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Influence of Various Drying Techniques on the Quality of Roselle (*Hibiscus Sabdariffa* L.) Calyces

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Abstract: Roselle calyces are extremely perishable, making the process of drying them without sacrificing quality quite difficult. Similarly, there are various commercial drying procedures available, each with its own set of benefits and drawbacks in terms of nutrition and qualities in the final product. The purpose of this research was to study the effect of using different drying methods such as sun, shade and microwave with powers (200, 400, 600 and 800 W) and drying times (6, 8, 10 and 12 min.) on specific energy consumption, moisture content, vitamin C, total phenols, anthocyanin, acidity and antioxidant activity for dried roselle calyces. The results showed that the minimum value of specific energy consumed at 200 W and 6 min was 5.09 MJ/kg and 5.08 MJ/kg for the first and second seasons, respectively. Microwave drying at 400 W with 12 min. and 600 W with 10 min. recorded the highest values of total phenols, acidity, anthocyanin and antioxidant activity compared with sun and shade drying, while vitamin C recorded the highest value at 200 W with 6 min. In addition, the results showed that roselle dried at 200 W had a damp appearance, while roselle dried at 800 W became severely distorted and very brittle. The results demonstrated that using microwave for drying roselle calyces preserves their quality.

Key words: Anthocyanin, Antioxidant activity, Microwave drying, Moisture content, Roselle calyces.

INTRODUCTION

Roselle (*Hibiscus sabdariffa* L.) is an annual plant belongs to Malvaceae family and is widely distributed around the world in tropical and subtropical regions (**Rocha *et al.*, 2014**). Roselle found in most warm countries, like Saudi Arabia, Philippines, India, Malaysia, Indonesia, Thailand, the Vietnam, Egypt, Sudan, and Mexico (**Rao, 1996; Chewonarin *et al.*, 1999**). It has been used for a long time as an herbal tea due to its rich content of active compounds like anthocyanins, flavonoids, phenolic acid, vitamin C, antioxidants and minerals, (**Ibrahim and Mazuki, 2013 and Sabet Sarvestani *et al.*, 2020**), which are useful to human health by prevent cancer tumor and decrease chronic illnesses like high blood pressure, dyslipidemia, diabetes, and disease of heart (**Shruthi and Ramachandra, 2019**). Roselle is used in the healing of urinary bladder and kidney stones in India. Roselle leaves and flowers used for curing hypertension in Mexico (**Riaz and Chopra, 2018**).

Anthocyanins are phenolic compounds soluble in water that are responsible for variety of color in plants, like orange, red, blue, and purple. The stability of anthocyanins is influenced by temperature, light, pH and structure (**Laleh *et al.*, 2006**). Phenolic compounds have a lot of beneficial effects, such as antioxidant properties. (**Kelebek *et al.*, 2013; Özşen and Erge, 2013**). also has an antidiabetic effect (**Martineau *et al.*, 2006 and Grace *et al.*,2009**) and an antibacterial effect (**Park *et al.*, 2011 and Chatterjee *et al.*, 2004**) and is known to be effective against vascular disease (**Neto, 2007).** Roselle content many organic acids, like malic, tartaric, citric, and ascorbic **(Puro *et al.*, 2014).** Fresh roselle withers rapidly and cannot be kept for long time or exported for long distances, it must be dried quickly after harvesting.

The drying process reduces the moisture content of plants by inhibiting enzymatic and microbial activity, preserving products, increasing shelf life, and keeping their value (**Rocha *et al.*, 2011**). Microwave drying decrease drying time and improve morphological, physicochemical, and functional properties (**Bhat *et al.*, 2023)**. Sun and shade drying are the most common methods of drying. There are many limits to sun and shade drying dried plant quality, like long time, elevated risk of contamination, inadequacy of drying, and the effect of the surrounding environmental conditions. (**Udomkun *et al.*, 2020**). Recently, drying techniques have been developed to decrease drying times, increase energy efficiency, and reduce the deterioration of plant quality (**Marilena, 2020**). Using the microwave technique for drying led to a shorter drying time, a low cost, and a high nutritional value for the plant. The microwaves are absorbed by the water molecules, fats and sugars contained in the plant and heat is generated inside the product, causing less sensory and nutritional reduction (**Espinosa *et al.*, 2017 and Martins *et al.*, 2019**). The microwave technology reduces power consumption, decreases the effect on the environment, and ensures security (**Zaidel *et al.*, 2014**). The quality of products which dried by using microwave is influenced by drying treatments such as microwave power, drying time, the initial moisture content of the product, and the dielectric properties of the materials **(Moses *et al.*, 2014**). Incrementing the microwave power from 360 to 900 W reduced the drying time of parsley by 64% and parsley which dried by microwave showed well color retention with only a slightly darker color than fresh parsley (**Soysal, 2004**).

This research aimed to investigate the effect of different drying methods (sun, shade and microwave) on the quality and chemical composition of roselle calyces.

MATERIALS AND METHODS

The present study was carried out during October 2020 and 2021 at the Agricultural Engineering Research Institute, Rice Mechanization Center in Met El-Debeh, Kafr El-Sheikh while, roselle plants were cultivated at the Agricultural Research Center farm at the Agricultural Research Station in Gemmayzeh, Gharbia Governorate, during the two consecutive summer seasons in order to study the effect of different drying methods on the quality and chemical composition of roselle.

Sun drying

Fresh roselle calyces were dried on a wooden tray with dimensions 30×20 cm in direct sunlight from 9 A.M. to 4 P.M. for 7 days.

Shade Drying

Fresh roselle calyces were dried in a shade chamber under ambient air temperature in wooden trays with dimensions 30×20 cm for 12 days. The trays were kept from direct sun during drying.

Microwave oven

Fresh roselle calyces were spread on the turntable glass plate with a diameter of 18 cm of a digital microwave oven (LG, Model: MS3948ASC/00, 230 V, 50 Hz, input 1450 and output power 1000 W).

Treatments:

- (T1). Dry in Sun.
- (T2). Dry in Shade.
- (T3). Drying at 200 watts+6 min.
- (T4). Drying at 200 watts+8 min.
- (T5). Drying at 200 watts+10 min.
- (T6). Drying at 200 watts+12 min.
- (T7). Drying at 400 watts+6 min.
- (T8). Drying at 400 watts+8 min.
- (T9). Drying at 400 watts+10 min.
- (T10). Drying at 400 watts+12 min.
- (T11). Drying at 600 watts+6 min.
- (T12). Drying at 600 watts+8 min.
- (T13). Drying at 600 watts+10 min.
- (T14). Drying at 600 watts+12 min.
- (T15). Drying at 800 watts+6 min.
- (T16). Drying at 800 watts+8 min.
- (T17). Drying at 800 watts+10 min.
- (T18). Drying at 800 watts+12 min.

Moisture content

Moisture content was determined according to the method of (**A.O.A.C., 2005**). About 100g of fresh roselle calyces were dried in the oven at (105°C) until a constant weight. The initial moisture content of fresh roselle calyces was found to be equal to 87.3 and 88.00% (w.b.) in the first and second season, respectively.

Energy consumption

Energy consumption (Et, W. min) was calculated by the equation:

$$\mathrm{Et} = p \times t$$

where: p: Power requirements, W

t: Drying time, min.

Specific energy consumption

The specific energy consumption (SEC, MJ/kg water) was calculated as mentioned by (**Soysal *et al.*, 2006**) who describe it as the energy needed to evaporate a unit mass of water.

$$SEC = \frac{60 \times \mathrm{Et}}{1000 \times \mathrm{mw}}$$

where: mw: Mass of evaporated water, g

Determination of V.C.

Vitamin C as mg/100g ascorbic acid was determined according to **(A.O.A.C., 2005)** methods.

Determination total phenols

Total polyphenols were determined spectrophotometrically by the method described by (**Amin *et al.*, 2006)** as g /100 g (gallic acid).

Determination of anthocyanin

Anthocyaninwas colourmetrically determined in samples (g/100g) according to **(Zhang *et al.*,2007).**

Determination of Acidity

Total acidity as mg/g of anhydrous citric acid determined according to (**A.O.A.C., 2005)** methods.

Antioxidant activity

Antioxidant activity of dried roselle samples was determined by 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging method according to (**Brand-Williams *et al.*, 1995**).

Statistical analysis

Each treatment replicated three times in two seasons. Data were analyzed as a completely randomized block design and LSD (least significant difference) tests ($P < 0.05$) used to assess the differences between treatments according to Test: **(Steel and Torrie, 1990**).

RESULTS AND DISCUSSION

Moisture content

Table 1 illustrated the effect of sun, shade and microwave power levels (200, 400, 600 and 800 W) and drying times (6, 8, 10 and 12 min.) on the moisture content of roselle calyces in first and second seasons. These results showed that microwave power and drying times significantly affected the moisture content. Increases in microwave power and drying times caused a reduction in the moisture content of the roselle calyces. Microwave drying at 400, 600 and 800 W recorded the lowest moisture content in comparison to sun and shade drying in two seasons. Calyces that dried at 200W resulted in a damp appearance. It may be that this is due to the reduced drying potential at this power. Undesirable changes were also noticed in calyces dried at 800 W. The calyces became severely distorted and brittle. These undesirable changes may be the result of overheating and unequal heating in the microwave oven (**Zhang *et al.*, 2006**). The power levels of 400 and 600 W and drying times of 12 and 10 min., respectively achieved the best moisture content as they were 11.01 and 11.24% in the first season and 11.14 and 11.28% in the second season, respectively. Increasing the microwave power reduced the drying time, as mentioned by (**Soysal, 2004; Mujaffar and Loy, 2016).** It was observed that drying in shade and sun consumed more time than microwave drying as they were 12 and 7days, respectively. In addition, using the shade and sun in drying gave the final moisture contents of roselle higher than the moisture content of the microwave, as they were 14.88 and 13.36% in the first season and 14.27 and 13.74% in the second season, respectively.

Energy consumption

Energy consumption is an important parameter in various drying systems due to high production costs. Hence, the drying technique chosen must be energy-saving. Fig. 1 has shown the total energy consumed by different microwave powers and drying times. With an increase in power and drying time, energy consumption increased significantly (P<0.05, LSD 0.05 = 0.0027). This may be due to the high power of the microwave and the long drying time during the drying process. The highest value of energy consumption was recorded at 800 W and 12 min., as it was 0.16 KW.h., while the lowest value of energy consumption was 0.02 KW.h. at the lowest power and drying time (200 W and 6 min., respectively).

Table (1). Effect of sun drying, shade drying and different powers of microwave with different drying times on the moisture content of roselle (*Hibiscus sabdariffa* L.) calyces in the two seasons of 2020 and 2021

Treatments	Drying time	Moisture content, %	
		1st Season	2nd Season
Dry in Sun	7 days	13.36	13.74
Dry in Shade	12 days	14.88	14.27
Drying at 200 watts	6 min.	29.21	29.35
	8 min.	20.99	20.98
	10 min.	18.29	19.13
	12 min.	15.04	15.47
Drying at 400 watts	6 min.	27.25	27.92
	8 min.	19.10	18.84
	10 min.	14.08	14.88
	12 min.	11.01	11.14
Drying at 600 watts	6 min.	25.04	25.26
	8 min.	15.24	15.35
	10 min.	11.24	11.28
	12 min.	9.73	9.71
Drying at 800 watts	6 min.	17.28	17.88
	8 min.	9.61	9.83
	10 min.	8.35	8.19
	12 min.	6.99	6.21
LSD at 5%		1.40	1.31

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Specific energy consumption

As shown in Figure 2, rising microwave powers and drying times caused a growth in specific energy consumption. The minimum SEC values of 5.09 and 5.08 MJ kg^{-1} water in the first and second seasons, respectively, were obtained at a microwave power of 200 W and a drying time of 6 min. The maximum values of 49.88 and 50.08 MJ kg^{-1} water in the first and second seasons, respectively, were obtained at a microwave power of 800 W and a drying time of 12 min. From the results, increasing microwave powers and drying times resulted in a significant increment in specific energy consumption (P<0.05, LSD 0.05 = 0.0299 and 0.0681) in the first and second seasons, respectively. These results are in line with those of (**Zarein *et al.*, 2013**; **Kouchakzadeh and Shabani, 2017**).

Effect of drying methods on vitamin C

Vitamin C is very sensitive to heat, water-soluble, the degradation of VC caused by many factors such as enzymes, temperature and leaching. It is important indicator for the value of dried plants. If VC is well maintained in drying, other nutrients also will be good preserved (**Lin *et al.*, 1998).** It has an antioxidant effects and can enhance immunity (**Karatas and Kamşl, 2007**). VC content in dried roselle by different drying methods showed in Table 2. The highest VC was noted in the microwave at 200 W for 6 min, followed by 400 W for 6 min, and the lowest VC was found in the microwave at 800 W and a sun-dried sample. The same way in the second season **(Ning and Aznan, 2018)** Found that the content of V C in dried guava decreased by increase in the level of microwave power. The highest vitamin C content was shown in dried guava by using a 300 W power level, while a 600 W microwave power level gave the least. (**Khraisheh *et al.*, 2004)** showed that the heat degradation of VC affected by temperature and time. Shortest time with high temperature led to a decrease in degradation of VC than low temperature and long duration of drying (**Sutar and Prasad, 2007**). As VC is very sensitive to oxygen, sunlight and the longtime of drying, the lowest VC content in samples dried by sun comparing with the other drying methods.

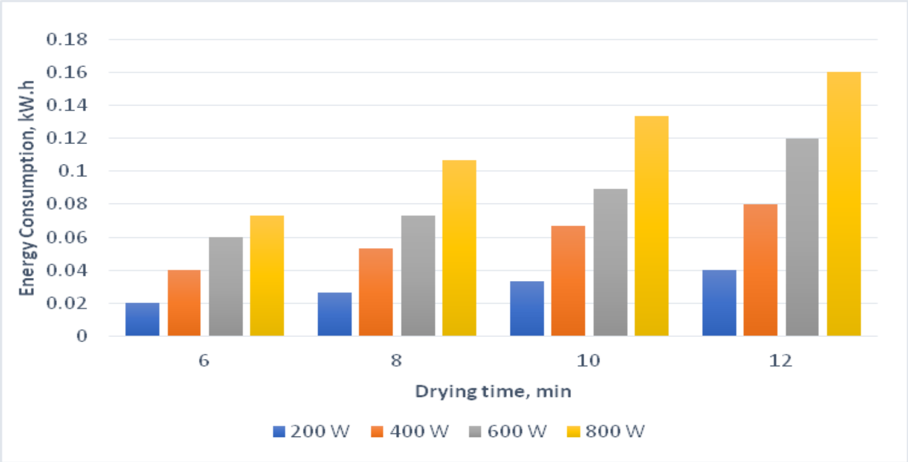

Fig. 1. Energy consumption values of the microwave dryer for different microwave powers and drying times

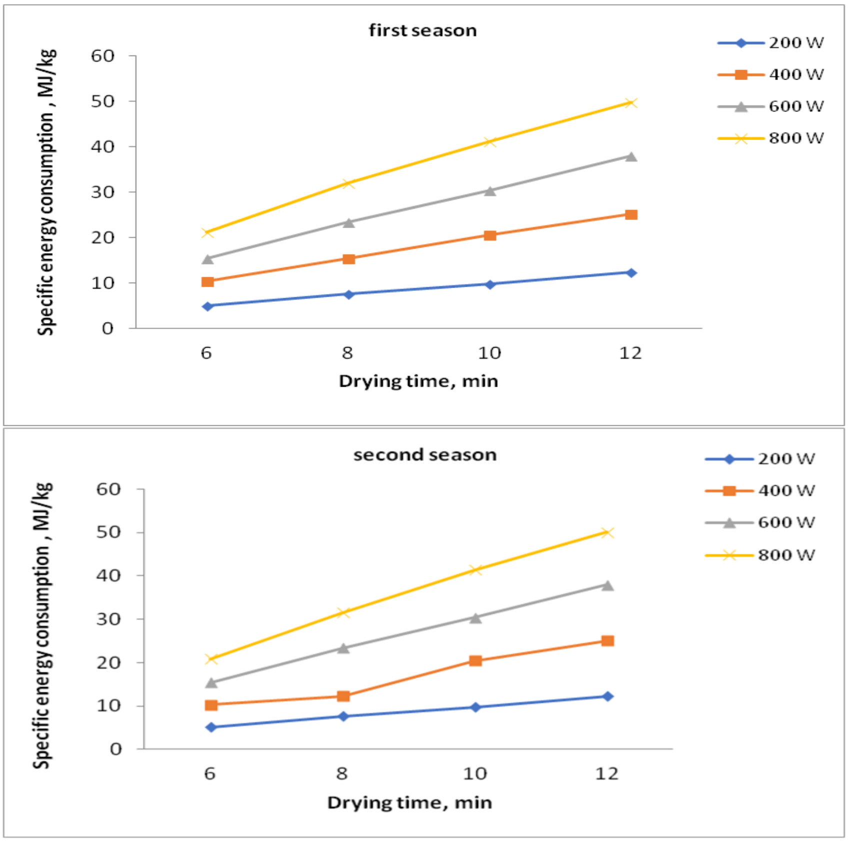

Fig.2. The specific energy consumption of roselle (*Hibiscus sabdariffa* L.) calyces at varying microwave powers and drying times during the drying in the two seasons

Table (2). Effect of Sun drying, Shade drying and different powers of microwave with different drying times on Vitamin C (mg/100g) of roselle (*Hibiscus sabdariffa* L.) calyces in the two seasons of 2020 and 2021

Treatments	Drying time	Vitamin C, mg/100g	
		1st Season	2nd Season
Dry in Sun	7 days	17.943	17.050
Dry in Shade	12 days	21.390	20.947
Drying at 200 watts	6 min.	28.685	32.050
	8 min.	24.664	25.303
	10 min.	22.388	23.298
	12 min.	20.606	21.321
Drying at 400 watts	6 min.	24.123	25.950
	8 min.	21.700	21.510
	10 min.	18.087	17.963
	12 min.	16.133	15.734
Drying at 600 watts	6 min.	19.920	19.157
	8 min.	16.760	16.400
	10 min.	15.883	15.700
	12 min.	14.140	14.993
Drying at 800 watts	6 min.	15.891	15.590
	8 min.	12.211	12.960
	10 min.	9.767	10.493
	12 min.	8.383	8.830
LSD at 5%		1.520	1.544

Effect of drying different methods on total phenols

The data in Table 3 described the result of drying methods on the total phenol (TP) content of roselle. It was noted that TP in microwave drying was higher than in sun and shade drying. The highest total phenolic contents were found in microwaves at 600 W for 10 min, followed by 400 W for 12 min in two seasons. This results in the same way as (**Sellami *et al.*, 2013** and **Imam *et al.*, 2023)** on sage. The highest TP was found in plant sample dried by using microwave. (**Inchuen et al., 2010**) reported that increasing microwave power caused an increase in the TP.

The high content of total phenolic in microwave-dried could be due to strong generation of heat from microwave, which creates the high temperature and vapour pressure in plant tissue, resulting in the disruption of cell wall polymers and thus causing the extraction of more phenolic compounds. Also, (**Caro *et al.*, 2004**) reported that the high content of polyphenols in microwave drying may be due to the intermediate compounds of non-enzymatic browning and formation of new compounds by the Maillard reaction (**Maillard and Berset, 1995)** clarify the behavior of polyphenols at high temperatures by three mechanisms: first, the insoluble phenolic compounds could be free when the phenolic acids to lignin bonds are broken. The amount of phenolic acids bound (measured after hydrolysis of tissue) is greater than that of free phenolic compounds; second, at high temperature, lignin may be degraded, giving more phenolic acids. The third thermal degradation of the polyphenols may occur at high temperature.

Table (3). Effect of Sun drying, Shade drying and different powers of microwave with different drying times on Total phenols (g/100g) of roselle (*Hibiscus sabdariffa* L.) calyces in the two seasons 2020 and 2021

Treatments	Drying time	Total phenols, g/100g	
		1st Season	2nd Season
Dry in Sun	7 days	1.780	1.987
Dry in Shade	12 days	1.293	1.687
Drying at 200 watts	6 min.	2.216	2.328
	8 min.	3.260	3.965
	10 min.	3.661	4.434
	12 min.	3.877	4.730
Drying at 400 watts	6 min.	2.518	2.488
	8 min.	4.744	5.246
	10 min.	5.141	5.023
	12 min.	5.493	5.311
Drying at 600 watts	6 min.	2.651	2.516
	8 min.	4.236	4.354
	10 min.	5.330	5.274
	12 min.	4.682	4.723
Drying at 800 watts	6 min.	2.738	2.818
	8 min.	3.772	3.661
	10 min.	2.233	2.420
	12 min.	2.570	2.813
LSD at 5%		0.231	0.216

Effect of different drying methods on total anthocyanin

Results in Table 4 clearly showed that anthocyanin content is affected by drying methods. Anthocyanin content in sun and shade drying was lower than microwave drying. The best results were obtained by microwave drying at 400 W for 12 min and 600 W for 10 min. As shown, there was degradation over a long period of time at high temperatures. The same way was noticed in the second season. Results are enraged with (**Sun *et al.,* 2020**) studied the effects of microwave on drying berry puree. The microwave intensity was set to 6, 7, 8, 9 and 10 W/g at (2, 4, 6, 8, and 10 min) for the stability of anthocyanins. Anthocyanin degradation mostly occurred in last drying time. Temperature and moisture content have direct effect on anthocyanin stability. (**Rabeta and Vithyia, 2013**) Microwave drying was found a good technique for keep the content of anthocyanin and TPC in dried *Vitex negundo* (VN) "chaste tree" tea.

Effect of different drying methods on acidity

Results in Table 5 revealed that there was variation in the acidity of dried roselle in two seasons under different drying conditions. High acidity found in dried roselle by microwave at 600 W for 10 min, followed by 400 W for 12 min. Sun and shade drying required a lower temperature and a longer drying time, the results were harmony with (**Bandaru and Bakshi**, **2021**) on apple and guava. Sun and shade drying, which requires a lower temperature and a longer drying time, acidity is directly proportional to temperature; by increasing temperature, the conversion of sugars to organic acids will happened causing increase in acidity, and also a decrease in pH (**Raj *et al.*, 2006**)

Table (4). Effect of Sun drying, Shade drying and different powers of microwave with different drying times on total anthocyanin (g/100g) of roselle (*Hibiscus sabdariffa* L.) calyces in the two seasons of 2020 and 2021

Treatments	Drying time	Anthocyanin (g/100 g)	
		1st Season	2nd Season
Dry in Sun	7 days	0.261	0.256
Dry in Shade	12 days	0.290	0.301
Drying at 200 watts	6 min.	0.290	0.301
	8 min.	0.317	0.332
	10 min.	0.341	0.338
	12 min.	0.320	0.316
Drying at 400 watts	6 min.	0.313	0.328
	8 min.	0.247	0.276
	10 min.	0.300	0.308
	12 min.	0.456	0.467
Drying at 600 watts	6 min.	0.345	0.352
	8 min.	0.362	0.355
	10 min.	0.482	0.470
	12 min.	0.381	0.391
Drying at 800 watts	6 min.	0.399	0.387
	8 min.	0317	0.328
	10 min.	0.181	0.170
	12 min.	0.137	0.143
LSD at 5%		0.023	0.036

Table (5). Effect of Sun drying, Shade drying and different powers of microwave with different drying times on acidity (mg/g) of roselle (*Hibiscus sabdariffa* L.) calyces in the two seasons of 2020 and 2021

Treatments	Drying time	Acidity, mg/g	
		1st Season	2nd Season
Dry in Sun	7 days	2.94	2.85
Dry in Shade	12 days	2.77	2.74
Drying at 200 watts	6 min.	2.24	2.30
	8 min.	2.64	3.02
	10 min.	3.13	3.74
	12 min.	3.43	3.33
Drying at 400 watts	6 min.	3.06	3.11
	8 min.	3.40	3.51
	10 min.	3.62	3.56
	12 min.	4.11	4.06
Drying at 600 watts	6 min.	3.37	3.29
	8 min.	3.51	3.55
	10 min.	4.24	4.16
	12 min.	3.77	3.80
Drying at 800 watts	6 min.	3.12	3.16
	8 min.	3.41	3.44
	10 min.	3.91	3.61
	12 min.	3.51	3.62
LSD at 5%		0.13	0.18

Effect of different drying methods on antioxidant activity

Antioxidant activity was affected by type and amount of the antioxidant compounds. Results in Table 6 showed that antioxidant activity affect by different drying methods in the two seasons. Sun, shade and microwave at 800 W for 8, 10, and 12 min had lower antioxidant activities of dried roselle. Microwave at 400W for 12 min and 600W for 10 min had the highest level of antioxidant activity. Our results were in harmony with (**Çoklar and Akbulut, 2017; Managa *et al.*, 2020**). Also, (**Hihat *et al.*, 2017**) recorded a rise in scavenging activity of DPPH and ABTS, when microwave (300 W and 500) was used. (**Bhat *et al.*, 2023**) Maximum antioxidant activity (FRAP and DPPH) was determined in apple pomace powder dried by microwave, while in oven drying, the values decreased. As mentioned by (**Inchuen *et al.*, 2010**), antioxidant activity is affected by the content of total phenolics and flavonoids. (**Purbowati *et al.*, 2019**) reported that the antioxidant activity is not caused by phenolic content only, but also it caused by some phytochemicals like pigments, tocopherol and ascorbic acid with synergistic mechanisms that also effect on the antioxidant activity. (**Tsai *et al.*, 2002**) anthocyanin content in roselle has a direct relationship with antioxidant activity.

Table (6). Effect ofSun drying, Shade drying and different powers of microwave with different drying times on antioxidant activity (%) of roselle (*Hibiscus sabdariffa* L.) calyces in the two seasons of 2020 and 2021

Treatments	Drying time	Antioxidant activity, %	
		1st Season	2nd Season
Dry in Sun	7 days	80.23	80.88
Dry in Shade	12 days	81.65	81.21
Drying at 200 watts	6 min.	84.52	84.45
	8 min.	85.94	85.33
	10 min.	86.39	86.22
	12 min.	86.03	86.07
Drying at 400 watts	6 min.	85.42	84.02
	8 min.	85.55	85.63
	10 min.	86.49	86.19
	12 min.	87.65	88.31
Drying at 600 watts	6 min.	84.83	83.62
	8 min.	85.92	85.31
	10 min.	86.92	87.88
	12 min.	79.44	78.43
Drying at 800 watts	6 min.	80.31	79.55
	8 min.	75.38	74.52
	10 min.	73.11	72.50
	12 min.	70.11	69.38
LSD at 5%		1.36	1.27

CONCLUSION

From the results of this study, microwave drying appears to be a suitable drying method for the speedy drying of roselle calyces. Microwave power had a significant influence on the specific energy consumption (SEC) and quality of dried roselle. Increasing in power resulted in an increased risk of scorching at 800 W. Drying at a 200 W power level was unfavorable in terms of high moisture content and roselle quality. Drying of roselle at 400W and 600W with drying times of 12 and 10 min., respectively, was favorable and similar with respect to the moisture content of dried roselle as well as energy consumption. The obtained results in this study are essential to maximizing the benefits of bioactive compounds present in Roselle during drying. According to its high phytochemical content and antioxidant activity, all studied drying methods (sun drying, shade drying, and microwave drying) had effects on total phenolics, acidity, anthocyanin and antioxidant activity. Sun and shade drying had negative effects, while microwave drying recorded the highest values of total phenolics, acidity, anthocyanin and antioxidant activity.

REFERENCES

A.O.A.C. (2005). Official Methods of Analysis of the Association of Official Analytical Chemists, 15th Ed, Arlington, Virginia USA.

Amin, I.; Norazaidah, Y. and Hainida, K. (2006). Antioxidant activity and phenolic content of raw and blanched Amaranthus species. Food Chem., 94: 47-52.

Bandaru, E. and Bakshi, M. (2021). Effect of different drying conditions on the quality of apple and guava fruit leather. The Pharma. Innovation Journal, 10(8): 233-237.

Bhat, I.M; Wani, S.M.; Mir, S.A. and Naseem, Z. (2023). Effect of microwave-assisted vacuum and hot air oven drying methods on quality characteristics of apple pomace powder. Food Production, Processing and Nutrition, 5 (1): 1-17. https://doi.org/10.1186/s43014-023-00141-4.

Brand-Williams, W.; Cuvelier, M.E. and Berset, C. (1995). Use of free radical method to evaluate antioxidant activity. LWT-Food Sci. Technol., 28:25-30.

Caro, A. D.; P.Piga, A.; Pinna, I.; Fenu, P. M. and Agabbio, M. (2004). Effect of drying conditions and storage period on polyphenolic content, antioxidant capacity, and ascorbic acid of prunes. Journal of Agriculture and Food Chemistry, 52: 4780–4784.

Chatterjee, A.; Yasmin, T.; Bagchi, D. and Stohs, S.J. (2004). Inhibition of Helicobacter pylori in vitro by various berry extracts, with enhanced susceptibility to clarithromycin. Molecular and Cellular Biochemistry, 265(1), 19–26.

Chewonarin, T.; Kinouchi, T.; Kataoka, K.; Arimochi, H. and Kuwahara, T. (1999). Effect of roselle (*Hibiscus sabdariffa*), a Thai medicinal plant, on the mutagen city of various mutagens in Salmonella typhnumurium and on formation of aberrant Crypt Foci induced by the colon carcinogens azoxymethane and 2-amino-1-methyl-6-phenylimidazo [4,5-b] pyridine in F344 rats. Food and Chemical Toxicology, 37(6): 591-601.

Çoklar, H. and Akbulut, M. (2017). Effect of sun, oven and freeze-drying on anthocyanins, phenolic compounds and antioxidant ativity of black grape (Ekşikara) (*Vitis vinifera* L.). S. Afr. J. Enol. Vitic., 38(2): 264-272.

Espinosa, W. E.; Garzón, L. C. A. and Medina, O. J. (2017). Microwave-assisted extraction in dry fruit of andean species Vaccinium meridionale: experimental conditions on the recovery of total polyphenols. Ciência e Agrotecnologia, 41(6): 701-712. http://dx.doi. org/10.1590/1413-70542017416016117.

Grace, M.H.; Ribnicky, D.M.; Kuhn, P.; Poulev, A.; Logendra, S.; Yousef, G.G.; Raskin, I. and Lila, M.A. (2009). Hypoglycemic activity of a novel anthocyanin-rich formulation from lowbush blueberry, *Vaccinium angustifolium*. Phytomedicine, 16(5): 406–415.

Hihat, S.; Remini, H. and Madani, K. (2017). Effect of oven and microwave drying on phenolic compounds and antioxidant capacity of coriander leaves. International Food Research Journal, 24(2): 503-509.

Ibrahim, R. and Mazuki, N.A.F. (2013). The quality of roselle (*Hibiscus sabdariffa* L.) juices made from roselle calyces stored at different cold temperatures. Malays. Appl. Biol., 42 (5): 67–71.

Imam, A. I.; Abd Elhamed, R. S.; Mohammed, M. H. M. and Elfek, W. Z. (2023). valuation of different drying methods of sage leaves, bioactive compounds content and its utilization as a natural additive to flatbread. The Future of Agriculture, 1:50-75.

Inchuen, S.; Narkrugsa, W. and Pornchaloempong, P. (2010). Effect of drying methods on chemical composition, color and antioxidant properties of Thai red curry powder. Kasetsart J. Natural Sci., 44: 142- 151.

Karatas, F. and Kamışlı, F. (2005). Variations of vitamins (A, C and E) and MDA in apricots dried in IR and microwave. Journal of Food Engineering, 78(2): 662-668.

Kelebek, H.; Jourdes, M.; Selli, S. and Teissedre, P.L. (2013). Comparative evaluation of the phenolic content and antioxidant capacity of sun-dried raisins. Journal of the Science of Food and Agriculture, 93(12): 2963–2972.

Khraisheh, W.M.; McMinn, T.R.A. and Magee, T.R.A. (2004). Quality and structural changes in starch foods during microwave and convective drying. International Food Research Journal, 37(5):497-503.

Kouchakzadeh, A. and Shabani, N. (2017). Effect of microwave energy on dehydration of celery leaves. Agricultural Engineering International: CIGR Journal, 19(1): 108–113.

Laleh, G.H.; Frydoonfar, H.; Heidary, R.; Jameei, R. and Zare, S. (2006). The effect of light, temperature, pH and species on stability of anthocyanin pigments in four Berberis species. Pakistan Journal of Nutrition, 5(1): 90-92.

Lin, T. M; Durance, T. D. and Scaman, C. H. (1998). Characterization of vacuum microwave, air freeze-dried carrot slices. Food Research Inter, 31(2): 111-117.

Maillard, M.N. and Berset, C. (1995). Evolution of antioxidant activity during kilning: Role of Insoluble Bound Phenolic Acids of Barley and Malt. J. Agric. Food Chem., 43: 1789–1793. [Google Scholar] [CrossRef]

Managa, M. G.; Sultanbawa, Y. and Sivakumar, D. (2020). Effects of different drying methods on untargeted phenolic metabolites, and antioxidant activity in Chinese cabbage (*Brassica rapa* L. subsp. sinensis) and Nightshade (*Solanum retroflexum* Dun.). Molecules, 25: 1326-1349. Doi:10.3390/molecules25061326

Marilena, R. (2020). Microwave drying process scale-up. Chemical Engineering & Processing: Process Intensification, 155 (8): 88-108. https://doi.org/10.1016/j.cep.2020.108088

Martineau, L.C.; Couture, A.; Spoor, D.; Benhaddou-Andaloussi, A.; Harris, C.; Meddah, B.; Leduc, C.; Burt, A.; Vuong, T. and Mai Le, P. (2006). Anti-diabetic properties of the canadian lowbush blueberry *Vaccinium angustifolium*. Phytomedicine, 13(9): 612–623.

Martins, C. P. C.; Cavalcanti, R. N.; Couto, S. M.; Moraes, J.; Esmerino, E. A.; Silva, M. Raices, C. R. S. L.; Gut, J. A. W.; Ramaswamy, H. S.; Tadini, C. C. and Cruz, A. G. (2019). Microwave processing: current background and effects on the physicochemical and microbiological aspects of dairy products. Comprehensive Reviews in Food Science and Food Safety, 18(1): 67-83. http://dx.doi.org/10.1111/1541-4337.12409

Moses, J. A.; Norton, T.; Alagusundara, K. and Tiwari, B. K. (2014). Novel drying techniques for the food industry.Food Engineering Reviews, 6 (3):43–55. doi:10.1007/s12393-014-9078-7.

Mujaffar, S. and Loy, A. L. (2016). Drying kinetics of microwave-dried vegetable amaranth (*Amaranthus dubius*) leaves. Journal of Food Research, 5(6):33-44. https://doi.org/10.1002/fsn3.406.

Neto, C.C. (2007). Cranberry and blueberry: Evidence for protective effects against cancer and vascular diseases. Molecular Nutrition and Food Research, 51(6): 652–664.

Ning, L. Y. and Aznan, A.A (2018). Evaluation of vitamin C content in microwave dried guava (*Psidium Guajava* L). JERE, 10 (1): 45-50.

Özşen, D. and Erge, H. (2013). Degradation kinetics of bioactive compounds and change in the antioxidant activity of wild strawberry (*Fragaria vesca*) pulp during heating. Food and Bioprocess Technology, 6(9): 2261–2267.

Park, Y.J.; Biswas, R.; Phillips, R.D. and Chen, J. (2011) Antibacterial activities of blueberry and muscadine phenolic extracts. Journal of Food Science, 76(2):101–105.

Purbowati, I. M.; Sujiman, S. and Maksum, A. (2019). Antioxidant activity and isolation bioactive compounds from roselle (*Hibiscus sabdariffa*) from various methods and drying time. AGROINTEK, 13 (1): 1-9.

Puro, K.; Sunjukta, R.; Sawir, S.; Ghatak, S.; Shatuntala, I. and Sen, A. (2014). Medicinal uses of roselle plant (*Hibiscus sabdariffa* L.): A mini review. Indian Journal of Hill Farming, 27(1): 47-51.

Rabeta, M. S. and Vithyia, M. (2013). Effect of different drying methods on the antioxidant properties of *Vitex negundo* Linn. tea. International Food Research Journal, 20(6): 3171-3176.

Raj, D.; Subhanna, V.C.; Ahlawat, O.; Gupta, P. and Huddar, A.G. (2006). Effect of pre-treatments on the quality characteristics of dehydrated onion rings during storage. J. Food, Sci. Technol., 43 (6):571-574.

Rao, P.U. (1996). Nutrient composition and biological evaluation of Mesta seed. Plant Foods for Human Nutrition, 49(1): 27-34.

Riaz, G. and Chopra R.A. (2018). review on phytochemical and therapeutic uses of Hibiscus Sabdariffa L. Biomed Pharmacother, 102:575–586.

Rocha, D, I.; Bonnlaender, B.; Sievers, H.; Pischel, I. and Heinrich, M. (2014). *Hibiscus sabdariffa* L.-A phytochemical ad pharmacological review. Food Chem., 165: 424–443.

Rocha, R. P.; Melo, E. C. and Radünz, L. L. (2011). Influence of drying process on the quality of medicinal plants: A review. J. Medicinal Plants Res., 33 (5): 7076-7084.

Sabet Sarvestani, S.; Hosseini, S.M. and Farhangfar, S.H. (2020). Effect of aqueous-alcoholic extract of *Hibiscus sabdariffa* calyx and leaf calyx and leaf on performance, egg quality, immune system and antioxidant balance of laying hens. Iran. J. Appl. Anim. Sci., 10 (2): 317–325.

Sellami, I.; Zohra, F. R.; Bettaieb, I. R.; Bourgou, S.; Limam, F. and Marzouk, B. (2013). Total Phenolics, Flavonoids, and antioxidant activity of Sage (Salvia officinalis L.) plants as affected by different drying Methods. Food Bioprocess Technol., 6:806–817.

Shruthi, V.H. and Ramachandra, C.T. (2019). Roselle (*Hibiscus sabdariffa* L.) Calyces: A Potential Source of Natural Color and Its Health Benefits. Food Bioactives, 1st ed.; Apple Academic Press: Boca Raton, FL, USA, pp. 169–190.

Soysal, A.; Oztekin, S. and Eren, O. (2006). Microwave drying of parsley: modelling, kinetics, and energy aspects. Biosystems Engineering, 93(4): 403–413.

Soysal, Y. (2004). Microwave drying characteristics of parsley. BiosystemsEngineering, 89 (2):167–73. Doi: 10.1016/j.biosystemseng.2004.07.008.

Steal, R. G. D. and Torrie, J. H. (1990). Principles and procedures of statistics. McGraw-Hill Book Inc., New York USA.

Sun, Y.; Zhang, Y.; Xu, W. and Zheng, X. (2020). Analysis of the anthocyanin degradation in Blue Honeysuckle Berry under Microwave Assisted Foam-Mat drying. Food, 9(4): 397 - 414.

Sutar, P. P. and Prasad, S. (2007). Modeling microwave vacuum drying kinetics and moisture diffusivity of drying technology: An Inter. J., 25: 1695-1702.

Tsai, P.J.; McIntosh, J.; Pearce, P.; Pearce, P. and Camden, B. (2002). Anthocyanin and antioxidant capacity in roselle (*Hibiscus Sabdariffa* L.) extract Food Research International, 35(4):351-356.

Udomkun, P.; Romuli, S.; Schock, S.; Mahayothee, B.; Sartas, M.; Wossen, T.and Müller, J. (2020). Review of solar dryers for agricultural products in Asia and Africa: An innovation landscape approach. J. Environ. Management, 268: 1-14.

Zaidel, D. N. A.; Sahat, N. S.; Jusoh, Y. M. M. and Muhamad, I. I. (2014). Encapsulation of Anthocyanin from Roselle and Red Cabbage for Stabilization of Water-in-Oil Emulsion, Agriculture and Agricultural Science Procedia, 2: 82-89.

Zarein, M.; Banakar, A.; and Khafajeh, H. (2013). Mathematical modeling, energy consumption and thin-layer drying kinetics of carrot slices under microwave oven. International Journal of Agriculture and Crop Sciences, 13(5):2057-2063.

Zhang, L.; Mou, D. and Du, Y. (2007). Procyanidins: Extraction and Micro encapsulation. J. Agri. Food Chem., 87: 2192-2197.

Zhang, M.; Tang, J.; Mujumdar, A. S. and Wang, S. (2006). Trends in microwave-related drying of fruits and vegetables, Trends in Food Science and Technology, 17(10): 524- 534. https://doi.org/10.1016/j.tifs.2006.04.011.