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Study on the drying kinetics of *Rosa* flower buds using different drying methods

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Abstract: This study investigated the drying kinetics of *Rosa* flower buds (*Rosa damascene* Mill) under environmental conditions (shade), as well as in direct and indirect solar dryers. The effects of 40 °C, 50 °C, and 60 °C temperatures on the drying of the buds were also examined using a laboratory cabinet dryer. The drying rate of the *Rosa* flower buds was compared with various mathematical models, and the parameters of these models were evaluated. The results illustrated that drying *Rosa* flower buds under shade required a lengthy period time of approximately 13 days. In contrast, utilising solar dryers significantly reduced the drying period time for *Rosa* flower buds. Also, compared to the ambient drying method, the use of indirect solar dryers had the most substantial effect on decreasing the drying period time of the buds up to 86.6%. Furthermore, applying a temperature of 60 °C in the laboratory dryer reduced the drying time of the buds by 76.2% compared to a temperature of 40 °C. The Midilli et al. model (MDM), Page model (PM) and approximate diffusion model (ADM) demonstrated a good fit with the experimental data and can be employed to represent the drying behaviour of *Rosa* flower buds. The effective of moisture diffusivity of *Rosa* flower buds during drying was found to be in a range from 6.87×10^{-12} to 1.89×10^{-10} $m^2 \cdot s^{-1}$ and the activation energy values were determined as 65.30 and 72.80 $kJ \cdot mol^{-1}$ for buds which were dried in the laboratory cabinet dryer and those dried using the ambient and solar dryer methods, respectively.

Keywords: activation energy; modelling; solar; moisture diffusivity; heated air

Rosa damascena Mill., commercially named "Gol Mohammadi", is a valuable, cultivated plant. An important oil is produced from the flowers in Iran from long time ago, which has several accessions from different parts of the country (Yoosefi et al. 2021). The purity, beauty, and quality of *Rosa* flower buds are only retained for a few days or weeks. However, the beauty and quality of dried buds can be retained from a few months to several years by applying a suitable drying technique. The drying technique is one of the primary methods for product preservation and protection. In the context of medicinal and aromatic plants, the drying technique is employed subsequently after harvesting in order to reduce the moisture content to less than 12% (w.b.), thereby establishing the optimal storage conditions. The drying process must be completed expeditiously to prevent the decomposition of roses and conserve energy for commercial purposes (Brennan 2003). The drying of flowers and medical herbs has been practised for many years throughout the world. Shade drying, solar drying and heated-air drying are the usual methods to dry flowers and medical herbs. In order to dry *Rosa* flower buds, other methods, such as freeze drying and vacuum drying for medi-

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cal usage and heated-air drying or solar drying for herbal beverage, were applied. Baydar et al. (2004) proposed that drying *Rosa* flower petals could lead to new forms of utilisation, such as in decorations, herbal products, aromas, hydrotherapy, and cosmetics. In recent years, the use of *Rosa* flowers in health and aroma therapy applications has led to a rising demand in herbal products trade. During the process of drying medical and aromatic plants, it is imperative to preserve the colour, flavour, and essential oils. Consequently, it is necessary to optimise the relationship between the temperature and humidity levels of the drying air, drying speed, and drying duration (Bayhan et al. 2011).

The initial moisture content of *Rosa* flower buds was about 78% (w.b.) and, after drying, it decreased to less than 10% (w.b.) for safe storage (Boyar et al. 2013). Shade drying of some medicinal plants and flower, such as mint leaves and jasmine flowers, has a lower effect on the essential oil quality (Khorramdel et al. 2013; Barman et al. 2022). A comparison of the oil content and composition of dried samples of *Rosa* flower petals showed that drying in the shade was better and produced higher percentage of oil and aromatic compounds (Ahmadi et al. 2008). It was noted that the phenomenon of moisture reabsorption occurred during the process of drying *Rosa* flowers in the shade (Boyar et al. 2013). Raol et al. (2013) reported that the shade drying of *Rosa* flower buds continued up to five days, while the microwave drying dried the buds in 13 minutes. Vacuum and microwave drying have been noted as being suitable methods for *Rosa* flower buds. Safeena et al. (2006) studied the response of drying roses in a hot air oven and concluded that silica gel drying at 40 °C resulted in the best quality flowers. Thin layer drying models described the drying process of food and agricultural products and mathematical models have been employed to illustrate the drying kinetics of agricultural products. Also, the effective moisture diffusivity and the activation energy have been calculated for agricultural products in several research studies (Midilli et al. 2002; Sharma et al. 2005; Goyal et al. 2007; Amiri Chayjan et al. 2011; Doymaz 2014; Chaji and Hedayatizadeh 2017). In the previous research, a two-term exponential model demonstrated a satisfactory degree of correlation with the experimental data concerning the drying process of ginger (Thorat et al. 2012). The Page model (PM) was selected as the best thin layer drying model for drying onions (Sharma et al. 2005), for pomegranate arils (Kingsly and Singh 2007) and lime slices (Yousefi et al. 2017). The Midilli et al. model (MDM) was selected as the best model for the drying of saffron (Akhondi et al. 2011). The approximate diffusion model (ADM), Bala model, and PM demonstrated a satisfactory degree of fitness to the experimental data for *Rosa* flower drying (Boyar et al. 2013; Raol et al. 2013; Stępień et al. 2019).

The present study investigated the drying kinetics of *Rosa* flower buds under different drying methods. The experimental set-up included three distinct drying methods including a convective hot air dryer in the laboratory, shade drying and solar dryers (direct and indirect). In order to evaluate the drying process, different drying models were fitted to the obtained data and the effective moisture diffusivity and activation energy were calculated.

MATERIAL AND METHODS

Sampling and experiments. In the first stage, in late May 2024, *Rosa* flower buds (Figure 1) were hand-picked from a farm in the Alborz province of Iran in the early morning and immediately transported to the laboratory. In the laboratory, uniform, healthy and pest-free buds were selected for the drying process. The moisture content of the harvested buds was measured and determined in the range of 233–300% (d.b.) (70–75% w.b.).

Figure 1. *Rosa* flower buds

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Digital callipers with an accuracy of 0.01 and 200 mm in length was used to measure the length and diameter of the *Rosa* buds. The average length and diameter of the wet buds was determined as 21.82 and 12.43 mm, respectively. The weight of the buds was also measured as 1.18 g with a model MX50 digital scale (0.01 g accuracy and 250 g capacity), from the AND Company, Japan (Mabellinia et al. 2011).

The drying operation of *Rosa* flower buds was carried out by spreading them out in the shade (control treatment), in a direct solar dryer, in an indirect solar dryer, and in a forced air cabinet dryer at temperatures of 40 °C, 50 °C, and 60 °C. In each of the methods, all the experiments were performed in three replicates.

Drying buds in ambient (shade). The experimental procedure of drying the buds in ambient (shade) conditions was conducted in early June 2024 in Alborz Province, Karaj City. The measurement of the ambient air temperature and humidity variation were observed using a model 610 portable temperature-humidity meter from the Testo Company, Germany. The ambient temperature ranged from 15 °C to 27 °C, while the relative humidity fluctuated between 35% and 52%. The process of drying the flower buds in the shade was achieved based on the elimination of exposure to direct sunlight (Figure 2). The weight changes of the samples were measured at regular intervals ranging from 2–4 h using a digital scale as mentioned before.

Drying buds in a direct solar dryer. The experimental samples were spread out on trays in the dryer chamber to be exposed to direct solar radiation. Solar radiation heat was utilised for the *Rosa* buds drying process. The drying chamber was equipped by a radial fan to facilitate air circulation. The weight of the samples was measured and recorded at regular intervals ranging from 2–4 hours. The direct solar dryer, during the drying of the flower buds, is depicted in Figure 3.

Drying buds in an indirect solar dryer. The *Rosa* flower bud samples were spread out on the trays of an indirect radiation solar dryer. Air flowed through the collector by a radial fan and absorbed solar heat energy. After that, warmed air passed below the trays and dried the buds. The dryer was equipped with a fan to facilitate the discharge of humid air. The weight of the samples was measured and recorded at regular intervals ranging from 2–4 hours. The indirect solar dryer is shown in Figure 4.

Drying buds in a cabinet dryer. Rosa flower buds were dried within a laboratory cabinet dryer at three inlet air temperature levels, 40 °C, 50 °C, and 60 °C. Air flow was heated by a 1.5 kW electrical element and conducted below the tray of the dryer by a blower. The experimental samples were

Figure 2. *Rosa* flower buds in the ambient (shade) drying conditions

Figure 3. Direct solar dryer for drying the *Rosa* flower buds

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Figure 4. Indirect solar dryer for drying the *Rosa* flower buds

placed on the tray and dried in contact with the heated air flow. The weight of the samples was measured and recorded at regular intervals ranging from 2–4 hours. The cabinet dryer is illustrated in Figure 5.

Drying kinetic and modelling. Drying curves were fitted with eight different moisture ratio mathematical models (Table 1). In most performed research studies related to thin-layer drying with solar energy or hot air, these models are used to describe the kinetics of drying the product (Doymaz 2009; Boyar et al. 2013; Chaji and Hedayatizadeh 2017; Chabane et al. 2019; Murugavelh et al. 2019; Dhande et al. 2024).

In these models, the moisture ratio (MR) of the buds during the drying experiments was expressed by the following equation:

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

where: M_t – the moisture content at any time (kg water·kg^{-1} dry basis); M_o – the initial moisture content (kg water·kg^{-1} dry basis); M_e – the equilibrium moisture content of the sample (kg water·kg^{-1} dry basis).

The values of M_e are relatively small compared to M_t or M_o, hence, the error involved in the simplification is negligible (Diamante and Munro 1993; Akpinar et al. 2003; Doymaz and Ismail 2011).

The regression analysis was performed using Statistica 7.0 software. Non-linear regression was used to evaluate the goodness of fit of the mathematical models to the experimental data. The evaluation of the model fit was conducted by employing three criteria including the coefficient of determination (R^2), the reduced chi-square (χ^2) and the root

Figure 5. Cabinet dryer for drying the *Rosa* flower buds

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Table 1. Selected thin layer drying models for drying the *Rosa* flower buds

Model	Equation	References
Newton (NM)	$MR = \exp(-kt)$	Westerman et al. (1973)
Page (PM)	$MR = \exp(-kt^n)$	Page (1949)
Henderson and Pabis (HPM)	$MR = a \exp(-kt)$	Henderson and Pabis (1961)
Two term exponential (TEM)	$MR = a \exp(-kt) + (1 - a) \exp(-kat)$	Akpinar et al. (2003)
Approximate diffusion (ADM)	$MR = a \exp(-kt) + (1 - a) \exp(-kbt)$	Doymaz (2007)
Logarithmic (LM)	$MR = a \exp(-kt) + b$	Togrul and Pehlivan (2002)
Wang and Singh (WSM)	$MR = 1 + at + bt^2$	Wang and Singh (1978)
Midilli et al. (MDM)	$MR = a \exp(-kt^n) + bt$	Midilli et al. (2002)

MR – moisture rate; *t* – time (min); *a*, *b*, *n*, *k* – constants

mean square of error (RMSE). The χ^2 parameters and RMSE were calculated as follows:

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

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

where: $MR_{\exp,i}$, $MR_{\mathrm{pre},i}$ – the experimental and predicted dimensionless moisture ratios, respectively; N – the number of observations; n – number of drying constants.

The best model which described the thin-layer drying characteristics of Rosa flower bud was chosen as the one with the highest coefficient of determination and the least reduced chi-square and root means square error (Akpinar et al. 2003; Doymaz 2007).

Calculation of the effective moisture diffusivity and activation energy. After determining the suitable model, the analytical solution of Fick's second law in spherical geometry presented by Crank (1975) is applicable under the assumption of constant effective moisture diffusivity and is in the form:

$$MR = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left(\frac{n^2\pi^2 D_{eff}\, t}{r^2}\right) \quad (4)$$

where: D_{eff} – the effective moisture diffusivity ($m^2 \cdot s^{-1}$); r – the radius of the buds (m); n – a positive integer.

For long drying times (setting $n = 1$), Equation (4) can be further simplified to a logarithmic equation as below (Pala et al. 1996):

$$\ln(MR) = \ln\left(\frac{6}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}\, t}{r^2}\right) \quad (5)$$

The effective moisture diffusivity was calculated using the method of slopes. Typically, the effective diffusivities are determined by plotting the experimental drying data in terms of ln(*MR*) versus time (Tutuncu and Labuza 1996). According to Equation (5), a plot of ln(*MR*) versus time creates a straight line with a slope K_2.

$$K_2 = \frac{\pi^2 D_{eff}}{r^2} \quad (6)$$

The dependence of the effective diffusivity on the temperature is generally described by the Arrhenius equation (Simal et al. 2005):

$$D_{eff} = D_0 \exp\left(-\frac{E_a}{R(T + 273.15)}\right) \quad (7)$$

where: D_0 – the pre-exponential factor of the Arrhenius equation ($m^2 \cdot s^{-1}$); E_a – the activation energy ($kJ \cdot mol^{-1}$); R – the universal gas constant ($kJ \cdot mol^{-1}$); K, T – temperature (°C).

RESULTS AND DISCUSSION

In accordance with the drying results of the flower buds in the solar dryers and ambient conditions (shade), the indirect solar dryer was required the least period of time for the drying process. After 42 h, the moisture content of the buds decreased from 261.7% to 9.6% on a dry basis. The longest drying period was related to the shade drying procedure where the moisture content

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of the flower buds decreased from 272.2% to 16.1% on a dry basis after 320 hours. The results were comparable to the research conducted in Turkey (Boyar et al. 2013). The direct solar dryer dried the buds in 61 h and reduced the moisture content from 251.7% to 10.12% on a dry basis. The average drying temperature of the buds in the shade was 21.3 °C. While the average bud drying temperature in the indirect and direct solar dryers was 43.6 °C and 37.8 °C, respectively. Increasing the temperature and decreasing the relative humidity of the air in solar dryers compared to drying the buds in the shade significantly reduced the drying time of *Rosa* flower buds. The drying curves for the buds in solar dryers and ambient conditions (shade) are revealed in Figure 6.

As shown in Figure 6, drying *Rosa* flower buds in ambient conditions (shade) required a considerable period of time due to the slow transfer of moisture from the inner layers to the surface of the buds at temperature below 23 °C. According to the increase in temperature in the two types of solar dryers, the rate of moisture transfer from the inner layers to the surface also was increased and significantly shortened the drying period. The drying time of *Rosa* flower buds in the indirect and direct solar dryers was 86.9% and 80.9% shorter than the shade drying, respectively. The result of other research showed that phenol reduction in buds was 22% lower when the buds were dried using a solar dryer compared to shade drying (Roustapour et al. 2024). The results of drying buds at temperatures of 40 °C, 50 °C, and 60 °C in a laboratory cabinet dryer indicated that the drying at 60 °C took the least amount of time. After 15 h, the moisture content of the buds decreased from 268.4% to 10.4% on a dry basis. The longest drying time was related to drying at a temperature of 40 °C, which reduced the moisture content of the buds from 269.8% to 10.1% on a dry basis over a period of 63 hours. Also, the drying process of buds at a temperature of 50 °C continued for 32 h and the moisture content of the samples decreased from 264.6% to 10.3% on a dry basis in this period of time. The increase in temperature from 40 °C to 60 °C in the laboratory cabinet dryer led to an increase in the rate of moisture transfer and a 76.2% decrease in the buds' drying time. When *Rosa* flower buds were dried at temperatures of 40 °C to 60 °C, the phenol reduction in the buds was 12–21.7% compared to the buds dried in the shade (Roustapour et al. 2024). The effect of increasing the temperature on the drying time reduction of *Rosa* flower buds was observed in the research by Raol et al. (2013). The drying curves of the flower buds in a cabinet dryer in three inlet air temperature levels are presented in Figure 7.

Modelling. Moisture ratio data were acquired from the experimental data and fitted to selected thin-layer drying models. The R^2, χ^2 and RMSE values are represented in Tables 2 and 3. The best model describing the thin-layer drying characteristics of *R*osa buds was chosen as the one with the highest R^2 values and the lowest χ^2 and RMSE values. In most cases, the models with an R^2 value greater than 0.95 showed good fitness with the experimental data. Generally, the R^2, χ^2 and RMSE values had a variation between 0.891 to 0.999, 0.00001–0.00860 and 0.00120–0.04520, respectively. The MDM revealed the highest R^2 values

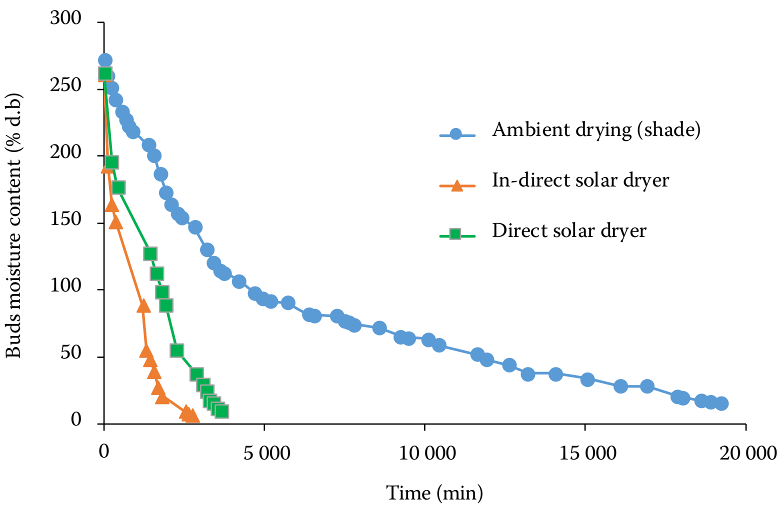

Figure 6. Drying curves of the *Rosa* flower buds under the three drying methods of drying

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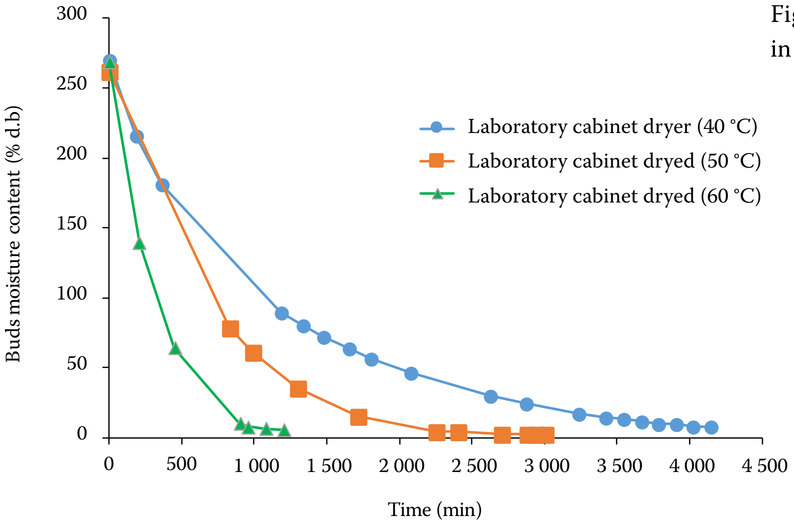

Figure 7. Drying curves of the *Rosa* buds in a laboratory cabinet dryer

as well as the lowest χ^2 and RMSE values in comparison with the others. Thus, the MDM assumed to represent the best air-drying behaviour of *Rosa* flower buds. Also, according to the modelling results, the PM and ADM can be used to express the behaviour of drying *Rosa* buds. Based on previous research studies, the drying behaviour of *Rosa* flower buds was estimated by the PM and ADM in (Boyar et al. 2013; Raol et al. 2013; Stępień et al. 2019). It can also be considered that among the three selected models for drying *Rosa* flower buds, the PM has better usability due to the small number of constants in the equation. The constants of the MDM, ADM and PM are presented in Table 4 for the experimental treatments.

For instance, the experimental and predicted moisture ratios were compared with the MDM and ADM for the buds drying in ambient conditions (shade). This evaluation is illustrated in Figure 8. Furthermore, comparisons of the experimental and predicted moisture ratios with the MDM and PM for cabinet drying (40 °C) are depicted in Figure 9. Similar results were reported on the drying of *Rosa* flower buds and some fruits (Raol et al. 2013; Boyar et al. 2013; Stępień et al. 2019; Midilli et al. 2002; Togrul and Pehlivan 2002; Doymaz 2007).

Effective moisture diffusivity and activation energy. The slope of the straight lines fitted to the experimental data, which displays the variations of ln(MR) vs. the time of drying, was calculated

Table 2. Statistical results from the Newton model (NM), Page model (PM), Henderson and Pabis model (HPM) and two term exponential model (TEM) of the experimental treatments

Treatments	NM			PM			HPM			TEM		
	R^2	χ^2	RMSE	R^2	χ^2	RMSE	R^2	χ^2	RMSE	R^2	χ^2	RMSE
Ambient drying (shade)	0.961	0.0030	0.0872	0.990	0.0008	0.0435	0.973	0.0021	0.0718	0.994	0.0005	0.0340
Direct solar dryer	0.955	0.0040	0.0539	0.955	0.0043	0.0534	0.958	0.0039	0.0518	0.958	0.0046	0.0518
In-direct solar dryer	0.961	0.0040	0.0496	0.980	0.0021	0.0351	0.974	0.0028	0.0402	0.974	0.0034	0.0400
Lab. cabinet dryer 40°C	0.995	0.0004	0.0187	0.999	0.0001	0.0066	0.997	0.0002	0.0140	0.999	0.0000	0.0034
Lab. cabinet dryer 50°C	0.998	0.0001	0.0079	0.999	0.0000	0.0025	0.998	0.0001	0.0078	0.998	0.2638	0.3118
Lab. cabinet dryer 60°C	0.999	0.0001	0.0056	0.999	0.0001	0.0036	0.999	0.0001	0.0059	0.999	0.0002	0.0059

R^2 – coefficient of determination; χ^2 – reduced chi-square; RMSE – root mean square of error

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Table 3. Statistical results from the approximate diffusion model (ADM), logarithmic model (LM), Midilli et al. model (MDM) and Wang and Sing model (WSM) of the experimental treatments

Treatments	ADM			LM			MDM			WSM		
	R^2	χ^2	RMSE	R^2	χ^2	RMSE	R^2	χ^2	RMSE	R^2	χ^2	RMSE
Ambient drying (shade)	0.994	0.0005	0.0339	0.984	0.0013	0.0557	0.989	0.0009	0.0452	0.891	0.0086	0.1459
Direct solar dryer	0.955	0.0046	0.0539	0.979	0.0021	0.0362	0.993	0.0008	0.0213	0.962	0.0036	0.0494
In-direct solar dryer	0.986	0.0016	0.0292	0.974	0.0031	0.0401	0.987	0.0017	0.0282	0.925	0.0082	0.0690
Lab. cabinet dryer 40°C	0.999	0.0000	0.0034	0.997	0.0002	0.0131	0.999	0.0000	0.0015	0.963	0.0031	0.0527
Lab. cabinet dryer 50°C	0.998	0.0002	0.0079	0.999	0.0001	0.0063	0.999	0.0000	0.0012	0.975	0.0024	0.0336
Lab. cabinet dryer 60°C	0.999	0.0002	0.0060	0.999	0.0001	0.0040	0.999	0.0001	0.0036	0.984	0.0026	0.0261

R^2 – coefficient of determination; χ^2 – reduced chi-square; RMSE – root mean square of error

in order to determine the effective moisture diffusivity for each drying condition. The results of the effective moisture diffusivity are shown in Figures 10 and 11. The effective moisture diffusivities of *Rosa* buds during drying were between 6.87×10^{-12} to 6.92×10^{-11} $m^2 \cdot s^{-1}$ in the ambient drying (shade) and solar drying procedures. Also, it was found to be between 4.21×10^{-11} to 1.89×10^{-10} $m^2 \cdot s^{-1}$ for *R*osa buds dried in the laboratory cabinet dryer at temperatures between 40 °C to 60 °C. Figures 10 and 11 display that an increase in temperature had a direct relationship to the effective moisture diffusivity. It was similar to previous literature results for fruit drying (Doymaz and Pala 2002; Akpinar et al. 2003; Demir et al. 2004; Doymaz 2009; Doymaz and Ismail 2011; Ghaderi et al. 2011).

The activation energy was calculated by plotting $\ln D_{eff}$ versus the reciprocal of temperature ($1\ (T + 273.15)^{-1}$). The activation energy values were determined to be 65.30 and 72.80 $kJ \cdot mol^{-1}$ for the samples dried in the laboratory cabinet dryer and the other procedures (shade and solar dryers), respectively. These results were similar to prior research studies on drying vegetables and fruits (Vagenas and Marinos-Kouris 1991; Tutuncu and Labuza 1996;

Table 4. Coefficients of the Midilli et al. model (MDM), approximate diffusion model (ADM) and Page model (PM) for the *Rosa* flower bud drying

Treatments	MDM				ADM			PM	
	k	*a*	*b*	*n*	*k*	*a*	*b*	*k*	*n*
Ambient drying (shade)	0.0509	1.0514	–0.0002	0.6664	0.0282	0.4738	0.0058	0.0325	0.7638
Direct solar dryer	0.1664	0.9997	–0.0099	0.2626	0.0391	0.5111	0.0387	0.0398	0.9937
In-direct solar dryer	0.1723	0.9945	–0.0026	0.6484	2.4393	0.1638	0.0634	0.1455	0.7802
Lab. cabinet dryer 40°C	0.0880	1.0001	–0.0003	0.8363	0.3590	0.1223	0.0479	0.0794	0.8801
Lab. cabinet dryer 50°C	0.0465	0.9999	0.0001	1.2317	0.0902	0.0993	0.0902	0.0534	1.1796
Lab. cabinet dryer 60°C	0.1724	0.9996	–0.0001	1.0575	0.1931	0.4692	0.1931	0.1704	1.0667

a, *b*, *n*, *k* – constants

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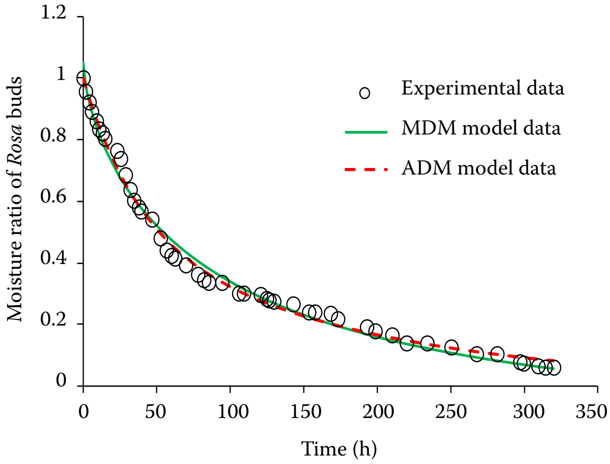

Figure 8. The experimental and predicted moisture ratios of the buds in ambient drying (shade)
MDM – Midilli et al. model; ADM – approximate diffusion model

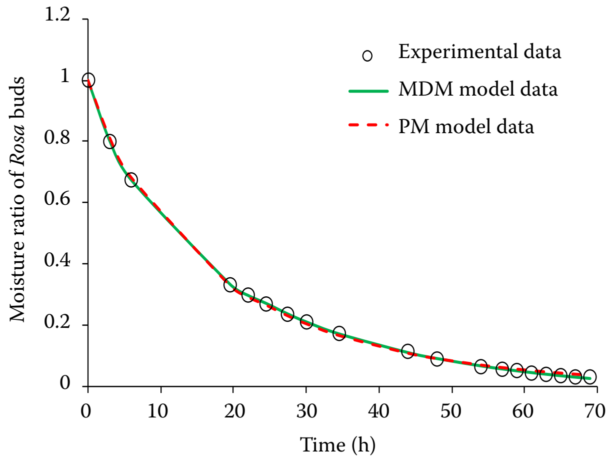

Figure 9. The experimental and predicted moisture ratios of the buds in the laboratory cabinet dryer at 40 °C
MDM – Midilli et al. model; PM – Page model

Doymaz and Pala 2002; Ertekin and Yaldiz 2004; Doymaz 2009; Amiri Chayjan et al. 2011).

CONCLUSION

Based on the results, it can be concluded that drying *Rosa* flower buds under ambient conditions (shade) took an excessively long period of approximately 13 days. In contrast, applying solar dryers considerably shortened the drying period of time for the *Rosa* flower buds. Compared to the ambient drying method, using indirect solar dryer had the greatest impact on reducing the drying period of the buds up to 86.6%. Additionally, employing an inlet air temperature of 60 °C in the cabinet dryer reduced the drying period about 76.2% in comparison with inlet air temperature of 40 °C. The MDM, PM and ADM had good fitness with the experimental data and can be used to represent the drying behaviour of *Rosa* flower buds. The effective moisture diffusivities of *Rosa* flower buds drying were found between 6.87×10^{-12} to 1.89×10^{-10} $m^2 \cdot s^{-1}$ and the activation energy values were determined to be 65.30 and 72.80 $kJ \cdot mol^{-1}$ in the laboratory cabinet dryer and the other drying procedures (shade and solar

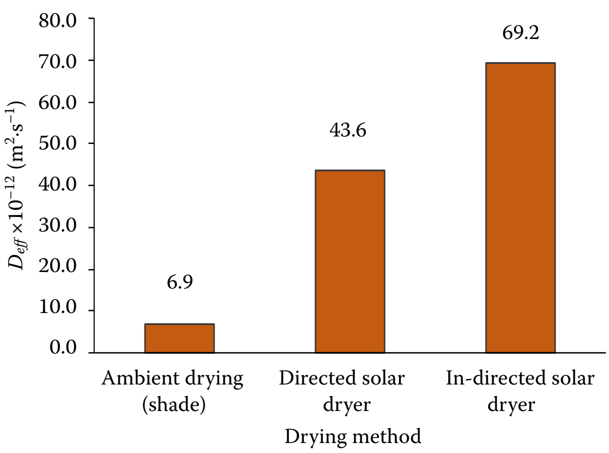

Figure 10. The *Rosa* flower buds effective moisture diffusivity (D_{eff}) in the solar dryers and ambient drying (shade)

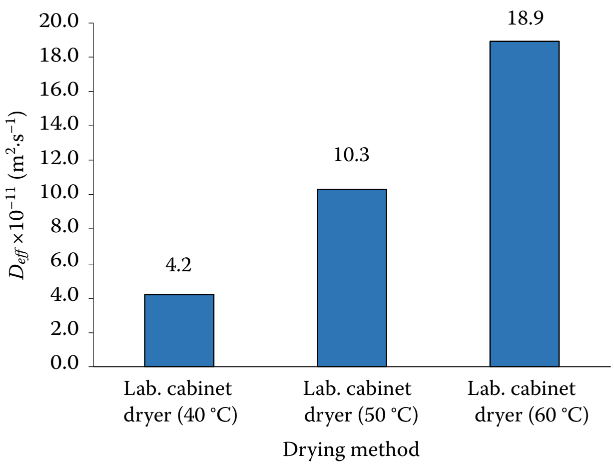

Figure 11. The *Rosa* flower buds effective moisture diffusivity (D_{eff}) in the laboratory cabinet dryer

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dryers), respectively. Based on the results, future research could be conducted on determining the moisture sorption isotherms of dried buds. The use of microwave and infrared energies to dry *Rosa* flower buds is also suggested as a future research area.

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