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Full Length Research Paper

Effective parameters on drying of *Hypericum perforatum* L. leaves

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Drying is one of the most important post harvest processes, which convert decaying products to resistant preparations so that it increases the storage duration and keep product quality (food stuff shelflife). *Hypericum perforatum* L. is an important kind of herbs, which its Iranian species characterized by high percent of Hyperisin as the most important substance of its leaves and flower. It has an important role in curing some diseases. The aim of this research was to investigate the effects of the temperature fluctuations at four levels (40, 50, 60 and 70°C), air velocity at three levels (0.3, 0.7 and 1 m/s) and bed depth at three levels (1, 2 and 3 cm) of St. John's wort leaves. A factorial experiment design was laid out in completely randomized design with three replications. In this research, the best treatment for drying time and rate of drying were obtained at temperature of 70°C, air velocity at 1m/s and 1 cm bed depth.

Key words: *Hypericum perforatum L.*, drying time, drying rate

INTRODUCTION

The main aims of drying agricultural products are to increase the shelf life, to prevent it from biological activities including microbial and enzymes, and to reduce the weight and volume of the materials in order to facilitate packaging, transporting and storing (Simal et al., 2005). During the drying process, it is important to preserve the texture, color, flavor, and nutritional value of the product. This means reducing a safe level of moisture content to minimize the quantity and quality losses during storage (Hall, 1980). The amount and the type of moisture, have direct effects on drying time. Extensive studies have been conducted on native flora and medicinal herbs in most developed countries (Ahmadi et al., 2010). The problems of research on medicinal herbs are indentifying and preserving the essential oils especially in different kinds of herbs. In summary, the most important causes of using herbs are as follows: 1) peripheral effects of consuming synthetic drugs; 2) uneconomic efforts of producing some synthetic drugs; 3) exclusiveness of curing of some diseases, such as leprosy, vitiligo and oriental sore, which are said to be cured just by herbs; 4) existence of valuable clinical experiences. One of the most useful medicinal herbs is *Hypericum perforatum* L. The property of the Iranian species of this crop is the high level of Hypericin as the most important essential oil of its flower and leaves, which plays an important role in the medical treatment of various diseases. Its annual trade level has been $ 210 m in USA and $ 570 m all over the world (Sirvent et al., 2002). This crop has been cultivated in western Europe. For example, in Germany, the production area reached to 300 ha in 1997, while it was only 15 ha in 1992 (Buter et al., 1998). The present study was conducted to determine the best treatment for time and rate of drying of *Hypericum perforatum* L. leaves, which has not been reported before. This information is helpful in designing an effective drying process to preserve quality and

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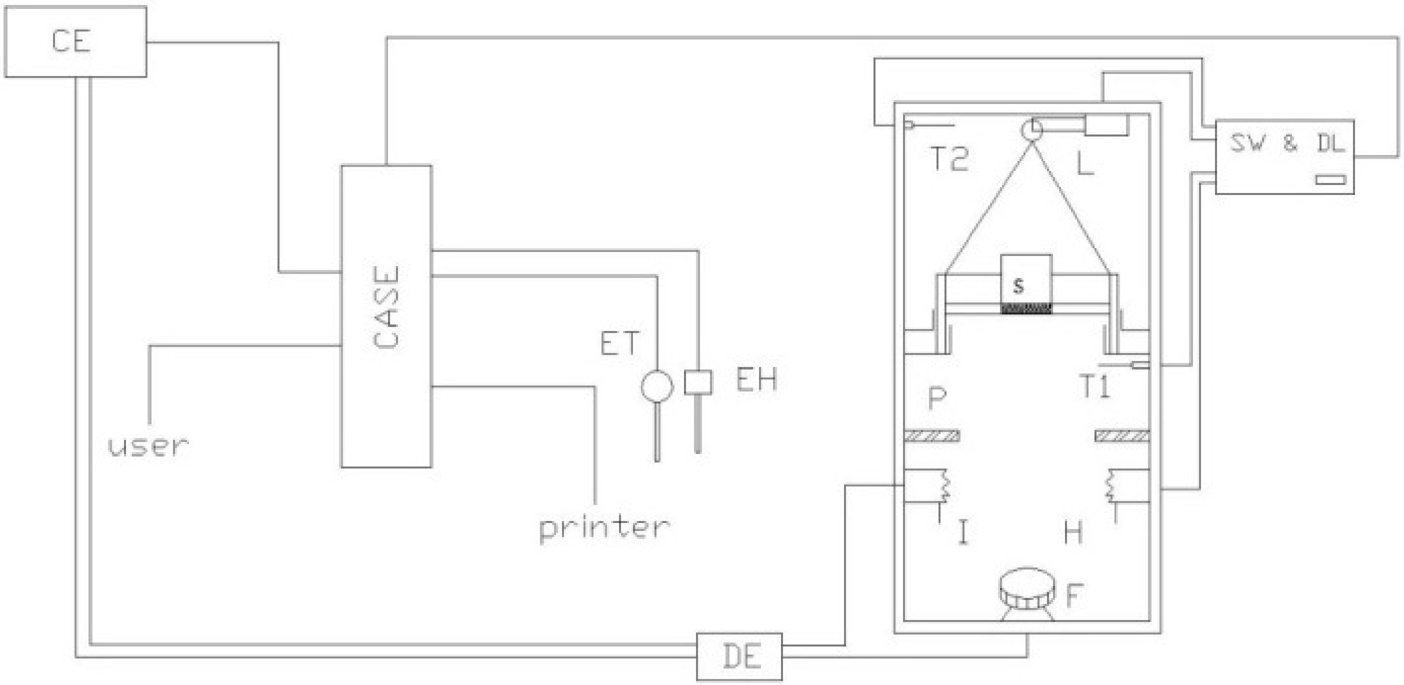

Figure 1. Diagram of the experimental dryer (F) fan, (H) heat generator, (S) sample, (T_1) Lower thermometer, (T_2)Upper thermometer, (Sw) switches, (DL) data logger, (CE) control electronic system, (DE) electronic driver, (EH) environment relative humidity sensor, (ET) environment temperature sensor.

effective chemical compounds of the leaves.

MATERIALS AND METHODS

Drying equipment

Three Kiln type laboratory dryers were utilized to conduct the drying experiments. Drying chamber is a 40×40×50 cm container located 70 cm above the heating elements (Figure 1). Each dryer has two electrical elements to generate the required heat, one of them is controlled by a digital thermostat and the other is controlled manually. Hot air flow is produced by a blower located under the elements, providing an adjustable flow rate in the range of 180 to 220 m^3/h using a dimmer. Two sensors are mounted in the upper and lower parts of the dryer to measure the temperature of the drying air before and after the sample location.

Prior to the starting of each experiment, air temperature was adjusted by the thermostat and the dryers were activated to reach the required temperature. Data collection for thin layer drying experiments was performed through weight of samples at 5 min intervals using a ±0.001 g digital balance (Sartorius, model PT210, Germany).

The mean value of the sample dry weight was used for calculations. Weight measurement of the samples continued until three consecutive readings showed the same value. Initial and final sample moisture contents were determined gravimetrically before and after the drying experiment. Moisture content of the samples was determined by drying in a vacuum dryer (model Galen Kamp) at 70ºC, 150 mbar for 8 h (Tsami et al., 1990). Then their moisture was determined using relation 1 on the dry basis:

$$M_m = \frac{M_w - M_d}{M_d} \quad (1)$$

In which M_m is moisture content (d.b%) , M_w is moisture sample weight (kg) , M_d is dry matter weight (kg).

The velocity of drying air was adjusted to the desired level by adjusting the blower motor and was measured by an anemometer (AM- 4201, Lutron) with an accuracy of ±0.1 m/s. During the experiments, the ambient air temperature and RH variations in the laboratory were measured to be between 25 to 29°C and 31 to 33%, respectively. Given the small size of the samples, 35 by 35 cm metal micro-pore meshes were used as tray to keep the samples in the dryers. Aluminum frames of 35 by 35 cm cross section with 1, 2 and 3 cm height were placed on the porous plates to obtain the desired bed depths. The samples were placed in the frame, while a metal mesh was used on top to prevent any sample movement caused by the air current.

Drying process of *Hypericum perforatum* L.

Samples of St. John's wort leaves were obtained from the Medicinal Herb Research collection of Jahad-e-Daneshgahi in May and June, 2009. The plants were harvested just before flowering and the leaves were immediately removed from the stems. The leaves were cut and stored separately in plastic bags and refrigerated at a temperature of 4±1°C to prevent microbial activity. Initial moisture content of the leaves was found to be 61% d.b. In this study, the independent variables were drying temperature at 40, 50, 60, and 70°C, air velocity at 0.3, 0.7, and 1 m/s and bed depth at 1, 2, and 3

Table 1. Analysis of variance of drying time data.

Variable	df	SS	MS	F
Air temperature	3	451273.42	150424.47	2524.74**
Air velocity	2	11273.11	5636.55	94.60**
Temperature × velocity	6	2449.5	408.25	6.85**
Depth	2	21471.1	10735.55	180.18**
Temperature × depth	6	5054.2	824.36	14.13**
Air velocity × depth	4	2751.21	687.80	11.54**
Temperature × velocity × depth	12	987.24	361.77	1.38ns
Error	70	4171	59.58	
Total	107	627154.56		

**: significant difference (α =1%); ns: no significant difference (α = 1%).

Table 2. Analysis of variance values of drying rate.

Variable	df	SS	MS	F
Air temperature	3	0.0411	0.0136	455.55**
Air velocity	2	0.0029	0.00145	48.33**
Temperature × velocity	6	0.009	0.0015	50**
Depth	2	0.003	0.0015	50**
Temperature × depth	6	0.0082	0.0013	45.55**
Air velocity × depth	4	0.0083	0.002	69.16**
Temperature × velocity × depth	12	0.0003	0.000025	0.833ns
Error	70	0.0021	0.00003	
Total	107	0.0571		

**: significant difference (α =1%); ns: no significant difference (α = 1%).

cm levels. Thus, there were 36 treatments. Dependent variable was drying time that needed to determine the proper model for thin layer drying of St. John's wort leaves. A factorial experiment design was laid out in completely randomized design with three replications. All data were subjected to analysis of variance and Duncan's multiple range test was used to compare the treatment means.

RESULTS AND DISCUSSION

Results of the analysis of variances on drying time and average rate of drying are presented in Tables 1 and 2. Based on these results, it can be concluded that variations of air velocity, temperature and bed depth have significant effects on time and rate of drying (α = 1%). In addition, interactions of these variables were significant.
Comparison of the means for drying time and rate of drying using Duncan´s multiple range test are shown in Tables 3 and 4.

Initially, it is very important to determine the required time for drying of agricultural products. In order to protect herbs from aflatoxin and fungous pollution, most researchers believe that final moisture content of herbs should be 10% on the basis of dry matter weight and that irregular decrease of moisture content of the product results in low quality and quantity of the end product (Hevia et al., 2002). Based on Duncan´s multiple range test presented in Tables 3 and 4 and with respect to values presented in Tables 5 to 7, at each three diameters and at each three air velocity, increasing temperature significantly increased the rate of drying and decreased the drying time. This effect was more pronounced in temperature increasing from 40 to 50°C than from 50 to 60 and 60 to 70ºC since at high temperatures, plant surface becomes dry and seriously wrinkled. This in turn results in decreasing surface opening diameter. Thus, moisture content can not escape from the leaf surface rapidly. In addition, accumulation of salts obtained from evaporation in capillary tubes results in severing surface layer, so, escaping moisture becomes difficult. At all depths and air speeds, the temperature of 70ºC was the most effective in decreasing time and increasing the rate of drying. This is caused by increase in water activity due to warm air and increase in evaporation speed. On one hand, with regard to means

Table 3. Comparison of the means for drying time (minutes) using Duncan´s multiple range test.

Depth (cm)	Air velocity(m/s)	Air temperature(℃)			
		40	50	60	70
1	0.3	215^{o}	134^{j}	45d^{e}	20^{cd}
	0.7	195^{n}	117^{h}	27^{c}	10^{b}
	1	182^{m}	108^{g}	15^{b}	8^{a}
2	0.3	245^{qr}	165^{kl}	95^{f}	75^{e}
	0.7	225^{p}	140^{j}	75^{e}	56^{cd}
	1	207nd	127^{i}	57^{cd}	37^{b}
3	0.3	256^{r}	170^{l}	106^{g}	80^{e}
	0.7	235^{q}	155^{k}	85^{e}	60^{d}
	1	216^{o}	136^{j}	66de	46^{c}

Table 4. Comparison of the means for drying rate (kg H_2o/kg DM.h) using Duncan´s multiple range test.

Depth (cm)	Air velocity(m/s)	Air temperature(℃)			
		40	50	60	70
1	0.3	0.03^{b}	0.060^{f}	0.09^{i}	0.109^{k}
	0.7	0.040^{d}	0.069^{g}	0.094^{j}	0.115^{l}
	1	0.041^{d}	0.070^{g}	0.096^{j}	0.117^{l}
2	0.3	0.029^{b}	0.057^{f}	0.087^{i}	0.107^{k}
	0.7	0.039^{d}	0.067^{g}	0.090^{i}	0.115^{l}
	1	0.04^{d}	0.069^{g}	0.065^{j}	0.116^{l}
3	0.3	0.026^{a}	0.051^{e}	0.080^{h}	0.107^{k}
	0.7	0.35^{c}	0.067^{g}	0.087^{i}	0.115^{l}
	1	0.036^{c}	0.069^{g}	0.094^{j}	0.117^{l}

Table 5. Effect of temperature on percent decrease in drying time at different air velocities (1 cm depth).

Air velocity(m/s)	Temperature (℃)					
	40-50	40-60	40-70	50-60	50-70	60-70
0.3	37.67	69.76	76.74	51.49	62.68	23.07
0.7	40	76.92	82.05	61.53	70.08	22.22
1	40.65	82.41	89.01	70.37	81.48	37.5

Table 6. Effect of temperature on percent decrease in drying time at different air velocities (2 cm depth).

Air velocity(m/s)	Temperature (℃)					
	40-50	40-60	40-70	50-60	50-70	60-70
0.3	32.65	61.22	69.38	42.42	54.54	21.05
0.7	37.77	66.66	75.11	46.42	60	25.33
1	38.68	72.46	82.12	55.11	70.86	35.08

Table 7. Effect of temperature on percent decrease in drying time at different air velocities (3 cm depth).

Air velocity(m/s)	Temperature (℃)					
	40-50	40-60	40-70	50-60	50-70	60-70
0.3	33.59	58.59	68.75	37.64	52.94	24.52
0.7	34.04	63.82	74.46	45.16	61.29	29.41
1	37.03	69.44	78.70	51.47	66.17	30.30

Table 8. Effect of air velocity on percent of drying time at different temperatures (1 cm depth).

Temperature (℃)	Air velocity(m/s)		
	0.3-0.7	0.3-1	0.7-1
40	9.3	15.34	6.66
50	12.68	19.40	7.69
60	30.76	4.61	28.88
70	30	60	42.85

Table 9. Effect of air velocity on percent of drying time at different temperatures (2 cm depth).

Temperature (℃)	Air velocity(m/s)		
	0.3-0.7	0.3-1	0.7-1
40	8.16	15.51	8
50	15.15	23.03	9.28
60	21.05	40	24
70	25.33	50.66	33.92

comparison, Tables 3, 4 , 8 and 9, at each of the four temperatures and at each of the three depths, it was observed that increase in air velocity from 0.7 to 1 m/s did not have a significant effect on rate and time of drying. However, when air velocity increased from 0.3 to 1 m/s, time and rate of drying changed significantly. On the other hand, increase in depth at four temperatures and three air velocities had a negative effect on the rate and time of drying (that is, it decreased drying rate and increased drying time significantly). This is caused by the effect of plant mass diameter on the amount of water presented in the whole drying product, which has to be evaporated surprisingly. When temperature increased, this process (decrease in drying rate and increase in drying time) decreased gradually. In other words, the effect of bed depth fades when air temperature is increased. Because high temperature evaporated moisture at used depths in the experiment to the desired level due to the possession of high energy, increase in diameter of product layer had no significant effect on drying rate and time. Based on comparison of the means tables, temperature of 70ºC, depth of 1cm and air velocity of 1 m/s was considered the best combination regarding decreased time and increased rate of drying. The effect of temperature variations on changes in the drying rate and time of *Hypericum peroratum* L. is shown in Figures 2 to 7. It is seen that in the early stage of drying, product moisture decreases with a steep slope. The slope decreases as temperature increases. As time passes, slope of the curve becomes slower and tends to become horizontal. In other words, as the leaves become dry, extracting moisture is more difficult. Researchers have reported that drying rate has a downward movement (descends gradually) in almost all the biologic products (Madamba, 1996). Doymaz (2006) obtained the effect of air velocity and different temperature on drying time and determined the effective diffusivity for drying of mint leaves. Mohamed et al. (2005) determined the effects of air velocity and air temperature on drying kinetics of citrus aurantium leaves.

The effects of percent increase in temperature on decreasing drying time at depths of 1, 2 and 3 cm is shown in Tables 5 to 7. As shown in these tables, temperature has a significant effect on drying time.

The effects of percent increase of air velocity on decreasing drying time are shown in Tables 8 to 10. As it

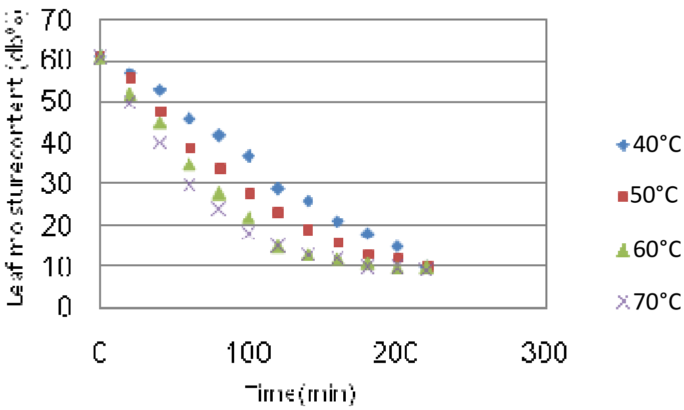

Figure 2. Effect of temperature on drying time (1 cm bed depth and 0.3 m/s air velocity).

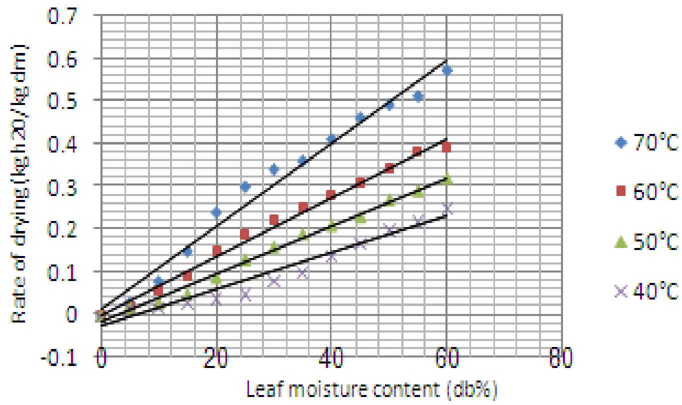

Figure 5. Effect of temperature on rate of drying (1 cm bed depth and 0.3 m/s air velocity).

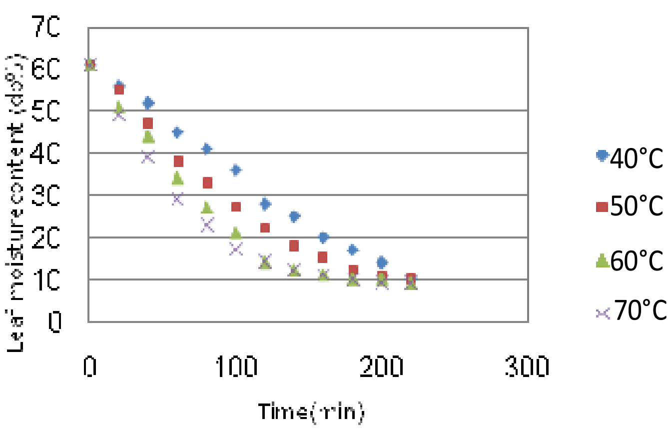

Figure 3. Effect of temperature on drying time (2 cm bed depth and 0.3 m/s air velocity)

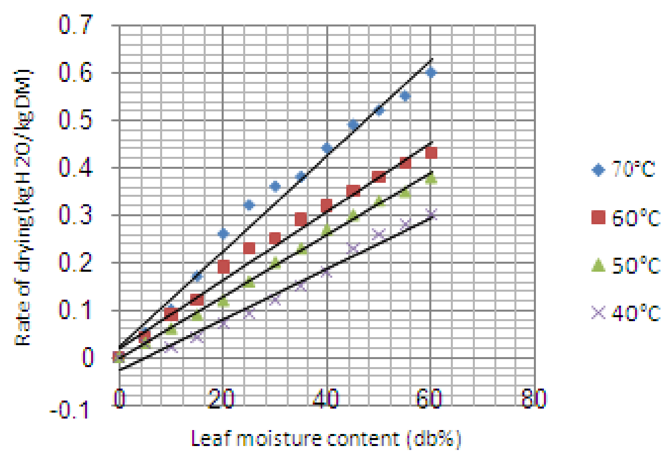

Figure 6. Effect of temperature on rate of drying (2 cm bed depth and 0.3 m/s air velocity).

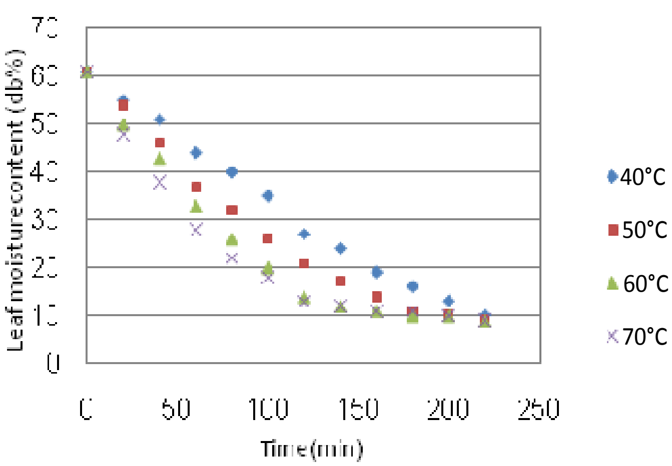

Figure 4. Effect of temperature on drying time (3 cm bed depth and 0.3 m/s air velocity).

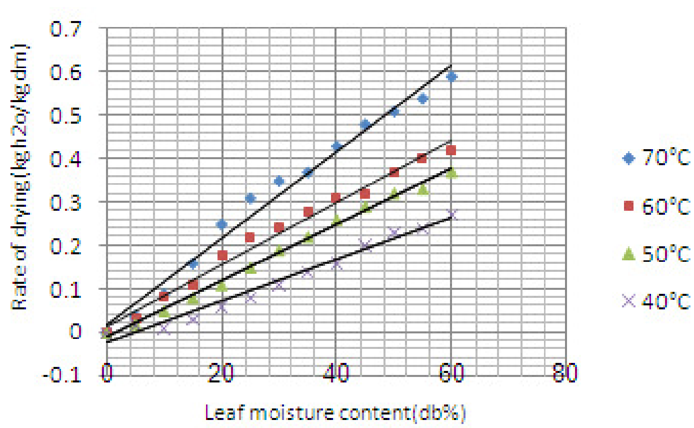

Figure 7. Effect of temperature on rate of drying (3 cm bed depth and 0.3 m/s air velocity).

Table 10. Effect of air velocity on percent of drying time at different temperatures (3 cm depth).

Temperature (℃)	Air velocity(m/s)		
	0.3-0.7	**0.3-1**	**0.7-1**
40	8.20	15.62	8.08
50	8.82	20	12.25
60	19.81	37.73	22.35
70	25	42.5	23.33

is shown, air velocity has a significant effects on drying time and this variable from 0.3 to 1 m/s was more than the others.

Conclusion

Temperature, air velocity and bed depth showed significant effects on time and drying rate of St. John's wort leaves. Based on this research, the best combination for drying leaves of *Hypericum perforatum* L. were temperature of 70℃, air velocity of 1 m/s and 1 cm bed depth.

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