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Microwave Vacuum Drying on Fruit: A Review

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ABSTRACT
Fruit is very perishable in the storage process and has short of shelf-life. To extend the shelf life, fruits need preservation process. Drying is generally acknowledged as a cost-effective and commonly used technique for preserving food by reducing post-harvest losses. The major challenge of drying fresh foods and agricultural products is to reduce the moisture content to an absolute minimum while preserving quality characteristics such as colour, texture, chemical components, and shrinkage. The vacuum drying technique has been explored as a possible method for generating high-quality dried food items such as fruits, vegetables, and grains. Microwave vacuum drying is a method that adopts the benefits of microwave drying and vacuum drying, especially enhancing energy efficiency in conjunction with product quality. This article reviews several studies on fruit drying using microwave vacuum drying, including cranberry, apple, dragon fruit, strawberry, Saskatoon berry, and pomegranate. Studies show that drying using microwave vacuum drying saves drying time many times over than conventional drying. The microwave vacuum drying technique can reduce undesired sensory transitions and nutrient loss caused by longer drying times or high surface temperatures. The use of microwave vacuum drying resulted in dried fruit similar to freeze-drying which did not significantly affect the color of the fruit and the phenolic content of the fruit.

Keywords: *Dried Fruit Characteristic, Drying Process, Fruit Drying, Microwave Vacuum Drying, Phenolic Content.*

1. INTRODUCTION

1.1. Fruit Drying Process

Fruit is very perishable in the storage process and has short of shelf-life. Fruits are very rich in nutrients of carbohydrates, polyphenols, vitamins, minerals and biologically active substances. To extend the shelf life, fruits need preservation process. Food has been preserved with drying methods for thousands of years, include fruits. Drying is generally acknowledged as a cost-effective and commonly used technique for preserving food by reducing postharvest losses [1]. It stabilizes and protects foods by reducing moisture content and water activity. It lowers raw material packaging, handling, and transportation costs by reducing product weight. The major challenge of drying fresh foods and agricultural products is to reduce the moisture content to an absolute minimum while preserving quality characteristics such as colour, texture, chemical components, and shrinkage. [2]. Although simple drying methods such as sun drying and air drying have been used in the past to produce dried fruit and vegetables, modern drying techniques have been created to minimize drying time and increase the energy efficiency and quality of dried fruit [3].

1.2. Microwave Vacuum Drying

Conventional drying can reduce the moisture content of fruits but have risk of quality degradation and takes long drying times. In order to prevent significant quality degradation, microwave vacuum drying is introduced to replace the conventional drying [36]. Microwave drying conduct microwave radiation to water, fat, and sugar molecules, all of which are commonly found in food. The electromagnetic energy will be absorbed by these molecules. Dielectric heating is the name for this type of energy absorption. Food molecules are electrically dipole (electric polished), which means that one side of the molecule has a negative charge and the other side has a positive charge. As a result, each side's presence of changing electric fields caused by microwaves will rotate to line with one another. The friction between these molecules will generate heat as they travel around. The heat energy generated by this event is used as a

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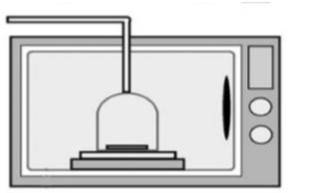

Figure 1 Illustration of Microwave Vacuum Drying Static System [14, 34]

heating agent in the microwave drying process of food items [4].

Microwave is an electromagnetic radiation with a wavelength of 12.24 cm and a frequency of 2.45 GHz. The objective behind microwave oven drying is to liberate moisture from organic compounds by agitating water molecules with electronically produced microwaves. The drying process is quite faster than other drying methods, taking only a few minutes and generating very little heat [5]. Microwaves manage the interior temperature of material regardless of the outside conditions since they deliver thermal energy directly to the entire volume of the product. Heat is produced as a result of friction caused by the rotation of dipoles in the material [6].

The vacuum drying technique has been explored as a possible method for generating high-quality dried food items such as fruits, vegetables, and grains. Microwave-vacuum drying is a relatively new drying technique in which water evaporation is boosted due to rapid heating of the food material caused by the action of microwave energy absorbed by the material in a high-frequency electric field on the water molecules in the material, as well as the low boiling temperature of water in the reduced-pressure environment [3]. Microwave vacuum drying is a method that adopts the benefits of microwave drying and vacuum drying, especially enhancing energy efficiency in conjunction with product quality [7]. The advantages of microwave heating and vacuum drying are combined in the microwave vacuum method. Microwave radiation is absorbed by water in the whole volume of the materials being dried during the drying process. This results in high vapor pressure in the material's core, allowing moisture to immediately move into the surrounding vacuum and preventing structural collapse. This process, also known as the puffing phenomenon, causes the material to have a porous texture, reducing its density [8]. Microwave drying is a drying process in which evaporation of water is accelerated due to rapid heating of the food by microwave energy [9,10]. Vacuum drying is a drying process with the help of microwaves to speed up the drying process. In addition, drying with this method uses vacuum pressure to reduce the boiling point of water, so that drying at low temperatures can occur [11]. Because of its unique heating capabilities, microwave radiation technology may be suitable for efficient drying

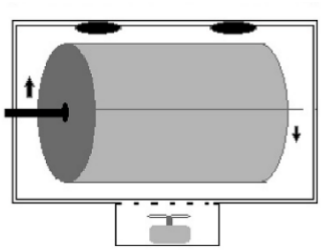

Figure 2 Illustration of Microwave Vacuum Drying Rotary System [33-34]

[12]. The microwave vacuum drying process removes water from food at a lower temperature, which reduces undesired chemical changes in the dried product. The microwave vacuum drying technique can reduce undesired sensory transitions and nutrient loss caused by longer drying times or high surface temperatures. Furthermore, by using lower temperatures and a shorter processing time in microwave vacuum drying treatment, a greater reduction in microbial count may be accomplished [13].

1.2.1. Schematic Diagram of Microwave Vacuum Drying Equipment

Microwave vacuum drying systems are divided into two categories: static system and rotary system. Microwave vacuum drying static system is similar to the usage of household microwaves in general, with the exception that vacuum chamber is added (Fig. 1). The key to these static systems is product thickness; if the food contains multiple layers with various components, microwave irradiation would take a long time to pass through the layers, resulting in an uneven temperature spectrum. Nonuniform food drying, poor rehydration [31], damage to food components, colour changes, and a more fragile structure are among concerns experienced with static systems [32].

The challenge of heat transmission in food prompted the development of microwave vacuum drying with rotary systems. Microwave radiation penetrates various areas in the food matrix as it rotates, resulting in a homogeneous distribution of radiation. Microwave vacuum equipment modified with a rotating system shown in Fig. 2, these systems feature a high-density polyethylene drum or cylindrical basket and a mechanism that helps drum rotation inside the microwave. The rotary system of drying process is based on rotational speed, which is added to rotational systems to prevent both poor temperature distribution and damage from electric arcs [32]. This innovation in varying power levels and rotational speeds could be explored more thoroughly in various food matrix by investigating into the correlation between rotational speed and power utilized in the drying process to avoid problems with food hardness and flavour [33].

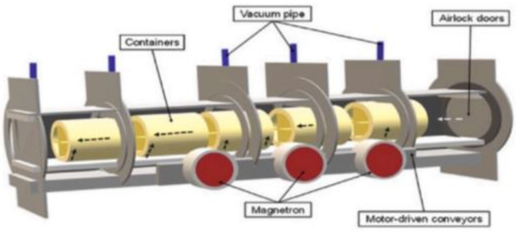

Figure 3 Schematic Diagram of Microwave Vacuum Drying Rotary System [34-35]

One of the schematics for the patented (US9267734B2) microwave vacuum drying equipment rotary system is shown on Figure 3.

The system consists of magnetrons that are located in a cylindrical vacuum chamber with numerous lock-type lateral access doors. Each door has eight 1500 W magnetrons, and each door lock has a power level of 12000 W, for a total power of 36000 W connected to a programmable logic controller (PLC) with vacuum pressure ranging from 0.01 to 13.32 kPa. The angular distribution of the waveguides for the magnetrons, which decreases interference and the potential of the arc in the vacuum chamber, is a unique characteristic of the patented equipment. The food is placed in cylindrical containers with sections inside to prevent the product from accumulating. The containers are moved within the vacuum chamber by a conveyor belt and rotated on their axis by lateral rollers to ensure uniform drying [34-35].

1.2.2. Advantage and Disadvantage Microwave Vacuum Drying

Microwave-vacuum drying provides numerous advantages over traditional drying, including a faster drying rate and less heating in regions with less water, resulting in reduced overheating of areas where heating is not needed. However, knowledge on moisture diffusion models that can correctly explain the process is needed for microwave-vacuum drying to be more effective at the industrial level [14]. The benefits of using the microwave as a drying tool include a heating time for many foodstuffs that is about half of what it takes to heat them in a regular oven [15]. The high microwave frequency compensates for the quick drying process. Microwaves high frequencies allow for rapid energy transfer and high heating rates, keeping nutrition and vitamin content as well as food taste, sensory properties, and colour [16]. Furthermore, microwave vacuum drying helps conserve heat-sensitive bioactive chemicals by decreasing the temperature of the material being dried and limiting its exposure to oxygen to some extent. Microwave heating is thought to be more efficient in terms of energy usage. Because heat is generated in the meal, microwave heating is more efficient than conventional heating [15]. In addition, due to microwave generating produces no exhaust gases or harmful waste, microwave equipment is suitable for on-site cleaning systems, low-cost system maintenance, and environmentally friendly processes [16]. Microwave heating systems may be turned on and off quickly [17]. Microwave technology now includes an automatic heating mechanism, making it easy to monitor usage and preventing overheating.

Microwave vacuum drying has some disadvantages including expensive vacuum installation due to initial, very intensive water evaporation from the raw material. The non-uniform temperature distribution is the fundamental downside of microwave heating especially with thick material [14,18]. Microwave heating produces non-uniform temperature distribution in solid foods and batch methods in cavity ovens, such as grains [19]. High starting expenditures, limited microwave penetration, and poor quality of heated food are some of the other downsides of the microwave [20]. The most significant downside of this technique is the high investment costs and inefficiencies in energy utilization, which can result in poor quality products such as discoloration, taste, and lower nutrition [21]. Advantage of microwave vacuum drying give the solution for prevent significant quality degradation on drying preservation of fruit. This article aims to review the effect of microwave vacuum drying on the fruit preservation

1.3. Application Microwave Vacuum Drying on Fruit Drying Processing

Many studies on the use of microwave vacuum drying in the food processing process one of them in drying fruit. Dried fruit products are quite much in demand by consumers, but the use of microwave vacuum drying in the industry is still rare. Fruits drying studies using microwave vacuum drying is shown in Table 1.

1.3.1. Cranberries

The content of bioactive compounds and the color of cranberry fruit dried by vacuum microwave were studied by Zielinska (2019). Microwave vacuum drying was carried out at 100-500 W with a chamber rotation speed of 6 rpm, and absolute pressure at 5 ± 1 kPa. The berries were dried to a final moisture content of less than 0.25 ± 0.02 kg water/kg dry mass. Microwave drying is up to several tens of times faster than conventional drying. During drying at 100 W, the vapor pressure in the fruit is very low and prevents rapid loss of fruit moisture. Microwave-vacuum drying time is shortened by increasing microwave power. The increase in microwave power from 100 to 500 W reduces drying time by up to 90%. Vacuum-microwave drying at 150-500 W causes rapid evaporation of moisture from the

Table 1. Application Microwave Vacuum Drying on Fruit

Fruit	Processing Condition	Result	References
Cranberries	Microwave vacuum drying; 100-500 W; rotational speed 6rpm; 5 kPa. 200 g cranberries.	Rapid evaporation of moisture from capillaries, reduced 90% drying time, and significantly increased total phenolic values, significantly higher antioxidant capacity, and higher redness and yellowness values in dried cranberries.	[22]
Apple	Microwave vacuum drying; 200W, 300W and 400 W; 1.5 kPa.	Spend more effectively for water evaporation. The Microwave vacuum drying sample showed a smaller stress value and highest the number of peaks crispness, and the non-frozen Microwave vacuum drying showed the highest stress.	[23]
Dragon fruit	Microwave vacuum drying; 200 - 600 W; 3, 6 and 9 kPa.	Increased power from 200 to 400 W (at 9 kPa vacuum level) the phenolic value was increased from 7.800 to 8.469 mg GAE/g dw; efficiency was found to be in the range of 43.395 – 62.639%. The microwave power causing a non-enzymatic browning reaction producing dark-colored products which increased in the fruit color.	[24]
Strawberry	Microwave vacuum drying; 50°C and 47mmHg	Energy consumption around 0,97 W h/g in 47mmHg and 50°C with final product moisture content is 6.8%. Energy efficiency improved from4 to 54%. Produce less elastic product.	[25]
Saskatoon berry	Microwave vacuum drying; 480/120 W; 4-6 kPa; rotational speed 6rpm	The Microwave vacuum drying shortened almost 10 times the process duration, The highest retention of polyphenolic compounds, higher values of antioxidant capacity than convective drying, 7.6% for DPPH, 12.9% for ABTS and 18.4% for FRAP	[26]

capillaries and increases the pressure in the capillaries near the surface. The shortest drying time of 8-10 minutes was indicated for fruit dried at 450 and 500 W.

Total phenolic content of dried cranberries was also affected by microwave power, and the content of phenolic compounds increased with increasing power up to 300 W while power over 300 W had phenolic content. The lower one. The highest total monomeric anthocyanin content of cranberry fruit was found in microwave-vacuum drying at 150 W at 84%, the higher that the power resulted lower the monomeric anthocyanin content of dried cranberry fruit. The total phenolic content of microwave-vacuum dried cranberries, on the other hand, was only slightly affected by initial freezing. The release of phenolic chemicals associated with cellular structures could explain the rise in total phenolic content of cranberries exposed to low microwave power. These findings are consistent with earlier studies [10]. On the other hand, a significantly higher value of iron-reducing antioxidant power was shown by microwave drying of 100-300 W. Microwave vacuum drying did not cause a significant change in color saturation. Drying berries in a microwave vacuum at a relatively low microwave power of 100–300 W produces fruit with the highest

Table 2. Drying properties of apple dried MVD and AD

Parameters	MVD 300W 1.5 kPa	AD 60 C
Drying time	**2h**	6.5h
thickness	**3.25 ± 0.44 mm**	3.18 ± 0.37 mm
Maximum stress	**55158 a ± 10997 Pa**	29968 b ± 3276 Pa
Elastic modulus number	**140633 b ± 44150 Pa**	36886 c ± 4752 Pa

content of bioactive compounds and the highest level of antioxidant activity.

1.3.2. Apple

Structural characteristics of apples after Microwave vacuum drying and structural properties were studied by Ando et al. (2018). Microwave power is controlled at 200, 300, and 400 W. Microwaves are emitted with 1-minute irradiation cycles and 1-minute pauses to prevent excessive sample temperature increase. The sample was dried until the moisture content reached below 0.2 g-water/g-dry. Vacuum drying was carried out at an absolute pressure of 1.5 kPa.

In this study, high water permeability was maintained during the drying process by first destroying the cell membrane, leading to a higher drying rate. Microwave vacuum drying reduces drying time by about half that of conventional drying. The results show that the applied microwave energy is more effectively spent on evaporation of water in the microwave vacuum drying samples that have been frozen. As a result, the porous structure of the frozen microwave vacuum drying samples showed a blank diameter of 400–600µm and lower stress. The more porous structure of the freeze-dried microwave vacuum drying sample compared to the conventional freeze-dried sample indicates that the heating and evaporation of moisture from the interior during microwave irradiation acts as heat arising from the interior of the sample.

1.3.3. Dragon Fruit

The drying of dragon fruit using microwave vacuum drying was studied by Raj (2020). Drying was carried out at a microwave power of 200–600 W and a vacuum pressure level of 3–9 kPa to obtain dried dragon fruit slices. The drying result of increasing the microwave power from 200 to 400 W at a vacuum of 9 kPa showed an increase in the total phenolic value from 7,800 to 8,469 mg GAE/g d.w. A further increase in power level in the 400–600 W range causes a decrease in the total phenolic content value to 6.875 mg GAE/g d.w. The reduction in total phenolic yield at higher power levels was associated with the degradation of polyphenols due to the temperature rise caused by internal heating. The vacuum had a favourable influence on total phenolic content yield because it prevented oxygen-dependent deterioration at high vacuum levels. Lower oxygen levels are better for phenolic compounds that are heat sensitive. [27-29].

Table 3. Range result physicochemical and best combination treatment of dragon fruit slice that dried by MVD

	Range Result	Best Combination Treatment (MV Power; kPa; %CA)
Total Phenolic Content	5.950 - 8.507 mg GAE/g d.w.	400 W, **9 kPa and 1.5% CA**
Drying Efficiency	43.395 – 62.639%.	600 W, **9 kPa and 1.5% CA**
Total Color Change	9.790 – 21.187	200 W, **9 kPa and 1.5% CA**
Rehydratio n ratio	1.108–3.826	600 W, **9 kPa and 1.5% CA**

The efficiency of microwave vacuum drying on dragon fruit slices is about 62.64%. The efficiency parameter shows that microwave power has the highest effect followed by vacuum treatment. The use of the Vacuum method has a positive effect on the drying efficiency, the higher the vacuum pressure the higher the drying efficiency. The colour change parameter shows an increase in value at the use of microwave power which is increased from 200 W to 600 W causing a non-enzymatic browning reaction and producing a dark-coloured product. The use of microwave vacuum drying has a positive effect on the rehydration characteristics associated with the enlargement and interconnection of micropores due to the tunnelling effect. The increase in microwave power improved the rehydration characteristics of dragon fruit pre-treated with the citric acid solution with the rehydration ratio increasing from 2.625 to 3.262 at increasing microwave power from 200 to 600 W at 9 kPa. Drying at a higher power level increases the internal pressure gradient, internal heating, and evaporation of water.

1.3.4. Strawberry

Drying Strawberry fruit drying using microwave vacuum drying was studied by Borquez et al. (2015)

Table 4. Physical parameters of raw strawberry and strawberry dried by MVD

Parameters		Raw Strawberry	Dried Strawberry
Color	h° (hue)	28.65±0.93	28.98±0.57
	L* (lightness)	25.15±0.78	22.75±2.52
	C* (chroma)	31.81±1.30	28.89±1.15
	ΔE (Color change)	-	5.76±2.56
Texture	Fcrit (N)	1.12±0.06	8.74±3.95
	E (MPa)	0.33±0.03	0.04±0.01
Shrinkage	%S	-	52.98±16.77

using a specially made lab-scale microwave with a power of 700 W, 2,450 MHz. The absolute pressure was set and maintained at 47 mmHg. Drying was carried out for 2.5 hours at a temperature between 50°C. The use of a temperature-controlled microwave in vacuum drying provides drier energy efficiency with a significant increase of 10 times more efficiency.

Microwave-vacuum drying of whole strawberries results in a final product that is denser and less elastic. The final moisture of the strawberries after drying was obtained about 19.5% wet basis in the low-pressure test and 12.0% wet basis in the high-pressure test. The resulting drying of rehydrated strawberries from dry produce yields at final moisture of about 55% on a wet basis. The results of the rehydration show high quality in color and texture parameters. Microwave-assisted vacuum drying techniques were shown to preserve strawberry tissue structure the best, with osmo active chemicals providing an extra structural strengthening impact and reduced macroscopic compactness. When comparing texture and shrinkage, there were no statistically significant changes between fresh strawberries and those dried via vacuum–microwave.

1.3.5. Saskatoon berry

Drying Saskatoon berry fruit treatment using microwave vacuum drying was studied by Lachowicz et el. (2019). Microwave vacuum drying was carried out in a microwave vacuum dryer using a magnetron power of 480 W/120 W. A 100 g sample of saskatoon berries was placed in a cylindrical drying vessel at a pressure between 4-6 kPa. The container is rotated at a speed of 6 rpm. Drying compares freeze-drying, conventional 70℃ drying, microwave vacuum, and combined conventional and microwave drying methods. Drying is carried out until the water content is about 0.04 kg H2O/kg d.m.

The drying results show the use of microwave vacuum drying saves time up to 10 times faster than other drying. In the color parameter, microwave vacuum drying has better color reduction than conventional drying. Among all the methods used (except freeze-drying), the highest retention of the phenolic compounds of saskatoon berries was noted when microwave vacuum drying at 480/120 W was applied, microwave vacuum drying at 480/120 W could be considered the preferred method in anthocyanin preservation. As for antioxidant levels, the highest values of antioxidant capacity were noted after microwave vacuum drying with an average antioxidant yield of 7.6% for DPPH; 12.9% for ABTS, and 18.4% for FRAP. Drying-induced changes in the antioxidant capacity of saskatoon berries observed changes in the antioxidant capacity of saskatoon berries as a result of drying and found that microwave vacuum drying allowed for improved antioxidant retention than vacuum-drying [30]. To summarize, when it comes to the antioxidant capacity of saskatoon berry dried products, Microwave Vacuum Drying may be deemed competitive to Freeze Drying. Microwave vacuum drying at 480 W with a 120 W reduction could produce a product with equivalent quality to that obtained by freeze-drying, especially in terms of polymeric procyanidins and flavonols retention. Microwave vacuum drying can reduce drying time by up to 20 times compared to freeze-drying.

Table 5. Drying properties of saskatoon berry dried by various drying methods

Drying method	Drying time (min)	L*	a*	b*	DPPH
FD	1440 ± 20	34.8 ± 0.1	16.3 ± 0.2	4.6 ± 0.0	**0.24+0.02**
CD	780 ± 15	33.2 ± 0.2	11.1 ± 0.1	3.8 ± 0.1	0.18+0.01
CD/MVD	298 ± 4	36.2 ± 0.3	14.7 ± 0.1	4.6 ± 0.0	0.21+0.02
MVD	**78 ± 4**	36.2 ± 0.3	14.7 ± 0.1	4.6 ± 0.0	**0.22+0.2**

2. CONCLUSION

Microwave vacuum drying is an alternative to fruit drying which provides many advantages. Microwave vacuum drying is proven to shorten the drying time of preservation fruit. The use of microwave vacuum drying also showed better in reduce damage of appearance especially color change and biochemical compound of fruit with short drying time. Drying fruit using microwave vacuum drying is proven to shorten the drying time many times so that it also saves energy use. The use of the vacuum method increases the water vapor pressure within the pores and results in the pressure-induced opening of the pores. This results in faster drying and lower temperatures. The use of microwave vacuum drying also showed higher antioxidant yields than other drying methods. Microwave vacuum drying method must be used with the right power to get efficiency and effectiveness in fruit drying process.

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