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COMPUTER SIMULATION OF THIN LAYER DRYING OF TOMATO (LYCOPERSICON ESCULENTUM L.) SLICES

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Abstract:

Solar drying experiments in thin-layer of tomato slices were conducted at Shambat, Faculty of Agriculture, University of Khartoum, Sudan. The objectives were to test the performance of an indirect forced convective solar dryer, to determine the drying characteristics of tomato slices in winter season and to build a computer mathematical model based on Lewis and Page drying models to simulate thin-layer solar drying of tomato slices. Temperature and relative humidity measurements of ambient air, the inlet, outlet of solar collector and weight of tomato slices were recorded at intervals of one hour. Results indicated that the air inside the solar was heated adequately. The thin-layer solar drying of tomato slices showed that the drying characteristics of tomato slices such as moisture content, moisture ratio and drying rate decreased with increase of the drying time; the drying process took place during the falling rate period. The simulation model predicted the moisture contents of the thin-layer solar drying of tomato slices adequately, but Page model gave closer agreement between measured and predicted data. Statistical validation for the models showed that the coefficient of determination (R^2) was 0.99 and 0.97 for Page and Lewis models, respectively. Root mean square error (RMSE) and Model efficiency (ME) were 0.00004 and 99% respectively for Page model and 0.031 and 97% respectively for Lewis model.

Key words: *Lycopersicon esculentum* L., Thin layer drying, Mathematical model.

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INTRODUCTION

The postharvest loss in vegetables has been estimated to be about 30-40% due to inadequate postharvest handling, lack of infrastructure, processing, marketing and storage facilities (Karim and Hawlader, 2005). Drying of agricultural products may be one of the most important unit operations for the preservation of food materials (Rajput, 2005 and Sacilik *et al*., 2006). Diminishing reserves of fossil fuels and increased costs have led to a search for alternative energy sources including solar energy for drying agricultural products (Basunia and Abe, 2001; Pangavhane *et al*., 2002; Sacilik *et al*. 2006; Steinfeld and Segal, 1986 and Yadliz *et al*. 2001). Open-sun drying used to be an appropriate means in many urban and rural areas, but this conventional method cannot protect food materials from rain, dust, the attack by insects, birds and other animals. Therefore, it may increase the loss of products and have some adverse economic impacts on them (Pangavhane *et al*., 2002). Solar drying is a well-known food preservation procedure used to reduce the moisture content of agricultural products, which reduces quality degradation over an extended storage period (Midilli *et al*., 2002).

Tomato (*Lycopersicon esculentum* L.) is one of the most important fruits/vegetables grown in a wide range of climates, mostly in open-field but also under protection in plastic green houses and heated glass houses. It is a commercially important crop both for fresh fruit market and for the food processing industries. The annual worldwide production of tomatoes has been estimated at 125 million tons in an area of about 4.2 million hectares. The global production of tomatoes (fresh and processed) has been increased by 300% in the last four decades (FAO, 2005) and the leading tomato producers are in both tropical and temperate regions.

The thin layer drying procedure has been found to be the most appropriate tool for characterizing the drying parameters (Akgun and Doymaz 2005; Akpinar *et al*., 2003a and Akpinar *et al*., 2003b). Currently, there are three types of thin layer drying models to describe the drying rate of agricultural products, namely, theoretical, semi-theoretical and empirical models (Demirats *et al*., 1998 and Midilli *et al*., 2002). The theoretical approach concerns either the diffusion equation or simultaneous heat and mass transfer equations. The empirical model neglects the fundamentals of drying processes and presents a direct relationship between average moisture and drying time by means of regression analysis (Ozdemir and Devres 1999). Also, the semi-theoretical model is a trade-off between the theoretical and empirical ones, derived from a widely used simplification of Fick's second law of diffusion or modification of the simplified model, such as the Lewis model, the Page model and the Modified Page model (Table 1).

Table 1. Lewis, Page and Modified Page models

Model name	Model equation
Lewis	$MR = \exp(-kt)$
Page	$MR = \exp(-kt^n)$
Modified Page	$MR = \exp(-kt)^n$

where:

MR = is the moisture ratio (dimensionless)

t = is the dried time (min.)

k and n = constants.

MATERIALS AND METHODS

Solar drying experiments were carried out at Shambat, Department of Agricultural Engineering, Faculty of Agriculture, University of Khartoum, during December 2013 – January 2014. Thin-layer drying experiments were conducted to generate constants required for model validation in winter season under Shambat conditions (Sudan). The tomato slices (5 cm thickness) were placed in the drying chamber of the solar dryer and periodically weighed using a sensitive balance at hourly intervals from 8:30 am till 17:30 pm to determine the weight loss.

Also, dry bulb temperatures (^oC) and Relative humidity (%) at the inlet, outlet of solar collector, ambient air and drying chamber were measured and recorded by the thermohygrometer. Drying process was continued for three days until the sample reached constant weight.

Construction of solar collector

The forced convective solar dryer used in this study was previously constructed for a research work. The solar dryer consists of a solar collector and a drying chamber. The solar collector consists of two boxes. The first box was 100 cm × 100 cm × 20 cm and it was made of wooden sides. It consists of a metal-plate base painted in non-shine black paint so as to absorb maximum solar radiation. A glass sheet (100 cm × 100 cm × 0.3 cm) was used to cover the box in order to minimize the loss of heat energy collected and to improve the solar dryer efficiency. The glass sheet was fixed tightly to the top of the solar collector by a silicon rubber, which allows the glass sheet to expand and contract due to the temperature fluctuations. The first box was placed inside a second box made of a metal frame and the sides were covered with wooden board. The second box had the same shape of the first box, but larger in dimension (114 cm ×114 cm× 25 cm); the gap between the two boxes was filled with fiber glass as insulation layer, so as to minimize the heat losses to the surrounding. All outsides of the outer box were painted in black in order to prevent the reflection of solar radiation. The drying chamber was attached to the upper opening of the solar collector by tube. It consisted of two cylinders. The out cylinder was 22 cm in diameter and 35 cm in height and it was welded at the bottom to that tube comes from the solar collector out let. The inner cylinder was 25 cm in diameter and 25 cm in height; it was movable and it had a detachable perforated base for the ease of taking the measurement. The two cylinders were designed to have a gap between their bases so as to guarantee uniform distribution of the hot air through the material to be dried .The solar collector was oriented to south and tilted to form an angle 15^{o} with ground surface

RESULTS AND DISCUSSION

Drying conditions of the solar dryer

Fig 1 showed temperatures of ambient air, inlet and outlet of solar collector and drying chamber of solar dryer for three successive days of the drying process of tomato slices. The four temperatures start to increase from the morning, reach the maximum at the noon and then decrease in the evening. From the Fig 1 it is clear that outlet of solar collector (heated air) and ambient air temperatures are close to each other at 8:30. The average difference between heated air and ambient air temperature is about 5.03^{o}C at 8:30 a.m. The maximum average different is 28.1^{o}C at noon (13:30) p.m. There is still average different temperature of 9.8^{o}C between heated air and ambient air temperature at 17:30 p.m. This shows that, the drying air heated by the solar collector satisfactorily in order to increase its capacity for picking up moisture. This is in agreement with the result of Ayoub (2006) and Ibn Idris (2007). Fig 2 shows the ambient air, inlet and outlet of solar collector relative humidity over the three days of drying process of tomato slices. The relative humidity has a zigzag shape and fluctuates during the day hours of the drying process. All air relative humidity start to decrease from the morning reaching minimum at the noon then increase towards evening. The maximum attained relative humidity difference between average ambient and outlet of the solar collector air relative humidity is 10.2%. This also confirms that, the drying air is heated by the solar collector satisfactory in order to increase its capacity for taking up moisture. This is also in agreement with the result of Ayoub (2006) and Ibn Idris (2007).

Fig 3 shows temperature and relative humidity of the heated air. As shown in the figure as average temperature of heated air increases its average relative humidity decreases and vice versa. Generally, the two curves converge at morning diverge at noon and then converge again at evening. This could be due to fact that at noon, the solar collector had absorbed sufficient heat, which resulted in raising the temperature of the drying air. In addition, if the temperature of the air increases, while its absolute humidity (moisture content of air) is constant, its relative humidity will decrease. This finding agrees with that Ayoub (2006) in the drying of tomato.

Drying characteristics of tomato slices

Figures 4 and 5 show the drying curves of tomato slices and they were obtained by plotting moisture content versus drying time and moisture ratio versus drying time respectively. From these curves it is clear that the drying process take place in the falling rate period .This result is in agreement with finding of Ayoub (2006). Also, it is clear that at the end of the first day and continuing through the second and third days of the drying process an equilibrium state, regarding drying of tomato slices, was attained.

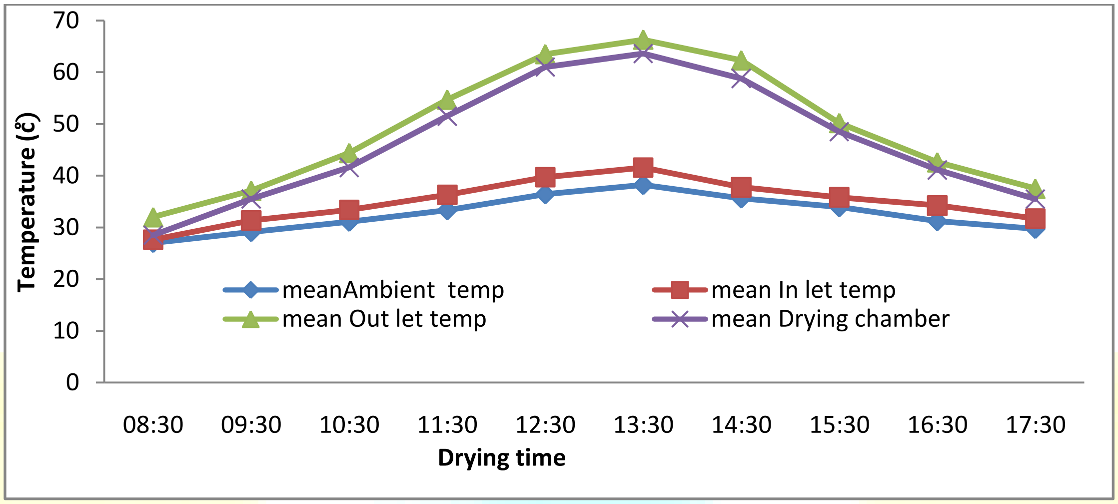

Fig 1. Mean inlet, outlet of solar collector, ambient and drying chamber temperatures

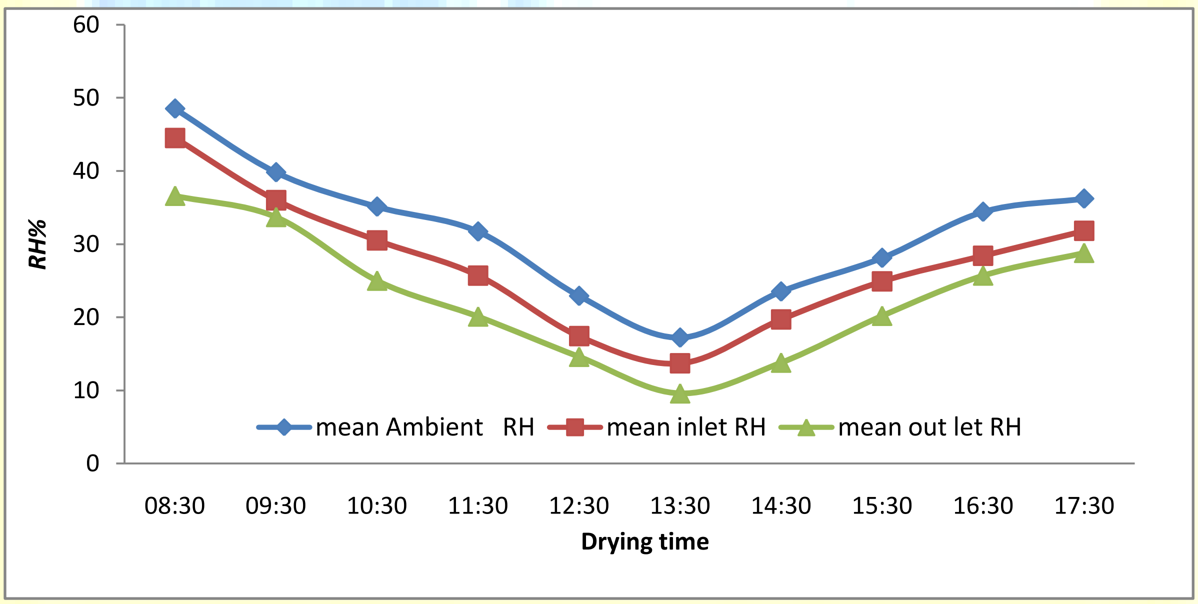

Fig 2. Mean inlet, outlet and ambient relative humidity of heated air

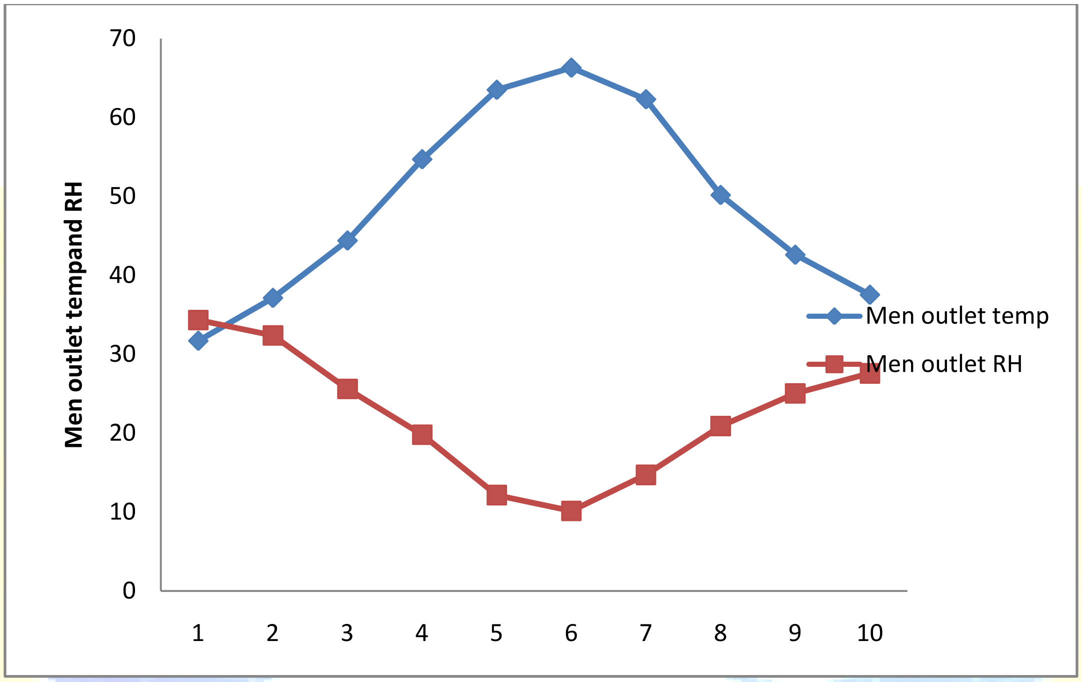

Fig 3. Heated air temperature and relative humidity versus drying time

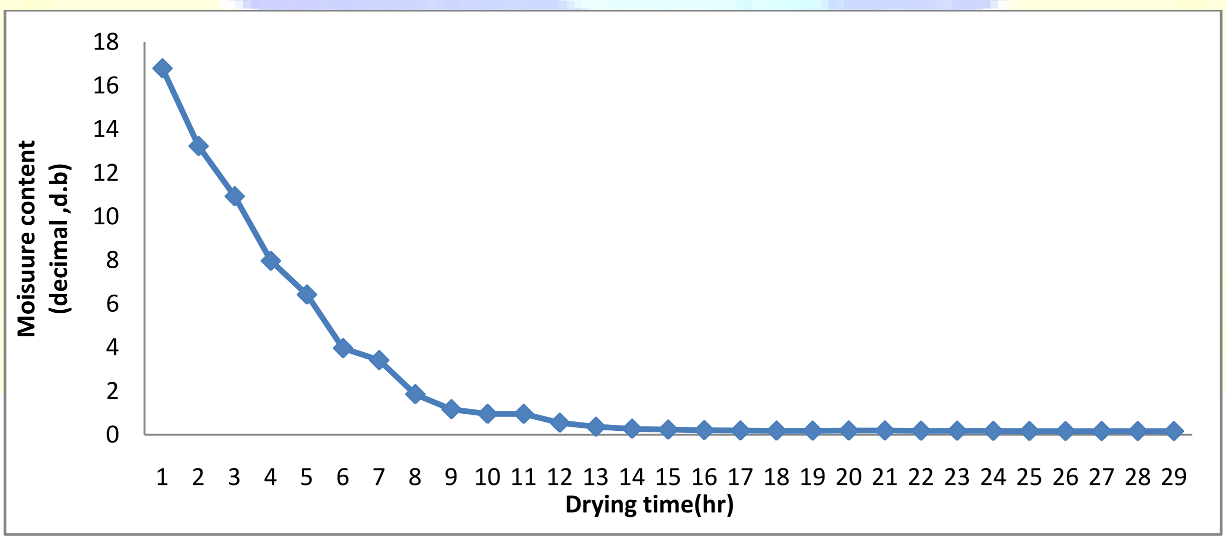

Fig 4. Variation of moisture content with drying time of tomato slices

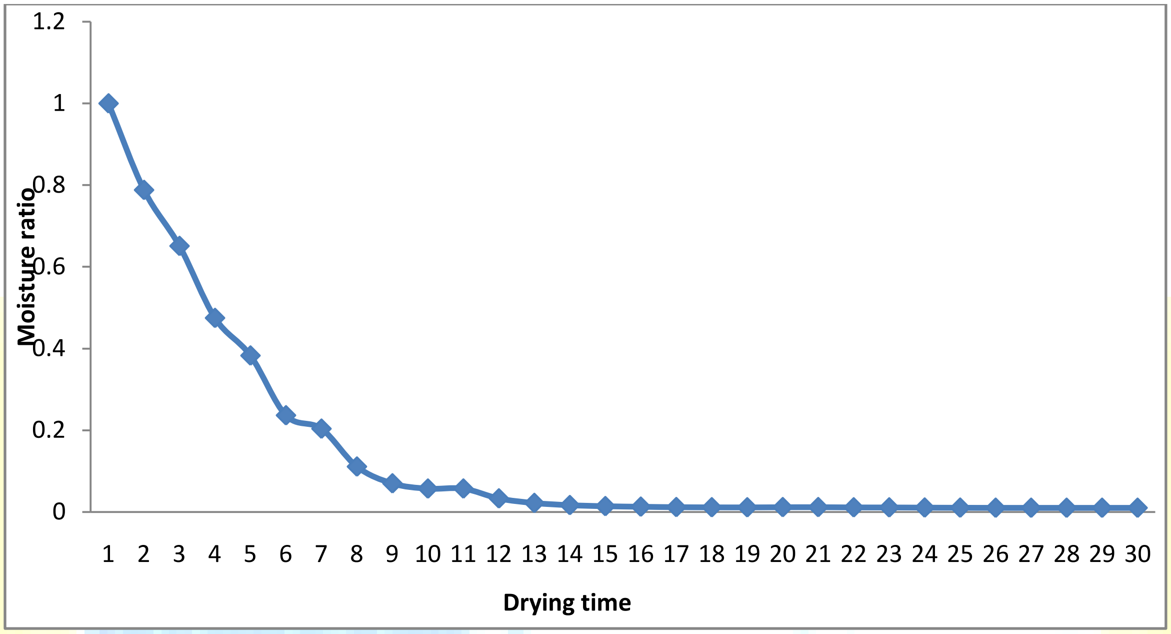

Fig 5. Variation of moisture ratio with drying time tomato

Validation of the two tested drying models

The drying constants for the two tested drying models namely; Page and Lewis models addition to the exponent (n) in Page model were obtained using data transformation and linear regression techniques as shown Figures 6 and 7, respectively. Table 2 shows the drying constant and coefficient of two tested drying models. Computer program output of the predicted tomato moisture contents and moisture ratio of a Thin-layer drying of tomato slices of Page and Lewis models are shown Table 4.

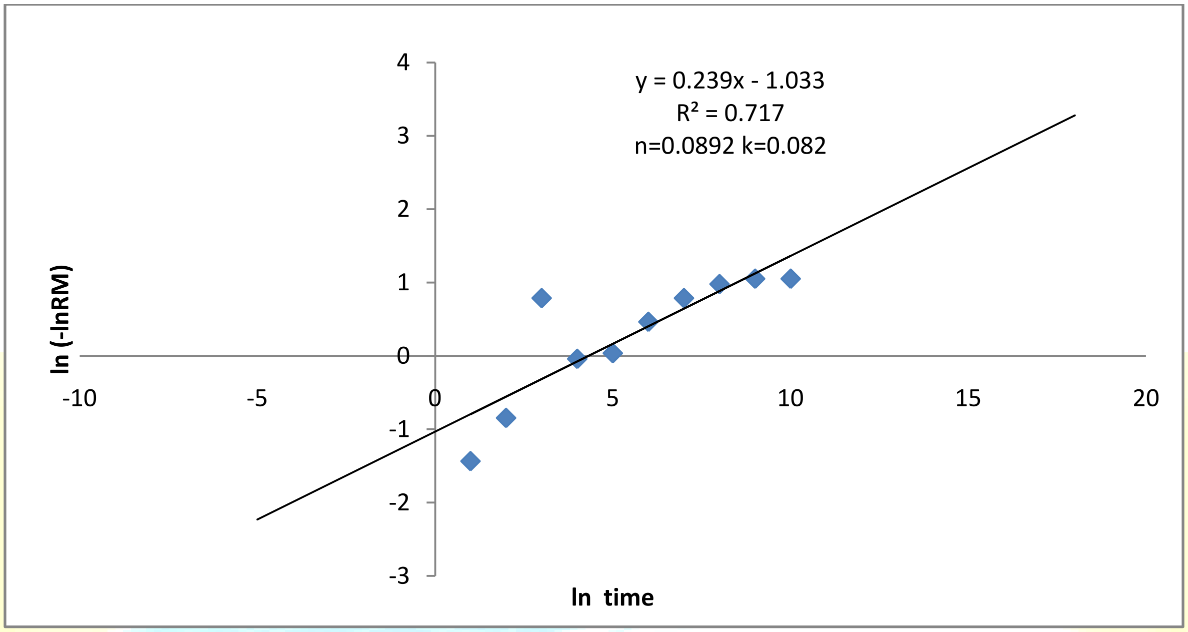

Fig 6. Calculation of the coefficient for Page model

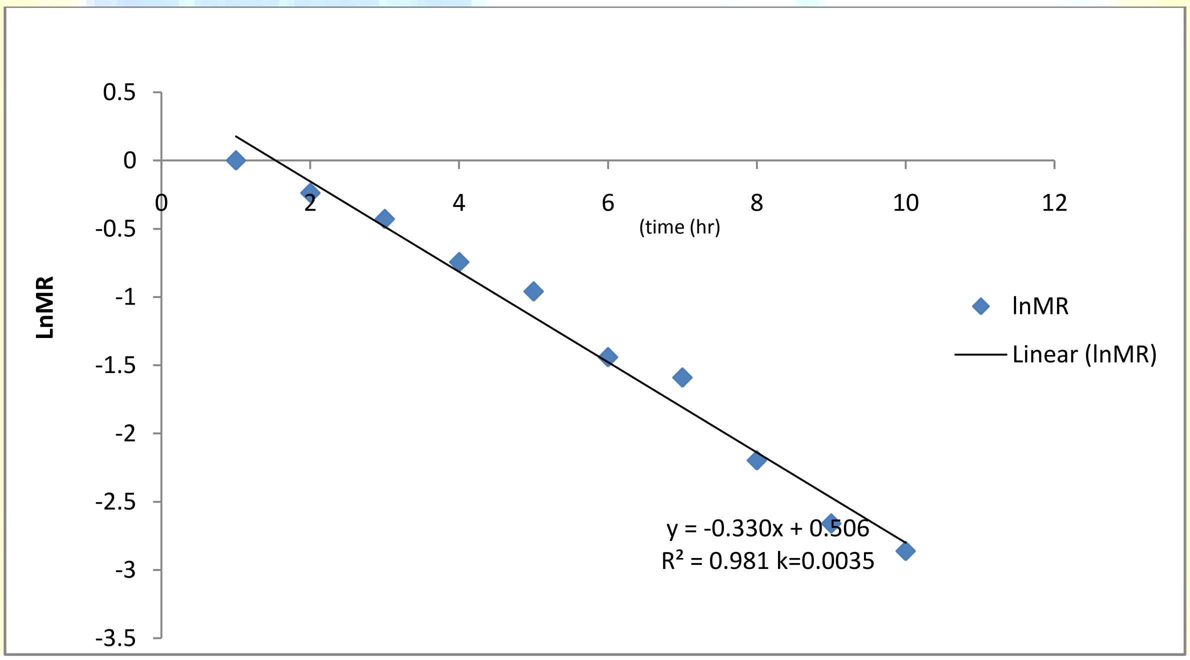

Fig 7. Calculation of the coefficient for Lewis model

Table 2. The drying constants and coefficients of the two tested drying models

Drying model name	Drying constants and coefficients
Lewis	K = 0.0035
Page	K = 0.0082 n = 0.0892

Graphical validation of the two drying models

Fig 8 shows the measured and predicted moisture contents of Thin-layer of tomato slices by the two drying models. Generally, the two models predicted tomato slices moisture ratio and moisture content satisfactorily but Page model gave a close agreement between measured and predicted data

Tomato quality

Plate 1 shows the difference in color and general appearance between the sun dried and solar dried tomato slices. As shows the color of the tomato slices indicates its Lycopene content. General appearance of the solar dried tomato slices seems more bright and clean and slices preserved their natural color drying. Ayoub (2006) concluded that when tomato dried by direct sun drying the resulting product is often insect-infested and sand covered all this lead to clean dried.

(a)

(b)

Plate 1. Comparison between (a) open-air dried tomato slices (5mm) and (b) solar dried tomato slices (5mm)

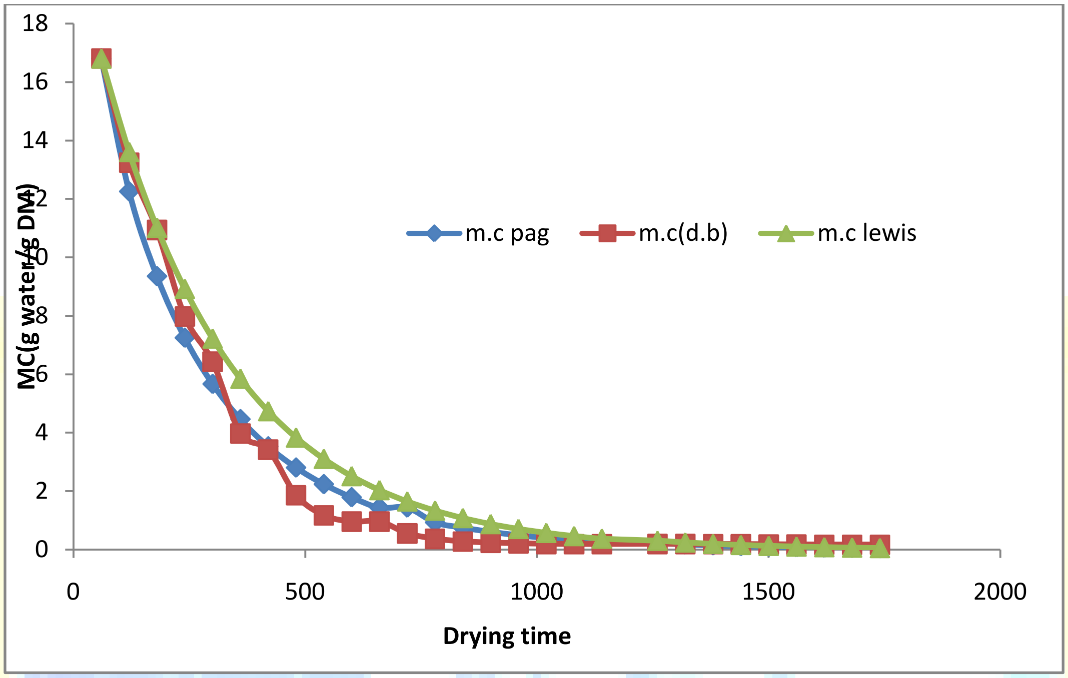

Fig 8. Measured and predicted moisture content of tomato

Statistical analysis

Figures 9 and 10 show the plotting of predicted moisture ratio versus experimental one of Lewis and Page models, respectively. Its clear that Page model gave the highest R^2 (0.99). Table 3 depicts the statistical validation parameters concerning both Page and Lewis drying models. With regard to Page model; the root mean square errors (RMSE), determination coefficient (R^2) and model efficiency (ME) are 0.0004, 0.99 and 99%, respectively. While for Lewis model the parameter is 0.031, 0.97 and 95%, respectively. These values show that the two tested drying models predicted of tomato slices moisture ratio and moisture contents accurately but Page prediction is in close agreement with measured data. The ME and R^2 of the Page model was higher than that obtained from Lewis and tends to be one. The RMSE were lower for the Page model than that obtained from Lewis model tend to be zero.

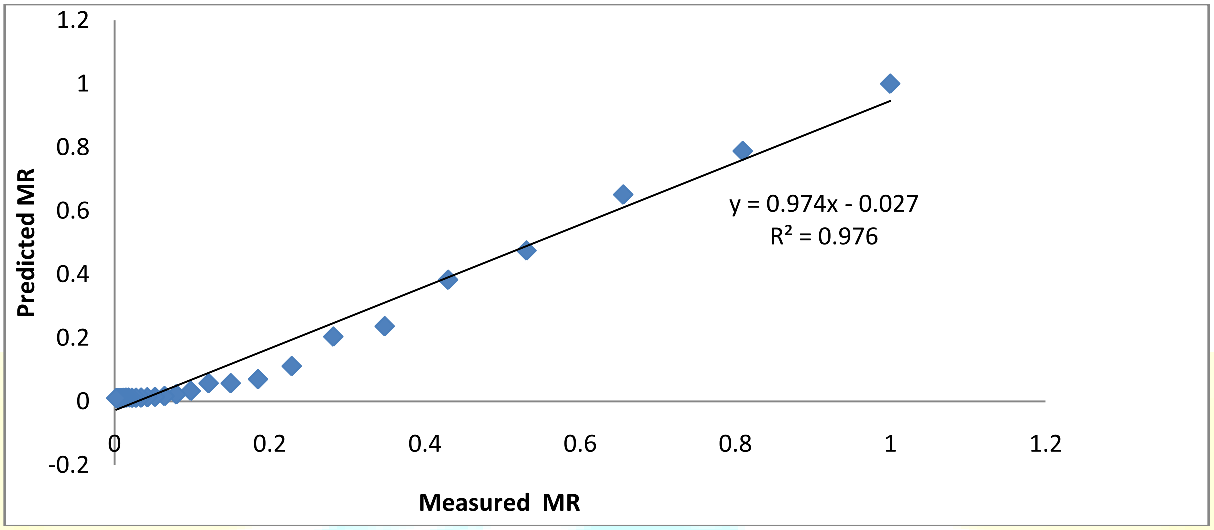

Fig 7 Lewis model predicted MR versus measured MR

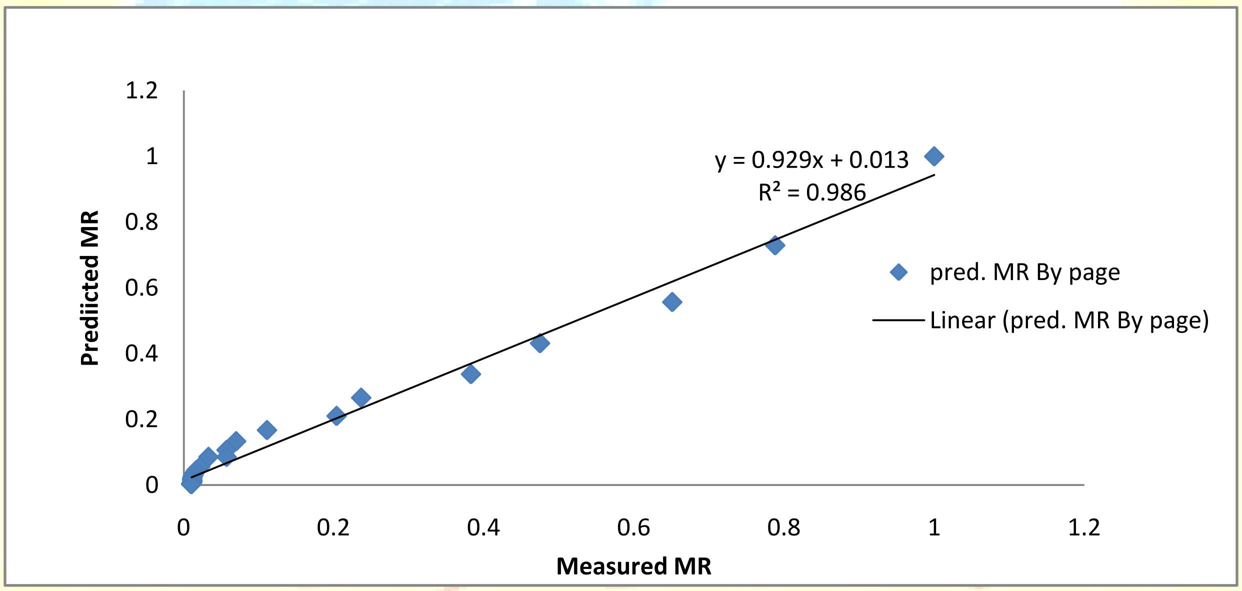

Fig 8 Page model predicted MR versus measured MR

Table 3. Determination coefficient, root mean square error and model efficiency of estimate between measured and predicted moisture ratio

Statistical parameters / Model name	Determination coefficient(□□)	Root mean square error and model	Model efficiency %
Page	0.99	0.0004	99
Lewis	0.97	0.03	95

Table 4. Computer output of the predicted tomato moisture contents and moisture ratio of a Thin-layer drying of tomato slices of Page and Lewis models

Time (min)	Measured MR	pred. MR By Lewis	pred. MR By Page	Measured m.c	Pred. m.c by Pages model	Pred. m.c by Lewis model
0	1	1	1	16.8	16.8	16.8
60	0.78811	0.809814525	0.729253353	13.2379	12.2515	13.60488
120	0.651004	0.655799564	0.556648618	10.9349	9.351697	11.01743
180	0.474835	0.531076012	0.431280354	7.97578	7.24551	8.922077
240	0.382817	0.430073068	0.337244379	6.43015	5.665706	7.225228
300	0.236515	0.348279417	0.265468747	3.97274	4.459875	5.851094
360	0.203774	0.282041731	0.210050512	3.42278	3.528849	4.738301
420	0.111039	0.22840149	0.166901862	1.86512	2.803951	3.837145
480	0.069923	0.184962844	0.133087277	1.1745	2.235866	3.107376
540	0.057138	0.149785598	0.10644788	0.95974	1.788324	2.516398
600	0.057167	0.121298553	0.085368904	0.96022	1.434198	2.037816
660	0.033076	0.09822933	0.085368904	0.55557	1.434198	1.650253
720	0.021981	0.079547538	0.055286884	0.36921	0.92882	1.336399
780	0.01671	0.064418752	0.044626437	0.28067	0.749724	1.082235
840	0.01414	0.052167241	0.036085652	0.23751	0.606239	0.87641
900	0.012846	0.042245789	0.029227262	0.21577	0.491018	0.709729
960	0.011764	0.034211254	0.023708305	0.19759	0.3983	0.574749
1020	0.01142	0.02770477	0.019258662	0.19182	0.323546	0.46544
1080	0.011248	0.022435725	0.015664809	0.18893	0.263169	0.37692
1140	0.01164	0.018168776	0.012757401	0.19551	0.214324	0.305235
1200	0.011712	0.014713339	0.010401742	0.19672	0.174749	0.247184
1260	0.011206	0.011915076	0.008490412	0.18822	0.142639	0.200173
1320	0.011073	0.009649001	0.006937531	0.186	0.116551	0.162103
1380	0.010685	0.007813901	0.005674295	0.17947	0.095328	0.131274
1440	0.010398	0.006327811	0.004645461	0.17466	0.078044	0.106307
1500	0.010198	0.005124353	0.003806597	0.1713	0.063951	0.086089
1560	0.010169	0.004149776	0.003121899	0.17081	0.052448	0.069716
1620	0.01016	0.003360549	0.002562469	0.17065	0.043049	0.056457
1680	0.01016	0.002721421	0.002562469	0.17065	0.043049	0.04572
1740	0.01016	0.002203846	0.002104949	0.17065	0.035363	0.037025

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