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Mathematical Modeling of Tilapia Fish Fillets Dried in Thin Layer

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ABSTRACT

This work aimed to evaluate using hot air for drying of fresh tilapia fillets. Effect of the drying temperature (40, 50, 60, and 70°C) on the moisture ratio and drying rate has been investigated. A constant level of air flow rate of 0.087 $m^3 s^{-1}$ was used and constant dimensions for tilapia fillets of 80 x 30 x 5 mm of length, width and thickness respectively. Seven different widely used thin layer drying models were fitted to the experimental drying data of fresh tilapia fillets under different conditions using nonlinear fitting techniques. Four statistical parameters, including coefficient of determination, standard error, reduced chi-square, and root mean square error, were used to compare all models. The obtained results showed that the drying process took place in falling rate periods. The result also showed that average value of determination coefficient in exponential linear combination model was 0.9988, and standard error, root mean square error and corresponding reduced chi-square values were 0.106, 0.0096 and 0.0001, respectively, which indicated that "exponential linear combination model" is the best of studied models for describing drying curves of fresh tilapia fillets. Meanwhile, effective moisture diffusivity D_{eff} increased by increasing drying air temperature and its value ranged from 3.47 to 6.86 10^{-10} $m^2 s^{-1}$, whereas drying activation energy value was 20.148 kJ/mol for the studied levels of air temperature.

Keywords: Tilapia fillets drying, thin layer drying, mathematical modeling, moisture diffusivity, activation energy.

INTRODUCTION

Tilapia, *Oreochromis* and *Sarotherodon* are three species and genera of fish in the family *Cichlidae* that go by the common name "tilapia.". These species, which are native to the Middle East and Africa, have spread around the world and are now the second most important fish species for human consumption. (Watanabe et al., 2002).

Due to the enormous growth of tilapia culture around the world, particularly in Egypt, which gets the third order in the world for tilapia production after China and Indonesia, tilapia is an important species in freshwater aquaculture. According to FAO (2020), more than 1.17 million ton of tilapia fish were produced in Egypt in 2018, accounting for more than 17.04% of global production.

Guan et al., (2013) mentioned that tilapias have numerous qualities that make them suitable for aquaculture, including their ease of reproduction, quick growth, familiarity with wide range of environmental conditions, and acceptance of artificial feeding. They are broadly utilized in a range of dishes, have good tasting meat with flavor, and are well recognized as fishy foods.

When fresh fish is not utilized by consumers and processed into other product then it stays in excess and is wasted (Jain, 2006 and Jain and Pathare, 2007).

Duan et al., 2005; Li et al., 2009 mentioned that Since tilapia is considered a perishable product because it contains a high moisture content of more than 80%, in addition to the low quantities used in the manufacturing processes, it was necessary to carry out conservation operations to preserve it from the problems resulting from the bacterial and enzymatic activity in fresh fish

The process of preserving fish is one of the important and necessary processes due to its easily spoilage. The process of preserving fish by drying is one of the most effective and widespread methods used, as it allows obtaining a high-quality dried product in terms of sensory qualities and nutritional value, in addition to prolonging the period of safe storage of the dried product (Shitanda & Wanjala, 2006).

Heat and mass transition are both processes that happen at the same time during the drying process of moist materials. The drying process of agricultural products is typically described using thin layer drying models based on the theory of liquid diffusion, and may be clarified by the second law of Fick (Doungporn *et al.*, 2012). Several agricultural products' drying dynamics and behaviour models have been published. (Figiel, 2007; Czopek *et al.*, 2007; Zaremba and Jaros, 2007; Orikasa *et al.*, 2008; Galvez *et al.*, 2009; Doymaz and Ismail, 2011; Akintunde and Ogunlakin, 2011; Doymaz, 2012)

The heated air drying of tilapia fillets was studied by Guan *et al.*, (2013) using a heat pump dryer at different drying temperatures ranging from 35 to 55°C, hot air speeds in the range of (1.50 to 3.50 m s^{-1}) and three different thicknesses ranging from 3 to 7 mm of tilapia fillets. They found that the drying process happened in the falling rate periods. They also examined nine thin layer drying models for describing drying curves of tilapia fillets and all studied models were compared according to statistical parameters. In accordance with the greatest R^2 value and the lowest corresponding reduced chi-square and RMSE values, they concluded that the Page's model is the most efficient among the examined models for explaining drying curves of tilapia fillets. They also found that the effective moisture diffusivity increased by increasing of

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the drying temperature and the hot air speed. The values of moisture diffusivity were in the range of (6.55×10^{-10} to 1.23×10^{-9}) $m^2 s^{-1}$ and the activation energy was 17.66 kJ/mol.

The effect of hot air-microwave heating on the drying and quality of fresh tilapia fish fillets was investigated by Duan *et al.*, (2011). Laboratory experiments were conducted at three microwave power levels of (200, 400, and 600W) after drying with the constant-speed hot air of 1.5 m/s at two different temperatures of (40 and 50 ˚C). The effect of previous drying treatments on rehydration, shrinkage, and recovery properties was studied. The obtained results showed that the higher the microwave power, the lower the final moisture content of the dried tilapia fillets for the same drying period. Also, the higher the temperature of the air used for drying, the higher the drying rate. By increasing the microwave power and the temperature of the air used, the shrinkage rate and the rehydration ratio increase, while the recovery rate decreases. The lower the air temperature and the microwave power, the higher the quality characteristics of the dried tilapia fillets can be obtained.

This work aims to test the effect of different levels of hot air temperatures on drying process of tilapia fillets in hot air dryer, and to evaluate seven different models for describing drying behavior of tilapia fillets and to calculate activation energy and effective diffusivity under the studied conditions.

MATERIALS AND METHODS

The laboratory dryer:

Drying experiments were conducted using a thin-layer hot air dryer at the Department of Agricultural Engineering, Faculty of Agriculture, Mansoura University as shown in figure (1). It is noted that air is supplied with a centrifugal fan (1.3 kW) that supplies air to the dryer at a regular rate, then air passes through heating unit that contains air heaters of capacity (6.0 kW) to raise air temperature to the required level and air temperature is controlled via a thermostat. The heated air is then passed through an insulated metal tube and into drying chamber which contains a drying tray with a perforated base of 270 mm diameter containing sample to be dried. A detailed description of the dryer has been given by (Matouk *et al.*, 2001).

Preparation of fresh fish samples:

Fresh tilapia fish (*Oreochromis niloticus*) were bought from a fish market in New Damietta, Damietta governorate, Egypt. Fresh fish were transported to the laboratory using a cork box containing ice. Fish were cleaned, the head, skin, and intestines were removed, then cut into fillets with the size of 80× 30× 5 mm for length, width and thickness respectively. The fillets were washed with tap water and then placed in a single layer inside a tray made of stainless steel wire mesh for the drying process. The initial moisture content of tilapia fillets was 395.22% (d.b.).

Experimental methodology:

Drying experiments were conducted at different heated air temperatures of 40 °C,50 °C, 60°C and 70°C, at constant air flow rate of 0.087 $m^3 s^{-1}$ with fillet thickness of 5 mm. The mass of the sample was measured at 10 minute intervals for the first two hours then at 20 minute intervals to the end of the experiment. For each laboratory experiment, the drying experiment is continued until a final moisture content of 7% is reached. Each run in the experiment was conducted in three replicates.

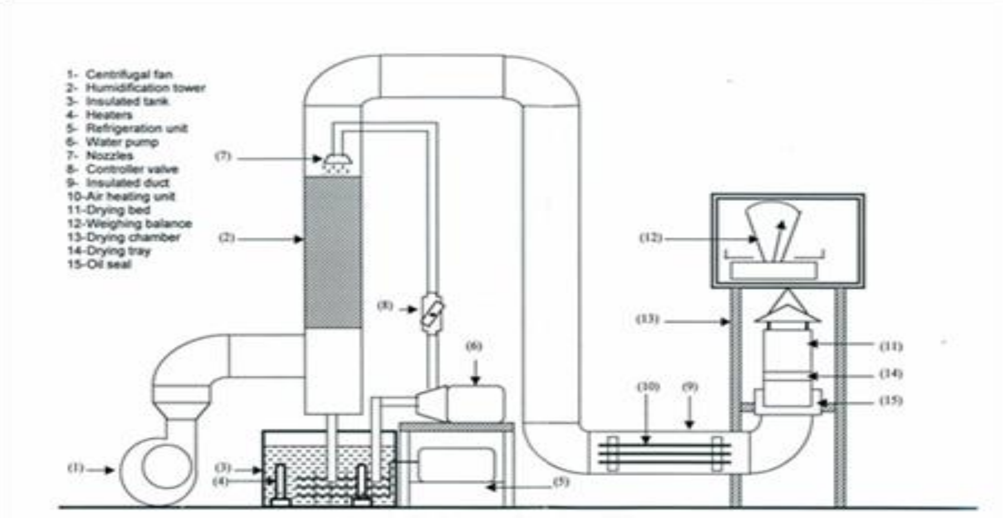

Figure 1. Schematic diagram of the hot air drier.

Measurements:

An electric oven (Binder, max 300ºC) was used to assess the test sample's moisture content at 105°C for drying until constant weight according to (AOAC, 2005).

For measuring the mass loss during the experiments, the sample is taken out of dryer at regular time intervals, to quickly find its mass, and then returned to the dryer.

Instrumentations:

An electric lab oven (Binder, max 300ºC) used for estimating the initial moisture content (IMC) of fresh tilapia fillets. A 200 ± 0.01 g capacity digital balance (AND EK-200GD) was used for massing tilapia fillets mass during the initial moisture content determination. Nevertheless, another digital balance (TR-6101) with (6000 ± 0.1 g) was used during drying experiments. Air velocity and temperature meter (9515, USA) was used for measuring both air flow rate and temperature during experimental work.

Mathematical modeling of tilapia drying curves:

To study the drying behavior of tilapia fillets, it is important to model the drying behaviors effectively. The experimental drying data were fitted to seven thin layer drying models as listed in Table (1).

Table 1. Mathematical models widely used in food drying process.

Model	Expression	Reference
Lewis model	$\mathrm{MR} = \exp^{-k\,t}$	Bruce (1985)
Page model	$\mathrm{MR} = \exp^{-k\,t^{n}}$	Page (1949)
Henderson and Pabis model	$\mathrm{MR} = \mathrm{a}\exp^{-k\,t}$	Henderson and Pabis (1961)
Logarithmic model	$\mathrm{MR} = \mathrm{a}\exp^{-k\,t} + c$	Togrul and Pehlivan (2002)
Two-term model	$\mathrm{MR} = \mathrm{a}\exp^{-k_0\,t} + \mathrm{b}\exp^{-k_1\,t}$	Henderson (1974)
Wang and Singh model	$\mathrm{MR} = 1 + \mathrm{a\,t} + \mathrm{b}\,t^{2}$	Wang & Singh (1978)
the exponential linear combination model	$\mathrm{MR} = \mathrm{a} + \mathrm{b}\exp^{-k\,t} + \mathrm{c\,t}$	Suggested by author

Moisture ratio calculation (MR):

The following equation may be used for calculating moisture ratio:

$$MR = \frac{M_t - M_f}{M_o - M_f} \qquad (1)$$

Where:

M_t: **moisture content at any time % (d.b.)**
M_o: **initial moisture content % (d.b.)**
M_f: **final moisture content % (d.b.)**

Drying rate calculation (DR):

The following equation may be used to calculate drying rate:

$$DR = \frac{M_i - M_t}{t - i} \qquad (2)$$

Where:

DR: **drying rate of the product, (g/g·min)**
M_i: **moisture content of the product at i % (d.b.)**
i,t: **beginning and end time period, min**

Calculation of effective moisture diffusivity:

Tütüncü and Labuza, (1996) revealed that, the drying properties of biological products during falling rate periods can be described using the Fick diffusion equation, which can be simplified as follows:

$$\ln(\mathrm{MR}) = \frac{8}{\pi^2} - \frac{\pi^2 \, \mathrm{D_{eff}} \, \mathrm{t}}{4\, \mathrm{L_0^2}} \qquad (3)$$

Where:

D_{eff}: **effective moisture diffusivity (m^2s^{-1})**
L_0: **half thickness of slab (m)**

Lomauro et al. (1985) mentioned that moisture diffusion can be calculated by plotting the relation between ln (MR) versus time (t) for obtained laboratory data and from equation (3), the slope of straight line can be obtained and represented by the following relationship:

$$\mathrm{slope} = -\frac{\pi^2 \, \mathrm{D_{eff}}}{4\, \mathrm{L_0^2}} \qquad (4)$$

Activation energy calculations:

The relation between the effective diffusivity D_{eff} and temperature (T) can be described by "an Arrhenius type" relationship (Akgun and Doymaz, 2005) as follows:

$$D_{eff} = D_o \, exp\left(\frac{E_a}{R\,T_a}\right) \qquad (5)$$

Where:

D_o: **the pre-exponential factor of the Arrhenius equation, (m^2s^{-1})**
R: **the universal gas constant, (kJ/mol·K)**
T_a: **the absolute temperature, (K)**
E_a: **activation energy (kJ/mol)**

Slope of a straight line resulting from plotting ln (D_{eff}) against (1/ T_a) represent $-\left(\frac{E_a}{R}\right)$ and activation energy (E_a) could be calculated.

Statistical analysis:

The effectiveness of tested mathematical models fitting experimental data was assessed using the correlation coefficient "R^2," reduced chi-square " χ^2," standard error "SE," and root mean square error "RMSE". It has been accepted that the higher values of "R^2" and the lower values of "χ^2, SE and RMSE", the better is the goodness of fit (Doungporn et al., 2012).

RESULTS AND DISCUSSION

The effect of air temperature on moisture ratio and drying rate:

The effect of the examined air temperature (40, 50, 60 and 70°C) on moisture ratio (MR) is shown in figure (2). It can be seen that the higher hot air temperature leads to a faster drying rate and a shorter drying time, indicated by the fact that drying times to reach the final moisture content of 7% (d.b.) were 520, 480, 400, and 300 minute at 40, 50, 60 and 70°C, respectively. With an increase in the drying air temperature, the rate of moisture transfers from inside the product to the surface layer increases and the rate of moisture evaporation from the surface layer increases and thus the drying rate increases as shown in figure (3).

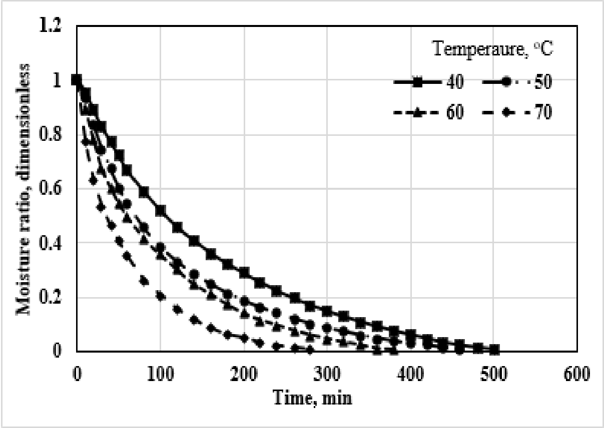

Figure 2. The relation between (MR) and the drying time (t).

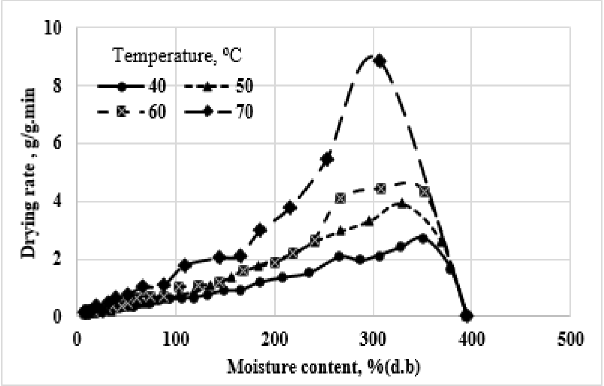

Figure 3. The relation between the Tilapia fillets (MC) and the drying rate (DR).

It can also be noted that the drying process occurred in the falling rate period at all temperature levels except for a very short period at the beginning of the drying process, which took place at the constant rate period, and therefore the internal mass transfer resistance is the main factor controlling the total time of the drying process and the rate of decrease in moisture ratio is lower at the beginning of the experiment compared to the end of the drying period.

The above mentioned results is similar to prior outcomes, as mentioned by Kituu *et al.*, (2010). This is due to the high amount of moisture in the tilapia fillets at first, and it is relatively easy to transfer them to the surface and vaporize.

The times required to remove 50% moisture in the initial period of the drying are 200, 140, 100 and 60 min. at 40, 50, 60 and 70°C, respectively, which are represent 38.5, 29.2, 25.0 and 20.0% of the total time required for drying.

As the drying time proceeded, the amount of water present between the cells decreases significantly, and the bounded moisture transfer becomes more difficult, and the drying process becomes slower.

In the last stages of the drying process, the tilapia fillet fibers shrink, which leads to a significant decrease in the moisture diffusion rate and the drying rate, especially when using high temperatures. Thus, the drying process appears to be controlled by internal diffusion.

Fitting of the drying curves:

Table (2) shows the results of the statistical analysis resulting from fitting moisture content data obtained from drying experiments under different air temperatures on 7 thin layer drying models listed in Table (1)

From the results shown in Table (2), all the tested models were able to describe the drying behavior of tilapia fillets well, except for Wang and Singh model, which had low values of the correlation coefficient R^2 compared to other models. While the average value of R^2 for the exponential linear combination model recorded the highest value of 0.9988, and the average standard error SE, corresponding χ^2 and RMSE values recorded the lowest values of 0.0106, 0.0001 and 0.0096 respectively, a good fit of the data to the exponential linear combination model is indicated.

The following equation shows the relationship between temperature and the value of the constant k in the exponential linear combination model:

$$\boldsymbol{k = 0 \cdot 0021\ \exp(0 \cdot 0349\ T)} \quad \mathbf{R^2 = 0.9751} \qquad \mathbf{(6)}$$

The average values of the constants a, b and c were 0.2120, 0.7842 and 0.0006 respectively.

Table 2. Statistical results for the studied drying models.

Model	T, °c	k				R^2	SE	X^2	RMSE
Lewis	40	0.0075				0.9939	0.0252	0.001511	0.03822
	50	0.0090				0.9970	0.0179	0.000362	0.018679
	60	0.0111				0.9953	0.0226	0.000648	0.02492
	70	0.0164				0.9930	0.0268	0.001429	0.036789
Average						0.9948	0.0231	0.0010	0.0297
		k	a						
Henderson and Pabis	40	0.0066	1.0077			0.9978	0.0154	0.000236	0.014839
	50	0.0089	0.9809			0.9966	0.0182	0.00033	0.017507
	60	0.0102	0.9581			0.9956	0.0206	0.000424	0.019719
	70	0.0165	0.9348			0.9929	0.0253	0.000641	0.023949
Average						0.9957	0.0199	0.0004	0.0190
		k	n						
Page	40	0.0043	1.0878			0.9910	0.1111	0.000408	0.01952
	50	0.0092	0.9954			0.9912	0.1000	0.000362	0.018329
	60	0.0140	0.9515			0.9890	0.1056	0.000405	0.019279
	70	0.0324	0.8636			0.9916	0.0804	0.00024	0.014651
Average						0.9907	0.0993	0.0004	0.0179
		k	a	c					
Logarithmic	40	0.0059	1.0306	-0.0369		0.9990	0.0104	0.000109	0.009883
	50	0.0093	0.9750	0.0134		0.9970	0.0175	0.000307	0.016543
	60	0.0104	0.9563	0.0039		0.9956	0.021	0.000442	0.019659
	70	0.0174	0.9280	0.0158		0.9937	0.0247	0.000609	0.022651
Average						0.9963	0.0184	0.0004	0.0172
		a	k_o	b	K_1				
Two term	40	0.4996	0.0066	0.5081	0.0066	0.9978	0.0159	0.000254	0.014839
	50	0.2138	0.0256	0.8056	0.0076	0.9988	0.0114	0.00013	0.010541
	60	0.1428	0.0555	0.8660	0.0093	0.9984	0.0128	0.000165	0.011729
	70	0.1885	0.1086	0.8121	0.0141	0.9996	0.0061	3.78E-05	0.005464
average						0.9987	0.0116	0.0001	0.0106
		a	b						
Wang and singh	40	-0.0047	$6x10^{-6}$			0.9818	0.049199	0.004185	0.062496
	50	-0.0059	$9x10^{-6}$			0.9393	0.198934	0.044205	0.202603
	60	-0.0071	$1.2x10^{-5}$			0.9334	0.22604	0.051596	0.217477
	70	-0.0106	$2.7x10^{-5}$			0.8712	0.25294	0.069488	0.249345
Average						0.9314	0.1818	0.0424	0.1830
		a	b	k	c				
The exponential linear combination model	40	0.2081	0.8010	0.0080	-0.0004	0.9997	0.0055	3E-05	0.005099
	50	0.2099	0.8049	0.0129	-0.0005	0.9995	0.0076	5.73E-05	0.007008
	60	0.2403	0.7504	0.0155	-0.0006	0.9986	0.0123	0.00015	0.011183
	70	0.1898	0.7805	0.0241	-0.0007	0.9972	0.0171	0.000292	0.015196
Average						0.9988	0.0106	0.0001	0.0096

Effective moisture diffusivity:

Equation (3) was used to calculate the effective moisture diffusivity under different air temperatures and is listed in table (3). It can be noticed that the effective moisture diffusivity of tilapia fillets within the temperature range under study in the field from 40 to 70 °C are in the range of ($3.4702x10^{-10}$ to $6.8645\ x10^{-10}\ m^2s^{-1}$).

The obtained values of the effective moisture diffusivity are in agreement with the results obtained by previous researchers. Whereas Madamba *et al.*, (1996) mentioned that the moisture diffusivity values were in the range of (10^{-9} to 10^{-11} m^2 s^{-1}) and also Guan *et al*., (2013) revealed that the effective moisture diffusivity for Tilapia fillets was in the range of 6.553 x 10^{-10} to 1.232 x10^{-9} m^2s^{-1} and also Zogzas *et al., (*1996) mentioned that for food materials the effective moisture diffusivities ranged from 10^{-8} to 10^{-12} m^2s^{-1}.

It also can be seen that; the values of the effective moisture diffusivity increased by increasing the drying air temperature. This can be explained by the fact that the increased heat to raise the drying temperature improves the movement activity of water molecules, thus increasing the rate of water diffusion.

Table 3. Values of the D_{eff} of tilapia fillets at different drying air temperature.

T, °c	Linear equation	R^2	The slope	D_{eff}, m^2/s
40	Ln(MR) = 0.226882 -0.000137t	0.9440	-0.000137	3.4702x10^{-10}
50	Ln(MR) = 0.058797-0.000154t	0.9719	-0.000154	3.9009 x10^{-10}
60	Ln(MR) = 0.109382-0.000193t	0.9603	-0.000193	4.8887 x10^{-10}
70	Ln(MR) = -0.027886-0.000271t	0.9870	-0.000271	6.8645 x10^{-10}

Activation energy determination:

Arrhenius-type equation was used to calculate the activation energy, according to the slope of Arrhenius plot, ln (D_{eff}) versus $1/Ta$ as in Equation (6). The relationship between ln (D_{eff}) and ($1/Ta$) shown in Figure (4), Where the slope of the resulting straight line represents the value of -Ea/R.

The moisture diffusivity of tilapia fillets could be expressed as follows:

$$\mathbf{D_{eff} = 7 \cdot 5315x10^{-7}\ exp\left(-\frac{2423 \cdot 4}{T_a}\right)}$$

The activation energy value may be calculated from the line slope -Ea/R, and the value of activation energy for the entire period of the falling rate was 20.15 kJ/mol. This value is close to the values obtained from other studies on food products. Where Corzo *et al*., (2008) stated that the value of the activation energy for mango was in the range of 11.4 – 22.3 kJ/mol. Also Asl *et al.*, (2010) revealed that it was in the range of 22.66–30.92 kJ/ mol. for apples. Also Zogzas *et al.*, *(*1996) mentioned that, the values of activation energy for various food materials were within the range of 12.7 to 110 kJ/mol.

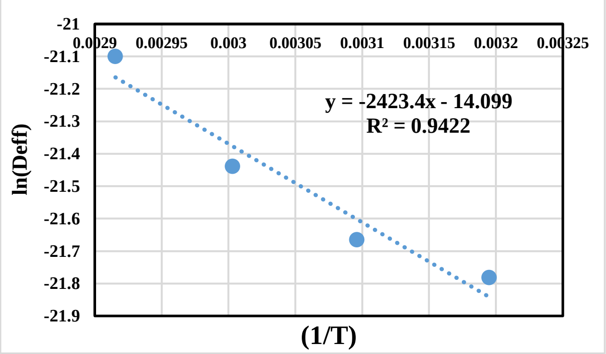

Figure 4. Relation between ln (D_{eff}) and reciprocal absolute temperature.

CONCLUSION

Tilapia fillets were dried during the falling rate period at all levels of the heated air temperature and by increasing the air temperature the drying rate increased while the moisture rate decreased. The results of the statistical analysis showed that all the mathematical models under study were able to describe the drying behavior of tilapia fillets, while the exponential linear combination model was the best. The effective moisture diffusivity increased by increasing air temperature and its values are in the range of (3.4702x10^{-10} to 6.8645 x10^{-10} m^2s^{-1}). The activation energy of tilapia fillets is 20.15 kJ/mol.

REFERENCES

Akgun, N. A., and Doymaz, I. (2005). Modelling of olive cake thin-layer drying process. Journal of food Engineering, 68(4), 455-461.

Akintunde T. Y. and Ogunlakin, G. O. (2011). Influence of drying conditions on the effective moisture diffusivity and energy requirements during the drying of pretreated and untreated pumpkin. *Energy Conversion and Management*, *52*(2), 1107-1113.

AOAC, (2005). Official Methods of Analysis. AOAC International, Maryland, USA.

Asl, M. E., Rafiee, S., Keyhani, A., and Tabatabaeefar, A. (2010). Drying of apple slices (var. Golab) and effect on moisture diffusivity and activation energy. Plant Omics, 3(3), 97-102.

Bruce, D. M. (1985). Exposed-layer barley drying: Three models fitted to new data up to 150 C. Journal of Agricultural Engineering Research, 32(4), 337-348.

Corzo, O., Bracho, N., and Alvarez, C. (2008). Water effective diffusion coefficient of mango slices at different maturity stages during air drying. Journal of food engineering, 87(4), 479-484.

Czopek T., Figiel, A., and Lisinska, G. (2007). Effect of pre-drying method on the quality and mechanical properties of French fries. *Polish Journal of Food and Nutrition Sciences*, *57*(4C), 555-562.

Doungporn, S.; N. Poomsa-ad and L. Wiset (2012). Drying equations of Thai Hom Mali paddy by using hot air, carbon dioxide and nitrogen gases as drying media. Food Bioprod. Process., 90:187-198.

Doymaz, İ. (2012). Evaluation of some thin-layer drying models of persimmon slices (Diospyros kaki L.). *Energy conversion and management*, *56*, 199-205.

Doymaz, İ., and İsmail, O. (2011). Drying characteristics of sweet cherry. *Food and bioproducts processing*, *89*(1), 31-38.

Duan, Z.H., Yi, M.H., Wang, Z.G., (2005). Processing technique of tilapia. Fish Sci. Technol. Inform. 32 (6), 250–252.

Duan, Z. H., Jiang, L. N., Wang, J. L., Yu, X. Y., & Wang, T. (2011). Drying and quality characteristics of tilapia fish fillets dried with hot air-microwave heating. Food and Bioproducts processing, 89(4), 472-476.

FAO (2020). FAO Global Fishery and Aquaculture Production Statistics (Fish Stat J; March 2020; www.fao.org/fishery/statistics/software/fishstatj/en).

Figiel, A. (2007). Dehydration of apples by a combination of convective and vacuum-microwave drying. *Polish Journal of Food and Nutrition Sciences*, *57*(4 [A]), 131-135

Gálvez V., Andrés, A., Gonzalez, E., Notte-Cuello, E., Chacana, M., and Lemus-Mondaca, R. (2009). Mathematical modelling on the drying process of yellow squat lobster (Cervimunida jhoni) fishery waste for animal feed. *Animal Feed Science and Technology*, *151*(3-4), 268-279.

Guan, Z., Wang, X., Li, M., and Jiang, X. (2013). Mathematical modelling on hot air drying of thin layer fresh tilapia fillets. *Polish journal of food and nutrition sciences*, *63*(1).

Henderson S.M., and Pabis S., (1961). Grain drying theory. II. Temperature effects on drying coefficients. J. Agric. Eng. Res., 6, 169–174

Henderson, S. M. (1974). Progress in developing the thin layer drying equation. Transactions of the ASAE, 17(6), 1167-1168.

Jain, D. (2006). Determination of convective heat and mass transfer coefficients for solar drying of fish. Biosyst. Eng., 94(3): 429–435.

Jain, D. and P. B. Pathare (2007). Study the drying kinetics of open sun drying of fish, study the drying kinetics of open sun drying of fish. J. Food Eng., 78: 1315–1319

Kituu, G. M., Shitanda, D., Kanali, C. L., Mailutha, J. T., Njoroge, C. K., Wainaina, J. K., and Silayo, V. K. (2010). Thin layer drying model for simulating the drying of Tilapia fish (Oreochromis niloticus) in a solar tunnel dryer. Journal of Food Engineering, 98(3), 325-331.

Lomauro, C. J., Bakshi, A. S., and Labuza, T. P. (1985). Moisture transfer properties of dry and semimoist foods. Journal of Food Science, 50(2), 397-400.

Li, J., Li, B.S., Li, W., (2009). Study on tilapia pickling technique. Modern Food Sci. Technol. 25 (6), 646–649.

Madamba, P. S., Driscoll, R. H., and Buckle, K. A. (1996). The thin-layer drying characteristics of garlic slices. Journal of food engineering, 29(1), 75-97.

Matouk, A. M., S. M. Abd El-Latif; Y. M. El-Hadidi, and A. Tharwat, (2001). Drying of ear corn: Part I: Determination of drying parameters. Misr J. Agric. Engng. 18 (3): 805-820.

Orikasa, T., Wu, L., Shiina, T., and Tagawa, A. (2008). Drying characteristics of kiwifruit during hot air drying. *Journal of Food Engineering*, *85*(2), 303-308.

Page, G. E. (1949). Factors Influencing the Maximum Rates of Air Drying Shelled Corn in Thin layers. Purdue University.

Shitanda D. and N.V. Wanjala (2006). Effect of different drying methods on the quality of jute (*Corchorus olitorius* L.). Drying Technol., 24, 95–98.

Toğrul, İ. T., and Pehlivan, D. (2002). Mathematical modelling of solar drying of apricots in thin layers. Journal of Food Engineering, 55(3), 209-216.

Tütüncü, M. A., and Labuza, T. P. (1996). Effect of geometry on the effective moisture transfer diffusion coefficient. Journal of Food Engineering, 30(3-4), 433-447.

Wang, C. Y., and Singh, R. P. (1978). Use of variable equilibrium moisture content in modeling rice drying. Transactions of American Society of Agricultural Engineers, 11(6), 668-672.

Watanabe, W.O., Losordo, T.M., Fitzsimmons, K., Hanley, F., (2002). Tilapia production systems in the Americas: technological advances, trends, and challenges. Rev. Fish Sci. 10 (3), 465–498.

Zaremba, R., and Jaros, M. (2007). Theoretical model for fluid bed drying of cut celery. *Polish* Journal of Food and Nutrition Sciences, 57(2 [A]), 211-214.

Zogzas, N. P., Maroulis, Z. B., and Marinos K. D. (1996). Moisture diffusivity data compilation in foodstuffs. Drying technology, 14(10), 2225-2253.

النمذجة الرياضية لشرائح السمك البلطي المجففة في طبقة رقيقة

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الملخص

يهدف هذا البحث الى تقييم عملية تجفيف شرائح السمك البلطي باستخدام الهواء الساخن . تم دراسة تاثير مستويات مختلفة من درجة حرارة الهواء (40 و 50 و 60 و 70 ^{o}م) على نسبة الرطوبة ومعدل التجفيف. تم استخدام مستوى ثابت لمعدل سريان هواء التجفيف عند 0.087 م3 / ث وسمك ثابت لشرائح البلطي 5 مم. تم تقييم سبعة نماذج رياضية مستخدمة على نطاق واسع في التجفيف لتحديد افضلها في وصف سلوك التجفيف لشرائح السمك البلطي تحت ظروف الدراسة. تم استخدام اربع معاملات احصائية اشتملت على معامل الارتباط R^2 و الخطأ المعياري SE و χ^2 وجذر متوسط الخطأ التربيعي RMSE للمقارنة بين النماذج الرياضية موضع الدراسة. أظهرت النتائج أن عملية التجفيف تمت خلال مرحلة معدل التجفيف المتناقص كما وجد أن متوسط قيمة معامل الارتباط لنموذج the exponential linear combination model كان 0.9988 ، والخطأ المعياري وجذر متوسط الخطأ التربيعي وقيم χ^2 المقابلة كانت 0.106 و 0.0096 و 0.0001 على التوالي مما يشير إلى أن يعتبر نموذج the exponential linear combination model هو الأفضل لوصف منحنيات التجفيف لشرائح البلطي الطازجة من بين النماذج التي تم فحصها. كما بينت النتائج أنه مع زيادة درجة حرارة هواء التجفيف ، زادت معدل انتشار الرطوبة D_{eff}. حيث تراوح معدل انتشار الرطوبة من 3.47 إلى 6.86 10^{-10} م^2 / ثانية بينما كانت قيمة طاقة التنشيط E_a 20.148 كج / مول

الكلمات الدالة: تجفيف السمك البلطي – التجفيف في طبقات رقيقة – النمذجة الرياضية – انتشار الرطوبة – طاقة التنشيط