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ENGINEERING STUDIES ON LEMON FRUIT DRYING WITHELECTRIC OVEN

Sara E. Nasr*, Mona M. Hassan and Taghreed H. Ahmed

Agric. Eng. Dept., Fac. Agric. Zagazig Univ., Egypt

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ABSTRACT: The present study aimed to assess the drying kinetic usingan electric oven dryer for drying lemon fruits using thin layer models. The drying behavior was investigated and simulated using four different thin layer drying models (Newten, Page, Modified Page, Henderson and Pabis's equations). The experimental work was conducted under two different levels of oven temperature (80 and 110°C) and, whole fruit, whole fruit with (1% NaOH) pretreatment and three different thickness (4, 5 and 6 mm). The variations in lemon moisture content was recorded versus drying time until reaching of 14.28 and 8.10 (% d.b) for whole fruit without pretreatment at (80 and 110°C), respectively, whilst it reaches (14.15, 12.86 and 14.15% d.b) at 80°C and (12.86, 14.15 and 16.82% d.b) at 110°C for lemon slices of 4, 5 and 6 mm, respectively. The whole lemon fruit with NAOH pretreatment recorded higher percentages of total crude fats (from 1.599 to 1.622%), total soluble sugar(from 6.40 to 6.80%), citric acid (from 5.95 to 6.21%) and ascorbic acid, vitamin c, (from 44.21 to 44.98 mg/100g) in comparison with the whole lemon without pretreatment and sliced lemon. All studied models could describe the drying behavior of whole lemon fruits and slices satisfactorily. However, the Page and Modified page models considered more proper for describing the drying behavior and predicting the changes in moisture content of both forms of lemons due to the higher values of coefficient of determination R^2 (0.9896).

Key words: Drying kinetic, oven dryer, lemon drying, thin layer models, moisture content.

INTRODUCTION

Lemons are nutritious fruits with a myriad of health benefits. They boast one of the nature's highest Vitamin C concentrations, Total Phenolic Content (TPC) and a unique flavour and aroma **(Santos and Silva, 2008).** In Egypt, lemon is growning along the banks of the River Nile in four areas: Delta, New lands (Sharkia, Ismailia and Behara), Upper Egypt and Middle Egypt. According to **Egyptian Ministry of Agriculture (2020)**, lemon trees have shrunk in the recent period, and their percentage does not exceed 10% of the total citrus trees in Egypt, as a result of a large number of lemon farmers getting rid of trees by uprooting them in the past years because of its economic inability. With the large number of lemon trees, their lifespan was reduced, which reduced the fruitful area to about 40,000 feddans, with an average production rate of 10 tons, so that Egypt would produce about 400,000 tons annually.

Pasławska *et al.* (2020) mentioned that, lemon thyme contains several bioactive health-promoting compounds of high antioxidant capacity such as polyphenols, carotenoids, and chlorophyll-which may undergo degradation during drying in incorrect processing conditions. Egypt is the most prominent citrus producers in Africa by (**Manner *et al.*, 2006**). **Chen *et al.* (2005) and Swanson (2009)** mentioned that, ripe lemons contain 90% of water. However, high water content causes the growth of microbial which eventually shortens the overall shelf life of the lemons. Therefore, drying works as a preservation method by removing the water from the lemons in order to extend its shelf life. Thus far, there are various drying methods which have been used for drying of slices such as closed type solar drying, infrared drying, open sun drying,

* **Corresponding author: Tel. :** +201018433413
E-mail address: radwansara97 @yahoo.com

hot air drying, and microwave drying. Alternatively, hot air drying is operated at an elevated drying temperature to enhance the drying rate. **Chin *et al.* (2009)** evaluated that this drying method requires great amount of energy for drying process and tends to produce low quality dried products especially in terms of the retention of heat-sensitive bioactive ingredients. **Fawzia *et al.* (2014)** developed that increasing the drying temperature caused an important increase in the drying rate of whole and sliced lemon fruit and the drying time is decreased. The time required for the moisture ratio to reach any given level was dependent on the drying conditions, being highest at 80ºC and lowest at 110ºC. **Matouk *et al.* (2019)** achived a standard dip emulsion pretreatment was used, this pretreatment increases drying rate because of cracks developed on the pretreated grape's surface. The quality evaluation experiments showed the advantages of the developed dryer in giving high quality raisin based on the Egyptian Standard of dried grapes (Raisins).

Yong Hong *et al.* (2014) reported that the highest drying rate found for oven drying of lemon slices at 60°C, followed by oven drying at 50°C and 40°C. Additionally, they reported that the Vitamin content of CF-HP dried slices was significantly higher ($p<0.05$) than oven dried slices although longer drying time was required. **Chen *et al.*, (2005)** invistigated that moisture content of the samples decreases along the drying process, drying temperature dominates the drying process and prolongs the total drying time required as compared to oven drying at elevated temperature. **Wesal *et al.* (2014)** reported the sliced lemon recorded higher percentages of total soluble sugar in comparison with the whole dried lemons; it was ranged from 0.71 to 1.1% for the whole dried lemon samples and from 0.83 to 1.21% for the dried lemons slices. In this context, the main objective of this study is assessing the drying kinetics of lemon fruits using the electric oven drying method considering thin layer drying mathematical models.

MATERIALS AND METHODS

The main experiment was carried out during the summer seasons of 2018 and 2019 at El-Sinbillawayn, Dakahlia Governorate to investigate using the electric oven for drying lemon fruit.

Lemon Fruits

Freshly-harvested lemon fruits (*Citrus aurantifolia*) were picked in Sinbillawayn city in an advanced stage of ripeness. The initial moisture content of the freshly harvested lemon estimated 84.53% in whole lemon fruit and 85.45% in lemon slices.

Electric Oven

Electric oven model No. : WO-03A, capacity 23 Liters and voltage 220-240V,1300W as shown in Fig.1 was used as a dryer. It contists of Heating elements, Grille and Convection vent and roasting spit drive sleeve.

Digital Balance

The moisture losses of samples were registered through the drying process by a digital balance (Ming Heng K1) with a rigor of ± 0.01 g. For measuring the bloc of the sample during experimentation.

Pretreatment of the Samples

Since the whole fruit lemons are a complex product with an outer waxy cuticle and pulpy material inside, the outer waxy cuticle affects the moisture diffusion from the lemons during the drying process. So, a chemical pretreatment is generally applied to decrease the skin resistance and hence improving moisture diffusion through waxy cuticle, for this experimental work the samples of whole lemon were blanched by dipping in boiling solution containing 1% of NaOH for 1.5 min and immediately cooled by immersing in running cold water as recommended for grapes by **Pangavhane *et al.* (2002) and Dosmaz and Pala (2002).**

The kinetics of the drying process was measured under the following parameters:

1- Two different levels of electric oven temperature (80°C and 110°C).

2- Two forms of lemon samples (whole fruit and slices (4, 5 and 6 mm thickness) as shown in Fig. 2 and a constant air velocity at 1 m/sec as recommended by **Sharma *et al.* (2005) and Arafa (2007)**.

3- Whole lemon fruit with (NaOH 1%) pretreatment and without.

Fig. 1. The experimental drying apparatus based on electric oven

Fig. 2. Sample of dried lemon slices

Studying the drying kinetics of lemon was investigated based on the following indicators:

Moisture content

Was set by drying the samples at (80 and 110°C) till reaching a fixed weight. Moisture content of lemon were 85.4% and 84.5% w.b. for slices and whole lemon respectively. The Moisture content was calculated as following :

M.c.(w.b.)=(w-d)100/w (1)

Estimation of the moisture ratio (MR) and drying rate

The moisture ratio (MR) and drying rate were calculated by using the following equations:

- Drying rate: was calculated as following:

$$Dr = \frac{(M_{t+dt} - M_t)}{(dt)} \quad \textbf{(2)}$$

Where:

M_t : Moisture content (g water/g dry matter) at time (t);

M_{t+dt}: Moisture content (gwater/g dry matter) at time (t+dt). **(Doymaz, 2012).**

-The moisture ratio (MR) was calculated using the equation:

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad \textbf{(3)}$$

Where:

M_t: Moisture content at t, db;

M_e: the equilibrium moisture content, db;

M_o: the initial moisture content, db.

Specific energy and drying efficiency

Energy consumption in drying (Qt, W.min) was calculated as following:

$$Qt = p \times t \quad (4)$$

Where:

P: Required power, W;

t: Drying time, min.

The specific energy (Qs, MJ/kgwater) was calculated as the energy needed to evaporate a unit mass of water (**Mousa and Farid, 2002; Soysal *et al.*, 2006**).

$$Q_s = \frac{60 \times Q_t}{1000 \times m_w} \quad (5)$$

The drying efficiency (η,%) was calculated as the ratio of the heat energy utilized for evaporating water from the sample to the heat supplied (**Yongsawatdigul and Gunasekaran, 1996; Soysal, 2004**).

$$\eta = \frac{m_w \times \lambda_w}{Q_t \times 60} \times 100 \quad (6)$$

Where:

mw: Mass of evaporated water, g;

λw: Latent heat of vaporization of water, kJ/kg.

The latent heat of vaporization of water at the evaporating temperature of 100°C was taken as 2257kJ/kg (**Hayes, 1987**).

Statistical Analysis

Regression analyses were done by using the statistical models. The coefficient of correlation (r) was one of the primary criterions for selecting the best equation to define the thin layer drying curves of lemon samples (**O'Callaghan *et al.*, 1971**). In addition to r, the various statistical parameters such as; reduced chi-square (χ2), mean bais error (MBE) and root mean square error (RMSE) were used to determine the quality of the fit model. These parameters can be calculated as following:

$$X^2 = \frac{\sum_{i=1}^{N}\left(MR_{obs.,i} - MR_{calc.,i}\right)^2}{N - n} \quad (7)$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N}\left(MR_{obs.,i} - MR_{calc.,i}\right) \quad (8)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{obs.,i} - MR_{calc.,i}\right)^2\right]^{\frac{1}{2}} \quad (9)$$

Where:

MRobs.,i: stands for the observed moisture ratio found in any measurement

MRcalc.,i : is the calculated moisture ratio for this measurement.

N and n are the number of observations and constants, respectively (**Pangavhane *et al.*, 2002).**

Studing the Estimation of the Dried Product Quality

Ascorbic acid (Vitamin C) :

For determining ascorbic acid in the product according to the method reported in (**A.O.A.C., 1975**) it was determined by titration with diclorophenol indophenol blue dye.

Citric acid

For determining citric acid in the product according to the method reported in **AOAC (1975)** it was determined by titration with 0-1 N sodium hydroxide after adding a few drops of phenolphthalein as an indicator.

Total soluble sugar

Total soluble sugars were determined by the anthron methods (**Sadasivam and Manickam, 1996**) through adding 3 mL anthron reagent to 0.1 mL filtrate, then heated for 10 min in a boiling water bath, cool rapidly and the developed green color was read at 630 nm by spectrophotometer.

Total crude fat

Total crude fat was estimated as follows; 0.5 g of each powdered sample was extracted using a continuous extraction apparatus (Suxhelt) with a solvent petroleum ether (b.p 60-80°C) for 16 hours. Each extract was dried over anhydrous Na2SO4 and evaporated to dryness. The residue was dried at 80°C for 10 minutes; cooled; weighed and expressed as lipids% (**AOAC, 1984**).

Table 1. Mathematical models given by various authors for the drying curves

No.	Model Name	Model	References
1	**Newton**	MR = exp(-kt)	**O'Callaghan *et al.*, 1971; Liu and Bakker, 1997**
2	**Page**	MR = exp(-kt^n)	**Agrawal and Singh, 1977; Zhang and Litchfield, 1991**
3	**Modified Page (I)**	MR = exp[-$(kt)^n$]	**Agrawal and Singh, 1977; Zhang and Litchfield, 1991**
4	**Henderson and Pabis**	MR = a exp(-kt)	**Westerman *et al.*, 1973; Chhninman, 1984**

RESULTS AND DISCUSSION

The discussion of the obtained results was under the following heads:

Drying Kinetics of Moisture Content Versus Drying Time at Different Temperature Levels Of The Oven

Increasing temperature from 80°C to 110°C decreased drying time this is due to rapidly heat and mass transfer within lemon samples, leading to heating the water molecules and carrying outside moisture by the hot air with high rates as follows:

Figs. 3 and 4 showed the difference in moisture content versus drying time for Lemon Samples at (80°C and 110°C) with different lemon samples slice thicknesses (4, 5 and 6 mm), whole fruit with and without pretreatment.

The drying rates of Lemon samples dried by various treatments are given in Figs. 5 and 6.

Drying Kinetics of Lemon Samples Quality Versus Drying Time at Different Temperature Levels for the Oven

T. Lipids %

Fig. 7 illustrated the changes in total crude fats of whole fruit, sliced lemon and whole fruit with (NaOH1%) pretreatment at different levels of oven temperature. As for the oven the percentage of total crude fats ranged from 1.512 to 1.540% for the whole lemon, from 1.093 to 1.571% for sliced lemon and from 1.599 to 1.622% for whole fruit with (NaOH1%) pretreatment. The whole lemon fruit with (NaOH1%) pretreatment recorded higher percentages of total crude fats in comparison with the whole and sliced lemon.

Total soluble sugar %

Fig. 8 illustrated the change in total soluble sugar related to oven temperature for whole, sliced lemons and whole fruit with pretreatment respectively. As for the oven the total soluble of the oven sugar was ranged from 6.16 to 6.24% for the whole lemon fruit, from 5.09 to 6.32% for the sliced lemon and from 6.40 to 6.80% for whole fruit with pretreatment. The whole lemon fruit with pretreatment recorded higher percentages of total soluble sugar in comparison with the whole and sliced lemon.

Citric acid %

Fig. 9 presented the percentage of citric acid in whole, sliced and whole lemon fruit with pretreatment related to oven temperature. As shown in the figure, the whole lemon fruit with pretreatment recorded higher percentages of citric acid in comparison with the whole and sliced lemon. The oven citric acid percentage ranged from 5.64 to 5.75% for the whole lemon, from 4.18 to 5.84% for the sliced lemon and from 5.95 to 6.21for whole lemon fruit with pretreatment.

Ascorbic acid (vitamin C) mg/100g

Fig. 10 presented the changes in ascorbic acid (vitamin C) related to different levels of oven temperature for whole, sliced and whole lemon fruit with pretreatment, respectively. The ascorbic acid of the oven in the whole lemon ranged from (43.36 mg/100 g dry matter to 43.67), from (39.15to 43.98 mg/100 g dry matter) for sliced lemon and from (44.21 mg/ 100 g to 44.98 mg/100 g) for whole lemon with pretreatment. As shown in the figure whole lemon with pretreatment showed higher ascorbic acid (Vitamin C).

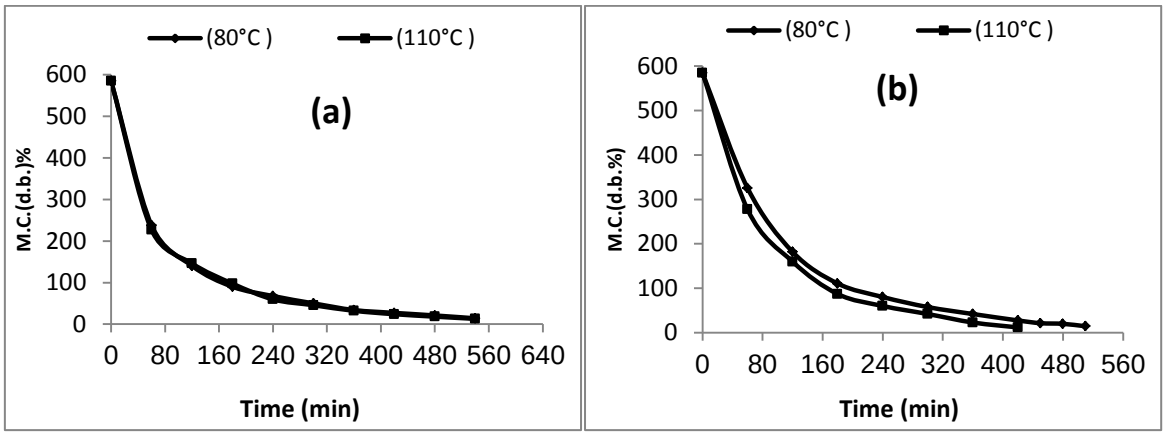

Fig. 3. Effect of electric oven temperature on whole lemon fruit moisture content as releated to drying time; (a) with NaOh1% pretreatment and (b) without

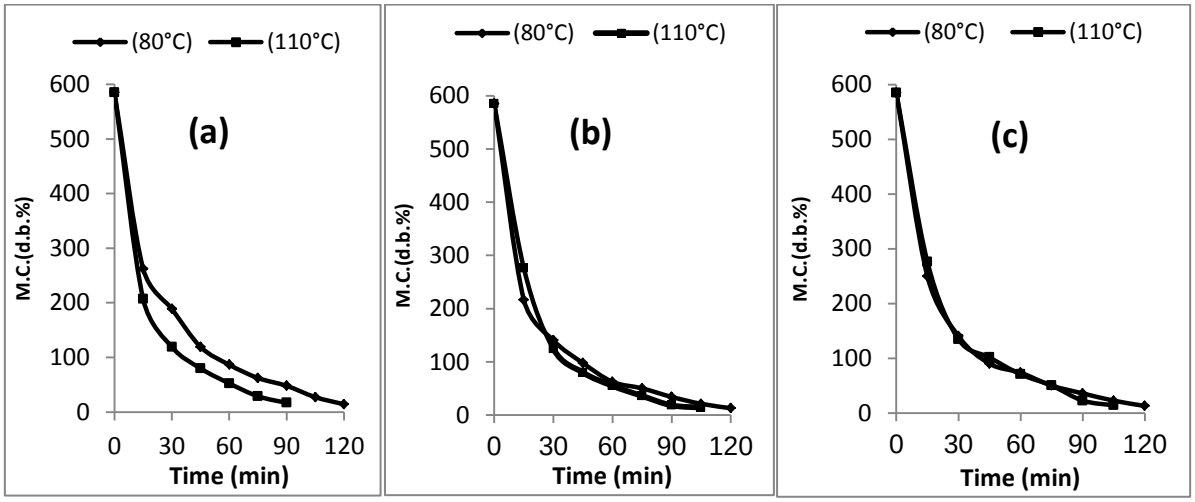

Fig. 4. Effect of electric oven temperature on lemon slices: (a) 4, (b) 5 and (c) 6 mm moisture contentas related to drying time

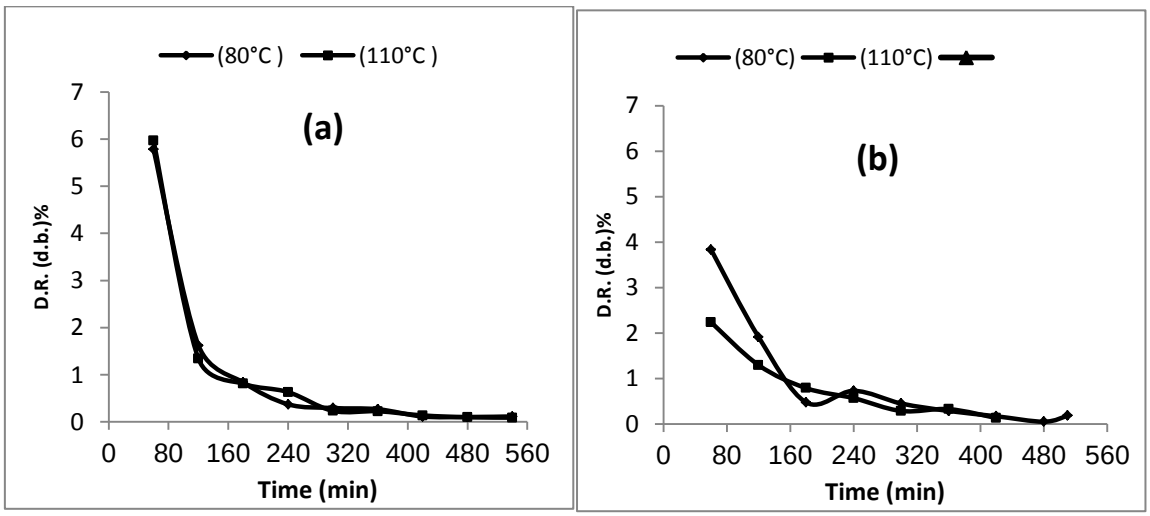

Fig. 5. Effect of electric oven temperature on whole lemon; (a) with NaOH1% and (b) without of drying rate as related to drying time

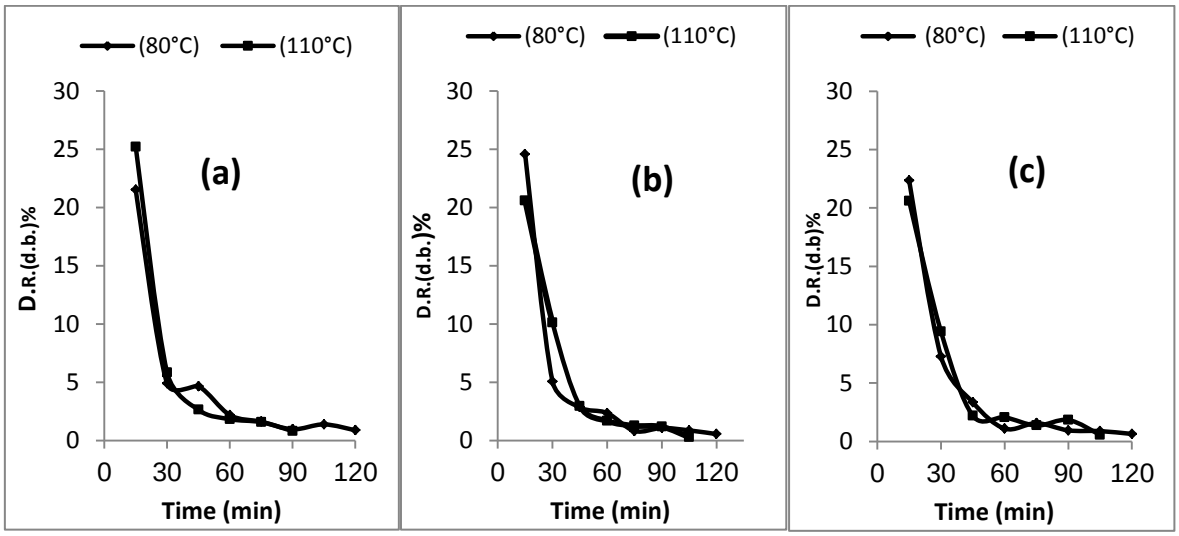

Fig. 6. Effect of electric oven temperature on lemon slices; (a)4, (b)5 and (c)6 mm of drying rate as related to drying time

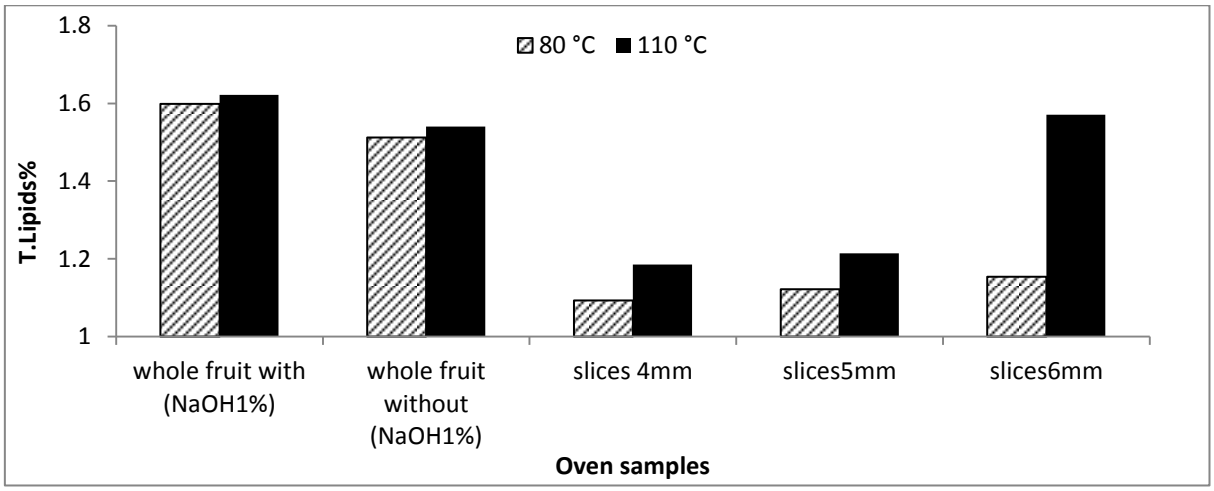

Fig. 7. Effect of electric oven temperature on total crude fats for whole and sliced lemon fruits

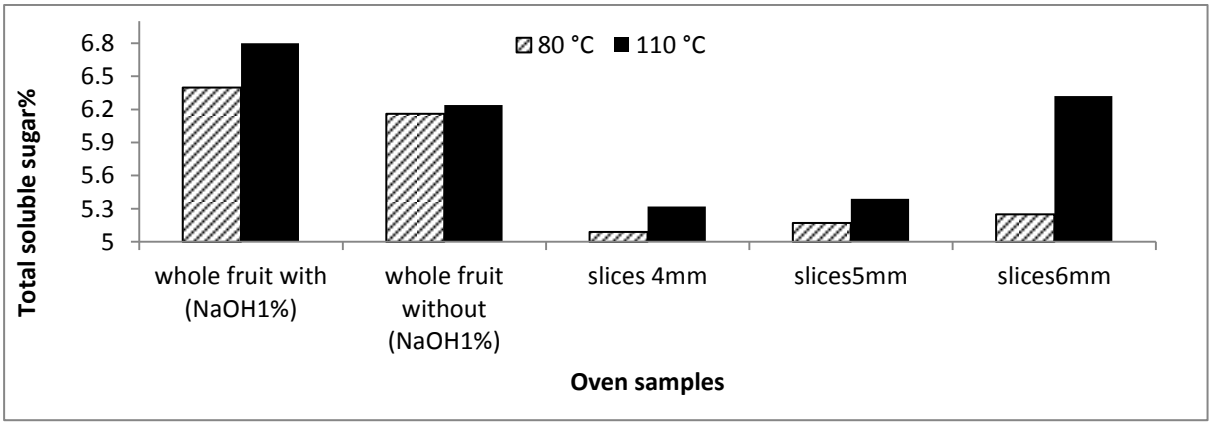

Fig. 8. Effect of electric oven temperature on total soluble sugar for whole and sliced lemon fruits

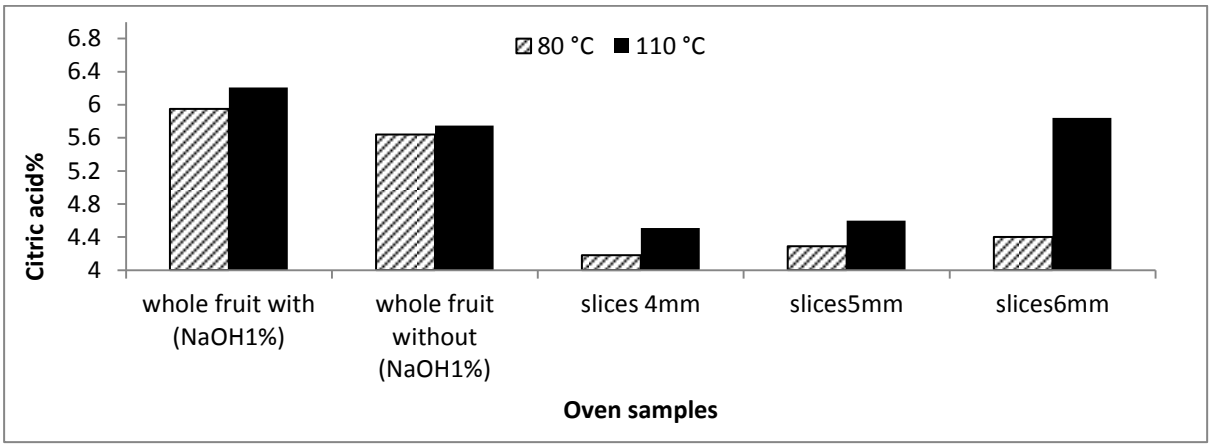

Fig. 9. Effect of electric oven temperature on Citric acid% for whole and sliced lemon fruits

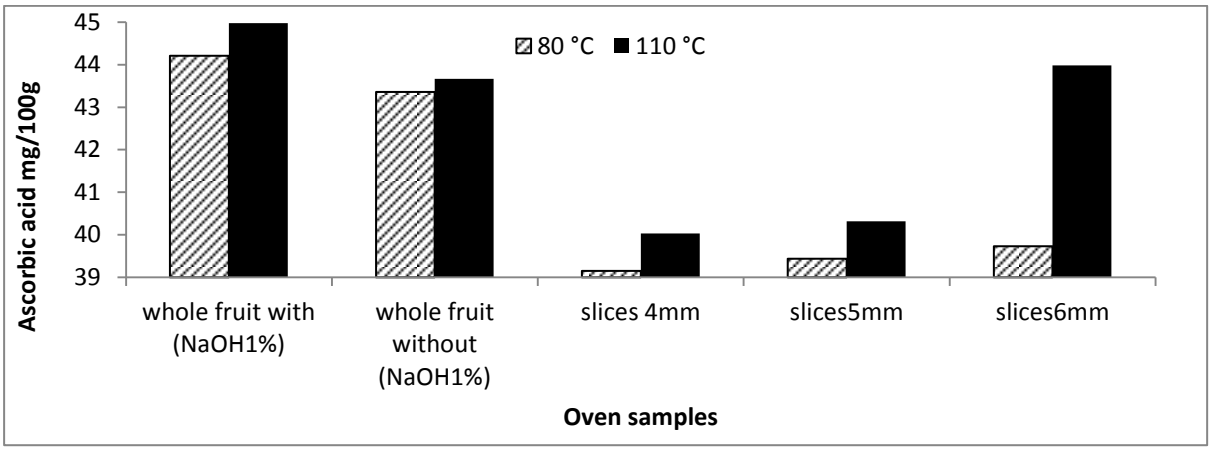

Fig. 10. Effect of electric oven temperature on Ascorbic acid% for whole and sliced lemon fruits.

The drying of the whole lemon fruit with (NaOH1%) pretreatment took more drying time, but it achieved greater quality characteristics than other treatments because of cracks developed on the pretreated lemon's surface.

Effect of different parameters on specific energy and drying efficiency

Specific energy and drying efficiency of lemon samples under different drying methods were shown in Figs. 11 and 12. Data clarified that the consumed specific energy for drying lemon is low and thus, the drying efficiency was increased. For 100g of lemon samples the lowest specific energy value was 98.87 MJ/kg for 4 mm slices at 110°C and thus achieved the highest drying energy efficiency 2.28%. The highest value of specific energy was 578.98 of whole lemon fruit with pretreatment at 80°C, and therefore its drying energy efficiency was low 0.39%. The reason for the high or low values is due to the shortening of the drying time.

Mathematical modeling of drying data

The data of moisture content versus time were transformed to moisture ratio versus time to normalize the drying curves. The data at different curve fitting computations with the drying time were conducted on four drying models predestined by the previous workers. The results of statistical analyses depend on these models are given in Tables 2 and 3, respectively. The predestined of the models were based on R2, Χ2, MBA and RMSE. For Lemon slices at (80°C) and (110°C).

The page and modified page models were the best descriptive models for all Lemon samples as shown in Table 2 and 3 this due to the higher values of coefficient of determination R2 (0.9896).

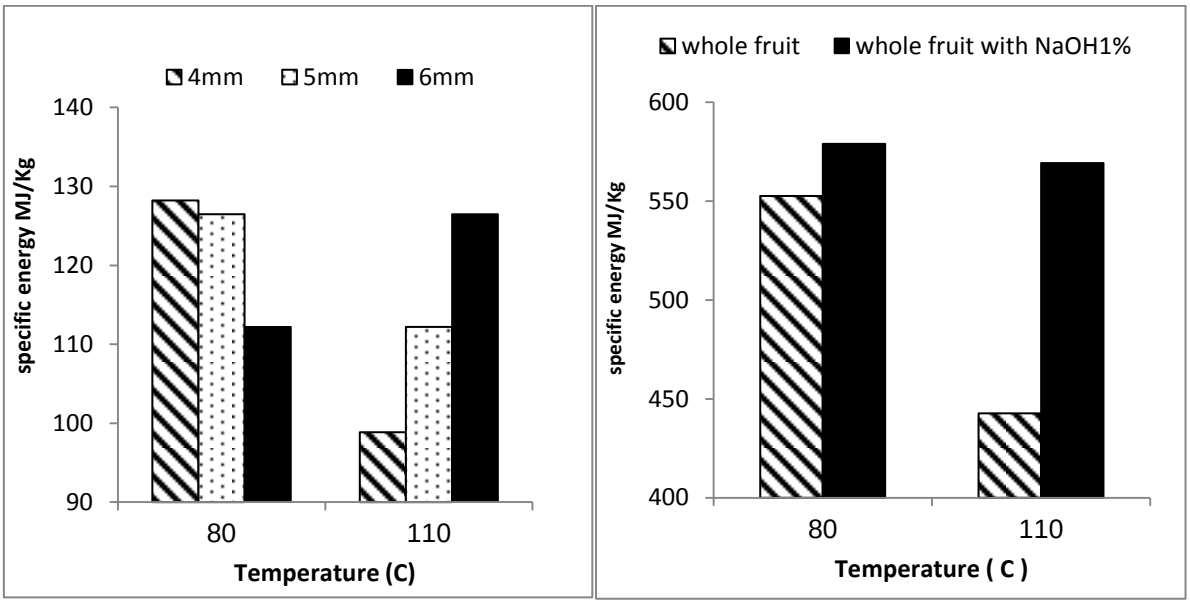

Fig. 11. The specific energy of electric oven for lemon slices and whole lemon fruits with pretreatment and without

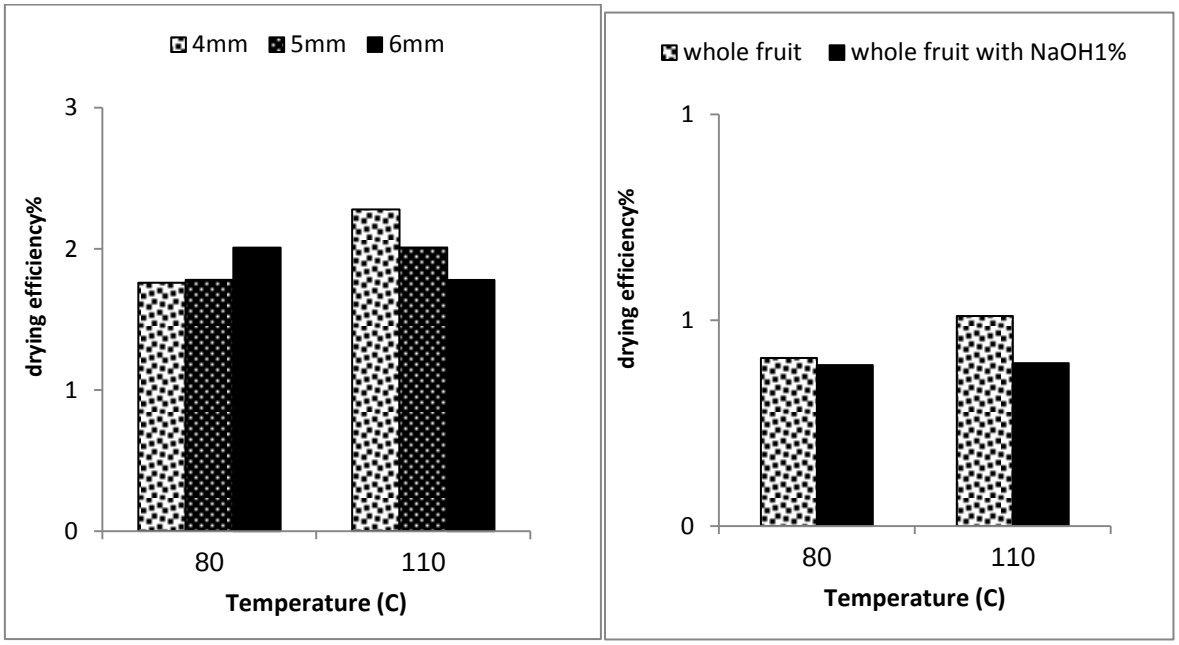

Fig. 12. The drying efficiency of electric oven for lemon slices and whole lemon fruits with pretreatment and without

Table 2. Values of chi-square (x^2), mean bias error (MBE) and root mean square error (RMSE) for all models of oven temperature (80°C)

Lemon Samples	Lemon samples	Newten model			Hendrson model			Page model			Modified page model		
		X^2	MBE	RMSE	X^2	MBE	RMSE	X^2	MBE	RMSE	X^2	MBE	RMSE
Slices thickness, mm	4	0.009223	0.059225	0.089832	0.007548	-0.010001	0.075240	0.064977	-0.172851	0.220755	0.064977	-0.172851	0.220755
	5	0.018823	0.090102	0.128336	0.018118	-0.023649	0.116569	0.000162	-0.001724	0.011036	0.000160	-0.001057	0.010970
	6	0.014574	0.080621	0.112927	0.014905	-0.022215	0.105729	0.000119	0.001078	0.009434	0.000114	-0.000206	0.009247
Whole fruir	Without pre-treatment	0.003760	0.042513	0.059488	0.003991	-0.018423	0.059341	0.001099	0.014106	0.031255	0.000833	0.006893	0.027115
	With pre-treatment	0.022067	0.104129	0.140052	0.022519	-0.021563	0.132343	0.039269	-0.129696	0.174764	0.039269	-0.129696	0.174764

Table 3. Values of chi-square (x^2), mean bias error (MBE) and root mean square error (RMSE) for all models of oven temperature (110°C)

Lemon Samples	Lemon samples	Newten model			Hendrson model			Page model			Modified page model		
		X^2	MBE	RMSE	X^2	MBE	RMSE	X^2	MBE	RMSE	X^2	MBE	RMSE
	4	0.014023	0.075066	0.108102	0.022440	-0.023755	0.109046	0.000136	-0.001570	0.008232	0.000134	-0.000858	0.009443
	5	0.006913	0.056449	0.076975	0.011154	-0.023862	0.089257	0.000380	0.000208	0.016483	0.000385	0.001034	0.016573
Slices thickness, mm	6	0.006689	0.050228	0.075721	0.007642	-0.010761	0.073882	0.000446	0.000098	0.017849	0.000444	-0.000461	0.017809
	Without pretreatment	0.020513	0.094680	0.133973	0.025902	-0.033929	0.139379	0.000029	-0.000462	0.004650	0.000029	-0.000267	0.004648
Whole fruir	With pretreatment	0.020742	0.099916	0.135785	0.020003	-0.036767	0.124733	0.000061	-0.001627	0.006904	0.000057	-0.000423	0.006664

Conclusions

Depending on the above results, the following are the conclusions

The reduction in moisture ratio of whole fruit of lemon and lemon slices was varied with the experimental treatments.it increased with the increase of oven temperature. The drying constant (k) of Newten increased with the increase of oven temperature. The drying constant (kp) Henderson and Pabis's decreased with the increase of oven Temperature at all samples but it increased with the increase of oven temperature at whole fruit. All studied models could describe the drying behavior of whole lemon fruits and slices satisfactorily. However, the Newten's model and Henderson and Pabis's considered more proper for describing the drying behavior and predicting the changes in moisture content of both forms of lemons. This due to the higher values of coefficient of determination R2 and the lower levels of standard error. Also, the more simplicity of this model application in comparison with the Page and Modified page models. The dried sliced lemon at (th) 6 mm of ven showed higher citric acid percentage. The oven temperature of 110°C recorded the highest percentage of citric acid (5.57%) for whole dried lemons, (5.84%) for the sliced lemon and (6.21%) for whole lemon fruit with pretreatment.

The oven temperature of 110°C recorded the highest percentage of ascorbic acid (43.67 mg/100g) for whole dried lemons, (43.98 mg/ 100g) for the sliced lemon and (44.98 mg/ 100g). The total soluble sugar of the oven was ranged from 6.16 to 6.24% for the whole lemon fruit, from 5.09 to 6.32% for the sliced lemon and from 6.40 to 6.80% for whole with pretreatment. The percentage of total crude fats of the oven ranged from 1.512 to 1.540% for the whole lemon, from 1.093 to 1.571% for sliced lemon and from 1.599 to 1.622% for whole fruit with pretreatment. However, no obvious trends were observed for the changes in the crude fats percentage with the studied treatments. The results showed that the higher of the temperature in the oven, the higher of the quality characteristics.

Recommendations

- The best level of oven temperature tothe process of drying for the whole lemon fruit and slices is 110̊ C for the electric oven where the best results obtained.
- Page and Modified page models considered more proper for describing the drying behavior and predicting the changes in moisture content of both forms of lemons.

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دراســات هندســية علي تجفيف ثمار الليمون بالفرن الكهربائي

سارة عصام نصر ـ مني محمود عبد العزيز ـ تغريد حبشي احمد

قسم الهندسة الزراعية ـ كلية الزراعة – جامعة الزقازيق – مصر

تهدف الدراسة الحالية إلى تقييم سلوك التجفيف باستخدام مجفف الفرن الكهربائي لتجفيف ثمار الليمون وذلك باستخدام النماذج الرياضية للطبقات الرقيقة. لذا تم فحص ومحاكاة سلوك التجفيف باستخدام أربعة نماذج رياضية مختلفة لتجفيف الطبقة الرقيقة (Newten, Page, Modified Page Henderson and Pabis's equations). أجريت التجارب العملية على مستويين مختلفين من درجة حرارة الفرن (80 و 110 درجة مئوية) ، وذلك باستخدام ثمرة الليمون الكاملة، والثمرة الكاملة مع معاملة مسبقة بواسطة حمض هيدروكسيد الصوديوم تركيز1% (NaOH1%) وثلاثة سماكات مختلفة (4، 5 ، 6 ملم). تم تسجيل التغيرات في محتوى رطوبة الليمون مع زمن التجفيف حتى الوصول إلى محتوى رطوبة (14.28 و 8.10)% (علي اساس جاف) للثمرة الكاملة دون معاملة مسبقة عند (80 و 110 درجة مئوية) ، بينما (14.15 ، 12.86 و 14.15) لشرائح الليمون 4 و 5 و 6 مم عند 80 درجة مئوية و (12.86 و 14.15 و 16.82)% (علي اساس جاف) عند 110 درجة مئوية تقريبًا كمستوى مماثل للعينة التجارية للعينات المجففة. سجلت ثمار الليمون الكاملة مع المعاملة المسبقة نسبًا أعلى من إجمالي الدهون الخام (من 1.599 إلى 1.622%)، وإجمالي السكر الذائب (من 6.40 إلى 6.80%)، وحمض الستريك (من 5.95 إلى 6.21%) وحمض الأسكوربيك (فيتامين ج) (من 44.21 إلى 44.98 مجم/100 جم) مقارنة بالليمون الكامل بدون معالجة مسبقة وشرائح الليمون. وأخيرا، يمكن لجميع النماذج المدروسة أن تصف سلوك تجفيف ثمار الليمون الكاملة وشرائحها بشكل مرضي. ومع ذلك ، اعتبرت نماذج Page وModified page اكثر النماذج المستخدمة ملاءمة لوصف سلوك التجفيف والتنبؤ بالتغيرات في محتوى الرطوبة لكلا الشكلين من الليمون بسبب القيم الأعلى لمعامل التحديد (R^2 = 0.9896).

المحكمون :

1- أ.د. طــه حســن مختــار أستاذ هندسة النظم الحيوية ـ كلية الزراعة ـ جامعة بنها.

2- أ.د. محمود مصطفي علي أستاذ الهندسة الزراعية ـ كلية الزراعة ـ جامعة الزقازيق.