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USING VACUUM DRYING SYSTEM FOR DRYING SOME LEAFY MEDICINAL PLANTS

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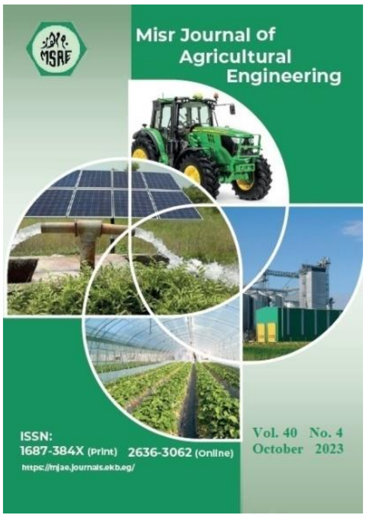


Keywords:
Drying; Arduino; Vacuum.

ABSTRACT

The aim of this study is to manufacture and evaluate a vacuum dryer for drying some leafy medicinal plants, namely mint (Mentha Piperita L), sage (Salvia Officinalis L.) and marjoram (Origanum Majorana L.) using an Arduino circuit to control the temperature and pressure inside the dryer. Three different levels of pressure, namely: atmospheric pressure, -5 and -10kPa, three different drying temperature are 40, 50 and 60 °C were studied for evaluating this dryer. Some a mathematical models for the thin layer were applied to describe the drying process of previous medicinal plants products and vacuum drying method. The results showed that Moisture content decreased from 88.9% to 13.4%, 89.1% to 14%, and 85.5% to 13.4% at drying times of 75, 120, and 90 min for Mint, Marjoram, and Sage, respectively. The moisture content of the samples was calculated on the basis of wet weight (% w.b.). At a drying temperature of 40°C, the specific energy consumption decreased from 1.62 to 1.06 kW.h/ kg (43.3% reduction) and from 0.99 to 0.5 kW.h/ kg (49.9% reduction) at 60°C when the vacuum was reduced from atmospheric pressure to -10kPa. A mathematical model describing the degree of vacuum and drying temperature was also evaluated. The results showed that the vacuum and drying temperature were effective in removing water from plants.

1. INTRODUCTION

Nowadays, the quality of food during drying is of great importance and various new drying methods are preferred in food drying technology. The purpose of food drying, besides the physical changes that occur during drying, has an overall effect on the quality of the dried food. Important factors such as drying temperature, drying time, etc. affect the physical properties of the dried material. **(Giri and Prasad 2013).** Food drying, typically used to keep food safe, extends the shelf life of food products**. (Younis et al. 2018).**

PepperMint (*Mentha spicata L.*) is a perennial plant cultivated primarily for its oil, called menthol. This is commonly used in the food, flavoring, pharmaceutical and cosmetic industries. In addition, the cooling and soothing properties of natural menthol make it a useful ingredient in pharmaceuticals and cosmetics **(Albaugh *et al*., 2002).** Mint is one of the most important aromatic plants in Egypt. One plant produces about 15-20 Mg of fresh herbs and provides about 25-30 kg of essential oil. Basil takes 2-3 hours. Steam distilled essential oils; one fardan can produce about 15 Mg of fresh herbs, yielding about 15 kg of essential oils. Salvia is also one of the most important aromatic plants. One ton produces about 10-12 Mg of fresh herbs and one ton of dried herb yields about 10-12 kg of essential oil **(CAGMC, 2002).**

Pepper Mint can be used as an herb to help fight colds, flu, indigestion, gas, motion sickness, food poisoning, and throat and sinus ailments. Its leaves are used in spices, tea making and condiments **(Park et al., 2002)**. Mint leaves are also an ingredient in various dishes such as vegetable curries, Mint chutneys, salad dressings, soups, desserts, juices and sweets **(Nasiru et al., 2019).** In foreign trade, the export volume of Egyptian pepper Mint oil reached about 291 tons in 2018, and the export growth rate accelerated. From 2014 to 2018, the export volume growth rate was about 87%, **(UNMS, 2018).** The results showed that the drying properties of Mint leaves are significantly affected by the influencing factors Drying pressure and temperature. **(Kovac et al. 2020).**

The aromatic and medical leaves, such as mint leaves, can be used fresh or stored in a cool place for a short time. These products are perishable because of the high percentage of water **(Boggia et al. 2015).** Marjoram is traditionally administered orally for the symptomatic treatment of gastrointestinal disorders and cough. Its antispasmodic and antibacterial properties are used in the treatment of bronchial diseases. Marjoram is used as a seasoning ingredient in meat dishes, sausage products, pizza, salads, eggs and vegetable preparations. This herb is characterized by a pleasantly aromatic taste with a slightly spicy and bitter aftertaste. Marjoram owes its subtle and delicate taste to its content of up to 1% steam distillable essential oil. This herb has aroused great interest among researchers, resulting in many publications since the 1960s **(Prakash, 1990).**

Marjoram is traditionally administered orally as a symptomatic treatment for gastrointestinal disorders and coughs. Its antispasmodic and antibacterial properties are used to treat bronchial disorders. Marjoram is also used externally to relieve cold symptoms such as nasal congestion and in mouthwashes for oral hygiene **(Bruneton, 1999).** Marjoram is a traditional herb that has been used since ancient times .This herb is rich a source of bioactive compounds such as monoterpenes, terpenes, flavonoids, phytosterols, tannins, etc. chemical components contained in marjoram have positive effects on health treatment of colds, coughs, headaches and other ailments diabetes, stomach infections, dysmenorrhea, and joint problems. **(Neha and Aparajita, 2022).**

One of the major problems in the world today is how to preserve seasonal agricultural products, especially fruits and vegetables, for long periods of time. Most of these products are exposed to spoilage. The rate of spoilage is not only related to the way they are harvested, stored, and used, but also to their moisture content (>80%), with 10% to 40% of fresh fruits and vegetables spoiling, **(Joardder, 2016).**

Drying is an energy-intensive and relatively time-consuming process. In addition, the loss of some quality parameters of fresh produce during drying is considered a drawback. Besides the conventional convection drying method, various alternative methods have been developed. An example is spraying drying, **(Sormoli and Langrish, 2016).**

Vacuum dried products are dried in a reduced pressure environment. Therefore, the heat required for rapid drying is lower. The lower pressure allows for lower drying temperatures, resulting in higher quality compared to conventional methods, including crispy texture, puffy structure, and retention of the natural color, shape, aroma, and flavor of fresh fruit, and minimal vitamin and mineral loss **(Jaya and Das, 2003).**

Vacuum drying is an alternative to conventional hot air drying, which evaporates moisture at lower temperatures than atmospheric conditions. Therefore, the product can be dried without exposing it to high temperatures. Furthermore, the absence of air during dehydration suppresses oxidation reactions. These advantages improve the color, flavor, and texture of the dried product **(Kiranoudis et al., 1997).**

Vacuum drying technology is considered the most suitable method. Vacuum drying applies negative pressure. Vacuum drying can be operated under less expensive conditions, including reduced power input. This drying process is applied to many types of manufacturing processes such as cream, yogurt, fruit milk, and card cake production. This technology overcomes the usual drying methods that use hot air **(Sunjka, 2004).**

Vacuum drying provides another way to improve the quality of dried products. Vacuum allows moisture to vaporize at a lower temperature and faster rate than under atmospheric pressure, resulting in a greater vapor pressure difference between the center and surface of the product, which allows moisture to move quickly from the food. Moisture is removed from the drying chamber by a watering pump that maintains a vacuum. Thus, products can be dried rapidly without exposure to high temperatures. In addition, because of the reduced time exposed to air during drying, oxidative degradation is reduced and the final color, flavor, and nutritional properties of the product are largely maintained **(Sham et al. 2001).**

Vacuum drying is a drying technique used to dry a variety of products while retaining color and vitamins **(Methakhup et al., 2005).** Vacuum increases the pressure gradient between the inside and outside of the sample to be dried, facilitating mass transfer and maintaining the low temperature levels essential for pyrolyzable products **(Pere and Rodier 2002).**

Vacuum drying has been successfully applied to many fruits, vegetables, and other heat-sensitive foods. Vacuum drying is characterized by excellent quality retention of nutrients and volatile aromas. However, the cost of vacuum drying is high **(Tsami et al., 1998).**

Traditional drying methods have many drawbacks because they are not compatible with mass production and do not achieve the quality standards required for medicinal plants. High temperatures and relative humidity during the harvesting and drying period promote insect and fungal infestation of the harvested crop. In addition, intensive solar radiation adversely affects quality, causing loss of vitamins and essential oils and changes in the color of the dried crop. Flavor is the quality factor most susceptible to hot drying **(Soysal and Oztekin, 2001).**

The objective of this study is to fabricate a smart vacuum dryer and conduct drying experiments on several leaf medicinal plants while maintaining product quality and safety during.

2. MATERIALS AND METHODS

Materials

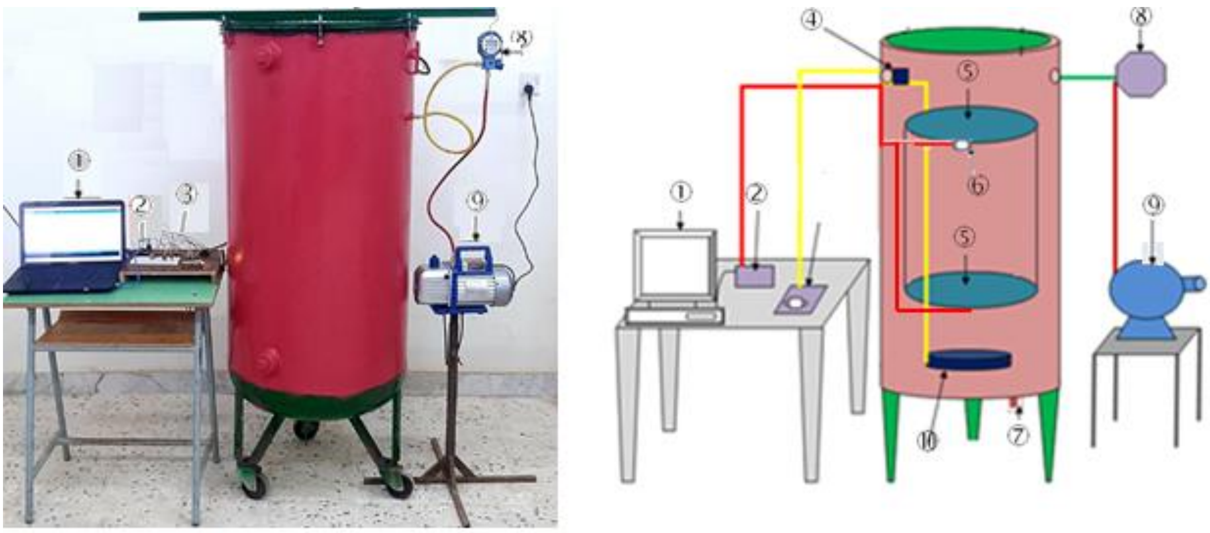
Raw materials:

The herbs under study were stared in harvested with scissors in a private farm in Al-Faydiyah (Al-Jabal Al-Akhdar), Libya, and stored in a refrigerator at 4°C before use. The experiment was conducted in the laboratory of the Department of Agricultural Engineering, Faculty of Agriculture, Omar Al-Mukhtar University, after the plucking season of 202١. The plants were washed with water to remove dirt and dust. Then they were gently watered and wiggled to dry from the water. Excess water was then wiped off with paper towels. The initial moisture content was then determined by the hot air furnace method using a laboratory furnace. An electronic balance was used to weigh the samples, with each sample weighing 100 g. The experiment was conducted in triplicate and the average was taken. The moisture content before drying was 88.9%, 89.1% and 85.5% for mint, marjoram and sage, respectively.

Vacuum dryer setup

As shown in Fig.(1) the developed dryer consists of two main parts:

- The first part consists of main body of the dryer: a reused iron electric heater body with a capacity of approximately 200 liters.
- The other part control circuit shown in Fig.(2) Consists of an Arduino Uno chip and sensors for vacuum temperature, humidity, and weight of sample. A relay module is used to control the temperature inside the dryer. Computer for data logging. The Arduino circuit programmed to record the temperature, humidity, and sample weight of the dryer every minute. The values are simultaneously recorded on the hard disk of the computer, displayed on an LCD screen, and updated periodically. Also, an electric heater (600 watt), controlled by an Arduino circuit, was installed at the bottom of the dryer.



1- Computer	2- Arduino Uno circuit	3- Control key
4- Temperature and humidity sensor	5- Rack	6-Weight sensor
7- Safety valve	8- pressure Gauge	9- Vacuum pump
10- Electrical heater		

Fig. (1): Photo and a schematic diagram of the developed vacuum dryer.

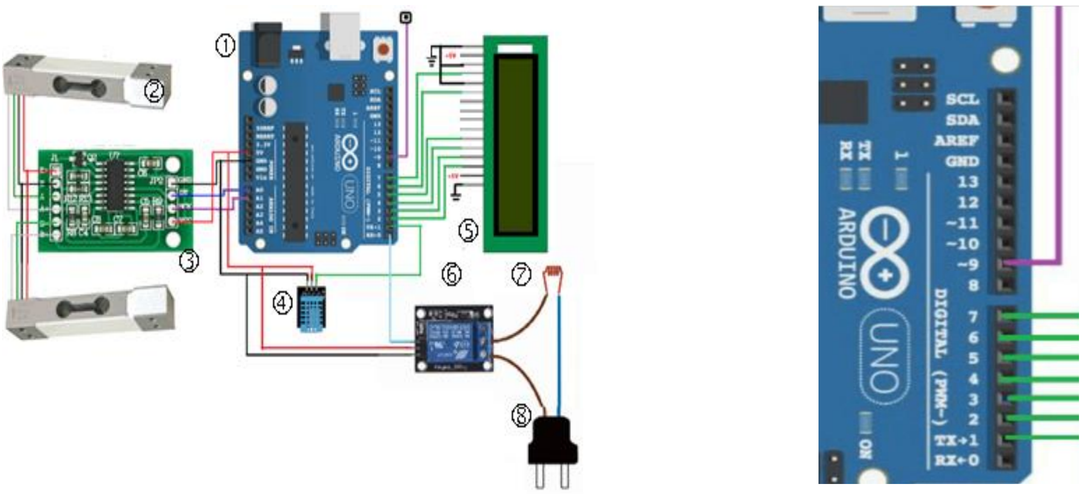
Vacuum pump

Model Vp245 vacuum pump used, pressure ranged from -1 to 3 bar, with displacement 120 l/min, half the horsepower and final vacuum of 3*10-1 Pa pressure level controlled by 2/2-way vacuum solenoid valve 3/4" normally open 220V model s301004170n.

Digital pressure gauge (range: -.01 ~6.0 MPa accuracy: 0.5).

Digital balance with an accuracy of 0.1 g was used to measure the samples mass changes (before and after drying) and to calibrate the load cells for control circuit.

Humidity and temperature are common parameters to measure environmental conditions. In this Arduino circuit the ambient temperature and humidity measured and displayed on a 16x2 LCD screen. A combined temperature and humidity sensor DHT11 is used with Arduino Uno to develop this Celsius scale thermometer and percentage scale humidity measurement circuit. Weight of drier samples also measured and recorded by using 5kg weight sensor with driver module HX711 amplifier



1	Arduino Uno	5	**Screen(LCD 2×16)**
2	Load cell	6	Relay module
3	Driver module HX711 amplifier	7	Heater
4	Temp. and humidity sensor DHT11	8	Electrical source 220 volt 50 hz

Fig. (2): Arduino Uno control circuit diagram.

Methods:

The experiments procedure:

To study the effect of the drying process, plant samples (Mint, Sage, and Marjoram) were dried at normal atmospheric pressure, two vacuum levels (-5 and -10 kPa), and three drying temperatures (40, 50 and 60 °C) and dried until the mass of each sample is approximately constant. The moisture content during the drying process was estimated by weighing the samples periodically with weighing sensors. The moisture content was measured with a sensor

The moisture ratio "MR":

The moisture ratio (MR) of each sample during the drying process and the drying rate of the sample were determined by the following equations;

$$MR = \frac{M_t - Me}{M_i - Me} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where, M_t, M_i and M_e are moisture content at any time, initial moisture content and equilibrium moisture content (d.b. %) respectively.

Compatibility of drying data to some mathematical models for thin layer drying:

Drying curves (MR vs. time) were plotted and fitted with two empirical drying models **(Lewis model, 1921 and Henderson and Pabis model, 1961).** Equations in Table 1 were tested to select the best model to describe the drying curve during the drying process. Model coefficients were calculated using the world's leading desktop statistical software package (PASW)Statistics 18 software.

Moisture content data observed during drying experiment converted to MR (Moisture Percentage) it is fitted to the two forms as described in Table (1).

Table 1: The examined mathematical models used for describing the drying data.

Model name	**Model equation**	**References**
Lewis's	MR= exp (-kt)	Lewis (1921)
Henderson and Pabis's	MR= a exp (-kt)	Henderson and Pabis (1961)

where: t = drying time; k and c = drying constants.

Goodness of fit was evaluated by the regression coefficient of determination (R^2), Root Mean Square Error (RMSE), mean square of the deviation between the experimental and calculated values of the model, or chi-square (X^2) defined in equations 5 and 6 below. The best model describing the vacuum drying process of the herb plant samples used was selected as the one with the highest R^2 and the lowest RMSE and X^2 **(Zakipour and Hamidi, 2011).**

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{model,i})^2}{n}} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where:

X_{obs} is observed values and X_{model} is modelled values at time/place *i*.

$$X^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{N-n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where:

$MR_{exp,I}$ is the i^{th} experimentally observed moisture ratio, $MR_{pre,I}$, the i^{th} predicted moisture ratio, N, the number of observations and n is the number constants.

The specific energy consumption (SEC):

The specific energy consumption to evaporate water from plants in this study was calculated by dividing the input energy consumption kW.h/ $_{\text{kgwater removed}}$ water removed by "ww" kg.

$$\text{The energy consumption} = P_p \times t_p + P_h \times t_h \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where:

"P_p"is the pump power (kW), "t_p" pump working time (h) and "P_h" power of heater (kW).and "t_h" heater working time (h)

3. RESULTS AND DISCUSSION

Effect of vacuum levels and drying temperatures on Plant drying curves:

Moisture content:

The data of the drying tests that were collected at Three different levels of pressure, namely: atmospheric pressure, -5 and -10kPa, three different drying temperature are 40, 50 and 60 °C, the moisture content of all dried plants decreased rapidly at the beginning of the drying time, especially with a lower vacuum level and a higher drying temperature, so the moisture content of mint decreased from 88.9% to 13.4%, and for sage it decreased from 85.5% to 13.4%, and for marjoram it decreased from 89.1% to 14%, then it decreased slowly at the end of the drying period, as a constant average drying period was not observed under the experimental conditions used, which is attributed to the fact that the product contains moisture High dries faster than a product with a high moisture content, low moisture content under the same drying conditions.

Fig. (3A, 3B and 3C) show that reduced the moisture content (%) of the mint plant from initial moisture of (88.5 ,88.7 and88.9 % w.b) to final moisture content (13.1 , 13.3 and 13.4 % w.b) at -10 kPa of the interior drier pressure requires 195, 135 and 75 min for the drying temperatures of 40, 50 and 60°C respectively.

Mint plants reached a moisture content of 134 after 75 min at 60 °C and a vacuum pressure of -10 kPa, while Sage plants reached a moisture content of 134 min and a vacuum pressure of -10 kPa after 90 min at a temperature of 60 °C, Figure 3(c). Marjoram stems take longer time than other plants. At 60°C and a vacuum pressure of -10 kPa, it takes 120 min for the moisture content to reach 140 min. The reason is that we are using dried whole Marjoram, not just the hanging leaves, and Mint has a shorter drying time than Sage and Marjoram at all the temperatures used. This is due to the weakness of the Mint leaves, Figure 3 (f).

Fig. (3g, 3h and3i) show the drying time of Sage drying speed at different vacuum levels of -5 and -10 kPa, and drying temperatures of 40, 50 and 60°C . The moisture content was reduced from 85.5% to 13.1% in 510, 300 and 210 min at atmospheric pressure, vacuum at -5 and -10 kPa, and drying temperature at 40°C, respectively. Also, increasing the drying temperature from 40°C to 60°C tended to decrease the drying durations from 510 min to 210 min, from 300 min to 180 min, and from 210 min to 90 min at the same vacuum levels above. It can be seen that increasing the drying temperature from 40 to 60°C tends to reduce the drying time from 210 min to 90 min at a vacuum level of -10 kPa.

The effect of the vacuum level can be clearly seen in all experiments, as when using a higher vacuum pressure -10 kPa) for vacuum drying than when we use pressure of (-5 kPa) and atmospheric pressure for vacuum drying, it results in shorter drying times. This result was agreed with the results obtained by **Sham *et al.*, (2001).**

Fig. (3) Shows the relationships between Moisture content (%) and drying time, min as affected by interior drier pressure kPa and temperature °C during all drying experiments. It is clear that the higher the drier temperature and the lower drier pressure tends to reducing the total drying time, and it was found that the least drying durations of were 75, 120 and 90 min for Mint, Marjoram and Sage respectively with interior drier pressure -10 kPa and temperature 60 °C, while the longest drying times were 495, 540 and 510 min for Mint, Marjoram and Sage respectively with atmospheric pressure and temperature 40 °C

From fig. (3) it can be seen that with the increase of drying time, the moisture content in the drying process decreased exponentially It can be seen that the drying and temperature has a great influence on the drying process.

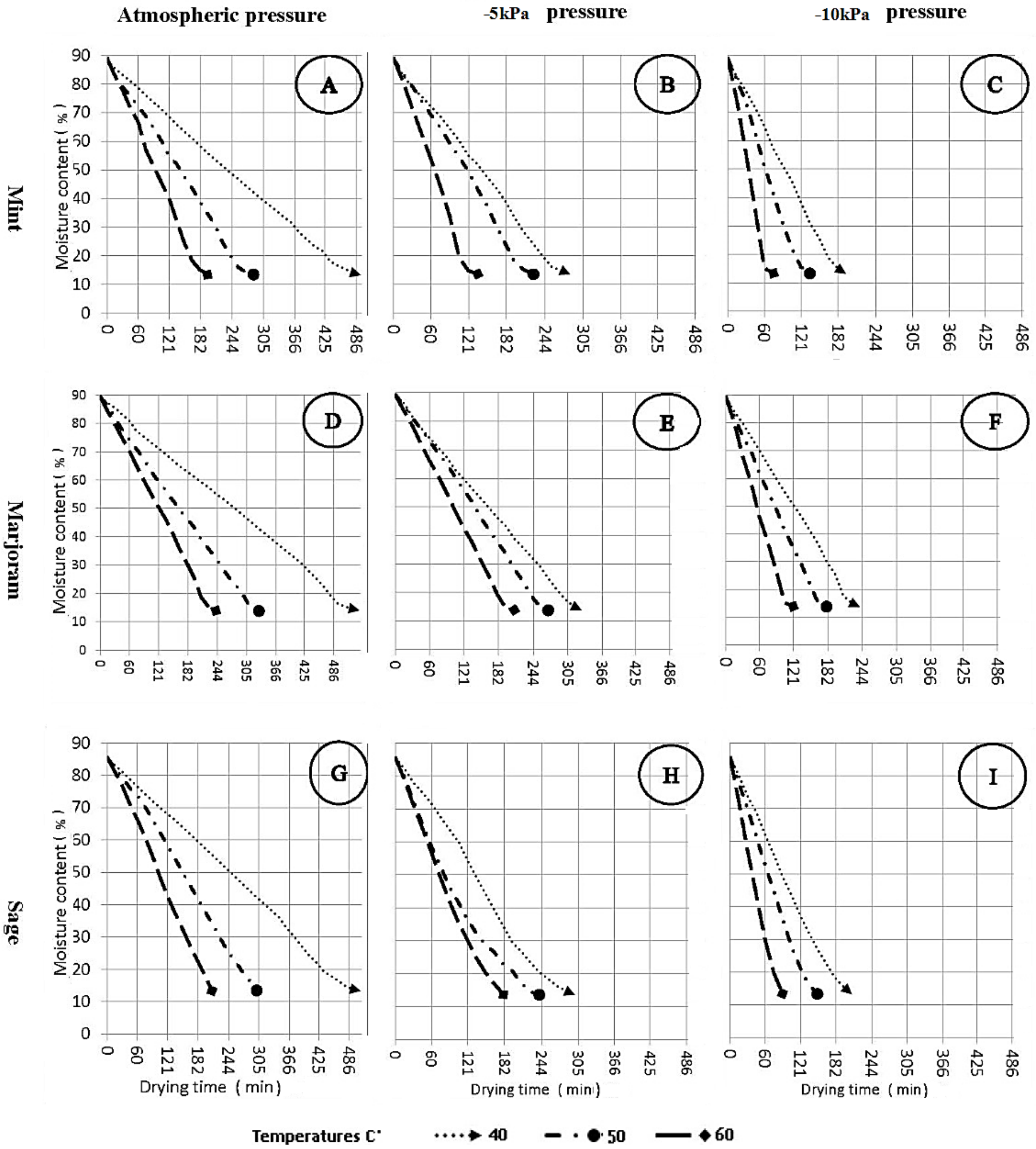


Fig. (3): Effect of pressure levels and drying temperatures on drying times for different medicinal plants under study.

Compatibility of drying data to Lewis and Henderson models:

The data obtained from laboratory experiments were used to study and analyze the applicability of two different drying models **(Lewis, Henderson and Pabis models)** in describing and simulating drying data. The results of the statistical analyzes performed on these Mint, Sage, and Marjoram models are presented in Tables (2, 3, and 4) respectively. Also, listed in these tables are the criteria used to estimate dry quality (R^2 and RMSE) and the constants in the model (a and k). Based on these criteria, the highest R^2 and lowest RMSE and x^2, the best model is selected. R^2, RMSE and x^2 values vary across all tables.

Table (2) shows the drying constants and statistical parameters of the two models using dried Mint samples. It was observed that the R^2 values in the two models at vacuum levels of -5 and -10 kPa were greater than 0.93, indicating good agreement. The coefficient of determination (R2) values of the Henderson and Babes model were greater than 0.92 at all temperature levels, and the mean square error (RMSE) ranged from 0.0353 to 0.0522.

Table 2: The constants of Lewis and Henderson models and its statistical analysis for Mint plant under all drying conditions in this study.

Model	Pressure kPa	Temp. °C	Constant a	Constant k	R^2	X^2	RMSE
Lewis's model	atm.	40		0.004	0.923	0.0016	0.0399
		50		0.006	0.906	0.0031	0.0539
		60		0.009	0.906	0.0044	0.0181
	-5	40		0.006	0.906	0.0032	0.0556
		50		0.008	0.893	0.0037	0.0586
		60		0.014	0.899	0.0057	0.0715
	-10	40		0.009	0.911	0.0043	0.0629
		50		0.014	0.910	0.0060	0.0729
		60		0.028	0.906	0.0071	0.0768
Henderson and Pabis's model	atm.	40	1.112	0.004	0.941	0.0012	0.0335
		50	1.106	0.007	0.923	0.0026	0.0493
		60	1.114	0.010	0.925	0.0034	0.0564
	-5	40	1.108	0.007	0.923	0.0027	0.0508
		50	1.115	0.009	0.913	0.0029	0.0515
		60	1.105	0.016	0.915	0.0048	0.0658
	-10	40	1.113	0.011	0.930	0.0033	0.0557
		50	1.114	0.016	0.928	0.0048	0.0656
		60	1.08	0.030	0.916	0.0063	0.0727

Table (3) shows the constants of two models for drying process and its statistical analysis for Sage. The results showed that all models had good suitability to the experimental data under all drying conditions in this study. Parameter estimations and the Henderson and Pabis model was best fitness to the experimental data.

The drying constants and statistical parameters of the two models using dried Marjoram are shown in Table 4.. It was observed that R^2 values in all models were greater than 0.90, indicating a good fit. The coefficient of determination (R^2) values for the Henderson and Pabis model was greater than 0.92 at all temperature levels, and the mean square error (RMSE) ranged from 0.0277 to 0.0530.

Table 3: The constants of Lewis and Henderson models and its statistical analysis for Sage plant under all drying conditions in this study.

Model	Pressure kPa	Temp. °C	Constant a	Constant k	R^2	X^2	RMSE
Lewis's model	atm.	40		0.003	0.905	0.0017	0.0403
		50		0.005	0.899	0.0040	0.0618
		60		0.008	0.914	0.0039	0.0604
	-5	40		0.006	0.906	0.0051	0.0699
		50		0.010	0.969	0.0014	0.0361
		60		0.011	0.946	0.0027	0.0501
	-10	40		0.009	0.933	0.0033	0.0552
		50		0.013	0.927	0.0039	0.0597
		60		0.022	0.943	0.0036	0.0555
Henderson and Pabis's model	atm.	40	1.121	0.004	0.926	0.0012	0.0353
		50	1.129	0.006	0.924	0.0029	0.0528
		60	1.114	0.009	0.935	0.0029	0.0522
	-5	40	1.138	0.007	0.930	0.0038	0.0601
		50	1.081	0.010	0.978	0.0010	0.0300
		60	1.092	0.012	0.959	0.0021	0.0438
	-10	40	1.104	0.010	0.949	0.0025	0.0484
		50	1.096	0.014	0.941	0.0032	0.0543
		60	1.069	0.024	0.950	0.0032	0.0522

Table 4: The constants of Lewis and Henderson models and its statistical analysis for Marjoram plant under all drying conditions in this study.

Model	Pressure kPa	Temp. °C	Constant a	Constant k	R^2	X^2	RMSE
Lewis's model	atm.	40		0.003	0.913	0.0011	0.0325
		50		0.005	0.922	0.0020	0.0440
		60		0.007	0.910	0.0027	0.0500
	-5	40		0.005	0.922	0.0020	0.0441
		50		0.006	0.904	0.0027	0.0510
		60		0.009	0.912	0.0029	0.0521
	-10	40		0.007	0.906	0.0027	0.0506
		50		0.010	0.920	0.0031	0.0536
		60		0.016	0.920	0.0039	0.0587
Henderson and Pabis's model	atm.	40	1.110	0.004	0.932	0.0008	0.0278
		50	1.105	0.006	0.939	0.0014	0.0365
		60	1.105	0.008	0.927	0.0020	0.0432
	-5	40	1.106	0.006	0.939	0.0026	0.0368
		50	1.117	0.007	0.925	0.0020	0.0435
		60	1.111	0.010	0.925	0.0022	0.0455
	-10	40	1.109	0.008	0.930	0.0020	0.0439
		50	1.097	0.011	0.924	0.0025	0.0480
		60	1.094	0.018	0.935	0.0032	0.0530

Figs. (4) Illustrates the observed and calculated values of moisture content of Mint, Saga and Marjoram leaves at examined temperatures and pressures. The results show that, studied models described the drying behavior of experimented plants leaves satisfactorily as indicated by the high values of coefficient of determination (R^2) and low values of standard error (SE).

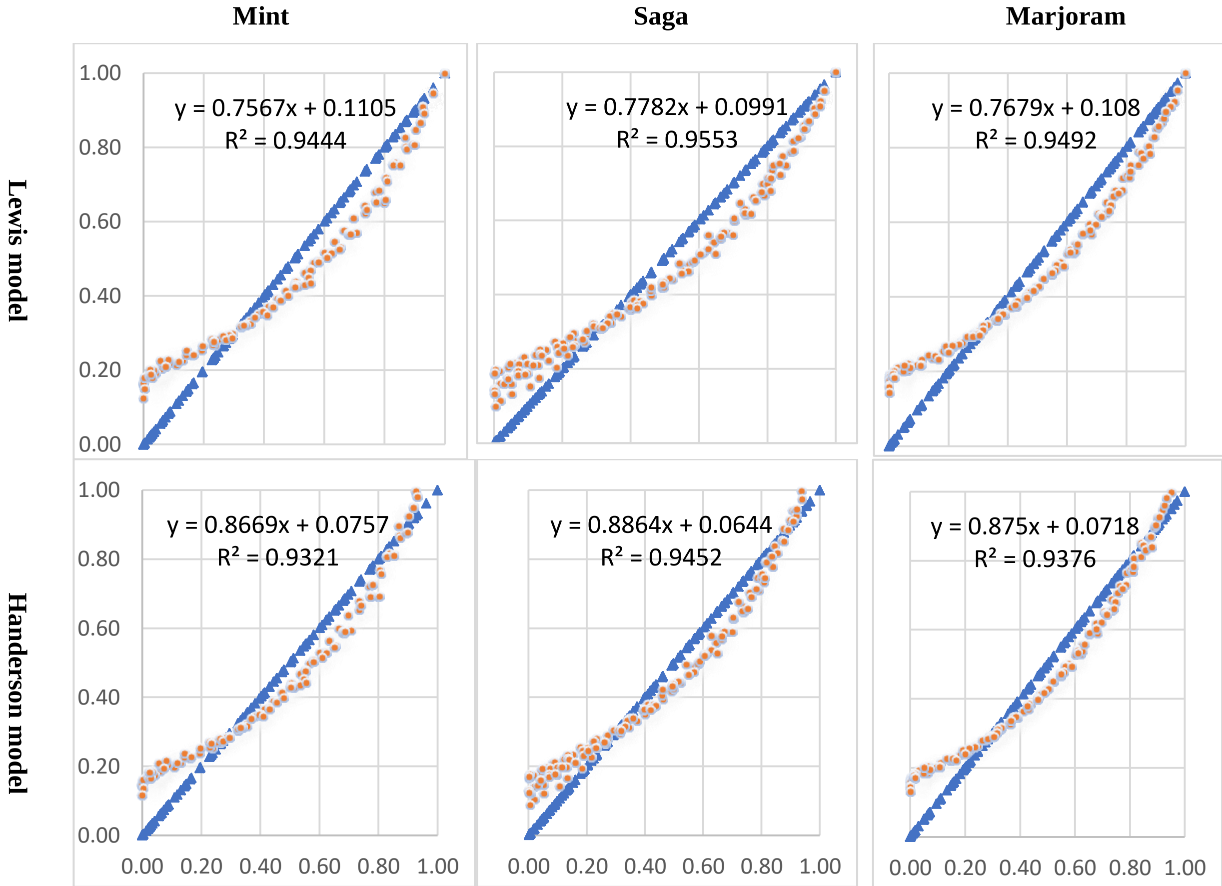


Fig. (4): The predicted and observed moisture ratio for used models to all experimented plants.

-Specific energy consumption, kW.h/ $_{\text{kgwater removed}}$:

Table (5) shows the specific energy consumption for drying Mint at normal atmospheric pressure and at two vacuum levels for the pump operating program. The results showed that energy consumption decreased with increasing drying temperature and decreasing vacuum level. At a drying temperature of 40 °C, a decrease in vacuum from atmospheric pressure -10 kPa tends to result in a decrease in specific energy consumption from 1.92 to 1.06 kW.h/ kg (43.3% reduction rate), whereas maintaining the same vacuum level above In the case of, it decreased from 1.1 to 0.5 kW.h/ kg (49.9%) as the drying temperature increased from 60 °C (% decrease rate).

Table (6) shows that when drying Sage, the energy consumption is the highest at normal pressure and drying temperature 40 °C, and the lowest energy consumption (0.50 kW.h/ kg) is at vacuum degree -10 kPa and drying temperature 60 °C. The result was agreed with **(Soysal and Oztekin 2001)** confirmed this result.

Table 5: Specific energy consumption at different conditions in this study for drying Mint plant, kW.h/ kg$_{\text{water removed}}$.

Pressure, kPa	Drying temperature, °C	Drying time, min.	Power consumption, Watt		Total power consumption, Watt	Specific energy consumption, kW.h/ kg
			Heater	Pump		
Atmospheric pressure	40	480	240	-	240	1.92
	50	280	286	-	286	1.34
	60	190	315	-	315	0.99
-5	40	284	281	41	322	1.33
	50	226	327	41	368	1.23
	60	136	356	41	397	0.81
-10	40	196	325	85	410	1.06
	50	134	371	85	456	0.83
	60	75	400	85	485	050

Table 6: Specific energy consumption at different conditions in this study for drying Sage plant, kW.h/ kg$_{\text{water removed}}$.

Pressure, kPa	Drying temperature, °C	Drying time, min.	Power consumption, Watt		Total power consumption, Watt	Specific energy consumption, kW.h/ kg
			Heater	Pump		
Atmospheric pressure	40	510	240	-	240	2.04
	50	300	286	-	286	1.43
	60	212	315	-	315	1.11
-5	40	302	281	41	322	1.41
	50	241	327	41	368	1.31
	60	180	356	41	397	1.07
-10	40	210	325	85	410	1.14
	50	152	371	85	456	0.94
	60	90	400	85	485	0.60

Table 7: Specific energy consumption at different conditions in this study for drying Marjoram plant, kW.h/ kg$_{\text{water removed}}$.

Pressure, kPa	Drying temperature, °C	Drying time, min.	Power consumption, Watt		Total power consumption, Watt	Specific energy consumption, kW.h/ kg
			Heater	Pump		
Atmospheric pressure	40	540	240	-	240	2.16
	50	330	286	-	286	1.57
	60	242	315	-	315	1.27
-5	40	331	281	41	322	1.55
	50	271	327	41	368	1.47
	60	210	356	41	397	1.25
-10	40	240	325	85	410	1.3
	50	180	371	85	456	1.11
	60	120	400	85	485	0.80

4. CONCLUSION

1. The vacuum drying process is a very effective method for removing moisture from plants. Moisture removal rates were easily improved with increasing vacuum and dryness.
2. The developed mathematical model developed was very accurate and can be used in computer programs to describe the drying characteristics of plants on a commercial scale.
3. The use of vacuum drying improves drying efficiency, retains nutrients, and enhances the appearance of dried samples
4. Vacuum drying can also be used to enhance the nutritional value of dried products.
5. Evaluation of the final product requires evaluation of the product appearance, i.e. product attractiveness is an essential evaluation parameter.
6. Vacuum drying is recommended at low temperatures in order to maintain the high organic properties of the dried product
7. Short processing times, i.e., suitable for automated production.

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استخدام نظام التجفيف تحت التفريغ لتجفيف بعض النباتات الطبية الورقية

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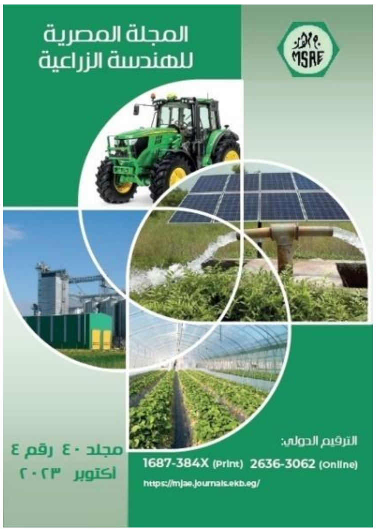

الملخص العربي

تهدف هذه الدراسة الي تصنيع وتقييم مجفف لتجفيف بعض النباتات الطبية الورقية من خلال إحداث تفريغ للضغط داخل غرفة التجفيف وذلك محاولة لتقليل الطاقة اللازمة لتبخير الرطوبة وبالتالي تقليل التكاليف اللازمة لعملية التجفيف. أجريت التجارب في ورشة قسم الهندسة الزراعية – كلية الزراعة – جامعة عمر المختار- البيضاء ٢٠٢١ تم تصنيع مجفف من جسم سخان كهربائي مع تحكم ذكي. تم التحكم في التفريغ الداخلي ودرجة الحرارة بشكل كامل باستخدام دائرة Arduino Uno ، وتم تسجيل عينات الأوزان المسجلة بشكل دوري في برنامج الكمبيوتر. واستخدم المجفف المصنع لدراسة خصائص التجفيف بالتفريغ للنعناع والمرمرية والبردقوش عند ثلاثة مستويات ضغط (الضغط الجوي العادي ، ومستويان من التفريغ عند - ٥ و - ١٠ كيلو بسكال) ، ثلاث درجات حرارة للتجفيف (٤٠ و ٥٠ و ٦٠ درجة مئوية). تم تقييم معاملات التجفيف وخصائص التجفيف واستهلاك الطاقة. كما تم دراسة مدي توافق البيانات التجريبية مع بعض صيغ التجفيف الآخري

وكان من أهم النتائج ما يلي:

انخفض محتوى الرطوبة من ٨٨,٩ إلى ١٣,٤٪ ومن ٨٩,١ إلى ١٤٪ ومن ٨٥,٥ إلى ١٣,٤٪ عند وقت تجفيف ٧٥ و ١٢٠ و ٩٠ دقيقة للنعناع والبردقوش والميرمية على التوالي عند درجة حرارة تجفيف ٦٠ درجة مئوية وضغط - ١٠ كيلو بسكال. وعند درجة حرارة التجفيف ٤٠ درجة مئوية ادي خفض مستوى الضغط من الضغط الجوي إلى - ١٠ كيلو بسكال إلى تقليل استهلاك الطاقة المحدد من ١,٩٢ الى ١,٠٦ كيلو وات. ساعة / كجم (بمعدل تناقص ٤٣,٣٪) للنعناع بينما انخفض من ٠,٩٩ إلى ٠,٥ كيلو وات. ساعة / كجم بنسبة ٤٩,٩٪ عند درجة حرارة ٦٠ درجة مئوية للنعناع . تم تقييم النماذج الرياضية التي تصف تغير خصائص تجفيف النباتات و أظهرت نتائج عملية التجفيف أن مستوى التفريغ ودرجة حرارة التجفيف كانا فعالين للغاية في إزالة الرطوبة من النباتات.

الكلمات المفتاحية:

التجفيف؛ تفريغ؛ اوردينيو.