MICROWAVE DRYING CHARACTERISTICS FOR GINGER ROOT (Zingiber officinale)

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ABSTRACT

This experiment was carried out at Agricultural Engineering Department Minofiya University to study microwave drying characteristics for ginger root. Five microwave drying powers (180, 360, 540, 720 and 900 Watt) and four levels of ginger thickness (0.5, 1, 1.5 and 2 cm) were used. Drying characteristics and quality aspects of the dried ginger were studied. The drying time to achieve the save storage moisture content was 14 minutes at 900 Watt with 0.5cm thickness. Total phenolic content of fresh ginger was 0.40 mg/g.d.m. and the highest phenol content in dried ginger was detected at the 900 Watt power with 1.5cm thickness, and the lowest phenolic value was recorded at 180 Watt with 2 cm thickness. The fresh ginger hardness ranged from 0.5 to 1 kg /cm² and the highest hardness of dried ginger was 6 kg /cm² at both 720 and 900 W with all thickness. The highest drying efficiency of ginger slices was 78% at 720 and 900 Watt with 2 cm thickness and the lowest efficiency (less than 10%) was recorded at 180 Watt with all used thicknesses (except at 2 cm. thickness). The highest value of energy consumption (10.2 MJ) was detected at 180 Watt and 2 cm thickness, while drying at 900 Watt with both 0.5 and 1 cm. thickness represent the lowest energy consumption (1.13 MJ). Veirma model can be used to describe the behavior of microwave drying of ginger, which gave the best results.

Key word: *microwave, drying, ginger, thickness*

1-INTRODUCTION

Microwave energy can be used to reduce the drying time, which is rapidly absorbed by the product water molecules and consequently results in rapid evaporation of water and thus higher drying rates. The interior temperature of dried microwave-heated food is higher than the surface temperature and moisture is transferred to the surface more dynamically than during convective drying (Torringa et al., 2001).

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Chan, et al. (2008) studied the effects of different drying methods on the antioxidant properties of leaves and tea of ginger species Microwave-drying of elation leaves resulted in significant losses in total phenolic compound and antioxidant but the declines were comparable between different drying durations.

Ginger products have varied applications in culinary preparation, bakery products, toiletry products, perfume industries, meat products, and soft drinks making. Dried ginger is used both as a spice and medicine. It contains an essential oil, which imparts an aroma, an oleoresin responsible for the pungent smell, starch, gums, proteins, carbohydrate, mineral matter, and fiber Rahman, et al. (2009).
A microwave drying at a constant temperature usually follows a typical drying curve. In the middle drying stage, moisture is rapidly removed, large amount of aroma is lost, and charring often occurs Li et al. (2010). Also, 'Puffing' usually happens in this stage, causing quality damage and undesirable changes in the food texture Zhang et al. (2006).
The overall aim of this research was:

- Evaluate the microwave drying technique,
- Study the relation between microwave power, ginger thickness and drying load on dried ginger properties

2-MATERIALS AND METHODS

Materials:

Fresh ginger (Zingiber officinal's) was purchased from locale market in Shibin El- Kom, Egypt. Manually recapped and sorted then cut to four thicknesses (0.5, 1, 1.5 and 2cm.)

Microwave oven dryer (KOR-9G2B)

Microwave oven (KOR-9G2B) with maximum output of 900W and 2450 MHz was used for drying experiments. The outside dimensions of the microwave were 465*280*282mm. cavity dimensions (W*H*D) 314*235*346mm and cavity volume 26L, Net weight approx. 11kg, Timer 59 min., 90 sec., Power selections 10 levels with one dish with diameter 30 cm.

Methods:

Ginger preparation:

Ginger roots (Zingiber officinal's) were washed with cold water manually recapped and sorted then cut to four thicknesses (0.5, 1, 1.5 and 2cm.) using a knife. Ginger slices was spread (single layer) with a near uniform distribution density on the mesh trays of the drying chambers for drying. The moisture content of ginger measured by putting them in the drying oven for 24 hours at 70 °C.

Table 1. Nutritional composition of ginger (per 100g). According to Shirin and Prakash (2010)

Constituent	Value	Constituent	Value
Moisture	15.02 ± 0.04	Ash (g)	3.85 ± 0.61 (4.53)
Protein (g)	5.087 ± 0.09(5.98)	Calcium (mg)	88.4 ± 0.97 (104.02)
Fat (g)	3.72 ± 0.03 (4.37)	Phosphorous (mg)	174±1.2 (204.75)
Insoluble fiber (%)	23.5 ± 0.06 (27.65)	Iron (mg)	8.0 ± 0.2 (9.41)
Soluble fibre (%)	25.5 ± 0.04 (30.0)	Zinc (mg)	0.92 ± 0 (1.08)
Carbohydrate (g)	38.35 ± 0.1	Copper (mg)	0.545 ± 0.002 (0.641)
Vitamin C (mg)	9.33 ± 0.08 (10.97)	Manganese (mg)	9.13 ± 001 (10.74)
Total carotenoids (mg)	79 ± 0.2 (9296)	Chromium (μg)	70 ± 0 (83.37)

All value in this table represent the mean ± SD (n = 4). Figures in the parenthesis represent the dry weight values.

Experimental design:

Four thicknesses (0.5, 1, 1.5 and 2 cm) and five different power levels (180, 360, 540, 720 and 900 W). Samples of ginger slices which were individually weighted and positioned at the center of the glass Microwave oven plate (dish).

Table 2.Thickness and drying load studied.

Thickness cm	0.5	1	1.5	2
Drying load kg/m^2	4	8	12	15

Measurements:

Moisture content:

According to El-Awady, et al. (1993), the moisture content of initial products was determined by drying the product in an electrical oven at 70 °C for 24 hours.

The moisture content on the dry basis (M_{db}) represented as,

$$M_{db} = \frac{w_o - w_d}{w_d} x100 \qquad \% \qquad (2.1)$$

Where:

Wo = wet mass of the sample (gm)

W_d = dry mass of the sample (gm)

Drying rate:-

Drying rate may be expressed as the thin layer drying equation:-

$$\frac{dM}{dt} = -k(M_t - M_e) \qquad (2.2)$$

Where, k and M_e, respectively are the dying constant (s^{-1}) and the equilibrium moisture content (%), t is the desired time period (s), and M_t is the instantaneous moisture content which can be estimated as well as the final moisture content throughout the drying process.

Microwave dryer efficiency

$$\eta_{Dm} = W_r * \frac{LHV}{P} * 100 \qquad (2.3)$$

Where :

W_r	= water removal	(kg/s)
LHV	= Latent heat of vaporization $2.25*10^3$	(kJ/Kg)
P	= Power consumed, 1350	(W)

Total phenolic compound:-

Total phenolic content was determined by the Folin-Ciocalteu micro-method Saeedeh and Asna, (2007) a 20 μL aliquot of extract solution was mixed with 1.16 mL of distilled water and 100 μL of Folin–Ciocalteu's reagent followed by 300 μL of 200 g L−1 Na2CO3 solution. The mixture was incubated in a shaking incubator at 40°C for 30min and its absorbance at 760 nm was measured. Gallic acid was used as standard for the calibration curve. Total phenolic content expressed as gallic acid equivalent (GAE) was calculated using the following linear equation based on the calibration curve:

$$A = 0.98C + 9.925 \times 10^{-3} \ (R^2 = 0.9996)$$

Where A is the absorbance and C is the concentration (mg GAE g-1 dry weight).

Hardnesse:

Hardness was determined using hardness tester and related penetrometers with quill diameter of 2 mm which pressed ginger slice until the beginning of the break and then take the reading device value.

Mathematical models:

The drying curves were fitted with eleven different moisture ratio equations given by several researchers and cited by (Idlimam et al., 2007), as listed in table 3.

Fitting the mathematical models:

The regression analysis was performed using the statistical computer program. (Data fit 9.0). The goodness of fit of the tested mathematical models to the experimental data was evaluated from the coefficient of determination R^2 and the reduced chi-square χ^2 between the predicted and experimental values. The higher the R2 values and the lower the χ^2 values, the better is the goodness of fit Ertekin and Yaldiz, (2004).The reduced chi-square can be calculated as follow:-

$$\chi^2 = \frac{\sum_{i=1}^{N} (MR_{exp,i} - MR_{pre,i})^2}{N - n} \quad (2.5)$$

$$MBE = \frac{1}{N} \sum_{i=1}^{N} (MR_{pre,i} - MR_{exp,i}) \quad (2.6)$$

Where:-

$MR_{exp,i}$: the experimental moisture ratio.

$MR_{pre,i}$: the predicted moisture ratio.

N : number of observations

n : number of constants.

MBE: mean bias error was used to determine the quality of the fit.

Table3. Mathematical models applied to the drying curves, (Idlimam et al., 2007).

Model number	Model name	Model expression
1	Newton	$MR = \exp(-k.t) = e^{-k.t}$
2	Page	$MR = \exp(-k.t^n) = e^{-k.tn}$
3	Henderson and Pabis	$MR = a.\exp(-k.t) = a.e^{-k.t}$
4	Logarithmic	$MR = a.\exp(-k.t)+c = a.e^{-k.t+c}$
5	Two term	$MR = a.\exp(-k_0.t) + b\exp(-k_1 t)$ $= a.e^{-k0.t} + b\, e^{-k1\, t}$
6	Two term exponential	$MR = a.\exp(-k.t) + (1-a)\exp(-k.a.t)$ $= a.e^{-k.t} + (1-a)\, e^{-k.a.t}$
7	Wang and Singh	$MR = 1 + a.t + bt^2 = 1 + a.t + bt^2$
8	Approximation of diffusion	$MR = a\exp(-k.t) + (1-a)\exp(-k.b.t)$ $= a\, e^{-k.t} + (1-a)\, e^{-k.b.t}$
9	Modified Henderson and Pabis	$MR = a\exp(-k.t)+b.\exp(-g.t)+c.\exp(-h.t)$ $= a\, e^{-k.t}+b.e^{-g.t}+c.e^{-h.t}$
10	Verma	$MR = a\exp(-k.t) + (1-a)\exp(-g.t)$ $= a\, e^{-k.t} + (1-a)\, e^{-g.t}$
11	Midilli–Kucuk	$MR = a\exp(-k.t^n) + b.t$ $= a\, e^{-k.tn} + b.t$

Where

MR : moisture ratio, T : time, h and a,b,c,g,h,k,n : constant

RESULT AND DISCUSSION

Moisture content:

Fig.1 (a, b, c and d) show the relation between moisture content of ginger and drying time. Achieving the equilibrium moisture content for ginger by five radiation microwave powers 180, 360, 540, 720 and 900 W, it required 88, 34, 24, 16, and 14 min, respectively,at 0.5 cm thickness while required 116, 42, 26, 16 and 14 min, respectively at 1 cm thickness and 118, 44, 30, 18 and 16 min. at 1.5 cm thickness and finally 126, 48, 32, 18 and 16 min, respectively at 2 cm thickness.

The moisture content of the ginger slices was very high during the initial phase of the drying which resulted in high drying rates due to the higher moisture diffusion.

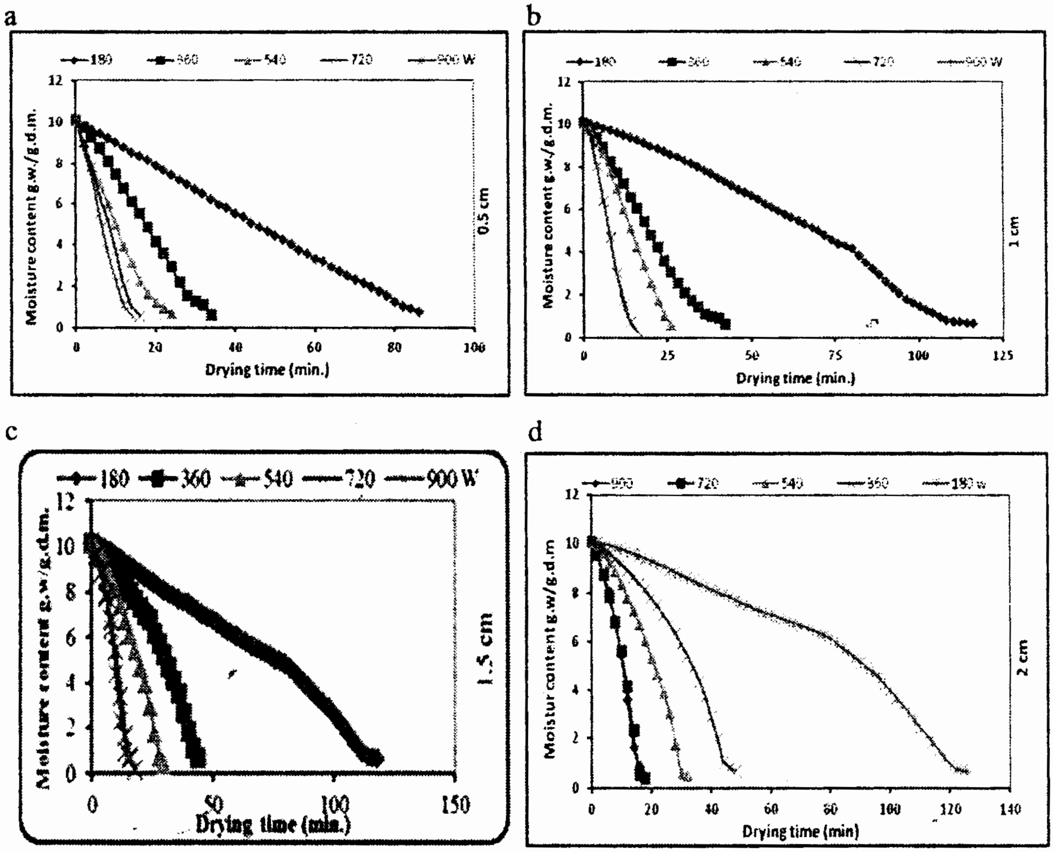

Fig.(1): Variation of drying time with change in moisture content of ginger by microwave

Drying rate:

At the beginning when moisture content was high, the drying rate under all drying conditions increased with time. This is due to high amount of free moisture availability, which was easily removed in the initial stage of drying. Fig.2(a) shows the change of drying rate of ginger slices at the thickness of 0.5 cm. clear difference in drying rate was found among the different power in microwave drying and all the drying rate apparently decreased. The average drying rates at 10 min. from the total drying time was 1.57, 1.27, 1.02, 0.52, and 0.22g. w/g. d. m. min for the different powers 900, 720, 540, 360 and 180 W respectively. A constant rate period was followed by a falling rate period in which moisture content decreased to 4.56, 3.88, 2.77, 2.2 and 1.7g. w/g. d. m. for the different microwave powers 180, 360, 540, 720 and 900 W, respectively.

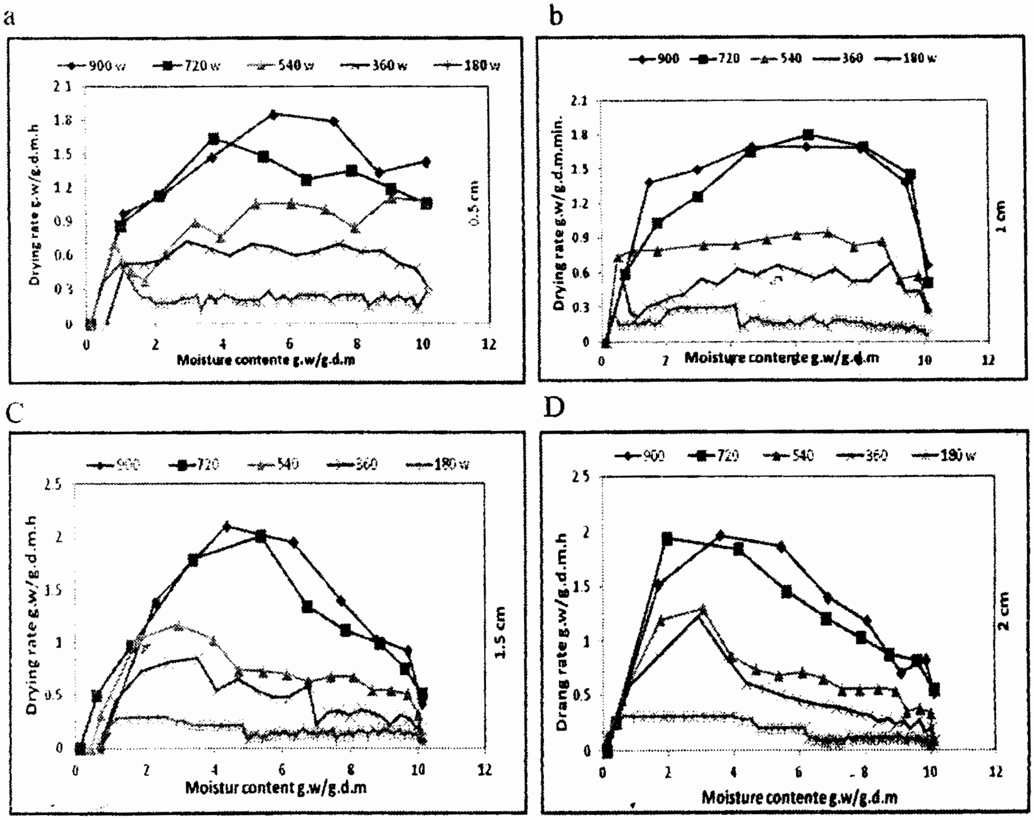

Fig. (2)Variation of drying rate with change in moisture content by microwave drying

The change of ginger drying rates at 1 cm thickness are shown in fig.2 (b). The average of drying rates at constant rate period ranged from 0.712 to 0.045 g. w/g. d. m. min for the different studied powers after 10 min of drying time, it can be seen remarkable difference in drying rate between the different powers in microwave drying and all the drying rate apparently decreased. A constant rate period was followed by a falling rate period in which moisture content decreased to 4.55, 4.03, 3.66, 2.06 and 2.03g. w/g. d. m. for the different microwave powers 180, 540,360 , 900 and 720 W, respectively.

Fig.2(c) revealed the changes of ginger drying rates dried in microwave powers at 1.5 cm thickness Clear differences were observed in drying rates among the different powers in microwave drying and all the drying rate apparently decreased.

The drying rates average at the constant rate period could be arranged in the following decreasing order 0.57, 0.47, .0.2, 0.12 and 0.054 g. w/g. d. m. min. for the different powers 900, 720, 540, 360 and 180 W, respectively after 4 min. from the total drying time. A constant rate period was followed by a falling rate period in which moisture content decreased to 3.02, 2.88, 2.7, , 2.2 and 2.15g. w/g. d. m. for the different powers 360, 180, 540,900 and 720 W, respectively.

Fig.2(d) represent the ginger slices (2cm thickness) drying rate of Clear differences in drying rate were observed among the different powers in microwave drying and also all the drying rate apparently decreased. On the drying conditions, the average drying rates at the constant rate period was ranged from 0.46 to 0.031g. w/g. d. m. min for the different powers 900, 720, 540, 360 and 180 W, respectively, at 4 min from the total drying time.

A constant rate period followed by a falling rate period in which moisture content decreased to 3.15, 3.0, 2.8, 2.52 and 2.28 g. w/g. d. m. for the different powers 180, 360, 540, 900and 720 W respectively. The highest average drying rate was 0.788 g/min at 0.5 cm thickness and 900W. From the results, at different thicknesses, the drying rate increased by decreasing the thickness. This is due to high amount of free moisture availability, which was easily removed in the initial stage of drying.

Total phenolic compound

Table (4) shows the total phenols content of fresh and dried ginger rhizome. The fresh ginger phenolic content (0.40 mg GAE/g d.W.) was affected by changing the microwave power and ginger thickness. The phenolic content of the microwave dried ginger slices ranged from (1.5, 2 cm thickness) which dried by microwave could be arranged from 0.14 to 0.72 mg GAE/g. d. m.. The highest phenolic contents was detected in the slices dried at 900 Watt at 1.5cm slices thickness while the lowest was recorded in the slices dried 180 Watt at 2cm thickness.

Table (4): Total phenols content of fresh and microwave dried ginger

Thickness cm.	Fresh mg/100g	Microwave power W				
		180	360	540	720	900
0.5	0.40	0.35	0.15	0.32	0.20	0.18
1	0.40	0.19	0.26	0.19	0.30	0.49
1.5	0.40	0.29	0.27	0.37	0.20	0.72
2	0.40	0.14	0.30	0.36	0.29	0.58

Effect of microwave drying on ginger hardness

The fresh ginger presented average hardness ranged from 0.5 to 1 kg/cm^2 and then increased gradually with decreasing in moisture content at all microwave drying powers and all thickness. As shown in table (5) the higher value (6 kg/cm^2)occurred when using all microwave drying powers at thickness 1.5 and 2 cm which was higher than the fresh ginger by 80 % .The lowest value (5.5 Kg/cm^2) occurred when using 180 and 360 W microwave drying powers at 0.5 cm thickness which was higher than other in fresh ginger by 90 %.

Table (5) Hardness of fresh and microwave dried ginger (kg/cm^2)

Thickness cm.	Fresh	Microwave power W				
		180	360	540	720	900
0.5	0.5	5.5	5.5	5.6	6	6
1	0.5	5.5	5.7	5.9	6	6
1.5	0.7	5.7	5.8	6	6	6
2	1	5.9	5.9	6	6	6

Drying Efficiency:

Fig.3 (a, b, c and d), describe the relation between the drying efficiency of ginger and drying time at the four studied thicknesses (0.5, 1, 1.5 and 2 cm), and different microwave powers (180, 360, 540, 720 and 900 W). The drying efficiency was always relative low at the beginning of the drying process due to decrease in drying rate. The drying efficiency increased by increasing both of thickness and microwave power. The highest efficiency was 78 % at 2 cm thickness and 720, 900 W. While the lowest was less than 0.10 % at 180 W and all studied thicknesses except at 2 cm. Furthermore, microwave power (180W) took the longest period time, this means more power consumption.

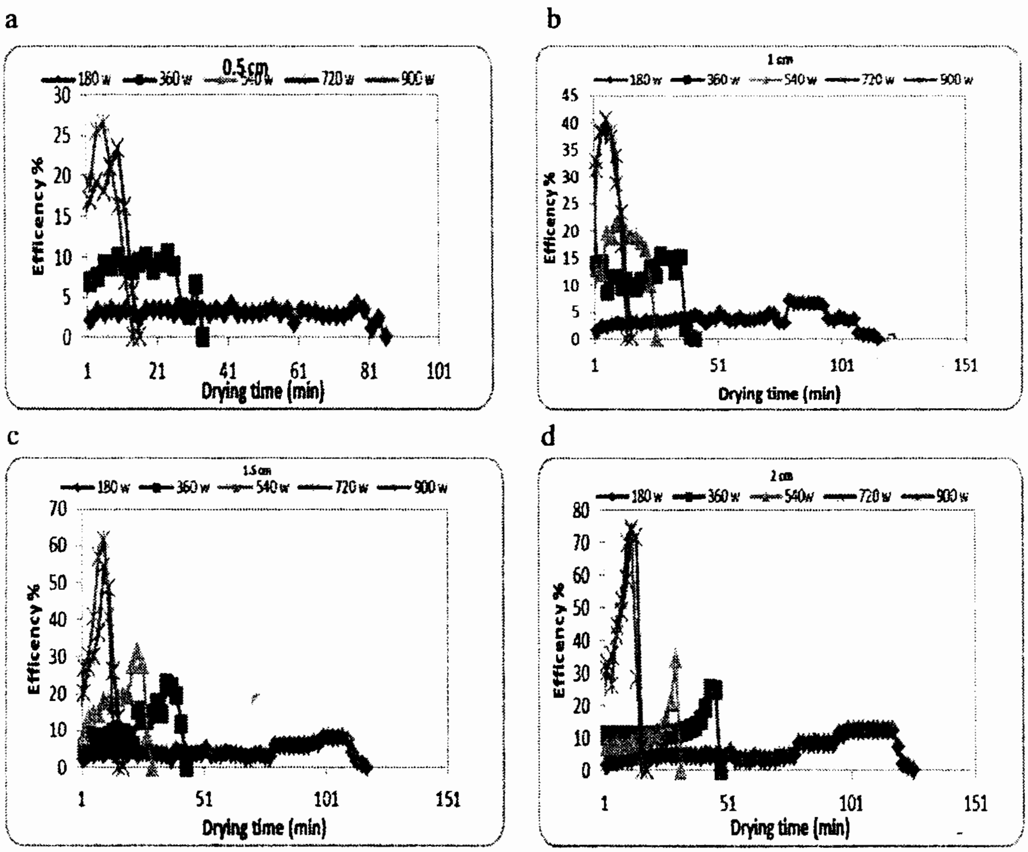

Fig. (3): Relation between the microwave efficiency and drying time of ginger

Consumption energy during drying ginger roots (KJ)

Table (6) shows the total consumption energy during drying of ginger by variant microwave power 180, 360, 540, 720 and 900W at the studied four thicknesses 0.5, 1, 1.5 and 2 cm. The highest amount of energy consumption was 10.2MJ at 180W of microwave drying power and 2 cm thickness, while the lowest amount of energy consumption was 1.1 MJ at 900 W powers and 0.5, 1 cm thicknesses.

Table (6): Total energy consumption (MJ) during drying ginger by microwave drying .

Thickness (cm)	Microwave power (W)				
	900	720	540	360	180
0.5	1134	1296	1944	2754	6966
1	1134	1296	2106	3402	9396
1.5	1296	1458	2430	3564	9558
2	1296	1458	2592	3888	10206

Mathematical models:

Drying curves were simulated using empirical models of reduced moisture content. These empirical models coming from the fundamental diffusion models that were generally suitable for drying fruits. The drying data as the moisture ratio (MR) versus drying time were fitted to the eleven drying models. The predicted (MR) of the ginger was obtained using the Data fit computer program. Table (3.4) shows the drying model coefficients and the comparison criteria used to evaluate goodness of fit, namely the coefficient of determination (R^2), the reduced Chi-square (χ^2), and mean bias error (MBE). For microwave dryer, the values of R^2, χ^2, and MBE for models ranged from 0.9871 to 0.9988, 4.1334e-9 to, 0.00254 and -7.288e-4 to, 0.014257 respectively. According to table (7) the Verma et al model showed good agreement with the experimental data and gave the best result for ginger samples at 180 W of microwave power and 0.5 cm thickness.

Table (7): Modeling of moisture ratio according to drying time for ginger by mic. drying.

Thick.	Power(w)	model	Model parameters (Coefficients)					R^2	χ^2	MBE
			a	b	C-g	k	n			
0.5 cm	180	V	-0.3145		6.4e-3	-9.72e-3		0.998	1.5e-5	-5.36e-4
	360	L	15.6826		-14.64	2.18e-3		0.998	4.1e-9	1.38e-5
	540	W	-5.87e-2	7.12e-4				0.997	6.5e-5	-2.03e-3
	720	L	15.6212		-14.59	4.32e-3		0.996	1.4e-5	0.00104
1	900	L	3.70905		-2.688	2.36e-2		0.995	6.8e-5	1.04e-4
	180	W	-5.15e-3	-3.2e-5				0.997	1.4e-4	-.00155
	360	P				4.36e-3	1.737	0.996	7.7e-4	5.65e-3
	540	P				2.00e-3	2.249	0.990	0.002	0.01166
	720	P				9.27e-3	2.210	0.992	0.001	0.01272
1.5	900	W	-5.84e-2	-1.4e-3				0.993	4.0e-4	0.00616
	180	W	-5.14e-3	-2.4e-5				0.993	3.9e-4	2.51e-3
	360	W	-6.46e-3	-3.4e-4				0.996	1.9e-4	0.00275
	540	W	-1.30e-2	-7.1e-4				0.997	7.7e-5	-0.0020
	720	P				2.19e-3	2.534	0.990	0.002	0.01425
	900	P				2.160e-3	2.636	0.992	0.001	0.00833
2 cm	180	W	-2.2e-3	-4.2e-5				0.987	0.001	0.00427
	360	V	-.29460		-2.e-3	-3.39e-2		0.996	1.8e-7	5.12e-5
	540	W	-9.93e-3	-6.8e-4				0.998	1.0e-5	-7.28e-4
	720	W	-3.05e-2	-1.6e-3				0.986	1.2e-4	-0.0031
	900	W	-1.71e-2	-2.9e-3				0.997	8.6e-5	-0.0027

CONCLUSION:

The drying time of ginger slices could be reduced by using the microwave power at both 720 and 900 W with a 0.5 cm thickness. The highest efficiency was 78% at 720 and 900 W with 2 cm thickness. The highest phenol content in dried ginger by microwave was 0.72 mg / g solid material when the power was 900 W and 1.5 cm thickness. Veirma et al model can be used to describe the behavior of microwave drying of ginger, which gave the best results at 180 Watts and 0.5 cm thickness.

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الملخص العربي

خواص التجفيف بالميكروويف لجذور الزنجبيل

د. احمد توفيق طه*

يهدف البحث الي دراسة كفاءة التجفيف باستخدام طاقة الميكرويف وتاثيرها علي المواصفات الطبيعية والميكانيكية للنبات.

استخدمت خمس مستويات من طاقة الميكروويف (٩٠٠, ٧٢٠, ٥٤٠, ٣٦٠ و ١٨٠ وات) لتجفيف شرائح الزنجبيل بمستويات مختلفة السمك لهذه الشرائح (٠,٥, ١, ١,٥ و ٢ سم) تضمن البحث دراسة خواص التجفيف (المحتوى الرطوبي, زمن التجفيف, معدل التجفيف و كفاءة التجفيف) كم تم دراسة تأثير طاقات الميكروويف المختلفة على خواص الجودة في الزنجبيل وكانت اهم النتائج المتحصل عليها كما يلي:

- أعلى زمن استغرق في تجفيف الزنجبيل من المحتوى الرطوبي الابتدائي ١٠ جم ماء /جم مادة جافة الى المحتوى الرطوبي المتوازن باستخدام الميكروويف كان ١٢٦ دقيقة عند مستوى الطاقة ١٨٠ وات والسمك ٢ سم واقل زمن كان ١٤ دقيقة عند الطاقة ٩٠٠ وات والسمك ٠,٥ و١ سم.
- محتوى الفينول الكلي للزنجبيل الطازج كان ٠,٤٠ ملجم /جم مادة صلبة وأعلى محتوى من الفينول في الزنجبيل المجفف بواسطة الميكروويف كان ٠,٧٢ ملغ /جم مادة صلبة عند الطاقة ٩٠٠ وات والسمك ١,٥ سم وأقل قيمة للفينول كان٠,١٤ ملجم /جم مادة صلبة عند استخدام ١٨٠ وات والسمك ٢سم.

قسم الهندسة الزراعية – كلية الزراعة – جامعة المنوفية

- كانت صلابة الزنجبيل الطازج تتراوح من ٠,٥ الى ١ كجم/سم٢ بينما كانت اعلى صلابة للزنجبيل المجفف هي ٦ كجم / سم٢ وهي اعلى من الصلابة في الزنجبيل الطازج بنسبة ٧٨٪ عند السمك ٢ سم وكانت اقل صلابة للزنجبيل بعد التجفيف بالميكروويف هى ٥,٥ كجم /سم٢ أعلى من الزنجبيل الطازج بنسبة ٨٤٪ عند السمك ٠,٥ سم.
- اوضحت النتائج ان أعلى كفاءة للتجفيف كانت ٧٨٪ عند ٩٠٠ و ٧٢٠ وات والسمك ٢ سم وأدنى كفاءة كانت أقل من ١٠٪، عند الطاقة ١٨٠ وات وعند جميع السموك باستثناء ٢ سم.
- وكانت أعلى كمية استهلاك للطاقة ١٠,٢ ميجا جول .عند استخدام القدرة ١٨٠ وات والسمك ٢ سم بينما كانت أقل طاقة مستهلكة كانت ١,١ ميجا جول عند استخدم القدرة ٩٠٠ وات والسمك ٠,٥ و ١ سم.