jotaf
Journal of Tekirdag Agricultural Faculty
Tekirdağ Ziraat Fakültesi Dergisi

Ocak/January 2025, 22(1)
Başvuru/Received: 25/01/24
Kabul/Accepted: 06/01/25
DOI: 10.33462/jotaf.1425152

http://dergipark.gov.tr/jotaf
http://jotaf.nku.edu.tr/

ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Modeling the Rehydration Behavior of Oven and Vacuum Oven Dried Shrimp at Different Rehydration Temperatures and Determination of Quality Parameters

Farklı Rehidrasyon Sıcaklıklarında Etüv ve Vakumlu Etüvde Kurutulmuş Karideslerin Rehidrasyon Davranışının Modellenmesi ve Kalite Parametrelerinin Belirlenmesi

Ali Can ERŞAN[1], Azmi Seyhun KIPÇAK[2], Nurcan TUĞRUL[3*]

Abstract

In this study, shrimps dried by oven (OD) and vacuum oven (VOD) in the previous study, were rehydrated at temperatures of 30, 40 and 50°C and the kinetics of rehydration during this time were examined and curves are modeled. In rehydration kinetic studies, rehydration contents, rehydration rates, moisture ratio and effective moisture diffusions were calculated. Modeling was done based on Peleg and Two-Term mathematical models from the obtained rehydration curve data, and the results were evaluated statistically using the reduced chi-square (χ^2), coefficient of determination (R^2) and root mean square error (RMSE) definitions. Color measurements were chosen as quality parameter analysis and interpretations were made based on the total color changes. When the results were examined, it was observed that all samples reached equilibrium in the 180 and 150 minute in oven drying and vacuum-oven drying, respectively and the sample with the highest rehydration value was observed in the one dried at 80°C in a vacuum-oven drying and rehydrated at 50°C. Since the drying time of the samples dried in the vacuum oven was shorter, their pores were less narrowed and thus they experienced more rehydration. It was observed that the samples were rehydrated more as the rehydration temperature increased. Since the rehydration rate, moisture content and effective moisture diffusivity values are in parallel with the rehydration contents the same increase occurred at these parameters. Looking at the mathematical modeling results, the Peleg model gave better results in samples rehydrated at 30 and 40°C, and the Two-Term model gave better results in samples rehydrated at 50°C. From the total color changes as expected vacuum-dried shrimps total color changes were less than the oven-dried shrimps and the color changes increased as the rehydration temperature increases due to the increase in the lightness values.

Keywords: Shrimp, Effective moisture diffusivity, Rehydration ratio, Seafood, Rehydration kinetics

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Atıf: Erşan, A. C., Kıpçak, A. S., Tuğrul, N. (2025). Farklı rehidrasyon sıcaklıklarında etüv ve vakumlu etüvde kurutulmuş karideslerin rehidrasyon davranışının modellenmesi ve kalite parametrelerinin belirlenmesi. *Tekirdağ Ziraat Fakültesi Dergisi,* 22(1): 108-121.
Citation: Erşan, A. C., Kıpçak, A. S., Tuğrul, N. (2025). Modeling the rehydration behavior of oven and vacuum oven dried shrimp at different rehydration temperatures and determination of quality parameters. *Journal of Tekirdag Agricultural Faculty,* 22(1): 108-121.

Öz

Bu çalışmada, önceki çalışmada etüv (EK) ve vakumlu etüvde (VEK) kurutulan karidesler 30, 40 ve 50°C sıcaklıklarda rehidrate edilmiş ve bu süre zarfındaki rehidrasyonun kinetiği incelenerek eğriler modellenmiştir. Rehidrasyon kinetiği çalışmalarında rehidrasyon içerikleri, rehidrasyon oranları, nem oranı ve etkili nem difüzyonları hesaplanmıştır. Elde edilen rehidrasyon verilerinden Peleg ve İki parametreli matematiksel modelleri baz alınarak modelleme yapılmış ve sonuçlar indirgenmiş ki-kare (χ2), belirleme katsayısı (R2) ve ortalama kare hatası (RMSE) kullanılarak istatistiksel olarak değerlendirilmiştir. Kalite parametre analizi olarak renk ölçümleri seçilmiş ve toplam renk değişimlerine göre yorumlar yapılmıştır. Sonuçlar incelendiğinde tüm numunelerin etüvde kurutmada ve vakumlu etüvde kurutmada sırasıyla 180 ve 150 dakikada dengeye ulaştığı ve vakum etüvünde kurutulup rehidrate edilen numunelerin daha fazla rehidrasyon değerine ulaştıkları görülmüştür. En yüksek rehidrasyon değerine sahip numunenin ise 80°C'de vakum etüvünde kurutulan ve 50 °C'de rehidrate edilen numunede olduğu ortaya çıkmıştır. Vakumlu etüvde kurutulan numunelerin kuruma süresi daha kısa olduğundan gözenekleri daha az daraldığı için rehidrasyon değerlerinde beklendiği üzere artış meydana gelmiştir. Rehidrasyon sıcaklığı arttıkça numunelerin daha fazla rehidrate edildiği gözlenmiştir. Rehidrasyon oranı, nem içeriği ve efektif nem yayılım değerleri rehidrasyon içerikleri ile paralel olduğundan bu parametrelerde de benzer miktarlarda artış meydana gelmiştir. Matematiksel modelleme sonuçlarına bakıldığında Peleg modelinin 30 ve 40°C'de rehidrate edilen numunelerde, iki parametreli modelinin ise 50°C'de rehidrate edilen numunelerde daha iyi sonuçlar verdiği ortaya çıkmıştır. Renk analizlerinde toplam renk değişimlerinden vakumla kurutulan karideslerde beklendiği gibi toplam renk değişimi fırında kurutulan karideslere göre daha az olarak ortaya çıkmış ve rehidrasyon sıcaklığı arttıkça açıklık değerlerinin artmasına bağlı olarak renk değişimleri de artmıştır.

Anahtar Kelimeler: Karides, Etkili nem yayılımı, Rehidrasyon oranı, Deniz Ürünleri, Rehidrasyon kinetiği

1. Introduction

Shrimp is one of the popular commercial seafood due to its flavor and nutritional value. Global Seafood Alliance indicates that world's farmed shrimp production in 2023 is expected to be at around 5.6 million metric tons (Gautam et al., 2021; Li et al., 2019; GSA, 2023). It contains high amounts of nutrients such as protein, free amino acids, calcium, and vitamins (Gao et al., 2023; Azizpour et al., 2016). High moisture and protein content cause shrimp to spoil quickly. For this reason, it must be preserved with the most appropriate method immediately after harvest (Murali et al., 2021; Abedini et al., 2022). Shrimps can be stored into dried, frozen, boiled, and fried forms. Storage conditions like time and temperature, would affect dried products quality and cause many complicated reactions (Wang et al., 2024; Zhang et al., 2020).

Drying is the most used food preservation methods and is suitable to a many kinds of seafood like shrimps. Several drying methods like conventional drying, infrared drying, microwave drying, solar drying, freeze drying are applied to prolong the shelf life of seafoods. Drying process reduce the post-harvest loss, the moisture level to prevent microbial growth, retard enzymatic reactions causing spoilage of food and increase the shelf-life (Akonor et al., 2016; Murali et al., 2023; Nanan et al., 2023). Between drying methods, hot air drying is one of the most frequently used methods because of the low investment cost and basic drying (Wang et al., 2023). Rehydration means to moistening of dried matter. It is a crucial determinative point in choosing the storage processes and processing. Dried foods need to be rehydrated before eating because the nutritional properties are influenced by dehydration followed by rehydration. One of the important properties of products that are dried is rehydration. Dried food is moistened, restoring their original structure and taste. Morphological structure, chemical composition, drying process, dipping medium, temperature and time are factors affected rehydration (Kumar et al., 2020; Nayi et al., 2023; Wang et al., 2016). Drying is a complicated process described by interactions of contemporaneous heat and mass transfer. Food product attitude through drying is determined from the drying kinetics analyses. To define and optimize the drying process several mathematical models have been used in the literature (Nayi et al., 2023; Ersan and Tugrul, 2021).

There are lots of study about food drying, but there are few studies about shrimp drying. Ultrasound assisted rehydration study was conducted by Riyanto et al. (2023) on sea cucumber also Jiang et al. (2022) examined hot air drying process of sea cucumber. Aktas et al. (2013) studied effects of different drying methods on drying kinetics and color parameters of strawberry tree (*Arbutus unedo* L.) fruit. Ozyalcin and Kipcak (2023) studied rehydration kinetics and characteristics of mussels with traditionally drying. Achaglinkame et al. (2020) studied the sensory and rehydration features on the freeze-dried snails. Arslan et al. (2020) infrared drying kinetics and color qualities of organic and conventional sweet red peppers. Seabass drying kinetics and mathematical modelling are studied by Ozyalcin et al. (2023). Lin et al. (2022) studied the drying of Pacific white shrimps by microwave method by applying salting pre-treatment. Alfiya et al. (2022) studied shrimps drying by solar and microwave drying technologies. In this study, oven (OD) and vacuum oven dried (VOD) shrimps were rehydrated at 30, 40 and 50°C, rehydration kinetics are examined, and curves are modeled. It was seen that vacuum-oven dried samples gave better results than the oven dried samples at all rehydration temperatures.

2. Materials and Methods

2.1. Samples and equipment

In a previous study, Ersan and Tugrul (2021) examined the characteristic drying kinetics and behavior of shrimps dried in a conventional oven and a vacuum oven. Products dried in OD and VOD at 60, 70 and 80°C are rehydrated in this study.

2.2. Experimental method

Rehydration experiments were carried out with 4.8 ± 0.05 grams of dried products in both methods. In the experimental procedure, dried products were put in distilled water beakers (1:100 (weight dried sample: volume water)). Rehydration temperatures were determined as 30, 40 and 50°C. Hot Plate with Magnetic Stirrer was used to heat the beaker at 300 rpm. Every 30-minute, rehydrated products were taken from the beaker and water on the shrimp surface were dried ordinary filter paper. Then weighted with a digital balance until reaching the equilibrium rehydration content.

2.3. Rehydration content and rehydration rate calculations

Rehydration rates and contents are the most important properties for dried food where rrehydration contents (kg water / kg dry matter) were calculated using equation (1). By using equation (2), rehydration rate (R_R) (kg water / kg dry matter . s), which is the rehydration contents per unit time in the product were determined (Kipcak et al., 2014. Sevim et al., 2019):

$$R_c = \frac{w_r - w_d}{w_d} \quad \text{(Eq. 1)}$$

$$R_R = \frac{R_{c\,(\Delta t+t)} - R_{c\,(t)}}{\Delta t} \quad \text{(Eq. 2)}$$

2.4. Diffusion of water inside shrimps

In rehydration kinetic studies in the literature, it is assumed that water is transported through a matrix from the center to the surface by simple mass transport (diffusion with constant spread) (Benseddik et al., 2019). Therefore, the concentration gradient is expressed by water content and directly affects mass transfer. The ratio of moisture (MR) (dimensionless) can be reported as a formula given below (Kipcak and Ismail, 2021):

$$MR = \frac{M_t - M_e}{M_i - M_e} \quad \text{(Eq. 3)}$$

The solution of Fick's second law by analytical means comes with the assumptions given in Ersan and Tugrul (2021), Kipcak and Ismail (2018) and by using cylindrical coordinates equation (4) obtained as:

$$MR = \frac{8}{\pi^2}\left[\sum_{n=1}^{\infty} \frac{4}{a^2 a_n^2} exp \frac{K a^2 a_n^2\, t}{\pi^2}\right]\left[\sum_{n=0}^{\infty} \frac{4}{(2n+1)^2} \exp\left[-K(2n+1)^2 t \left(\frac{a}{l}\right)^2\right]\right] \quad \text{(Eq. 4)}$$

The first terms of the equations are neglected as they do not affect the results, so equation (4) can be written as equation (5):

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) - \frac{D_{eff} \times \pi^2}{a^2} \times \left(\frac{a}{l}\right)^2 \times t \quad \text{(Eq. 5)}$$

From the curve of ln(MR) versus t graph, , Effective Moisture Diffusion Coefficient (D_{eff}) can be calculated by using the slope.

2.5. Evaluation of the mathematical modelling

Peleg model (PM) and Two-Term model (TTM) equations (Equations 6–7) of were used on the experimental data, respectively (Kipcak, 2017; Demirhan and Ozbek, 2011)

$$MR = a + t/(k_1 + k_2 \times t) \quad \text{(Eq. 6)}$$

$$MR = a \times \exp(k_0 \times t) + b \times \exp(k_1 \times t) \quad \text{(Eq. 7)}$$

The computer software used for modelling calculations nonlinear regressions based on the Levenberg-Marquardt algorithm (Statistica 6.0; Statsoft Inc., Tulsa, OK). The best model was determined by using statistical analyses of; reduced chi-square (χ^2), coefficient of determination (R^2) and root mean square error (RMSE) (equations (8-10)) (Kipcak et al., 2014; Benseddik et al., 2019):

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(RR_{exp,i} - RR_{pre,i})^2}{\sum_{i=1}^{N}\left(\frac{RR_{exp,i}}{\frac{\sum_{i=1}^{N} RR_{exp,i}}{N}} - RR_{exp,i}\right)^2} \quad \text{(Eq. 8)}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}(RR_{exp,i} - RR_{pre,i})^2}{N-n} \quad \text{(Eq. 9)}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(RR_{exp,i} - RR_{pre,i})^2}{N}} \quad \text{(Eq. 10)}$$

From the values of R^2, χ^2 and RMSE most appropriate model were chosen (Kipcak et al., 2019; Kipcak and Doymaz, 2020; Kipcak and Ismail, 2021).

2.6. Color measurement

For aquatic products that has been dried and rehydrated, its color is the most important criterion for the consumer in terms of the quality of the product. The L parameter refers to the darkness or measurable value of the Hunter color policy product (0 for black, 100 for white). The parameter a refers to the redness and greenness values of the products, and the parameter b refers to the yellowness and blueness values of the products. To determine these color parameters, a colorimeter device was used before and after the rehydration processes. Before the color analysis for each product, the device was calibrated with a calibration kit. Color measurements were recorded for shrimp rehydrated at different temperatures in both methods. The total variation in color (ΔE) of rehydrated products was calculated using Equation (11) (Kipcak et al., 2014).

$$\Delta E = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2} \quad \text{(Eq. 11)}$$

where L_o, a_o and b_o are the color values of dried samples. L, a and b color parameters of samples were measured from five points of every sample just after rehydration processes.

3. Results and Discussion

3.1. Rehydration curves

Figure 1 shows the rehydration ratio and R_R curves after rehydration of shrimps dried by two different methods. It can be seen from the obtained rehydration ratio curve that all rehydrated products reach equilibrium in 180 and 150 min at OD and VOD, respectively. In both methods, rehydration rates increase as the drying and rehydration temperature increase. The reason for increasing the rehydration rate as increasing the temperature of drying can be due by the decreasing drying times, which achieved at high temperatures and therefore the decrease in the collapse of the pores of the shrimps. In addition, since drying times are shorter in a vacuum oven than in an oven, the rehydration rates are expected to increase more.

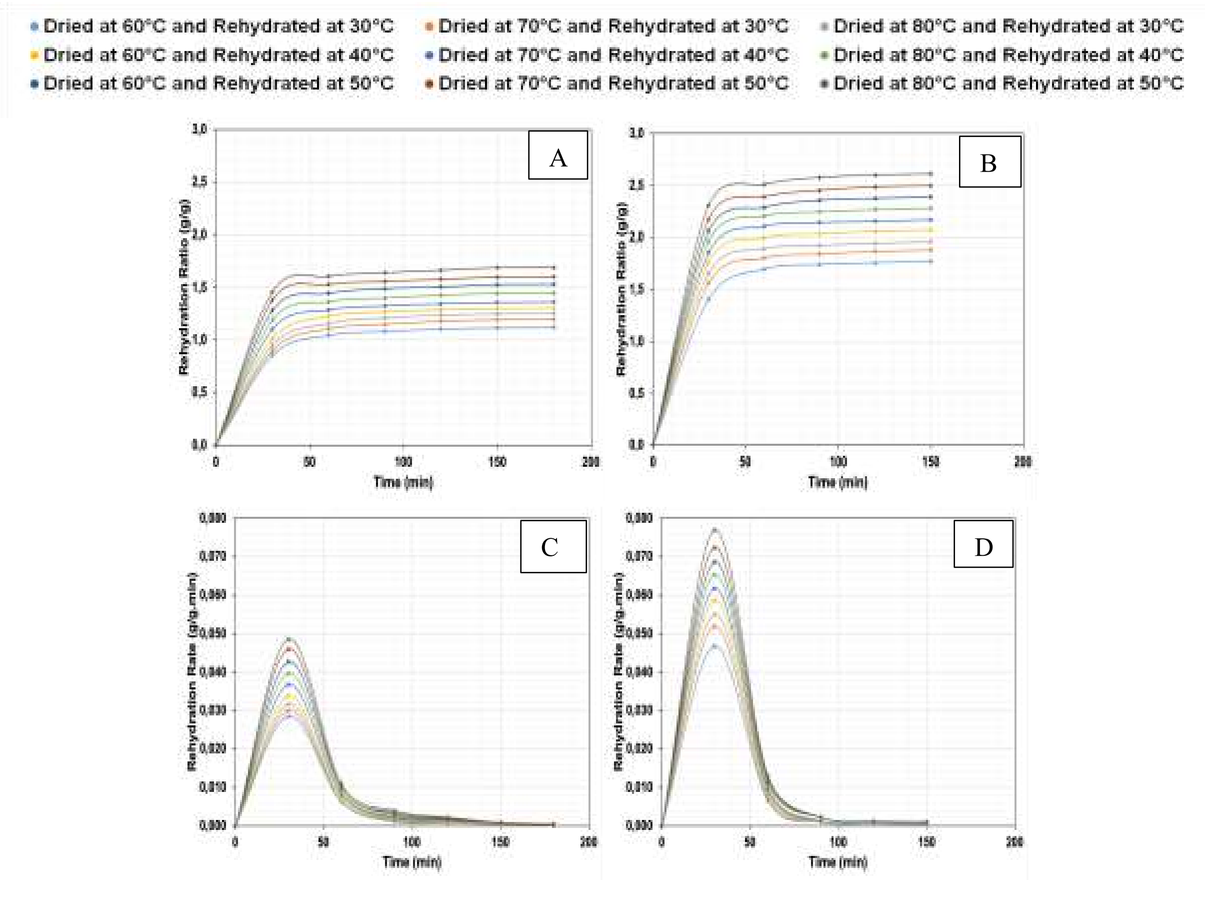

Figure 1. $R_C/R_{C,0}$ plots of A. OD shrimp, B. VOD shrimp, and R_R plots of C. OD shrimp, D. VOD shrimp

The maximum rehydration ratio was acquired for products 80°C dried and 50°C rehydrated. Rehydration ratios for OD and VOD methods were obtained as 1.6901 g/g and 2.6135 g/g, respectively. Minimum rehydration ratio were procured at products 60°C dried and 30°C rehydrated. Rehydration ratios for OD and VOD methods were obtained as 0.8525 g/g and 1.4038 g/g, respectively. Maximum R_R appear on the R_R curve (peak values) between 0 and 30 minutes. This area can be named the increasing R_R period region. The period among 30 and 180 minutes can be named the decreasing R_R period. For OD and VOD methods, the values of maximum acquired in the products 80°C dried and 50°C rehydrated are calculated as 0.0486 and 0.0769 g/g.min, respectively. The lowest peak values were determined as 0.0285 and 0.0468 g/g.min for the products 60°C dried and 30°C rehydrated, respectively.

3.2. Diffusion mass transfer coefficient results

For comparison and calculation of D_{eff} values, sample graphs of ln (MR) versus time and versus D_{eff} are given in *Figure 2*, respectively. In *Table 1*, the slope obtained from the plot of ln (MR) versus t and the calculated D_{eff} values are given. D_{eff} values are estimated in the range of 1.3-1.43×10^{-8} m^2/s, 1.54-1.63×10^{-8} m^2/s, for OD and VOD, respectively. It is seen that D_{eff} values increase as the rehydration rate increases. Higher D_{eff} values are obtained in the vacuum oven method compared to the drying oven method as expected from the data presented in *Figure 1*.

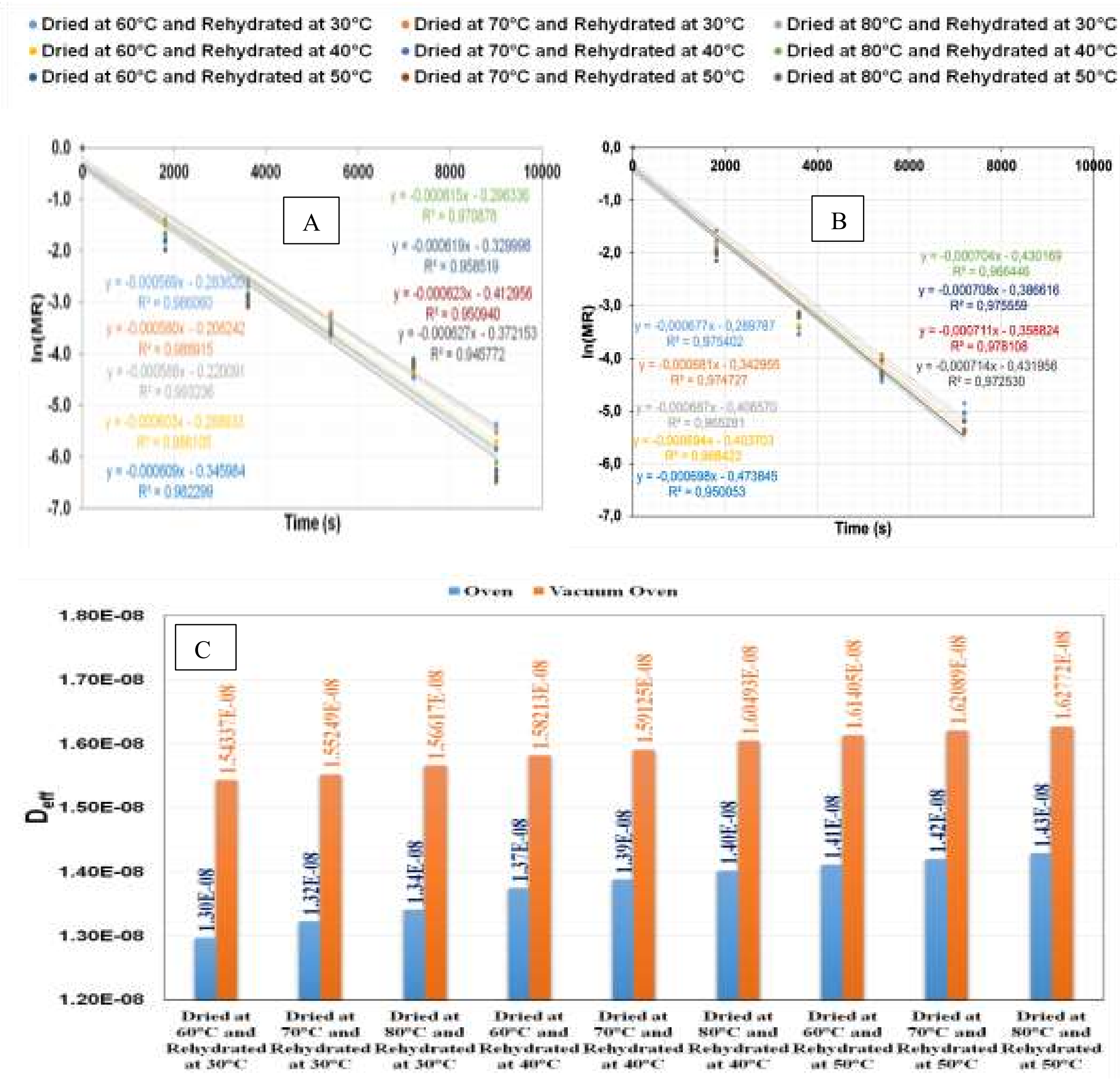

Figure 2. Logarithmic form of moisture ratio against time plot of D_{eff} for a. OD shrimp, b. VOD shrimp and c. D_{eff} versus dried and rehydrated temperatures bar graph

Table 1. Effective moisture diffusivities

	OD		VOD	
	Slope	**D_{eff} (m²/s)**	**Slope**	**D_{eff} (m²/s)**
Dried @ 60°C & Rehydrated @ 30°C	-0.000569	1.3×10^{-8}	-0.000677	1.54×10^{-8}
Dried @ 70°C & Rehydrated @ 30°C	-0.000580	1.32×10^{-8}	-0.000681	1.55×10^{-8}
Dried @ 80°C & Rehydrated @ 30°C	-0.000588	1.34×10^{-8}	-0.000687	1.57×10^{-8}
Dried @ 60°C & Rehydrated @ 40°C	-0.000603	1.37×10^{-8}	-0.000694	1.58×10^{-8}
Dried @ 70°C & Rehydrated @ 40°C	-0.000609	1.39×10^{-8}	-0.000698	1.59×10^{-8}
Dried @ 80°C & Rehydrated @ 40°C	-0.000615	1.40×10^{-8}	-0.000704	1.60×10^{-8}
Dried @ 60°C & Rehydrated @ 50°C	-0.000619	1.41×10^{-8}	-0.000708	1.61×10^{-8}
Dried @ 70°C & Rehydrated @ 50°C	-0.000623	1.42×10^{-8}	-0.000711	1.62×10^{-8}
Dried @ 80°C & Rehydrated @ 50°C	-0.000627	1.43×10^{-8}	-0.000714	1.63×10^{-8}

3.3. Mathematical modelling results

As a result of the calculations, it was seen that the PM and TTM determined among the mathematical models were compatible with the experimental rehydration rate values. *Table 2* demonstrate that, the experimental data were appropriate good with the R^2 values higher than 0.99. Among the models TTM were fitted better than PM. For the product by 80°C OD and 30°C rehydrated, the highest R^2 and lowest χ^2 and RMSE values were calculated according to the PM with values of 0.998672, 0.0004 & 0.0154, respectively. For the product by 80°C VOD and 30°C rehydrated the highest R^2 and lowest χ^2 & RMSE are found by TTM with the values of 0.99999, 0.000010 & 0.000009.

For product by 80°C OD and 40°C rehydrated the highest R^2 and lowest c^2 and RMSE values are calculated by TTM with the values of 0.999926, 0.0002 & 0.0099, respectively. For the product by 80°C VOD and 30°C rehydrated, the highest R^2 and lowest c^2 and RMSE values are found by TTM with the values of 0.999999, 0.000002 & 0.0008. For the product by 80°C OD and 50°C rehydrated, the highest R^2 and lowest χ^2 and RMSE values are found by TTM with the values of 0.999929, 0.000055 & 0.0048, respectively. For the product by 80°C VOD and 50°C rehydrated at the highest R^2 and lowest χ^2 and RMSE values are found by TTM with the values of 0.99992, 0.000143 & 0.0078. Calculated R_R and experimental R_R are shown in *Figure 3* and *Figure 4* for both methods. The plots obtained are on the 45° meaning that the models were fitted very good to the experimental data obtained.

3.4. Color Values

L, a and b values of rehydrated products are given in *Table 3* gives. L value changes relate to decreasing rehydration temperatures for the OD and VOD. L values change between 31.10 and 33.99, 34.78 and 36.01, 38.43 and 40.03 for the OD 30 °C, 40 °C and 50 °C, respectively. The highest and the lowest redness values attained in the OD 30 °C and VOD 50 °C, respectively. Redness values, a, for the oven method changed between 0.98 and 0.76 and for the VOD method between-3.21 and-3.76. The highest and the lowest yellowness values for b were obtained in VOD 50 °C and OD 30 °C, respectively. Yellowness values, b, for VOD 30 °C changed between 3.31 and 3.95 and for the OD 30 °C between -4.16 and -4.62.

As expected, the total color change in VOD shrimp was less than that in OD shrimp, and as the rehydration temperature increased, the color changes increased due to the increase in lightness values.

4. Conclusions

Shrimps dried by oven and vacuum oven were rehydrated at the temperatures between 30-50°C. Kinetic studies; rehydration contents, rehydration rates, moisture ratio and effective moisture diffusions were evaluated and from the effective moisture diffusions curve Modeling was done based on Peleg and Two-Term mathematical models. Best model was selected statistically using R^2, χ^2) and RMSE. Quality analysis of color measurements were applied and interpretations were made based on the total color changes. From the results obtained in this study it is seen that the rehydration experiments were finished at 180 and 150 min at OD and VOD, respectively. The highest and the lowest rehydration rates were observed in the samples of 80°C vacuum-oven dried and rehydrated at 50°C and 60°C oven-dried and rehydrated at 30°C. Vacuum-dried samples leads to take more

Table 2. Model coefficients and statistical data

Rehyd. Temp. (°C)	Model	Parameter	OD			VOD		
			Temp. (°C)			Temp. (°C)		
			60	70	80	60	70	80
30	Peleg	R^2	0.998364	0.998533	0.998672	0.998024	0.999109	0.999125
		RMSE	0.015302	0.0154	0.0154	0.026157	0.0187	0.0193
		χ^2	0.000410	0.0004	0.0004	0.001197	0.0006	0.0007
		a	-0.000617	-0.000698	-0.000685	-0.000748	-0.000346	-0.000299
		k_1	9.468.547	9.450.920	8.854.537	5.304.961	3.997.953	3.478.465
		k_2	0.827416	0.772380	0.737940	0.520963	0.500106	0.482224
	Two-Term	R^2	0.949421	0.952001	0.951923	0.994143	0.997547	0.99999
		RMSE	0.085087	0.0883	0.0926	0.045031	0.0310	0.0021
		χ^2	0.016893	0.018184	0.020019	0.004732	0.002241	0.000010
		a	156.040	443.635	382.176	-207.826	-191.753	-190.261
		k_0	0.009	0.0087	0.0086	0.03594	0.05027	0.06621
		b	-155.974	-442.946	-381.450	210.093	192.775	190.256
		k_1	0.009	0.0093	0.0095	0.00132	0.00028	-0.00019
40	Peleg	R^2	0.998255	0.999140	0.999589	0.999335	0.999094	0.999429
		RMSE	0.018432	0.0135	0.0099	0.017817	0.0219	0.0182
		χ^2	0.000595	0.0003	0.0002	0.000556	0.000836	0.000582
		a	-0.000661	-0.000339	-0.000205	-0.000249	-0.000290	-0.000224
		k_1	7.555.117	5.988.077	5.281.367	3.131.028	2.883.560	2.650.427
		k_2	0.714010	0.694083	0.657530	0.458421	0.437431	0.417196
	Two-Term	R^2	0.947413	0.978440	0.999926	0.999994	0.999995	0.999999
		RMSE	0.101195	0.0677	0.0042	0.001711	0.0016	0.0008
		χ^2	0.023894	0.010683	0.000041	0.000007	0.000006	0.000002
		a	486.930	160.714	136.055	-199.913	-212.092	-220.802
		k_0	0.009	0.00122	-0.00036	0.06875	0.06783	0.07095
		b	-486.852	-156.612	-136.050	199.911	212.089	220.802
		k_1	0.009	0.03215	0.06607	-0.00023	-212.092	-0.00022
50	Peleg	R^2	0.999741	0.999899	0.999899	0.99974	0.99991	0.999927
		RMSE	0.008324	0.0057	0.0057	0.012869	0.0080	0.0074
		χ^2	0.000121	0.0001	0.0000	0.000290	0.000113	0.000097
		a	-0.000146	-0.000052	-0.000052	-0.000158	-0.000087	-0.000061
		k_1	4.529.770	3.373.687	3.373.687	2.536.293	2.275.392	1.919.479
		k_2	0.624671	0.571313	0.571313	0.398597	0.383182	0.368116
	Two-Term	R^2	0.999927	0.999952	0.999929	0.999934	0.999937	0.99992
		RMSE	0.004412	0.0038	0.0048	0.006480	0.0066	0.0078
		χ^2	0.000045	0.000033	0.000055	0.000098	0.000102	0.000143
		a	144.137	151.564	158.880	-228.425	-236.463	-248.687
		k_0	-0.00035	-0.00033	-0.00037	0.07367	0.07868	0.08280
		b	-144.129	-151.562	-158.876	228.435	236.471	248.695
		k_1	0.06972	0.07688	0.07871	-0.00031	-0.00039	-0.00035

moisture and rehydration temperatures also increased the rehydration capacity. The effective moisture diffusivities are obtained between 1.3- 1.43×10^{-8} m^2/s and 1.54- 1.63×10^{-8} m^2/s for the vacuum and oven dried samples respectively at the rehydration temperatures between 30-50°C. From the modelling at 30 and 40°C Peleg model gave the best results with the R^2 values between 0.998024 and 0.999125, respectively. And at 50°C Two-Term model gave the best results with the R^2 values between 0.999920 and 0.999952. For the quality analysis of total color change values, oven-dried samples total color changes (5.38 - 9.91) were higher than the vacuum-oven dried samples (2.70 - 9.46). As a result, for the quality analysis and maximum rehydration values vacuum-oven dried samples gave better results the oven dried samples at all rehydration temperatures.

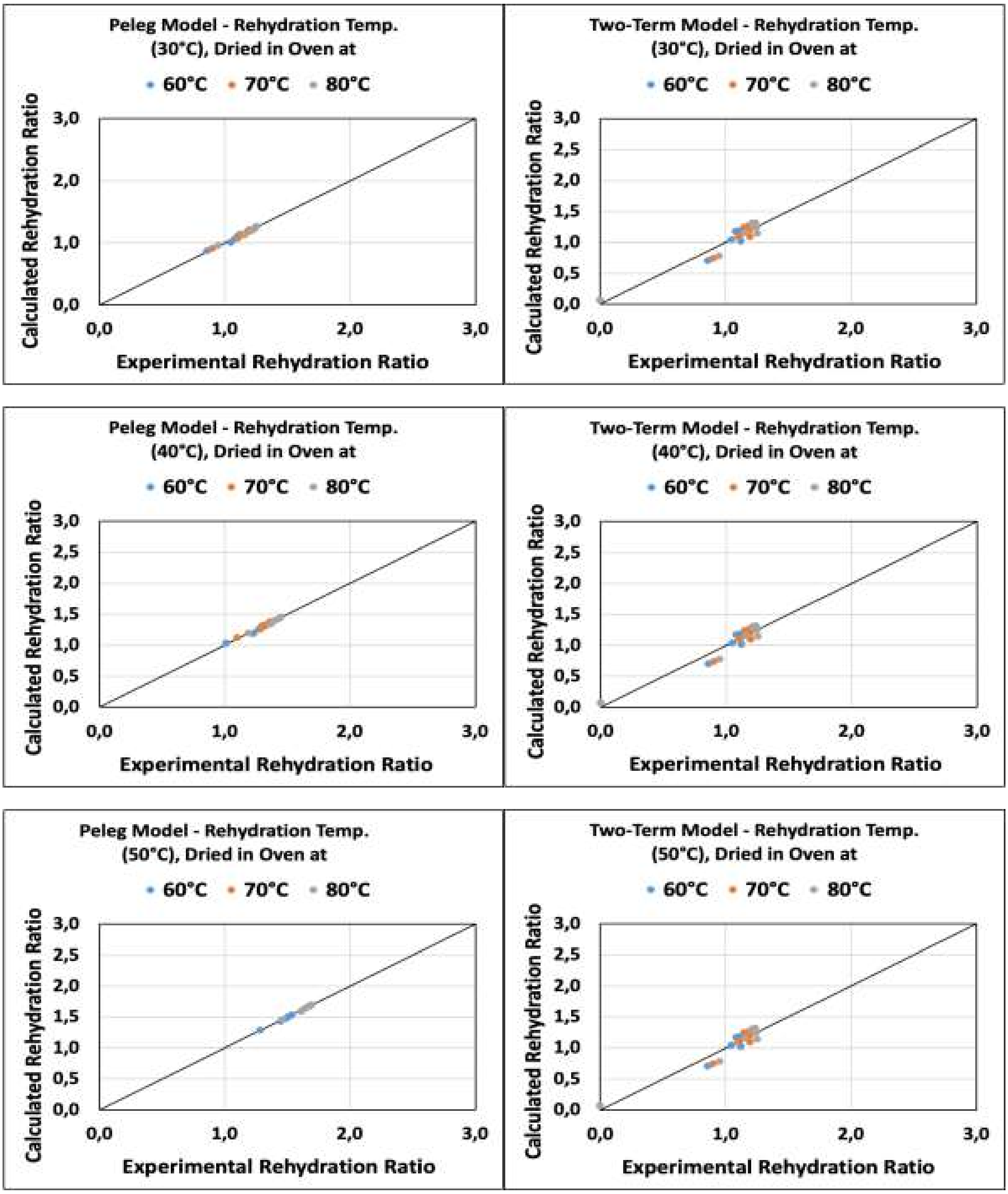

Figure 3. Exp. and calc. $R_C/R_{C,0}$ values obtained from the PM and TTM for OD shrimp

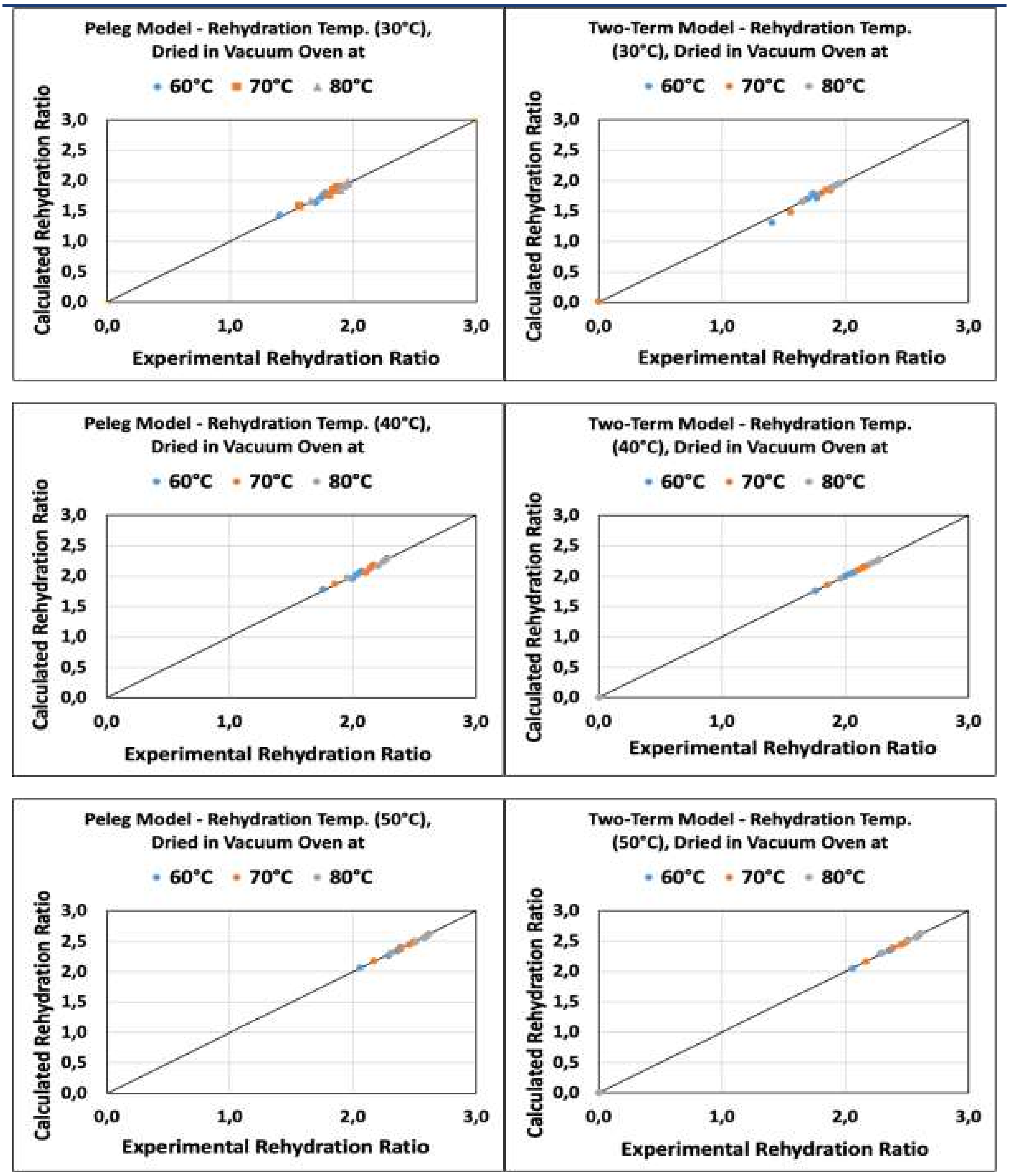

Figure 4. Exp. and calc. $R_C/R_{C,0}$ values obtained from the PM and TTM for VOD shrimp

Table 3. Color values of rehydrated shrimp different temperatures with OD and VOD

	L	a	b	
Dried Sample Oven 30°C	25.76	1.49	-4.98	
		Oven 30°C		
Temperatures (°C)	**L**	**a**	**b**	**ΔE**
60	31.10	0.98	-4.62	5.38
70	32.31	0.89	-4.5	6.59
80	33.99	0.76	-4.16	8.30
	L	**a**	**b**	
Dried Sample Oven 40°C	27.59	0.56	-3.8	
		Oven 40°C		
Temperatures (°C)	**L**	**a**	**b**	**ΔE**
60	34.78	-0.4	-3.61	7.26
70	35.69	-0.53	-2.99	8.21
80	36.01	-0.94	-2.72	8.62
	L	**a**	**b**	
Dried Sample Oven 50°C	30.4	0.21	-2.63	
		Oven 50°C		
Temperatures (°C)	**L**	**a**	**b**	**ΔE**
60	38.43	-1.08	-1.93	8.16
70	39.02	-1.17	-1.57	8.79
80	40.03	-1.39	-0.91	9.91
	L	**a**	**b**	
Dried Sample Vacuum Oven 30°C	39.12	-1.25	-0.78	
		Vacuum-Oven 30 °C		
Temperatures (°C)	**L**	**a**	**b**	**ΔE**
60	41.75	-1.76	-0.44	2.70
70	42.56	-2.1	-0.6	3.55
80	44.57	-2.29	0.68	5.74
	L	**a**	**b**	
Dried Sample Vacuum Oven 40°C	43.67	-1.96	1.35	
		Vacuum-Oven 40 °C		
Temperatures (°C)	**L**	**a**	**b**	**ΔE**
60	47.22	-2.55	1.58	3.61
70	49.59	-2.82	2.18	6.04
80	50.34	-3.13	3.01	6.97
	L	**a**	**b**	
Dried Sample Vacuum Oven 50°C	46.06	-2.14	2.23	
		Vacuum-Oven 50 °C		
Temperatures (°C)	**L**	**a**	**b**	**ΔE**
60	50.75	-3.21	3.31	4.93
70	53.58	-3.48	3.87	7.81
80	55.25	-3.61	3.95	9.46

Acknowledgment

This work supported no grants from any funding agency or industry.

Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Erşan, A. C., Kıpçak A. S., Tuğrul, N.; Design: Erşan, A. C., Kıpçak A. S., Tuğrul, N.; Data Collection or Processing: Erşan, A. C., Kıpçak A. S., Tuğrul, N.; Statistical Analyses: Erşan, A. C., Kıpçak A. S.; Literature Search: Erşan, A. C., Kıpçak A. S., Tuğrul, N.; Writing, Review and Editing: Erşan, A. C., Kıpçak A. S., Tuğrul, N.

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