative Humidity, %	41.6±9.80	57.3±12.59	49.9±13.15	60.6±12.74
Mean Outside Relative Humidity, %	41.1±18.18	56.1±20.00	50.7±20.46	66.2±20.41
Initial Moisture Content, % w.b.	81.7±4.10	80.1±2.80	80.4±0.30	76.3±1.20
Final Moisture Content, % w.b.	7.23±1.45	5.93±0.35	7.90±0.20	7.37±0.21
Final Drying Time, h	96	162	102	72
Total Exposure Time, h	162	162	120	162
Initial Weight, g	1000			
Final Weight, g	188.5±5.24	211.5±29.83	208.6±11.50	247.7±11.74
Dried Rose, %	18.85	21.15	20.86	24.77
Moisture Loss, %	81.15	78.85	79.14	75.23

(Table 3). Some parameters of thin layer drying under natural shade conditions for Isparta Rose flowers are shown in Table 3.

Drying performance is affected by drying ambient air temperature and relative humidity, which are related to outside climate conditions. It is observed that in experiments conducted on hot and dry days, the drying process took less time and more water evaporated. In this way, the end products with lower equilibrium moisture were produced. However, in experiments conducted on cooler and rainy-humid days, the drying process took more time and less water evaporated from the flowers. Moreover, initial moisture contents must be close to each other under natural shade drying.

In experiments conducted a while after the harvest showed that for Isparta Rose flowers if the analysis of the initial moisture contents and laying of the samples into shelves occur late, while initial moisture contents were lower, drying times and moisture losses will also be lower, as seen as in Experiment IV.

Experiment I

Experiment I was conducted over a period of 7 days. Outside air temperature had a lower relative humidity (RH) value for the first 3 days, after that it increased considerably due to the decreasing temperature. On the last 4 days, it was partly rainy and cloudy. During the experiment, the average outside temperature was 19.9°C (8.4 - 42.0°C). The average relative humidity was 41.2% but it also varied between 83.0% and 23.6% (Figure 2).

In Experiment I, the relationship between drying ambient air temperature and moisture, and daily changes in moisture content in the wet base of drying Isparta Rose flowers were examined. During the first 3 days of drying, a rapid drying rate was observed due to higher outside temperature and the lower RH value. In later days, a decrease in drying ambient air and an increase in RH value was observed. According to these, while Isparta Rose wet base moisture content was decreasing, after the 4th day it took moisture again due to the increase in ambient air moisture (Figure 3).

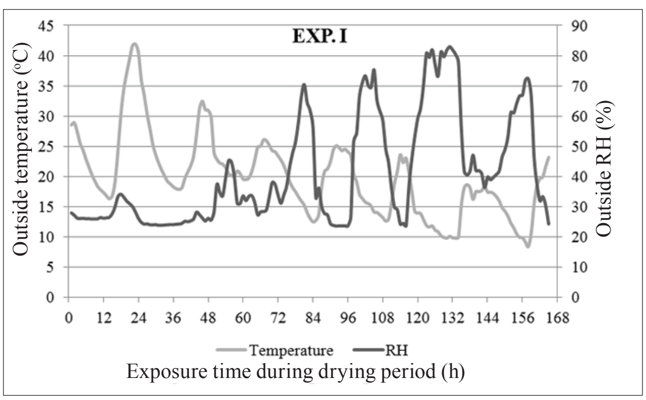

Fig. 2. Experiment I, changes in average hourly outside temperature and relative humidity values

Experiment II

Experiment II was conducted over a period of 7 days. Outside air temperature had a lower RH for the beginning of the drying period, later increased considerably due to decreasing temperature. During the experiment, the average outside temperature was 17.7°C (8.9 -29.5°C). The average relative humidity was 56.0% and it varied between 94.5% and 25.2% (Figure 4).

In Experiment II, the daily changes in the humidity content of the rose flowers dried with the temperature and the humidity of the drying area according to the wet basis examined. During the first 3 days, the drying process was slow because of low air temperature and the high RH value. In the following days, temperature of the drying area increased and consequently, the RH value decreased, which positively affected the drying speed and the product wet basis humidity content continued to decrease constantly and reached the drying -end humidity parallel to the decrease in the drying area humidity (Figure 5).

Experiment III

Experiment III was conducted over a period of 5 days. The outside air temperature had a lower RH value for the

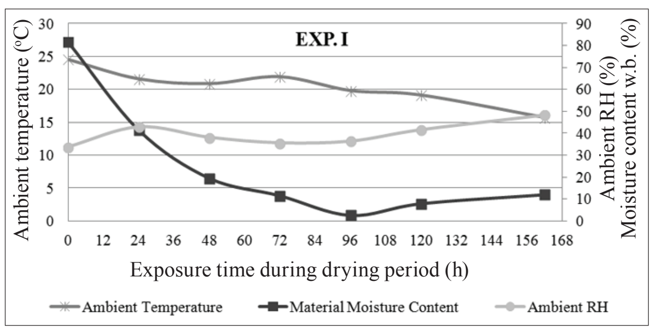

Fig. 3. Experiment I, changes in average daily ambient temperature, RH and material moisture content

beginning of the drying period, after that it increased considerably due to the decreasing temperature. During the experiment, the average outside temperature was 20.4°C (12.3 -30.5°C). The average relative humidity was 50.8% and it also varied between 87.9% and 23.9% (Figure 6).

In Experiment III, the daily changes in the humidity content of the flowers dried with the temperature and the humidity of the drying area according to the wet basis are examined. From the first day of the experiment onwards, while the outdoor air heat decreased, the RH value increased. Therefore, the drying speed remained constant. As there were no sudden changes in the outdoor temperature, it had a positive effect on the drying speed and the wet basis humidity content of the product continued to decrease. However, with the increase in the humidity of the drying area, flowers regained humidity after the drying (Figure 7).

Experiment IV

Experiment IV was conducted over a period of 7 days. The outside air had a lower RH value for the beginning of the drying period, after that it increased considerably due to the decreasing temperature. During the experiment, the average outside temperature was 18.3°C (12.6 -29.0°C). The average relative humidity was 66.9%, and it also varied between 94.6% and 25.8% (Figure 8).

In Experiment IV, the daily changes in the humidity content of the flowers dried with the temperature and the humidity of the drying area according to the wet basis are examined. In this experiment, the flowers brought to

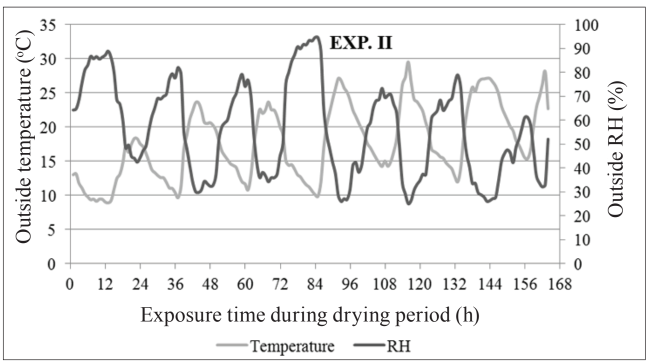

Fig. 4. Experiment II, changes in average hourly outside temperature and relative humidity values

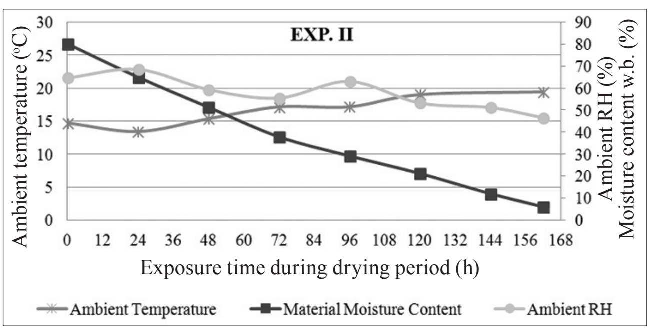

Fig. 5. Experiment II, changes in average daily ambient temperature and RH and material moisture content

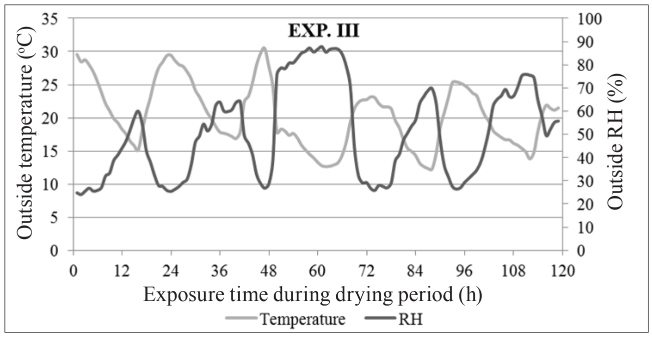

Fig. 6. Experiment III, changes in average hourly air temperature and relative humidity values

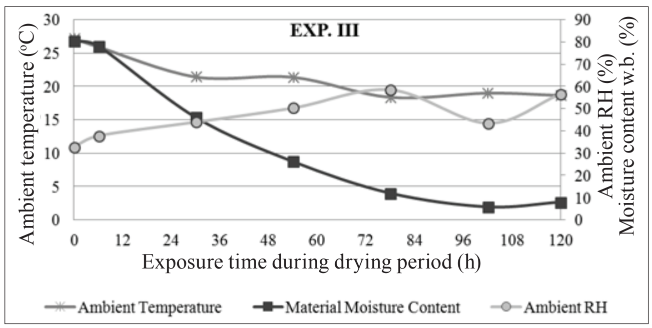

Fig. 7. Experiment III, changes in average daily ambient temperature, RH and material moisture content

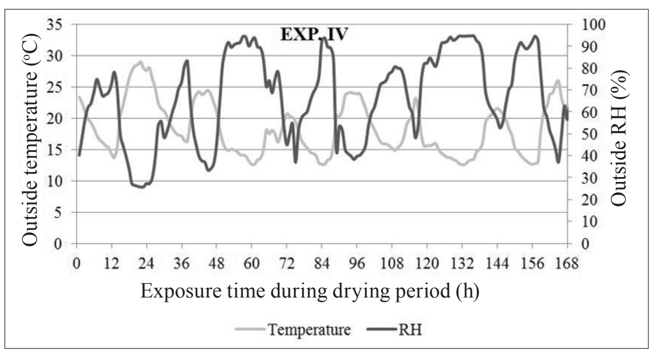

Fig. 8. Experiment IV, changes in average hourly outside temperature and relative humidity valuest

the drying area after the harvest and they were spread to a wide area from the sacks. The process of lying onto shelves was carried out by delaying for 5 hours compared to other drying experiments. Accordingly, the beginning humidity level of the product after the process of lying onto shelves came in at 5% lower compared to the other experiments. In Experiment IV the flowers dried faster compared to the other experiments based on the high air temperature of the outdoor air and low RH value in the first 3 days. In this period, as the product dried fast, the moisture content (w.b.) of rose flower reached to drying-end of humidity according to the day-night humidity changes by becoming constant based on the environment in the following days (Figure 9).

According to the changing moisture ratio values of flowers used in the drying process under natural shade conditions, the relationship between drying times and different drying air properties and initial moisture content is seen in Figure 10. The drying speeds of the Exp I. and Exp III, of which the average drying speed was higher compared to other experiments during the period of drying, were higher. As the Exp II was carried out during the cloudy and rainy period, the drying speed was rather slow. Thus, based on the observations of the researchers, the drying was completed on the 7th day. In Exp IV, since the process of lay onto the shelves was carried out after delaying for 5 hours after harvest, the initial humidity was lower compared to the others and the drying period was shortened. Equilibrium moisture can be achieved at different drying exposure time varying between 72 hours and 162 hours (3-7 days) (Figure 10; Figure 11).

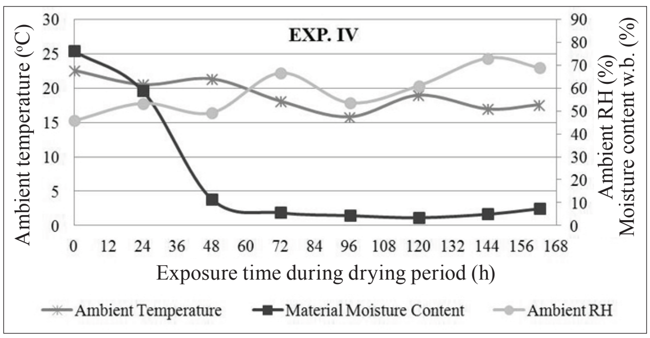

Fig. 9. Experiment IV, changes in average daily ambient temperature, RH and material moisture content

The measured variables were air temperature, relative humidity (RH) and sample mass loss during drying. In general, the drying of agricultural products takes place in two periods, a constant rate and a falling rate period (Figure 12).

Mathematical models for MR drying curves have been used for different leaf and flower plants by others such as: medicinal and aromatic plants (Oztekin and Soysal, 2000b; Soysal and Oztekin, 2001; Oztekin, 2001; Akpinar, 2006; Müller and Heindl, 2006; Arafa, 2007; Arslan et al., 2010; Rayaguru and Routray, 2011), purslane (Demirhan and Ozbek, 2010), spinach leaves (Doymaz, 2009) and parsley (Akpinar et al., 2006; Soysal et al., 2006).

The results showed that the Bala Model was found to be the most suitable for describing the drying curve of Isparta Rose with high value and low r^2, χ^2 and RMSE values, respectively (Table 4). However, the Verma et al. model described the drying curve of Isparta Rose satisfactorily with a r^2 value of 0.9963 for the shade drying under natural conditions.

The moisture content data under the different natural shade drying conditions were converted to moisture

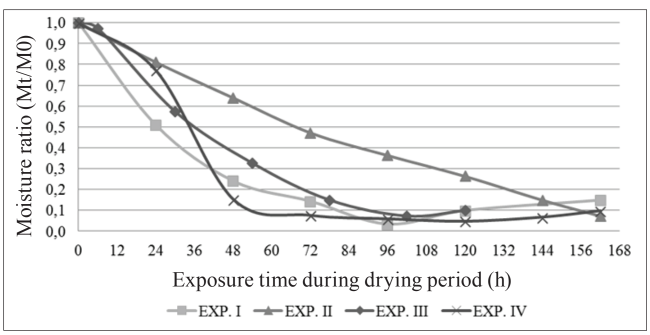

Fig. 10. Changing moisture ratio values of Isparta Rose flowers in experiments

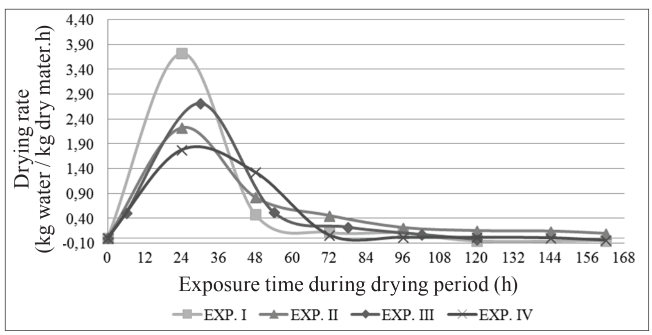

Fig. 11. Changing drying rate values of Isparta Rose flowers in experiments

ratios and the data were analyzed for the mentioned thin layer drying models. The correlation coefficient and the results of statistical analyses are listed in Table 4. For all mentioned thin layer drying models, r^2 values were greater than 0.90 except for the Midilli et al. model for Exp I and Exp IV. The analysis indicated that the Bala model, which has inside temperature and relative humidity, had the highest values of r^2 with the lowest values of χ^2 and RMSE. However, the Verma et al. and Page models also had good results. As the product was laid onto shelves after waiting in Exp IV, the model r^2 values were lower compared to those in other experiments. Thus, the Bala model and others represented the thin layer drying behavior of Isparta Rose flower in trays under natural shade drying conditions (Table 4).

The values of parameters on mathematical models fitted to thin layer drying under natural shade conditions of Isparta Rose flower were given in Table 5.

Sensory Evaluation

Dried flowers from the experiments were used for visual and olfactory evaluations. Flowers from Exp III was rated as like moderately and flowers of Exp I, IV, and II were rated as neither like of dislike and dislike moderately by the panelists (Figure 12).

Conclusions

In this study, the drying behavior of Isparta Rose flowers was investigated under natural shade drying conditions. The drying of Isparta Rose under natural shade conditions in a drying building occurred during the falling rate period; a constant rate period of drying was not observed. To explain the drying behavior of Isparta Rose, 13 different thin-layer drying models were applied.

With the thin layer drying, the Isparta Rose flowers were dried in their natural shade-drying environment.

During the period of experiments, while the outdoor average daily temperature was 19.2±1.23°C and the humidity level was 53.5±10.48 %RH, the average daily temperature of the drying area was 18.8±1.11°C and the humidity level was 52.4±8.44 %RH.

The average beginning humidity of the rose flowers was 79.6±2.32% and the flowers were laid onto each shelf as 1000±1 g. The end-humidity level after drying was 7.11±0.83% and average 214.1±24.6 g end product was obtained. The appropriate humidity level for storing the product was reached after 72-96 h (3-4 days) except for in Exp II.

Under natural drying conditions the drying period was shortened or prolonged depending on temperature and humidity as was observed in Exp II where drying period was slower than the other experiments. In the end, it was observed that as the flowers decayed the visual appearance of the flowers decreased and received the lowest rank.

Studies for the determination of the different heat and humidity sorption curves of the Isparta Rose were necessary. If such a study is carried out, the completion

Fig. 12. Samples of dried Isparta Rose flowers used for sensory evaluations

Table 4
Statistical quality analyses of fitted mathematical models to thin layer drying under natural shade conditions of Isparta Rose flowers

Name of Model	MR model equation	Experiment	Constant		
			r^2	χ^2	RMSE
Newton	MR=Exp(-kt)				
		I	0.963	0.00821	0.06529
		II	0.977	0.00287	0.04955
		III	0.986	0.00241	0.04806
		IV	0.907	0.01351	0.11625
Henderson and Pabis	MR= a exp(-kt)				
		I	0.963	0.0062	0.07148
		II	0.98	0.00259	0.04944
		III	0.99	0.00199	0.04396
		IV	0.911	0.01447	0.12283
Page	MR= exp(-kt^n)				
		I	0.967	0.00679	0.06837
		II	0.994	0.00086	0.02628
		III	0.995	0.00099	0.03175
		IV	0.979	0.00345	0.0599
Logarithmic	MR= a exp(-kt) + c				
		I	0.982	0.00601	0.05592
		II	0.999	0.00018	0.01179
		III	0.991	0.00221	0.0464
		IV	0.911	0.01734	0.13451
Two-Term	MR= a exp(-k$_0$t) + b exp(-k$_1$t)				
		I	0.995	0.00111	0.03502
		II	0.98	0.00432	0.06055
		III	0.99	0.00332	0.05676
		IV	0.911	0.02174	0.15043
Verma et al.	MR= a exp(-kt) + (1-a) exp(-gt)				
		I	0.995	0.00083	0.03041
		II	0.999	0.00015	0.01088
		III	0.989	0.00283	0.05214
		IV	0.982	0.00345	0.06012
Wang and Singh	MR= 1+at+bt^2				
		I	0.957	0.00766	0.0779
		II	0.999	0.0002	0.0128
		III	0.995	0.00107	0.03191
		IV	0.929	0.01202	0.10966
Midilli et al.	MR= a exp(-ktn) + bt				
		I	0.595	0.09348	0.3071
		II	0.983	0.00273	0.05579
		III	0.904	0.03119	0.1755
		IV	0.625	0.07498	0.30943

Table 5
Values of parameters on mathematical models fitted to thin layer drying under natural shade conditions of Isparta Rose flowers

Name of Model	MR model equation	Exp.	Constant					
			k	A	b	c	n	g
Newton	MR=Exp(-kt)							
		I	0.02785					
		II	0.01122					
		III	0.02086					
		IV	0.02603					
Henderson and Pabis	MR= a exp(-kt)							
		I	0.02771	0.9948				
		II	0.01172	1.042				
		III	0.02192	1.05				
		IV	0.02726	1.06				
Page	MR= exp(-kt^n)							
		I	0.0534				0.8277	
		II	0.003				1.292	
		III	0.007364				1.261	
		IV	0.0000237				2.932	
Logarithmic	MR= a exp(-kt) + c							
		I	0.03546	0.9306		0.07899		
		II	0.0056	1.544		-0.5438		
		III	0.0196	1.093		-0.0499		
		IV	0.02754	1.056		0.00436		
Two-Term	MR= a exp(-k$_0$t) + b exp(-k$_1$t)							
		I	k_0= 0.03546 k_1=0.02951	0.001009	1.003			
		II	k_0=0.01173 k_1=0.01172	0.514	0.5278			
		III	k_0=0.02213 k_1=0.02172	0.5264	0.5229			
		IV	k_0=0.02932 k_1=0.02723	-0.01147	1.07			
Verma et al.	MR= a exp(-kt) + (1-a) exp(-gt)							
		I	-0.03094	0.0009603				0.02938
		II	-0.00866	-0.05024				0.00821
		III	0.01047	-1.46				0.01386
		IV	1.853	-2.818				0.06686
Wang and Singh	MR= 1+at+bt^2							
		I		-0.01814	8.173E-05			
		II		-0.00823	0.000016			
		III		-0.01654	0.0000743			
		IV		-0.01799	7.842E-05			
Midilli et al.	MR= a exp(-kt^n) + b^t							
		I	0	0.6586	0		0	
		II	0	0.9373	-0.005613		0	
		III	0	0.9102	-0.008158		0	
		IV	0	0.7127	-0.005242		0	

continued on next page

Table 5 continued

	MR= Aexp(-Bt)	$A=a_o+a_1RH+a_2T+a_3RH^2+a_4T^2$		$B=b_o+b_1RH+b_2T+b_3RH^2+b_4T^2$		
Bala	I	$a_o=$	2.200035	$b_o=$	-0.11873	
		$a_1=$	-0.02356	$b_1=$	0.00224	
		$a_2=$	-0.0633	$b_2=$	0.02236	
		$a_3=$	-0.00029	$b_3=$	-8.60E-05	
		$a_4=$	0.002442	$b_4=$	-0.00066	
	II	$a_o=$	3.745456	$b_o=$	0.063102	
		$a_1=$	0.099403	$b_1=$	-0.00748	
		$a_2=$	-0.97225	$b_2=$	0.018503	
		$a_3=$	-0.00067	$b_3=$	6.32E-05	
		$a_4=$	0.036713	$b_4=$	-0.0005	
	III	$a_o=$	0.092337	$b_o=$	-0.04146	
		$a_1=$	0.1073169	$b_1=$	0.002356	
		$a_2=$	0.0147598	$b_2=$	0.005376	
		$a_3=$	-0.001681	$b_3=$	-3.56E-05	
		$a_4=$	-0.001629	$b_4=$	-0.000187	
	IV	$a_o=$	76.47495	$b_o=$	0.727205	
		$a_1=$	-0.904511	$b_1=$	-0.019161	
		$a_2=$	0.023483	$b_2=$	-0.005149	
		$a_3=$	0.002017	$b_3=$	-0.000146	
		$a_4=$	-0.075755	$b_4=$	7.38E-05	

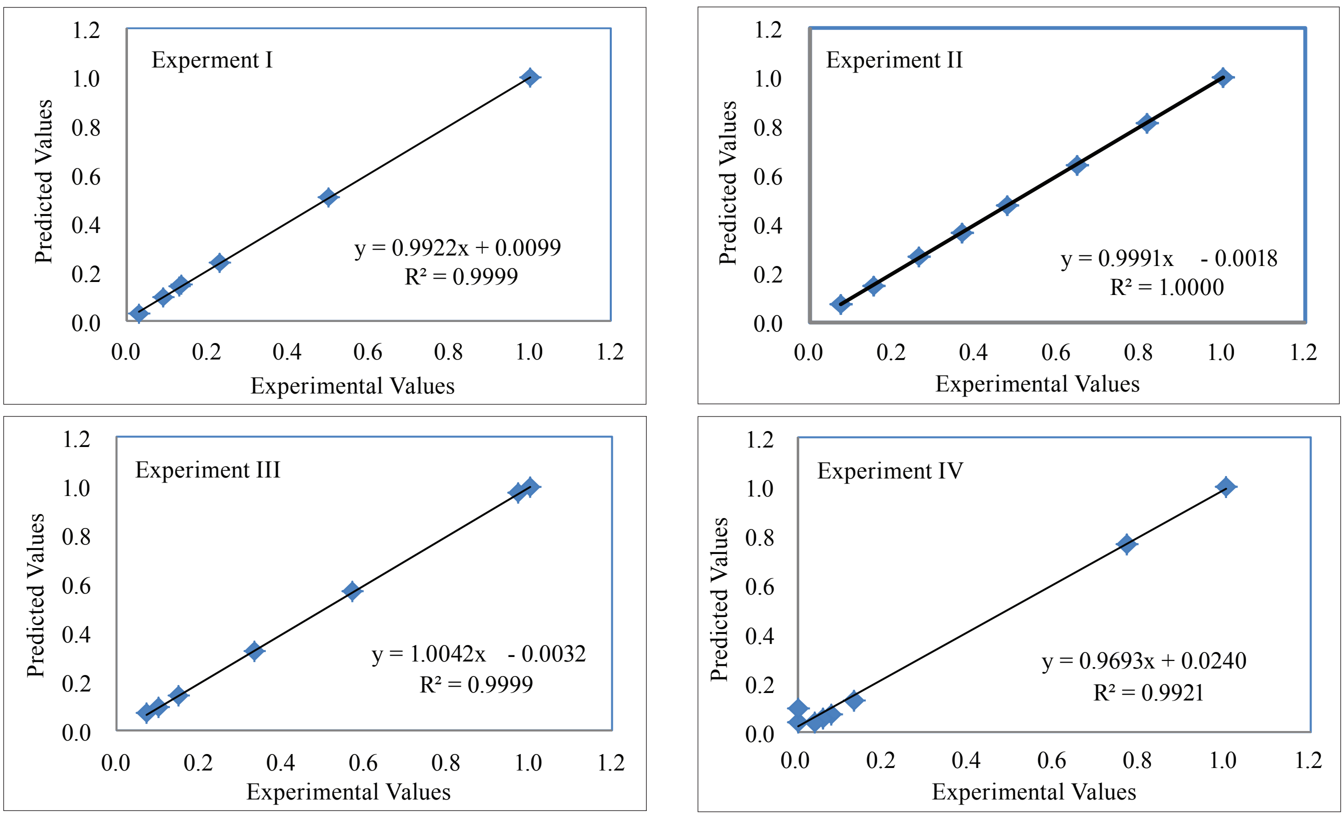

Fig. 13. Experimental and predicted moisture values under different drying conditions by the Bala model

of drying at the right time and the determination of the most appropriate storing conditions will be possible.

Rose flowers are collected from fully bloomed flowers or from rosebuds. During the harvest and transport after the harvest, petal and sepal separation may occur. The drying patterns of flowers and buds are different. While the petal dries fast, the rosebuds dry slowly. Thus, the specific yield for the drying material to be uniform, a classification or a separation system will decrease the drying period. Besides, the uniformity of the product will enable accurate estimation for the completion of drying.

In upcoming studies, parameters showing the product quality should be determined such as the drying efforts of oil-bearing roses under controlled conditions and the oil components of the dried products, color, scent and aromatic features.

MR observed and expected values Bala model showed the best fit for all experiments (Figure 13).

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