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Describe the Behavior of Microwave Drying of Split Lemon Fruit

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ABSTRACT

This research considered the effects of microwave drying technique on drying behavior, color and some chemical components of dried splits lemon fruit. A laboratory scale microwave dryer was used to dry the ripe lemon splits of half, quarter and slices under different microwave output power of 240, 288, 396 and 510 W. Two thin layer drying models were examined for describing the drying behavior of lemon slices (Lewis's & Henderson and Pabis's). Also, color values and contains of vitamins C and A were determined and analyzed. From the results it was found that the optimum model for describing the drying behavior of split lemon fruits is lewis' model. Also, the microwave output power can be used to dry lemon but at level of not more than 288 W to keep good properties of split lemon as color properties and chemical components.

INTRODUCTION

Lemons (Citrus Limon) benefits as a high nutrient flavor as a fresh fruit or dried. The black lime used as a food flavor also. Therefore, lemons are nutritious fruit with a myriad of health benefits. They boast one of the nature's highest vitamin C and A concentrations, total phenolic content (TPC) and a unique flavor and aroma (Santos and Silva, 2008). In addition, phenolic acids such as chlorogenic acid, syringic acid and vanillic acid are also claimed to comprise cyto-protective. Ripe lemons contain about 90% of water, however, high water content effects the microbial growth which eventually shortens the overall shelf life of the lemons. Drying improves the product shelf life without addition of any chemical preservative (Al-Harahsheh et al., 2009; Figiel, 2010; Singh et al., 2010). Drying also assists in reducing post-harvest losses of fruits and vegetables which can be as high as 70% (Tunde-Akintunde and Ogunlakin, 2013). Central administration for exports (2012) concluded that the dried limes most uniform in color, natural taste, haven't foreign materials, disease and scratch and MC equal or less 7%.

Ozkan, et al. (2007) indicated that microwave rays has several advantages when use to dry fruits and vegetables as fewer drying time, higher retention of some vitamins, and as pasteurize operation of material. Li et al. (2010) conducted that a low microwave output power may lead to a low temperature and short wave length these results in a slightly drying rate visa versa a high microwave power mean an undesirable great temperature, enhance the uneven distribution of the microwave energy, and produce a bad nutrient of final product .

Many researches considered the quality evaluation of drying food using microwave. The variation of food contents of vitamins A, C and E determined in spinach leaves (Ozkan, et al., 2007), apricot, (Karatas and Kamişli, 2007) and potato. Ozkan, et al. (2007) and Khraisheh (2004) found that the decrease in ascorbic acid was mainly depending on the drying time which due to the microwave power.

Sharma and Prasad (2006) showed that when using the drying with microwave the moisture content loss as the moisture diminution causes a reduction in the absorption of microwave power. Hihat, et al. (2017) compared the effects of drying by microwave and oven on antioxidant properties in coriander leaves. They found that the drying rate was faster using microwave with 900 W at 70 s than by oven at 120°C and 290 s.

The current research were aims to determine the drying behavior and constants at the quality of dried split lemon using microwave dryer.

MATERIALS AND METHODS

The tests carried out in the Agric. Eng. Res Inst. at season 2018 using a laboratory microwave oven model (JAC, NGM- 200l New) with maximum microwave out¬put of 600 W. It was operated by 230 – 240 V With 50 Hz. The outside dimensions of the microwave unit are 264 × 315 × 309 mm height, width and depth respectively. The maximum capacity is 20 Liters. The power of microwave dryer can be adjusted to give six levels of power.

To prepare the lemon samples, of fresh fruits were purchased from local market. The samples were selected with approximately same mass (22.5±2.3g) and size (as a spherical in shape with about 2.6 cm diameter), then they were washed and cut into the required shapes without seeds. The initial and final moisture contents of split lemon was determined using oven dryer by recommended method (AOAC, 1995) at 103°C for 4 hours. The initial M.C found about 88.7±2.2% w.b.

Studied variables:

Lemon sizes (half "2587 mm^3", quarter "1294 mm3" and slices of about 5 mm thickness "266 mm^3")

Microwave power (240, 288, 396 and 510 W)

The measurements and evaluations include:

Behavior of drying split lemon fruits by examine two thin layer drying models of:

1- Lewis's model

[MR = exp (-kt)], O'Callaghan *et al.* (1971),

2- Henderson and Pabis's model

[MR = A exp (-kt)], Henderson and Pabis (1961),

Where:

MR : Moisture ratio, dimension less

$$MR = \frac{M-M_e}{M_0-M_e} \qquad (1)$$

M : Moisture content at any time, % (d.b).
Me : Equilibrium moisture content.
M_0: Initial moisture content, % (d.b)
t : time, min
k, A : The drying constants

Different shapes of lemon samples were charged into the microwave oven then samples were taken every 30 s at the first 4 min (three samples were taken to determine their moisture content by a conventional method (AOAC, 1995)). The next samples were taken every one min until approaching the constant moisture content.

-Lemon splits quality:

The color parameters of lemon samples were determined using a Minolta Chroma Meter, model DP-30/CR-300 diffuse illumination, measuring area Φ 8mm. It was used to measure the color axes "L", "b", "a", and print the data in sheet. The color properties as total color differences (ΔE), hue angle (h), (R) values and chroma (c), were calculated using the following equations (Gözde, et al., 2015):

$$\Delta E = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \quad (2)$$

$$h = \tan^{-1} \frac{b^*}{a^*} \quad (3)$$

$$R = \frac{a^*}{b^*} \quad (4)$$

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad (5)$$

Chemical components of vitamin A and C determined according to (AOAC, 2006) methods for treatments before and after dried.

The experiments were done in three replicates. The simple and multiple analysis regression analyses were done using excel program version 2013.

RESULTS AND DISCUSSION

1- The behavior of drying split lemon fruit

Influence of drying time on split lemon moisture content at different split shapes:

Figure (1) shows the effect of drying time on split lemon moisture content "half, quarter and slice" at different microwave power output. From the figure generally, it can be seen that the drying time decreases by increase the microwave power output. The final moisture contents of 5.20, 5.02, 4.93 and 4.81 % d.b were obtained at 9, 8, 7 and 5 min drying time respectively using microwave power output of 240, 288, 396 and 510 W for half lemon fruit as shown in Fig. (1-A). While the corresponding final moisture contents were 4.85, 4.73, 4.70 and 4.69% d.b for quarter split lemons (Fig. 1-B) at the above drying time, but for slices split lemons the M.C were 4.50, 4.32, 4.28 and 4.20 % d.b at 8, 7, 7 and 4 min drying time respectively using microwave power output of 240, 288, 396 and 510 W as shown in Fig. (1-C). These results may be due to the strong effect of wave-length on the slice lemon more and quick than the thicker slice of half lemon.

Effect of drying time on lemon splits moisture contents at different power output

Figure (2) demonstrated the effect of drying time on split lemon moisture content at different power output. From the figure it can seen that the drying time decreases by decrease the lemon fruit size and increasing the power output. The final moisture content were 5.20, 4.85 and 4.5 % d.b obtained at 9, 9 and 8 min and microwave power output of 240 W for half, quarter and slice lemon fruit respectively as shown in Fig. (2-A). The same trends were found by increasing the microwave output power as illustrated in Figs(2-B through 2-D).The final moisture contents (Fig 2-D) were 4.81, 4.69 and 4.20% d.b at drying times of 5, 5, and 4 min for half, quarter and slice lemon fruits respectively, at microwave power output of 510 W. These results may be due to more effective influence of the power on the lemon fruit moisture based the sample surface area, on other words as the surface area increases the effectiveness of power increase.

A multiple regression analysis was proceeded to determine the relationship between moisture content (MC) and drying time (t), output power (P) for different split lemon sizes as follow:

Half	**MC = 636.57 – 0.02 P – 106.38 t**	**(R^2 = 0.9289)**	**(6)**
Quarter	**MC = 565.01 – 0.13 P – 86.87 t**	**(R^2 = 0.9490)**	**(7)**
Slice	**MC = 512.47 – 0.19 P – 83.28 t**	**(R^2 = 0.9761)**	**(8)**

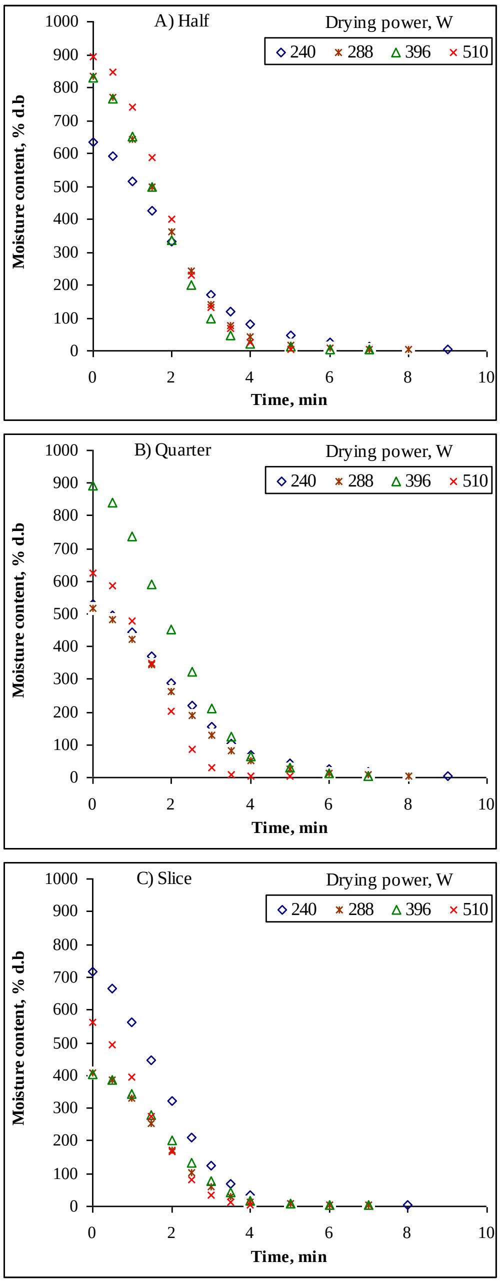

Fig. 1. Effect of drying time on lemon split moisture content at different lemon split sizes.

The multiple regression analysis shows highly significant effect of both moisture content and different lemon shapes.

Mathematical analysis to describing the drying behavior of lemon size

Using two thin models the moisture ratio (MR) was calculated based on the equation shape:

$$MR = \frac{M - M_f}{M_0 - M_f} \quad (9)$$

Where: M_f **= Final moisture content**

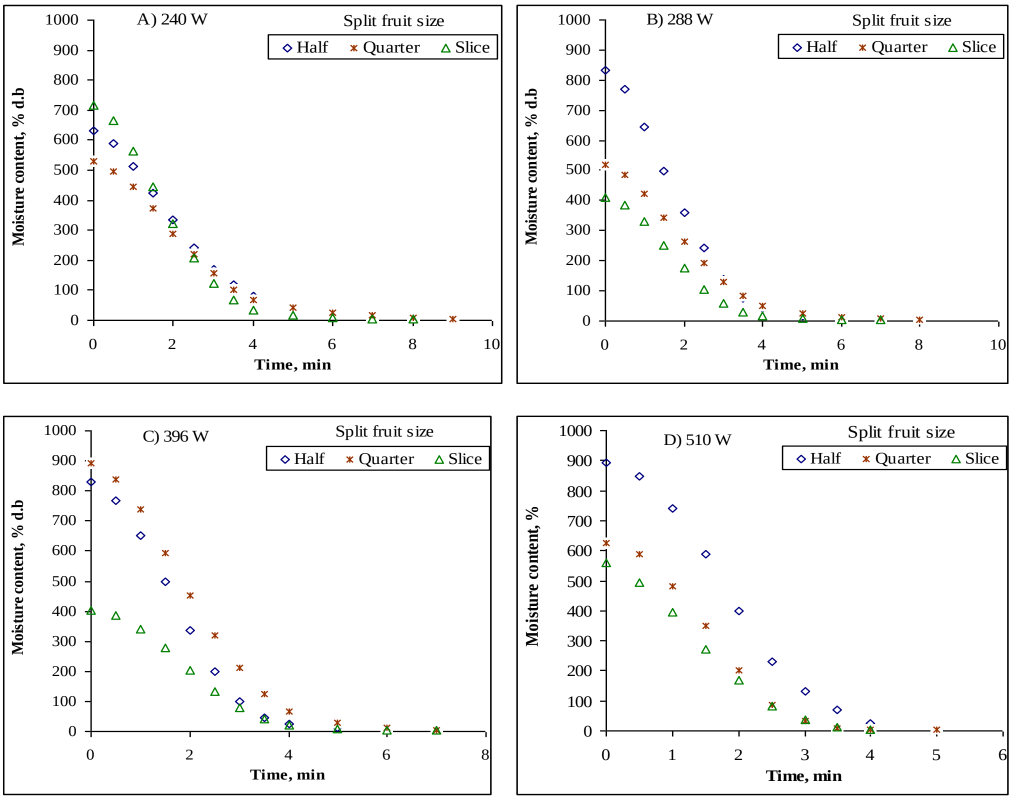

Fig. 2. Effect of drying time on lemon split moisture content at different microwave power output

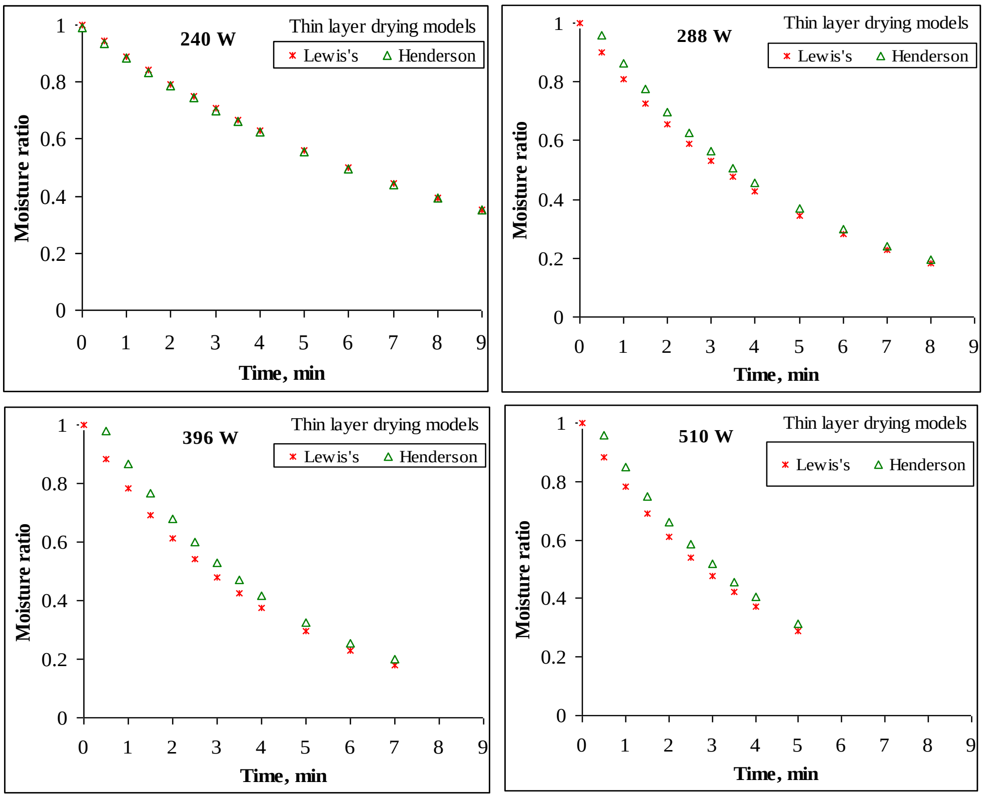

Fig. 3. Moisture ratio via drying time for half lemon fruits

Figs. (3 through 5) show the relation between moisture ratios via the drying time. at different levels of microwave power output and different split lemon fruit sizes

A multiple regression analysis was proceeded to institute the relationship between the drying time (T), output power (P) and split lemon fruit size (S) and moisture ratio (MR) as follow:

Half; $MR = 1.1883 - 0.1141\,t - 0.0007\,P$ ($R^2 = 0.9427$) **(10)**

Quarter; $MR = 1.3489 - 0.1125\,t - 0.0011\,P$ ($R^2 = 0.9229$) **(11)**

Slice; $MR = 1.0929 - 0.1386\,t - 0.0003\,P$ ($R^2 = 0.9797$) **(12)**

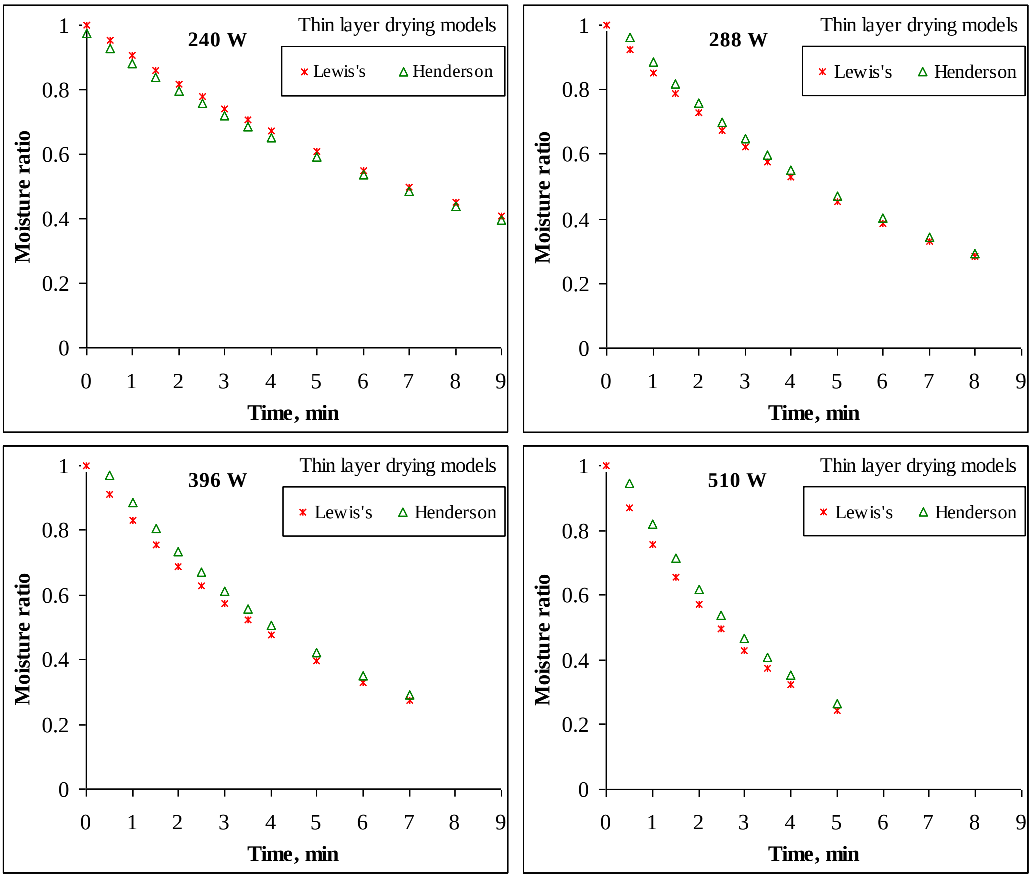

Fig. 4. Moisture ratio via drying time for quarter lemon fruits.

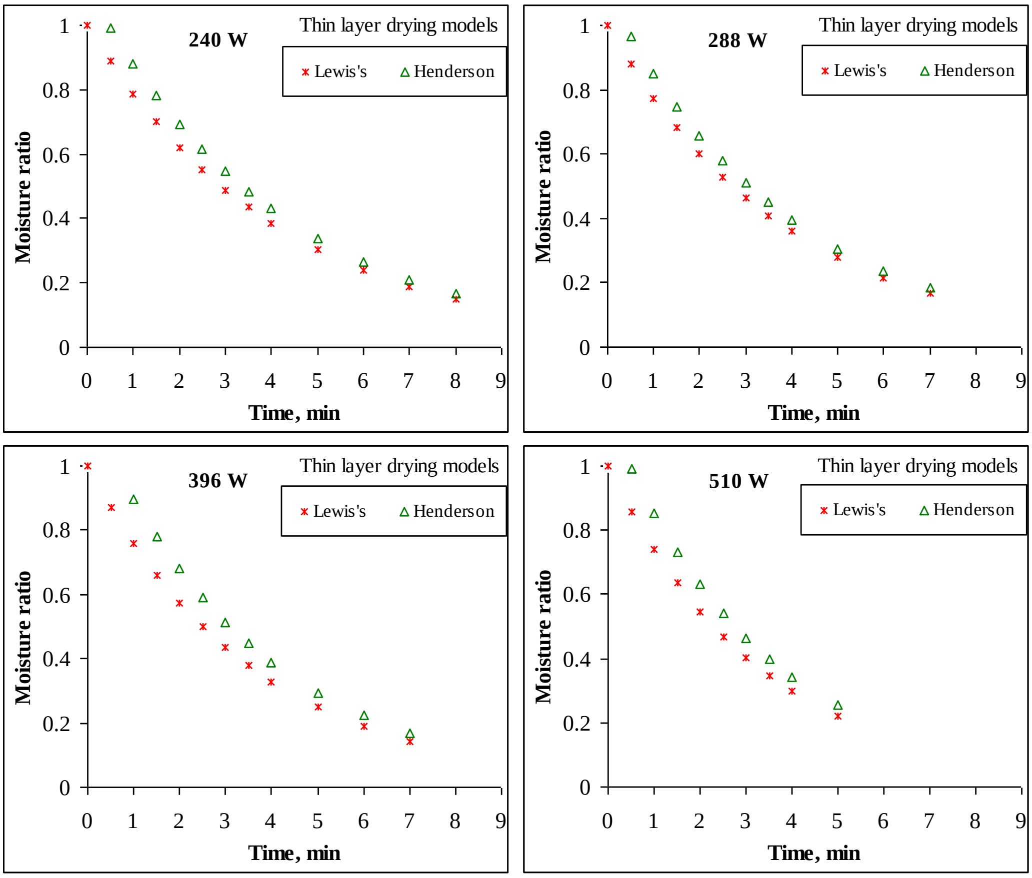

Fig. 5. Moisture ratio via drying time for slice lemon fruits.

Drying constants and the coefficient of determination of the studied three thin layer drying models

The constants of the studied thin layer drying models are calculated from the relationship of drying time and moisture ratio as shown in table (1). From the tabulated data both Lewis's constant "kL"and Henderson and Pabis's constant "kH" had a directly proportion to the power output while the Henderson and Pabis's constant "A" has no trend while the average value could be considered for calculations. The average values of Lewis constant "k_L" were 0.2049, 0.1813 and 0.2689 for half, quarter and slice lemon fruits respectively. Furthermore, the average values of Henderson and Pabis's constant "k_H" were 0.2051, 0.1813 and 0.2688 and constant "A" were 1.0521, 1.0414 and 1.1386 for half, quarter and slice lemon fruits respectively.

The relationship between the Lewis's and Henderson and Pabis's constants and the experimental treatment are shown in Fig. (6). The figure shows direct proportional between the drying constants and the output power.

Table 1. Constants and correlations of determination for thin layer equations.

Fruit size	Drying power, W	Lewis's K	Lewis's R^2	Henderson and Pabis's K	Henderson and Pabis's A	Henderson and Pabis's R^2
Half	240	0.1159	0.9896	0.1159	0.9929	0.9896
	288	0.1220	0.9589	0.1226	1.0168	0.9729
	396	0.2245	0.9855	0.2245	1.0610	0.9855
	510	0.2472	0.9424	0.2472	1.0865	0.9424
Quarter	240	0.1000	0.9841	0.1000	0.9735	0.9841
	288	0.1582	0.9874	0.1582	1.0203	0.9874
	396	0.1857	0.9804	0.1857	1.0665	0.9804
	510	0.2814	0.8977	0.2814	1.0863	0.8977
Slice 5mm	240	0.2386	0.9676	0.2386	1.0272	0.9676
	288	0.2556	0.9844	0.2556	1.0770	0.9844
	396	0.2778	0.9563	0.2778	1.1336	0.9563
	510	0.3035	0.9401	0.3035	1.1885	0.9401

Figs (6) and (7) show the measured and predicted values of moisture content for different split lemon sizes using Lewis's and Henderson and Pabis's models. Generally, the figures cleared that coefficients of determination (R2) of Henderson and Pabis's model were slightly higher than Lewis's model for all split lemon fruits.

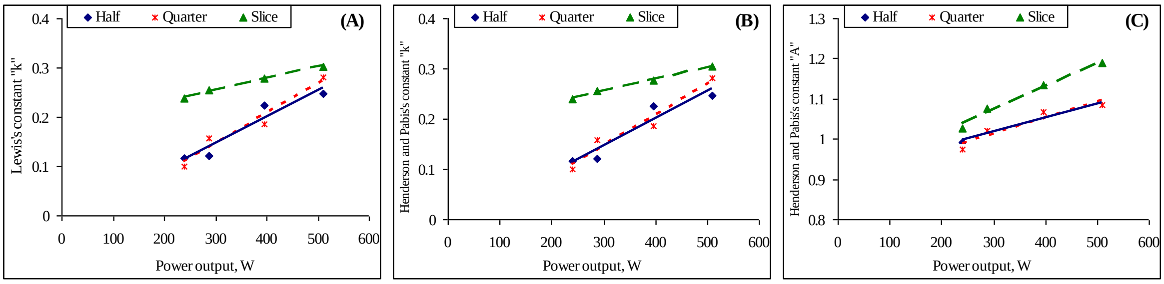

Fig. 6. Relationship between the drying constant and output power

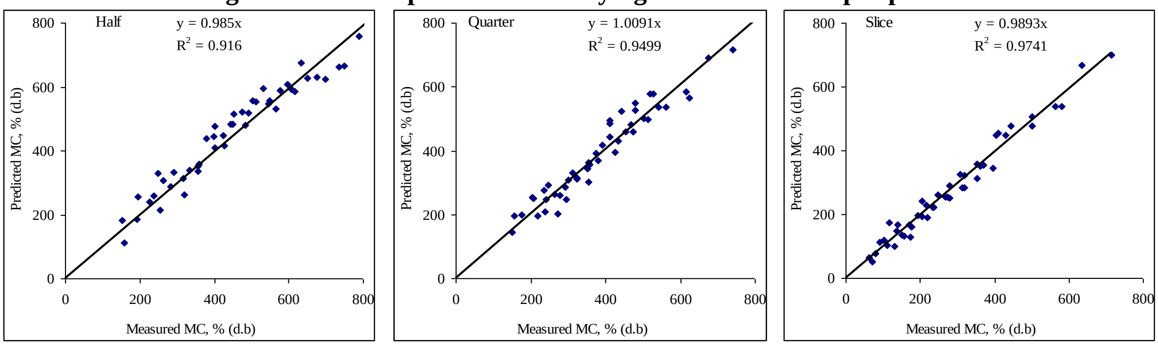

Fig. 7. Measured and predicted values of split lemon sizes moisture content using Lewis's model

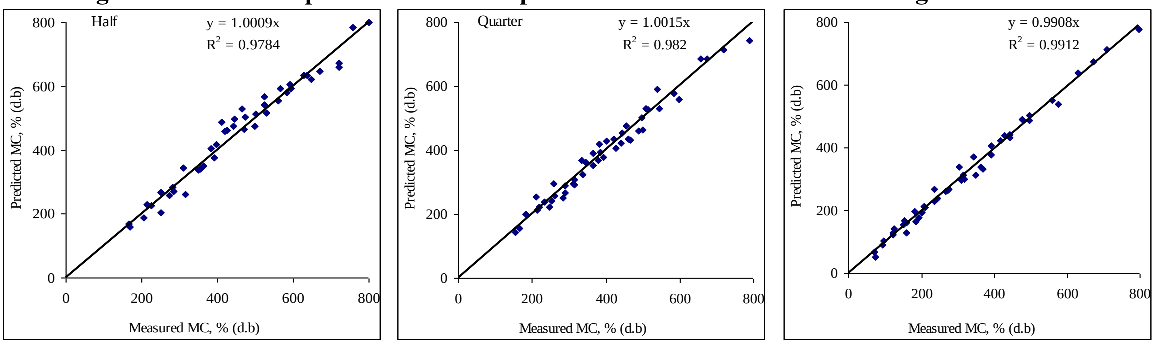

Fig. 8. Measured and predicted values of split lemon sizes moisture content using Henderson and Pabis's model

The above mentioned analysis showed that both studied drying models (Lewis's, Henderson and Pabis's) could describe the drying behavior of different lemon shapes and also predict the change in moisture content during microwave drying process satisfactory. This was clear from the high values of coefficient of determination (R^2) 0.9160 and 0.9489 for Lewis's and Henderson and Pabis's models respectively. However, for simplifying the calculations, the Lewis's model is recommended.

2- Color properties of drying split lemon fruit

The color parameters L*, a*, b* which measuring before and after drying, then the total color difference (ΔE), hue angle (h), (R) values and chroma (c), were calculated and the obtained results illustrated in Figs. from (6 through 9).

The total color differences (ΔE)

Fig. (9) shows that the effect of microwave power output on total color differences have a direct proportion relationship. The figure clear that increasing of drying power from 240 to 510 W increase the total color differences from 6.1 to 12.1, 16.0 to 18.0 and 18.9 to 21.4 respectively at half, quarter and 5 mm of split lemon sizes.

The best fit curve shows the polynomial equation for total color differences (ΔE) and microwave power output (P) at different lemon size as follows:

Half, $\Delta E = -2E\text{-}05P^2 + 0.0372P - 0.7459$ $R^2 = 0.8735$ (13)
Quarter, $\Delta E = -5E\text{-}05P^2 + 0.0447P + 8.3192$ $R^2 = 0.9586$ (14)
Slice 5 mm, $\Delta E = -4E\text{-}05P^2 + 0.0421P + 11.288$ $R^2 = 0.9991$ (15)

The fit curve equations show high significant effects on total color differences. Also it clear that the high coefficient of determination was found for lemon slice followed by quarter then half split.

The hue angle (h)

Fig. (10) shows that the microwave power output affects the on hue angle (h) in an inversely proportion relationship. The figure clear that increasing of drying power from 240 to 510 W decreased the hue angle from 81.91 to 76.82, 85.74 to 77.56 and 89.52 to 77.68 respectively for half, quarter and 5 mm of split lemon sizes.

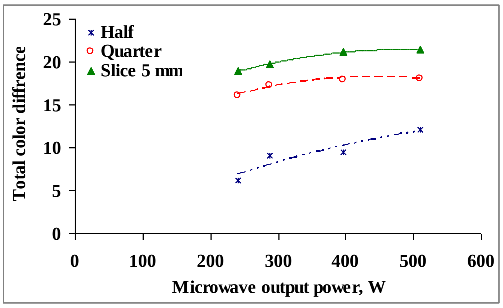

Fig. 9. The effect of microwave power output on total color differences

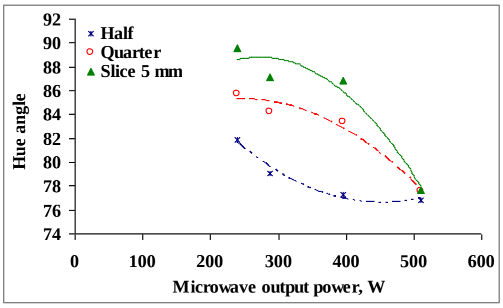

Fig. 10. The effect of microwave power output on hue angle

The best fit curves show polynomial equation relating hue angle (h) and the microwave power output (P) at different lemon size as follows:

Half, $h = 0.0001P^2 - 0.1001P + 99.276$ $R^2 = 0.9675$ (16)
Quarter, $h = -0.0001P^2 + 0.0534P + 78.681$ $R^2 = 0.9664$ (17)
Slice 5 mm, $h = -0.0002P^2 + 0.1067P + 74.225$ $R^2 = 0.9453$ (18)

The fit curve equations show high significant effects on hue angle. Also it clear that highest coefficient of determination was found for lemon slice followed by quarter then half split.

The (R) values

Fig. (11) shows that the effect of microwave power output on (R) values has a direct proportion relationship. The figure clear that increasing of drying power from 240 to 510 W increased the (R) values from 0.008 to .218, 0.075 to 0.221 and 0.142 to 0.234 respectively for half, quarter and 5 mm of split lemon sizes.

The best fit curves show the polynomial equation relating (R) values and microwave power output (P) at different lemon sizes as follows:

Half, $R = 3E\text{-}06P^2 - 0.0019P + 0.2847$ $R^2 = 0.9459$ (19)
Quarter, $R = 2E\text{-}06P^2 - 0.0010P + 0.2047$ $R^2 = 0.9667$ (20)
Slice 5 mm, $R = -2E\text{-}06P^2 + 0.0018P - 0.1706$ $R^2 = 0.9686$ (21)

The fit curve equations show highest significant effects is 0.9686 for lemon slices. Also it cleared high coefficient of determination found at lemon slice followed by quarter then half split.

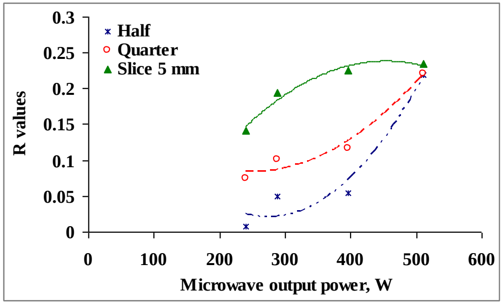

Fig. 11. The effect of microwave power output on (R) values

The chroma (c)

Fig. (12) shows that the effect of microwave power output on chroma (c) has a direct proportion relationship. The figure cleared that increasing of drying power from 240 to 510 W increased the total color differences from 4.838 to 9.114, 4.151 to 5.671 and 3.610 to 4.782 respectively for half, quarter and 5 mm split lemon size.

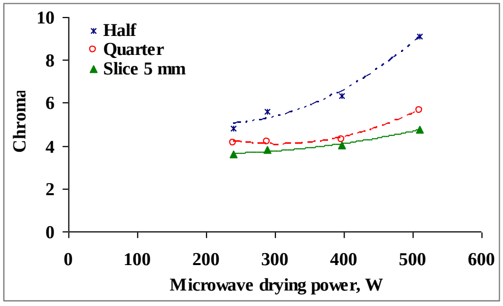

Fig. 12. The effect of microwave power output on chroma (c)

The best fit curves show the polynomial equations relating chroma (c) and microwave power output (P) at different lemon size as follows:

Half, $c = 5E\text{-}05P^2 - 0.0201P + 7.184$ $R^2 = 0.9790$ (22)
Quarter, $c = 4E\text{-}05P^2 - 0.023P + 7.5532$ $R^2 = 0.9881$ (23)
Slice 5 mm, $c = 1E\text{-}05P^2 - 0.0042P + 4.0383$ $R^2 = 0.9779$ (24)

The fit curve equations show that the high significant effects on chroma (c) for the quarter lemons. Also it cleared highest coefficient of determination was found at lemon quarter followed by half split then slices.

3- Chemical properties

Figs. (13) and (14) show the effect of microwave power output on the amount of vitamin "C" mg/100g and vitamin "A" IU comparing with the fresh lemon. The results indicated that vitamins A and C decreased by increasing the drying power and decrease the split size. As shown in Fig. (13) illustrate the reduction in vitamin "A" which were 12.74, 19.24, 30.62 and 39.57 % in comparison with the fresh lemon at 240, 288, 396 and 510 W drying power respectively. While Fig. (14) Vitamin "C" reduced by about 24.09, 29.34, 42.12 and 52.28 % in comparison with the fresh lemon at 240, 288, 396 and 510 W drying power respectively.

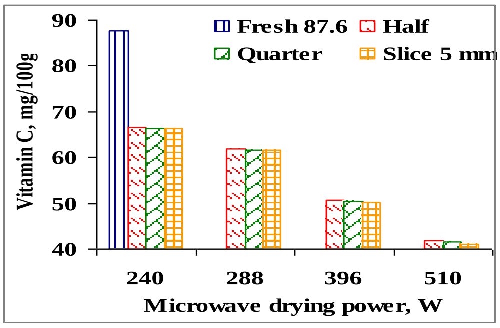

Fig. 13. The effect of microwave power output on vitamin A component

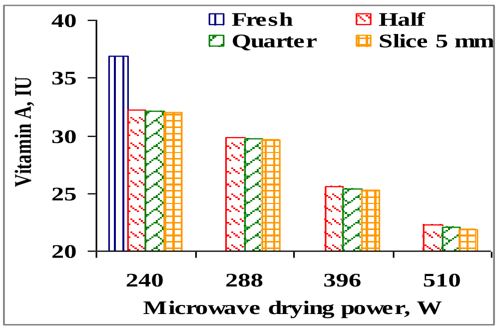

Fig. 14. The effect of microwave power output on vitamin C component

CONCLUSION

From the results it can be concluded that both studied models could describe the drying , behavior of split lemon fruits. However Lewis's model was selected for simplifying the calculations. The microwave output power can be used to dry lemon at output power not more than 288 W to keep good quality of split lemon such as color and chemical components for all studied split lemon fruit sizes.

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وصف سلوك التجفيف بالميكروويف لثمار الليمون المجزأة

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ثمار الليمون من الفواكه ذات المميزات الخاصة حيث تحتوى على العديد من العناصر الغذائية المفيدة وكذلك النكهة المميزة سواء كانت طازجة أو مجففة حتى تصل إلى ما يعرف باليمون الأسود. ويعد إستخدام الميكروويف فى التجفيف من التقنيات الجديدة والتى تتميز بسرعتها فى أداء عملية التجفيف لما لها من التأثير المباشر على جزيئات المياه. لذا فإن هذا البحث يهدف إلى إختبار نموذجين رياضيين لوصف سلوك التجفيف لأجزاء مختلفة الشكل من ثمار الليمون خلال عملية التجفيف بإستخدام الميكروويف وكذلك التنبؤ بالمحتوى الرطوبى . وقد تمت التجارب فى معهد بحوث الهندسة الزراعية فى فرن ميكروويف معملى حيث إشتملت المتغيرات الدراسية على إستخدام أربع مستويات لقدرة الفرن 240، 288، 396، 510 وات وثلاث مستويات لأجزاء الثمار نصف، ربع، شريحة بسمك 5مم. ولتقييم جودة الثمار تم: - تحديد خصائص اللون للثمار بقياس L*, a*, b* وتشتمل على: Total color difference (ΔE), hue angle (h), (R) values and chroma (c).، - تقدير نسب فيتامين C, A. أظهرت النتائج أن سلوك عملية التجفيف يتأثر بدرجة معنوية بكل من القدرة المستخدمة وزمن التجفيف وحجم أجزاء الثمرة. كما أظهرت أيضاً أنه يمكن تجفيف كل أجزاء الثمار تحت الإختبار بإستخدام الميكروويف عند قدرة لا تزيد عن قدرة 288 وات للحصول على جودة أفضل لأجزاء الثمار. وقد أمكن لكلا النموذجين الرياضيين موضوع الدراسة وصف سلوك التجفيف والتنبوء بالمحتوي الرطوبي للأشكال المختلفة من شرائح الليمون بطريقة مرضية الا أنه يوصي بأستخدام نموذج (Lewis's model) وذلك لتبسيط الحسابات.