J. Agric. Sci. Mansoura Univ., 33(5): 3457 - 3468, 2008

DRYING TECNOLOGY OF ROSELLE UNDER VACUUM

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ABSTRACT

The characteristics for vacuum drying of roselle at three pressure levels (normal atmospheric pressure, two vacuum levels at -125 and -250 mbar), three drying temperatures (30, 40 and 50°C) and the effectiveness of tempering periods in drying cycle were studied. The drying coefficients, drying characteristics and energy consumption as well as the product quality after drying were evaluated. Mathematical models describing the change of drying characteristics of roselle as dependent variables with vacuum level and drying temperature as independent variable were also evaluated. The drying process continued until the calyces of roselle moisture content decreased from 67.5 %, (wet basis) to the mass of each sample remained almost constant. The results revealed that, vacuum level and drying temperature were very effective in removing moisture from fresh roselle calyces. Increasing rates of moisture removal and reduced energy consumption for drying were readily achieved with decreasing vacuum levels and increasing drying temperatures for about 2.4 times the rate currently achieved in atmospheric pressure drying. The developed mathematical models were highly accurate and can be used to describe the drying conditions of roselle in the commercial scale. Short vacuum drying and tempering cycles are more effective in removing moisture than long ones. The quality of dried product achieved through vacuum drying was higher than that currently being experienced in normal atmospheric pressure drying process.

INTRODUCTION

Roselle (*Hibiscus Sabdariffa* L) or karkade is a strong annual herbaceous, as multi-purposes economical plant and cultivated in a wide range of climatic conditions. It contains citric acid and salts, serving as a diuretic. Karkade is used in jams, jellies, sauces, wines, syrup, gelatin, refreshing beverages, and dried roselle is used as tea. Seeds have been used as an aphrodisiac coffee substitute, Alian *et al.*(2006). Recently, the biological activities of anthocyanins, such as antioxidant activity, protection from atherosclerosis and anticarcinogenic activity have been investigated, and shown to have some beneficial effects in the treatment of diseases, Tsai *et al.*(2002). Also, the red, blue and violet pigments in the calyces of roselle are due to anthocyanins, hibiscingrossypetin and falconoid which are receiving more attention as natural food colorant source instead of artificial synthetic colorants which have side effects, Bridle and Timberlake (1997). Thus, a roselle is one of the important medicinal plants. Most natural plant pigments, including anthocyanins and betacyanins are easily affected by temperature, oxygen, light and water activity, Cai and Corke (2000). Therefore, the immediate drying is the most important operation in postharvest processing to avoid quality losses of these valuable, but perishable crops, Oztekin (1999). Traditional drying methods have many drawbacks due the inability to handle the large production and to achieve the high-quality standards required for medicinal plants. High ambient air temperature and relative humidity during the harvesting and drying season promote the insect and mould development in the harvested crops. Furthermore, intensive solar radiation adversely affects quality, causing vitamin and essential oil losses or colour changes in the dried crops. The flavor is the most sensitive quality factor affected by high-temperature drying, Soysal and Oztekin (2001). Also, Muller *et al.* (1989) reported that, the specific energy consumption for peppermint, sage and hops were 8640, 9360 and 5580 kJ/kg of evaporated water, respectively at 45°C drying air temperature. Also Muller and Martinov (1998) reported that temperatures above 50°C have a deleterious effect upon leaf colour of Hypericum perforatum, while, temperatures below 60°C have no effect of flower colour and hypericin content. To overcome these problems, producers mostly adopt the new drying techniques. Vacuum drying offers an alternative way to improve the quality of the dried products. The vacuum permits water to vaporize at a lower temperature and faster rate than at atmospheric pressure, Sham *et al.*(2001). This results in a greatly increased vapor pressure difference between the center and the surface of the product, allowing rapid transfer of moisture out of the food. The moisture is removed from the drying chamber by the water-ring pump, which maintains the vacuum. Therefore, the products can be dried rapidly without exposure to high temperatures. Further, the reduced exposure time to air during drying may help to reduce oxidative deterioration, end color, flavor, and nutrient properties of products can be largely preserved. Kiyohisa (1978) reported that as the pressure above the product decreased, the temperature at which the change of state occurs is also decreased, and the latent heat involved is slowly increased. He also reported that the relation between the pressure and boiling point of water as shown in Table 1.The boiling point of water was sharply decreased with decreases the pressure, while the heat of evaporation was slightly increased. Because the drying proceeds as the evaporation goes on, this method is also suitable to leaf- vegetables, to reduce the energy consumption, which have higher surface to volume ratios, and water easily movable within plants.

Table 1: Relation of pressure and boiling point of water.

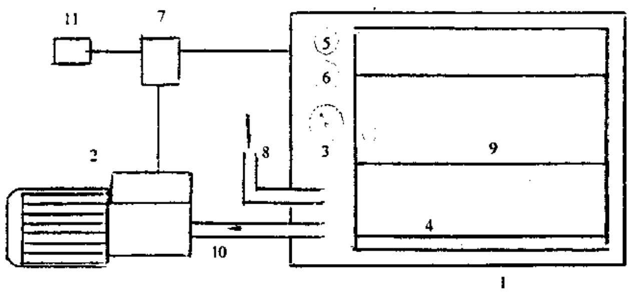
Pressure, kPa	Boiling point, °C	Heat of evaporation, Kcal/kg
101.1	100	538.8
13.6	52	567.6
4.0	29	580.8

(Cited from Kiyohisa, 1978).

These principles are involved in the operation of a vacuum drying system. The vacuum drying process is a very effective method for removing moisture from freshly dug peanuts, Kunze *et al.* (1968); cranberries, Yongsawatdigul and Gunasekaran (1996); krill, Durance (1997); shrimp, Lin *et al.*(1999) and apple, Sham *et al.* (2001). This paper was initiated to determine the characteristics of vacuum drying, energy consumption and quality of roselle calyces at different temperatures when the vacuum pump at various vacuum levels and operation cycles were used.

MATERIALS AND METHODS

The experiments were conducted in the laboratory of Sakha Agriculture Research Station, Kafr El-Sheikh Governorate, Agric. Res. Center after 2007 Roselle harvesting season. Quality analysis was evaluated in the laboratory of Food Tech. Dep., Faculty of Agric., Kafr El-Sheikh University. The dark roselle sepals were collected after 30 days from fruit set at initial moisture content 67.5% from Sakha experimental farm. To obtain the final moisture content of 12% (w.b.), 631kg water per 1000kg fresh mass had to be evaporated. In drying experiments, fresh roselle was harvested and the calyces were separated from flowers and stored in closed plastic pages in refrigerator at 4°C until used. The vacuum oven (*Model Gallenkamp OVL-570*) was used in this study, which had a working chamber of 0.031m^3 and a maximum operating temperature of 200°C. The oven-wall temperature was indicated on a mercury-in-glass thermometer and was controlled by a temperature-control dial and a calibration control as indicated in Figure 1



No.	Part name
1	Vacuum oven
2	Vacuum pump
3	Manometer
4	Glass termomter
5	Temperature-control dial
6	Calibration control
7	Electeric meter
8	Fresh air
9	Oven shelfs
10	Outlet air
11	Power supply

Figure 1: Schematic diagram of vacuun drying apparatus

Two shelf's (366 x 290mm) were used to hold the roselle calyces while they were in the vacuum oven with layer thickness of about 2cm. A vacuum pump with a fresh-air capacity of 100 L/min and 200-watt power supply was used to reach the desired vacuum levels and remove the water vapors from the oven. To examine the effect of drying parameters, the samples weight of 1.6 kg from fresh dark roselle calyces were dried under normal atmospheric pressure (as control) and two vacuum levels (-125 and -250 mbar) and three drying temperatures (30, 40 and 50°C) until reach to the mass of each sample remained almost constant. The vacuum levels were adjusted by manometer attached with oven. Moisture content during the drying process was estimated by periodically weighing the samples as reported by Correa *et al.*(1999). To determine moisture content, the samples in triplicate were dried according to AOAC (2005). The moisture content of the sample on a wet weight basis (%w.b) was then calculated. A reference sample of roselle calyces was also dried in the open area under sunshine, since it was spread out in a thin layer of 2cm with average temperature of 25 ± 2°C at variable humidity until reached about 12.2% moisture content through 36 hr (with drying rate around 1.5%/hr) as a traditional method. The electric power consumption for each test was measured by using an electrical meter, *model (GG 150E)* which connected at the source of power supply as reported by Shoughy (2001). The effectiveness of tempering periods in drying cycle was also studied. The vacuum pump was operated with the time clock to give drying and tempering of ½-hr dry, ½-hr temper cycle and the 2-hr dry, 2-hr temper cycle at constant drying temperature at 40°C and -125mbar vacuum level. The effect of drying temperatures and vacuum levels on drying coefficients, drying characteristics and energy consumption as well as the aqueous extracts quality of dried calyces were evaluated.

Quality analysis:

Preparation of calyces extracts:

The extracts were prepared by soaking the dried calyces in distilled water, where a part was extracted at room temperature for 5, 15 and 30 min and the second part was placed in boiling water under reflective air condenser for 5, 15 and 30 min. After cooling the aqueous extracts to room temperature, their properties (pH value, total soluble solids and anthocyanin content) were determined as following:

1. **PH-value:**

   The pH value was measured by pH-meter according to AOAC (2005).

2. **Total Soluble Solids, %:**

   Mass of 3g from each dried sample were extracted in 100ml of distilled water either at room temperature or boiling water as previously indicated. The extracts were evaporated to dryness and the total soluble solids (TSS,%) were determined according to AOAC (2005).

3. **Anthocyanin content (mg/g)**:

   The extracts anthocyanin content (AC) as mg/g of dried roselle calyces was determined according to the method described by Wong *et al.*, (2003).

The statistical analysis:

The multiple linear regression analysis was employed in this experimental work to examine and assess the effect of vacuum level and drying temperature on the drying time, drying rate and energy consumption of roselle.

RESULTS AND DISCUSSION

1.Drying Coefficients:

The experimental data of roselle to reached moisture content of about 12%, which were collected from drying tests at three levels of vacuum pressure and drying temperature are summarized in figure 2. The calyces moisture content decreased rapidly at the beginning of drying time especially with lower vacuum level and higher drying temperature and slowly decreased at the end of drying period. Although the initial moisture content of the samples were quite high (67.5%), a constant drying rate period was not observed under the experimental conditions employed, and the overall drying process took place in the falling rate period. The drying rate at the beginning of drying time was higher than that at the enter drying period. This was attributed to the fact that the product, which had high moisture content, dried faster than that of low moisture content at the same drying conditions.

To avoid the effect of original moisture content on the drying rate, the dimensionless moisture ratio was used to indicated the effect of drying parameters on the drying rate of roselle as indicated in figure 3. Several forms of thin-layer drying equations have been used to describe the drying rate of grains and other agriculture product. A simple exponential model, analogous to Newton's low of heat convection, which described the moisture loss in thin-layer was used as follows (Matouk *et al.*, 2002):

$$MR = \frac{M - M_f}{M_o - M_f} = e^{-kt} \qquad (1)$$

The drying coefficient k for each test were determined by fitting the data generated in the thin-layer drying experiments with the corresponding time interval to equation 1 as follows:

$$k = \frac{Ln(M - M_f) - Ln(M_o - M_f)}{t} \qquad (2)$$

where: MR = moisture ratio, dec.;

M = roselle moisture content, w.b, %;

M_f = final moisture content, w.b., %;

M_o = initial moisture content, w.b., %;

t = drying time, h and

K= a coefficient related to product type and conditions, h-1.

The drying rate coefficients determined from each test were used to derive equation for calculating drying rate coefficients based on a given vacuum level and air drying temperature of dried bed. The relationship between drying coefficient (K, hr –1) as dependent variables and vacuum levels (V, mbar) and drying temperature (T, °C) as independent variables was found and may be written in general form as follows:

$$Y = a + bX1 + cX2 \qquad (3)$$

where: a, b and c are constant for any given condition and units used.

The values of a, b and c, the coefficient of multiple determination (r^2) and standard error (SE) in the previous relationship were determined for each tested drying condition by using standard multiple linear regression analysis as follows:

K = 0.839 – 9.6x10 –4 V+ 9.19x10 –3 T (r2 = 0.91, SE = ± 0.028)...(4)

The vacuum levels and drying temperatures were very effective in removing moisture from fresh roselle calyces. Also, the effect of vacuum levels was more effect than the drying temperature. A comparison between the experimental moisture ratio (MR) and the moisture ratios calculated by Page equation, using the parameter K which was calculated by equation 4 is summarized in table 2. It was found that, the predicted value lie close with the observed values and this equation indicate high accurate and can be used to describe the drying conditions of roselle calyces in the commercial scale.

Table 2: Calculated and predicted values of moisture ratios of roselle calyces.

Vacuum level, mbar	Drying temperature, °C	Drying ratio, dec.	
		Observed	predicted
Atmospheric pressure	30	0.892	0.864
	40	0.821	0.788
	50	0.793	0.719
-125	30	0.846	0.767
	40	0.749	0.699
	50	0.727	0.638
-250	30	0.738	0.680
	40	0.636	0.621
	50	0.571	0.566

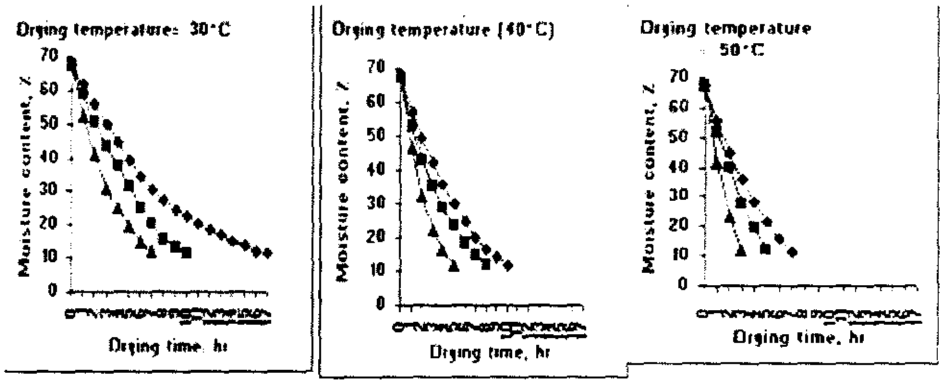


Figure 2: Effect of vacuum levels on drying time of roselle at different drying temperatures

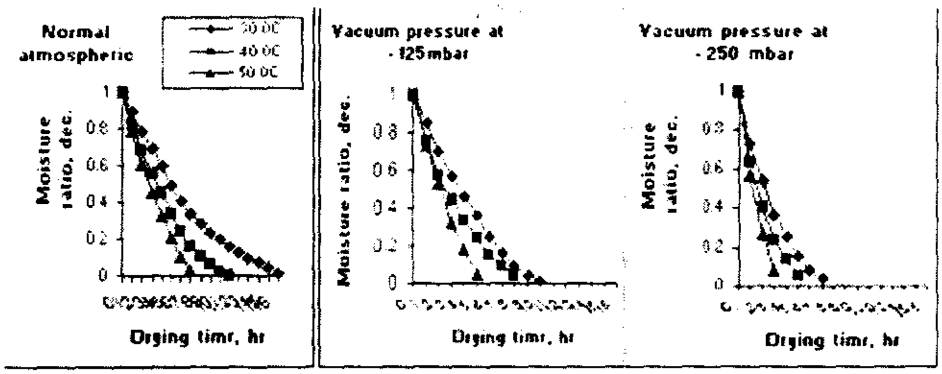


Figure 3: Effect of vacuum level and drying temperature on moisture ratios of roselle.

2. Drying characteristics:

From figure 2 and 3, it can be shown the drying time and drying rate at different vacuum levels and drying temperatures. Decreasing moisture content from 67.5 to 12% needed 17, 10 and 7hr at normal atmospheric pressure, vacuum levels of -125 and -250 mbar, respectively at 30°C drying temperature. Also, increasing drying temperature from 30 to 50°C tends to decrease drying time from 17 to 7hr, from 10 to 5hr and from 7 to 3hr, at the same vacuum levels mentioned above. It can be seen that, at vacuum level -250 mbar, increasing drying temperature from 30 to 50°C tends to decrease drying time from 7 to 3hr. This sample was sufficiently dry for commercial storage moisture content after only 3hr of drying. This result may be due to, the lower the pressure in the chamber during drying process, the higher the pressure differential, resulting in a greater outward force causing the roselle calyces to expand, spongy and increasing the removed moisture from the dried product. On the other hand, drying rates were increased from 3.28%/hr to 7.96%/hr, from 5.63%/hr to 11.24%/hr and from 7.94%/hr to 18.57%/hr with increasing drying temperature from 30 to 50°C at normal atmospheric pressure, two vacuum levels of -125 and -250 mbar, respectively. While, the drying rate was increased from 3.28 %/hr to 7.94%/hr when decreasing vacuum level from normal atmospheric pressure to the vacuum level of -250 mbar for 30°C drying temperature due to the large vapor pressure differential between the center and surface of products. It is evident that the vacuum level had a significant effect on the drying process especially on the drying rate. This is about 2.4 times the rate currently achieved in drying at normal atmospheric pressure. This result was agreed with the results obtained by Sham *et al.*, (2001).

4. Pump operation procedures:

The effectiveness of tempering periods in drying cycle was studied. This type of procedure could have commercial application by permitting one vacuum pump to operate two or more vacuum system. Figure 4 and 5 compare the result of drying time and drying rate of ½-hr dry, ½-hr tempering cycle to the 2-hr dry, 2-hr tempering cycle. The two cycles performed similarly with the shorter cycle showing a slight advantage by drying faster. The abscissa indicates hours of pump operation but the roselle calyces stayed actually in the system twice as long as the time indicated. The initial drying rate per hour of vacuum pump operation was found to essentially equivalent to the continuous drying process at 50°C and -125 mbar vacuum level as showed in figure 2 or drying rate of about 11%/hr of pump operation. Thus, tempering periods could substitute for high temperature in a commercial process, however, each batch of roselle calyces would stay in the system twice as long, and hence a specific operation would require more vacuum chambers for given drying capacity.

5. Specific energy consumption, kJ/kg:

Table 3 shows the specific energy consumption for drying roselle with normal atmospheric pressure, two vacuum levels and different drying air temperatures for pump operation procedures. The results showed that the energy consumption decreased with increasing drying temperature and decreasing vacuum levels. At 30°C drying temperature, decreasing vacuum level from atmospheric pressure to -250 mbar tends to decreased specific energy consumption from 13158 to 7812 kJ/kg (by 41% decreasing rate) while, it decreased from 7207 to 4114 kJ/kg (by 43% decreasing rate) with increasing drying temperature from 30°C to 50°C at the same vacuum levels maintained above. The highest energy consumption was obtained with normal atmospheric pressure and 30°C drying temperature and the lowest energy consumption was obtained at -250 mbar vacuum level and 50°C drying temperature (4114 kJ/kg) with continuous pump operation. This result was confirmed with the result obtained by Soysal and Oztekin (2001). However, with intermittent pump operation at constant 40°C drying temperature and -125 mbar vacuum level, the specific energy consumption decreased from 8467 to 4763 kJ/kg (by 43.7% decreasing rate) with short cycle (½-hr dry, ½-hr temper cycle) and from 8467 to 5292 kJ/kg (by 37.5% decreasing rate) with long cycle (2-hr dry, 2-hr temper cycle) but the drying time was extended due to roselle calyces would stay in the system twice as long as continuous pump operation. This result may be due to the shorter drying time and higher drying rate with decreasing vacuum level and increasing drying temperature.

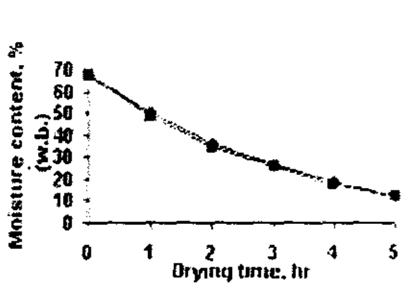


Figure 4: Effect of tempering cycles at constant temperature (40°C) and vacuum level (-125 mbar) on drying time of roselle.

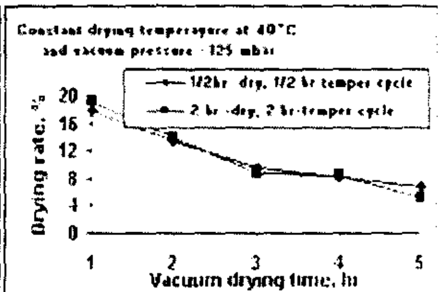


Figure 5: Effect of tempering cycles at constant temperature (40°C) and vacuum level (-125 mbar) on drying rates of roselle.

(The abscissa represents hours of vacuum pump operation).

Table 3: Energy consumption for drying roselle, kJ/kg.

Pump operation		Pressure, mbar	Drying tempe-rature, °C	Drying time, hr	Power consumption, Watt		Total power consu-mption, Watt	Specific energy consum-ption, KJ/kg
					Pump	Heater		
Continuous		Atmospheric pressure	30	17	-	215	215	13158
			40	10	-	242	242	8712
			50	7	-	286	286	7207
		-125	30	10	52	215	265	9540
			40	8	52	242	294	8467
			50	5	52	286	338	6084
		-250	30	7	95	215	310	7812
			40	5	95	242	337	6066
			50	3	95	286	381	4114
Intermi-ttent	Short cycle*	-125	40	4.5	52	242	294	4763
	Long cycle**	-125	40	5	52	242	294	5292

Short cycle*: 1/2hr-dry, 1/2hr-temper cycle , long cycle**: 2hr-dry, 2hr-temper cycle

5. Product quality:

The pH value, TSS % and anthocyanin content (AC) are important properties for the quality of roselle calyces extracts, since the low pH value and high TSS% and AC are indicators for the best quality. The effect of drying conditions, soaking time and extraction temperature on pH value, TSS and AC was recorded in table 4. It could be observed that there was variation between the samples depending on drying conditions, soaking time and extraction temperature. The results revealed that product quality increased with decreasing vacuum level and slowly decreased with increasing drying temperature. Also, the value of total soluble solids and anthocyanin content increased and pH-value decreased with increasing soaking time and water temperature at the same drying treatment. The results also indicated that at drying temperature of 50°C and extraction at room temperature for 15min soaking time, the change from atmospheric pressure to -250 mbar vacuum level, tends to decreasing pH value by 10.5%, increasing total soluble solids by 35.5% and anthocyanin content by 34.1%. Thus, the best results of product quality was obtained with drying roselle calyces at 50°C drying temperature and -250 mbar vacuum level, which gave high values of total soluble solids and anthocyanin content and low pH-value. This result may be attributed to the drying under vacuum give spongy texture of dried product which help in rapidly extraction of the pigments and another compounds, (Alian *et al.*, 2006).

Table 4: Effect of drying method on some properties of aqueous extracts prepared at different temperatures for various soaking time.

Vacuum level	Drying Temper-ature, °C	Quality values	Extracted at room temperature (25 ± 2°C)			Extracted at boiling temperature		
			5 min	15 min	30 min	5 min	15 min	30 min
Atmospheric pressure	Sun drying	pH value	4.5	3.9	3.7	3.6	3.4	3.3
		T.S.S%	10.2	18.4	20.7	25 9	33.3	34.6
		A.C.	8.8	12.5	15.5	23.6	26.15	26.15
	30°C	pH value	4.3	3.9	3.6	3.6	3.3	3.3
		T.S.S%	12.4	20.3	23.5	30.5	35.0	35.3
		A.C.	9.25	15.95	16.85	23.65	26.45	26.15
	50°C	pH value	4.2	3.8	3.6	3.5	3.3	3.2
		T.S.S%	16.5	22.7	25.8	31.1	35.1	35.9
		A.C.	10.75	18.90	20.45	24.85	26.45	26.3
- 125mbar	30°C	pH value	4.0	3.7	3.6	3.5	3.3	3.2
		T.S.S%	17.3	20.3	30.5	33.2	35.4	36.4
		A.C.	12.7	23.45	25.5	25.5	26.65	26.50
	50°C	pH value	4.0	3.6	3.5	3.4	3.2	3.1
		T.S.S%	17.6	26.0	35.6	38.6	39.8	40.4
		A.C.	13.85	24.45	24.8	26.75	27.3	27.15
- 250mbar	30°C	pH value	3.9	3.5	3.4	3.3	3.1	3.0
		T.S.S%	18.9	28.4	35.9	36.2	41.9	42.3
		A.C.	14.45	24.2	25.4	26.65	27.45	27.3
	50°C	pH value	3.8	3.4	3.3	3.2	3.1	3.0
		T.S.S%	19.4	30.9	36.7	38.1	42.2	42.8
		A.C.	14.45	25.35	26.65	26.65	27.45	27.45

In addition, the drying under vacuum carry out far from oxidation also in shorter time and that is very suitable for the protection of quality compounds such as pigments, flavors and acids.

Conclusions

1. The vacuum drying process is a very effective method for removing moisture from freshly roselle calyces. Increasing rates of moisture removal were readily achieved with increased vacuum levels and drying temperatures for about 2.4 times the rate currently achieved in atmospheric pressure drying.
2. The developed mathematical models were highly accurate and can be used with computer program to describe the drying characteristics of roselle in the commercial scale.
3. At 30°C drying temperature, decreasing vacuum level from normal atmospheric pressure to -250 mbar tends to decreased specific energy consumption by 41%, while, it decreased by 43% with increasing drying temperature to 50°C.
4. Short vacuum drying and tempering cycles are more effective in removing moisture than long ones. The drying rate per hour of intermittent vacuum pump operation was found to essentially equivalent to the continuous drying process at higher temperature.
5. The drying under vacuum gave a high quality of dried product where the texture was spongy and the components were extracted rapidly at room temperature comparing to that currently being experienced in atmospheric pressure drying.

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تكنولوجيا التجفيف تحت تفريغ لمحصول الكركديه

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أجريت هذه التجارب فى المعمل المركزي بمحطة البحوث الزراعية بسخا حيث تم الحصول على عينات الكركديه من المزرعة البحثية فى موسم حصاد ٢٠٠٧م. وتم استخدام تكنولوجيا التجفيف تحت تفريغ بغرض تجفيف المنتج فى وقت قصير حتى لا يحدث أكسدة وبدون استخدام درجات الحرارة المرتفعة التى تسبب تلف لمكونات المنتج. تم تجفيف ثمرة الكركديه من محتوى رطوبى ٦٧,٥% الى ١٢% (على أساس رطب) باستخدام فرن التجفيف تحت تفريغ عند درجات حرارة ومعدلات تفريغ مختلفة مع نظامين تشغيل لطلمبة التفريغ. تم دراسة تأثير ثلاث معدلات ضغط (الضغط الجوى العادى ، -١٢٥ ، -٢٥٠ ملي بار) مع ثلاث درجات حرارة (٣٠، ٤٠، ٥٠ °م) وكذلك التشغيل المستمر والمتقطع لطلمبة التفريغ (٠,٥ ساعة تجفيف- ٠,٥ ساعة تهوية ، ٢ ساعة تجفيف- ٢ ساعة تهوية) عند درجة حرارة ٤٠ °م وضغط تفريغ -١٢٥ ملي بار على خصائص التجفيف مثل زمن التجفيف ومعدل التجفيف للمنتج والطاقة اللازمة للتجفيف بالإضافة الى جودة المنتج النهائي بعد عملية التجفيف. وتم أيضا تجفيف عينه من الكركديه فى الشمس كعينه مقارنة تمثل الطريقة التقليدية.

وكان من أهم النتائج ما يلي:

١- انخفض المحتوى الرطوبى للمنتج من ٦٧,٥ الى حوالى ١٢% (على أساس رطب) فى زمن قدرة ١٧، ١٠، ٧ ساعات عند تغير معدلات التفريغ من الضغط الجوى العادى ، -١٢٥ ، -٢٥٠ ملي بار عند درجة حرارة تجفيف قدرها ٣٠ °م. وبزيادة درجة الحرارة أنخفض الزمن اللازم للتجفيف.

٢- تم استنباط نمازج رياضية توصف خصائص التجفيف للكركديه تحت تفريغ عند درجات الحرارة المبينة يمكن أن تستخدم فى برنامج حاسب آلي للتنبؤ بظروف التجفيف على النطاق الاقتصادي.

٣- زاد معدل التجفيف مع زيادة درجة حرارة وانخفاض مستوي التفريغ تحت الدراسة بحوالي ٢,٤ ضعف بينما كان تأثير الانخفاض فى معدل التفريغ أعلى من زيادة درجة الحرارة.

٤- انخفضت الطاقة النوعية اللازمة للتجفيف بمقدار ٤١% عند الانخفاض من الضغط الجوى العادى الى -٢٥٠ مللي بار عند درجة حرارة ٣٠ °م. وبزيادة درجة الحرارة الى ٥٠ °م انخفضت الطاقة اللازمة للتجفيف بمقدار ٤٣%.

٥- معدل التجفيف عند التشغيل المتقطع لطلمبة التفريغ عند الدورات القصيرة كان أعلى منه عند الدورات الطويلة عند درجة حرارة ٤٠ °م. وكان يعادل التجفيف المستمر للطلمبة عند درجة حرارة أعلى (٥٠ °م) عند نفس المستوى من التفريغ (-١٢٥ ملي بار). وذلك أفضل من ناحية الجودة وكذلك توفير الطاقة بالإضافة الى إمكانية استخدام طلمبة التفريغ للتخفيف فى أكثر من غرفة تجفيف فى وقت واحد فى حالة التشغيل على النطاق الاقتصادي.

٦- إستخدام تكنولوجيا التجفيف تحت تفريغ لثمار الكركديه أدى الى زيادة معدل التجفيف مع انخفاض زمن التجفيف وانخفضت الطاقة اللازمة للتجفيف ودرجة الحرارة التى يتعرض لها المنتج أثناء التجفيف مما يقلل من عملية الأكسدة وأعطى منتج إسفنجي ذو جودة استخلاص عالية عند درجة حرارة الغرفة بالمقارنة بطريقة التجفيف التقليدية عند الضغط الجوي العادي مما يجعلها مناسبة لتجفيف الكركديه كأحد أهم النباتات الطبية.