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Research Article/Araştırma Makalesi

The Study of Dehydration and Rehydration Kinetics of Phaseolus Vulgaris

Zehra Gülten YALÇIN[1], Burcu Didem ÇORBACIOĞLU[2], Ercan AYDOĞMUŞ[3] & Mustafa DAĞ[4]

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Dehydration, Rehydration, Phaseolus Vulgaris, Modelling kinetic, regression analysis.

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Abstract
In this study, the green beans supplied from a supermarket in Istanbul have firstly been sun-dried, and then rehydration tests of these dried beans have been performed at temperatures of 25 ^{o}C and 45 ^{o}C. Wang, Singh, Lewis and Midilli models have been used to examine the drying kinetics of the beans; Peleg, Exponential and First Order Kinetics models have been used in order to examine rehydration kinetics. The closest results for the experimental data have been provided with Midilli model for dehydration, and Peleg model for rehydration. Regression analysis is used in the MathCad program. The regression coefficient (R^2) is taken as the main criterion for choosing the equation that defines the drying curves of the products. In addition, the suitability of modeling the estimated standard error (RMSE) and chi-square (χ^2) values was also determined. Standard deviations between experimental and model equations have been shown to allow us to defer for the appropriate model.

1. Introduction (Giriş)

Being one of the species of Fabaceae (legume family), the green bean (Phaseolus Vulgaris) is a kind of a herbaceous plant whose origin is Central America. Being among 50 species of Phaseolus, Phaseolus Vulgaris accounts for 75% of legumes grown up in the world (Broughton 2003) and it's a kind of vegetable which is grown up widely in Turkey, and consumed as fresh, frozen, canned and dried.

Sun-drying and drying under open sun are the most common drying methods used to dry fruit and vegatables all over the world and in Turkey. As solar energy is renewable, clean and cheap source of energy, sun-drying is widely used in tropical countries. The only disadvantage of sun-drying method is that its drying duration is slower than the other processes. (Basunia and Abe 2001) Hence, some pre-treatments are carried out in sun-drying methods in order to increase the drying

[1] Corresponding Author. Çankırı Karatekin University of Chemical Engineering Department, zaltin@karatekin.edu.tr
[2] Yıldız Technical University, Faculty of Chemical and Metallugical
[3] Elazığ Fırat University of Chemical Engineering Department
[4] Çankırı Karatekin University of Chemical Engineering Department

rate. Chemical component addition, osmotic pre-treatments and boiling process are the methods studied most in recent years. (Adedeji 2008; and Saravacos 1988).

Many studies have been carried out in the area of drying vegetables in the sun. Sun-drying characteristics of many vegetables like fig, okra, beans (Doymaz 2005; Doymaz 2011) , pepper (Hossain 2005), chili pepper (Tunde-Akintunde 2011), green pepper (Akpınar and Bicer 2008) and mint (Akpınar 2010) have been examined in literature. As these characteristics can be determined with experimental methods, they can also be found by using theoretical models. Many mathematical models like Fick's law of diffusion, Page, Newton (Lewis) have been used to examine drying kinetics of food. (Midilli 2002).

Although dried products have some advantages like long shelf-life, shrinking during transportation; most of their raw material characteristics are regained by exposing them to water before using. This process known as rehydration is theoretically just the opposite of drying. Many studies have been carried out about damp diffusion in water of dried vegetables and fruits; and various models like Peleg, Weibull and Becker have been applied. (Apar 2009).

In this study; sun-drying of the green beans in open air, and after being dried, its rehydration at different temperatures have been examined. Using Lewis, Wang, Singh, and Midilli models in dehydration; Peleg, Exponential, and First Order Kinetics models in rehydration; the most appropriate models have been determined to describe dehydration and rehydration kinetics of the green beans.

2. Experimental

In this study, the green beans bought from a supermarket in Istanbul have been sun-dried. Before the drying process, strings of the green beans have been cleaned, their tips have been cut and the beans have been cut into pieces that are 3-4 centimetres long.

Before drying, being applied two different pre-treatments, the green beans have been dried with three different ways. (as being natural and pre-treated samples). Application of pre-treatments have been given in the Table 1 below. Firstly the determination of dry matter and damp have been carried out for the samples taken with the aim of drying. In a sample jar whose tare was determined in advance, the samples that were weighed at about 10 g were regulated to 105 ^{o}C and have been dried (about 4 hours) in Memmert disinfector till it reaches to a fixed weighing. (AOAC, 1990). After being waited in desiccator for half an hour, the samples taken from disinfector have been weighed, and moisture contents of the samples have been calculated. Following the calculations, while dry matter content of the green beans have been found as 10,8%, initial moisture content has been found as 89,2%.

Natural and pre-treated green beans that are definite at weight have been put into sifter trays and left to sun-drying. They have been weighed hourly and the temperature rates have been recorded at every weighing. In weighing process, electronic scale has been used (Radwag AS/310/C/2). The drying hours period is between 8.30 and 20.30. The tests have been continued till the samples reach a constant weighing. Then, the dried samples have been preserved in low density polythlene envelopes (LPDE) for rehydration tests.

2.1. Mathematical Modeling of Drying Curves

In order to determine the effects of sun-drying on drying rate, the dried green beans have been weighed at regular intervals and the changes emerged at moisture rate during drying time have been calculated according to the equation below:

$$MR_D = \frac{M_t - M_e}{M_0 - M_e}$$

In equation, M_t is at any *'t'* time, M_0 is at initial time and *Me* is the equilibrium moisture contents of the product. As it is also seen in the Figure 1, moisture loss of the beans is high at the beginning, and decreasing in time, this rate reaches a stable value. The drying time of natural beans has been determined as 25 hours, beans that have been plunged into the salty water been determined as 22 hours, and the boiled ones as 19 hours. Three models that have been adapted to test results in order to examine drying kinetics have been given in Table 2.

2.2. Regration Analysis of Drying

Statistica (Version 10) programme has been used in regration analysis. Regration coefficient (R^2) has been taken as key criterion in order to choose the equation determining the drying curves of the products. In order to explain the adaptation statistically between the models found experimently and seperable moisture rate values which is predicted with models, standard error of estimate (RMSE) and x square value (x^2) have been calculated with the equations below. (Tunç and Menges, 2010). Standard error of estimate (RMSE) shows deviation between the predicted rates obtained with models and the experimental values. It has been indicated that the value of adaptation increases, with decreasing value of X-square which shows the degree of goodness. Besides these, being close to 1, modeling adequacy (R^2) value of the model which explains experimetal data is an indication of the model's applicability.

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N} \left(MR_{pre,i} - MR_{\exp,i} \right)^2 \right]^{1/2}$$

$$\chi^2 = \frac{\sum_{i=1}^{N} \left(MR_{\exp,i} - MR_{pre,i} \right)^2}{N - z}$$

$MR_{exp,\ i}$ and $MR_{pre,\ i}$ are respectively experimental and predicted non-dimensional moisture rates; N is observation number, n is the number of constraints in the model. For a quality adaptation, high R^2 value and low χ^2 value and RMSE values have been required. (Lee ve Kim, 2008).

In dehydration of the green beans, the coefficients calculated by using curve fitting method and Statistica programme are seen as a, k, n, b; and R^2, RMSE, χ^2 values acquired by using of these coefficients are seen in Table 3. Statistical data

belonging to three models which have been used to express drying event occured in drying stage at falling-rate period of the green beans has been examined and seperable humidity rate has been provided by Midilli model in every three tests with minimum error. For this reason, Midilli model as being the most stable model given in Equation 4, has been determined in order to examine the change occured temporaly in the moisture content of the green beans.

$MR = a\ exp(-kt^n) + bt$

Through the use of these coefficients, it is possible to determine the most suitable seperable moisture rate (MR) of the beans in given working conditions. In drying of the beans, Standard error of estimate (RMSE) that is made of this model changes between 0.075983 and 0.112813. Concordantly, as it is seen in Table 3, X- square (χ^2) values, being quitely close to zero, are between 0.000482 and 0.005298; and modelling adequecy of the model has been acquired between (R^2) 0.9830 and 0.9936.

2.3. Rehydration

Sun-dried in three different ways and packaged beans have then been subjected to rehydration tests at 25 ^oC ve 45 ^oC temperatures. Weighed samples have been put into the beakers which contain 100 ml of distillated water and have been weighed again after being taken out the beakers and dried with paper towel half-hourly. The tests have been continued till the samples reach stable weighing. The increase of weighing in rehydration has been calculated in the equation below:

$$M = \frac{M_t}{M_o}$$

In equation, M_o shows the first weight of the dried beans, M_t shows the weight at any 't' time. The graphics of the datas versus time which belong to the beans been dried in natural and two different pre-treaed ways, and subjected to rehydration tests at two different temperatures have been shown in Figure 2 and Figure 3 below. The rehydration rate which was high at first reaches a constant value starting to decrease after 5. and 6. hours. This finding accords with the studies of the other researchers who studied on the subject of rehydration before. (Maldonado et al. 2010). In rehydration tests that belong to dried beans, values acquired at 25 ^oC temperature are very close to eachother and the best result has been provided with the beans that are boiled. In rehydration tests that are at 45 °C temperature, the highest rehydration value has been reached by the beans dried naturally.

2.4. Mathematical Modeling of Rehydration Kinetics

Model equations that have been preferred in the examination of rehydration kinetics: Peleg model (Peleg 1988), Explonantiel model (Noshad et al. 2011) and First Order Kinetics model (Apar et al. 2009) have been shown in Table 4. Statistica (version 10) programme has been used again in the application of rehydration test results to the models and in regration analysis. In model equations M expresses moisture content of any 't' time, M_0; initial moisture content, t; rehydration time, k_1, k_2, k_{R1} *ve* k_{R2} coefficients, and; M_e; equilibrum moisture content. The models used

have been applied for the temperatures at 25°C and 45°C and mean values of the model parametres are shown at Table 5-6. As it is seen in the charts, in every three tests, as the temperature increases, the value of k_1 parameter used in Peleg model decreases. With the increase in temperature, the decrease of k_1 parameter shows the high rate of water absorption rate (Solomon, 2007). With the increase in temperature, k_2 parameter in Peleg model also decreases. On the other hand, k_{R1} and k_{R2} parameters in other two models increase as the temperature increases. As it is concluded from each model, k_1, k_2 and, Me parametres change inversely proportional with temperature. k_{R1} and k_{R2} values increase as the temperature increases. As it is seen in the models, water transfer is inversely proportional for k_1, k_2 and M_e, and directly proportional for k_{R1} and k_{R2} with the increase of temperature.

As it is seen in Table 5, R^2 values used for rehydration tests change between 0.938 and 0.998, RMSE values between 0.040141 and 0.174353, χ^2 values between 0.001294 and 0.039088. When R^2, RMSE and χ^2 values, acquired from these equations are compared, the values predicted with Peleg model are seen that it is in accord with the experimental data.

2.5. Model Equations

The moisture content relative to the dry basis is the ratio of the water weight to the dry weight of the product.

$$M = \frac{W_{wet}}{W_{dry}} \quad (1)$$

$$\frac{dM}{dt} = \left(\frac{M_{t+dt} - M_t}{dt}\right) \quad (2)$$

$$M = \frac{M_t - M_e}{M_{initial} - M_e} \quad (3)$$

$$\ln M = \ln \frac{8}{\pi^2} - \frac{D\pi^2}{4L^2}.t \quad (4)$$

Me : (g water/g dry material),

$M_{initial}$: initial humidity content of the product (g water/g dry material)

L half thickness of the solid in which diffusion takes place in meters

D (m^2/s) in Equation (4) is liquid diffusion coefficient and it is assumed to be constant when the equiation is derived. However, it is known that the iquid diffusion coefficient is a function of temperature and humidity content of the solid.

$$M_{linear} = A.T + B \quad (5)$$

$$M_{exponential} = Ae^{B.T} \quad (6)$$

$$M_{power} = A.T^{B} \quad (7)$$

$$M_{logarithmic} = A.\ln(T) + B \quad (8)$$

$$M_{polynomial} = A.T^{2} + B.T + C \quad (9)$$

2.6. Regression Analysis

Statistica program was used for regression analysis. The regression coefficient (R^2) was taken as the main criterion in choosing the equation that defines the drying curves fort he products. Moreover, the model, which is also used with values of the standard deviation of the estimate (RMSE) and chi-square (χ^2), was found appropriate (Equation 10-11).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(KH_{i,a} - KH_{i,d}\right)^2}{N}} \quad (10)$$

$$\chi^2 = \frac{\sum_{i=1}^{n}\left(KH_{i,d} - KH_{i,a}\right)^2}{N - n} \quad (11)$$

Here, KHa denotes the ampirical drying rate that is estimated via the model, KHd denotes the experimental drying rate, N denotes the number of experimental data and n the coefficient used in the model (D.K. Rabha et al 2017).

The standard error of prediction is the deviation between empirical and experimental values. This valuation is in the vicinity of zero. It is also stated that the correlation with the decrease of the value of the chi-square increases.

The diffusion coefficients were calculated by using equation (4). The slope of the line obtained when period of drying is plotted against $\ln\frac{\pi^2 M}{8}$ gives $(\pi^2 D/4L^2)$. Since the half thickness (L) of the solid into which diffusion takes place is known the diffusion coefficient can be calcualted as m^2/s. L is take to be 1.

3. Results and Discussion

In this study, being subjected to natural process and pre-treatment, sun-drying of the green beans in three different ways and the rehydration tests of these dried beans have been examined at 25 ^oC and 45 ^oC temperatures. During drying, the initial drying rate was very high, and then some decrease has been observed in this tendency in time. The longest drying time has been observed in the beans that have been dried naturally. The results obtained have shown that pre-treatment is effective in drying of the beans and it decreases the drying time. The shortest drying time has been obtained from the beans that were dried by plunging into the hot water. The drying time of the beans that were plunged into the hot water

achieves savings of 6 hours compared to the drying time of the beans dried naturally. Experimental data has been regulated to drying models and this regulation has been determined by using R^2, RMSE and $\chi 2$ values. It has been decided that Midilli model, giving the highest value of R^2, the lowest value of $\chi 2$, and RMSE values, is the best model equation in explaining of drying beans.

The rehydration tests of the green beans at 25 °C ve 45 °C temperatures have been performed and it is seen that the rehydration increases as the temperature increases. In rehydration, the best result has been provided by boiled green beans for 25 °C, and the best result has been provided by the beans dried naturally for 45 °C. In rehydration tests, beans have been confirmed to be able to get between 3,5 and 5 times as much water as their dry weight. In model equations that are used for each temperature in rehydration, it has been decided that Peleg model is the best model equation giving the highest value of R^2, the lowest value of χ^2, and RMSE.

The parameters can include the parameters that affect drying, speed and humidity of air, type and porosity of the solid that is dried, temperature, pressure of the medium. While a solid is dried two different phenomena take place at the same time, wich are namely, transfer of heat to the material dried and the mass transfer which happens as passage of internal liquid and vapor. Both the heat and mass transfer processes are effective parameters in resolving the rate of drying.

In this study, at the beginning a fast drying zone would be observed as long as the surface characteristics of the solid, which is to be dried, and the drying air come to equilibriumwith the surface conditions of the matter to be dried. In other words, the rate of vaporization of humidity from the surface is equal to the rate humidity rises from inside the solid matter to the surface. In the decreasing rate region the rate humidity vaporizes from the surface is greater than the rate the humidity rises to the surface.

In regression analysis MathCad program was used. The regression coefficient (R^2) is taken to be the main criterion in choosing the equation that defines the drying curves of the products. Moreover, the model that can also be used with the standard deviation of the estimate (RMSE) and chi-square (χ^2) is determined to be appropriate. The standard deviations between the experimental and the model equations would allow a comparison to be made for the most appropriate model.

While for beans kept in natural and salt the most appropriate model was determined to be the exponential model, for boiled beans the polynomial model was determined to be the most appropriate model. Also in the rehydration experiments the most appropriate models were observed according to the R^2 values. The data in Table 7 were obtained via Linear Regression whereas the data in Table 8 were obtained via non-linear Regression.

In the equations used in the studies, separate model equations are applied for each experiment.

While for beans kept in natural and salt the most appropriate model was determined to be the exponential model, for boiled beans the polynomial model was determined to be the most appropriate model. Also in the rehydration

experiments the most appropriate models were observed according to the R^2 values. The data in Table 7 were obtained via Linear Regression whereas the data in Table 8 were obtained via non-linear Regression.

In Table 2 comparisons were made with the most commonly used model equations. Also for the Lewis, Page, Modifiye Page, Henderson and Pabis Models the most appropriate models are presented in the table. It was observed that the Modifies Page model was the most appropriate model for all experimental conditions. In Table 9 diffusion coefficients were calculated according to the conditions for each experiment.

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Attachments

Figure 1. Moisture ratio of the green beans versus time

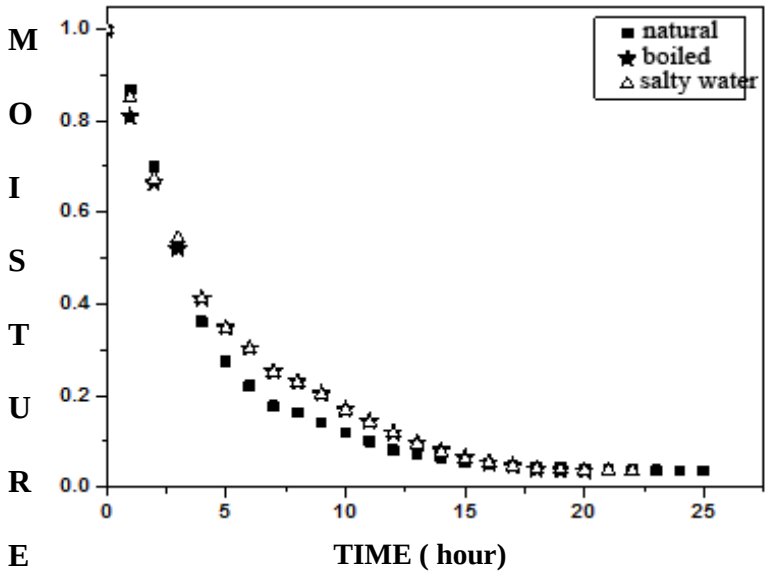


Figure 2. Rehydration curves of the green beans at 25 °C

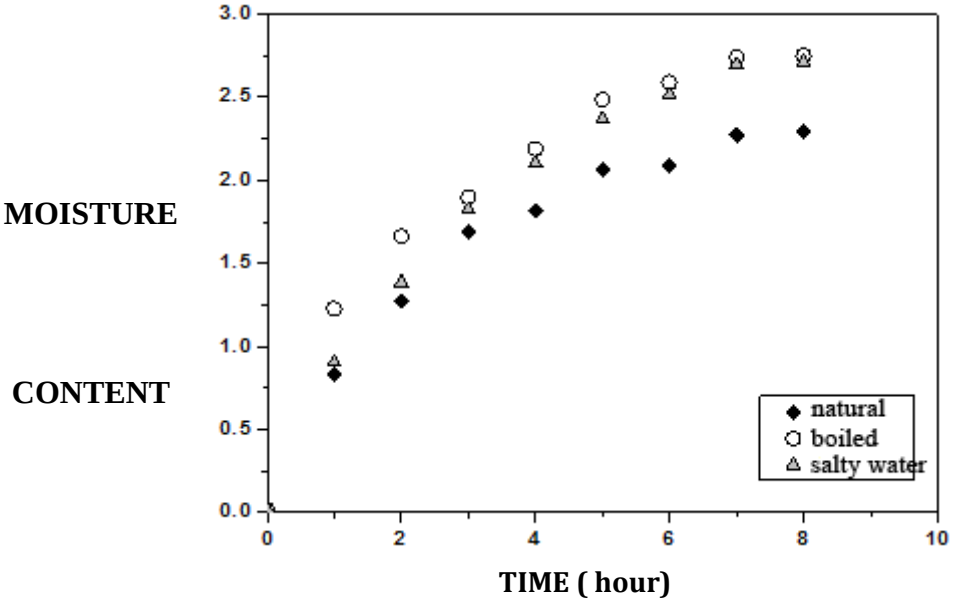
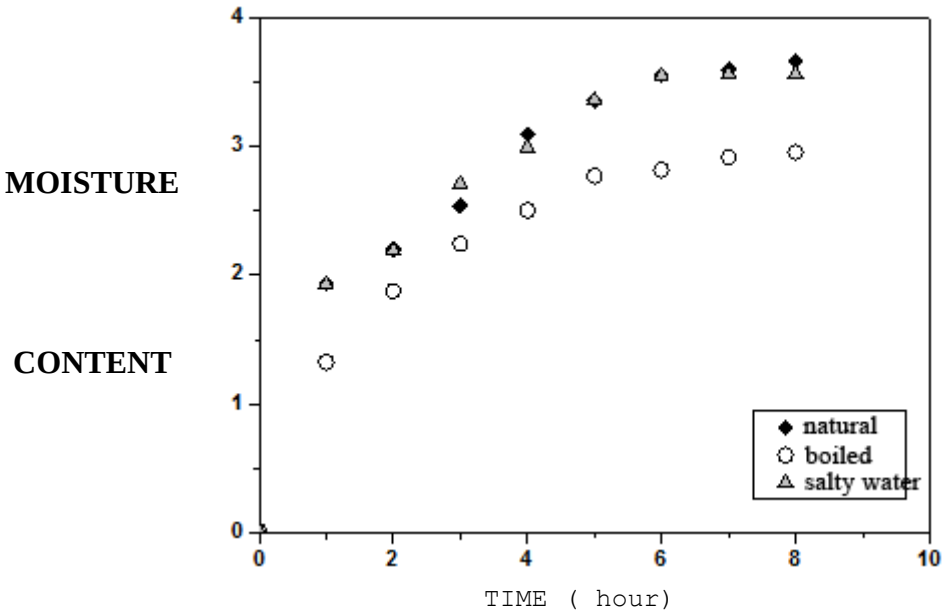


Figure 3. Rehydration curves of the green beans at 45 °C



Highlights

The Phaseolus Vulgaris was investigated to dry by the Sun and the phaseolus were examined rehydration and kinetics were with models equation. Wang, Singh, Lewis and Midilli models have been used to examine the drying kinetics of the beans; Peleg, Exponential and First Order Kinetics models have been used in order to examine rehydration kinetics. The closest results for the experimental data have been provided with Midilli model for dehydration, and Peleg model for rehydration.Which model equation was investigated by regression analysis.

Table 1. List of the pretreatment methods

Pre-Treatments	Explanation
Salty Water	The samples have been waited for 1 minute in 10 per cent of salty water solution at room temperature.
Boiled	The samples have been waited for 1 minute in water at 85 ^{o}C temperature. Then, the samples have been plunged into water at room temperature and waited for 3 minutes.
Natural	No pre-treatment has been performed.

Table 2. Dehyration model equations

Model Name	Model Equation	Source
Wang ve Singh	$MR=1+at+bt^2$	Wang ve Singh 1978
Lewis	$MR=\exp(-kt)$	Lewis 1921
Midilli	$MR=a\exp(-kt^n)+bt$	Midilli 2002

Table 3. The coeffients obtained with the dehyration models

Model	**Wang ve Singh**			**Lewis**			**Midilli et al.**		
Pre-Treatments	Salty Water	Boiled	Natural	Salty Water	Boiled	Natural	Salty Water	Boiled	Natural
Model Constants	a= 0.138595 b=0.004732	a=-0.127908 b=0.004179	a=-0.145957 b=0.005104	k=0.215201	k=0.195552	k=0.250618	a=1.083237 b=0.002342 k=0.248783 n=0.652312	a=0.970236 b=0.003064 k=0.235335 n=0.598376	a=1.061785 b=0.002100 k=0.271002 n=0.450918
R^2	0.9715	0.9749	0.9137	0.9713	0.9718	0.9368	0.9936	0.9931	0.9830
RMSE	0.170222	0.161506	0.316063	0.181405	0.174130	0.270159	0.075983	0.081297	0.112813
χ^2	0.002061	0.001853	0.006943	0.001968	0.001974	0.004768	0.000482	0.000533	0.005298

Table 4. Rehydration model equations

Model Name	Model Equation
Peleg Equation	$M = M_o + \frac{t}{k_1 + k_2 t}$
First order rehydration kinetics equation	$M = M_e + (M_o - M_e)\exp(-k_{R1}t)$
Exponential related equation	$M = M_e\left[1 - \exp(-k_{R2}t)\right]$

Table 5. The regression analysis for the rehydration of the green beans (25 °C)

Model	Pre-Treatments	Model Constants		R^2	RMSE	χ^2
	Salty Water	k_1=1.66033	k_2=0.29023	0.998	0.040141	0.002072
Peleg	Hot Water	k_1=1.36231	k_2=0.37548	0.997	0.037786	0.001836
	Natural	k_1=1.90104	k_2=0.40107	0,996	0.046652	0.002800
First order rehydration kinetics equation	Salty Water	k_{R1}=0.15106	M_e=3.04250	0.993	0.073929	0.007028
	Hot Water	k_{R1}=0.14039	M_e=3.01772	0.972	0.132387	0.022534
	Natural	k_{R1}=0.10582	M_e=3.07064	0.973	0.114709	0.016919
Exponential related equation	Salty Water	k_{R2}=0.16802	M_e=3.06432	0.987	0.101112	0.013146
	Hot Water	k_{R2}=0.14901	M_e=3.09003	0.941	0.174353	0.039088
	Natural	k_{R2}=0.11312	M_e=3.15897	0.938	0.154326	0.030624

Table 6. The regression analysis for the rehydration of the green beans (45 °C)

Model	Pre-Treatments	Model Constants		R^2	RMSE	χ^2
	Salty Water	k_1=0.67175	k_2=0.20499	0.968	0.170059	0.037186
Peleg	Hot Water	k_1=0.96848	k_2=0.36756	0.998	0.031724	0.001294
	Natural	k_1= 0.67670	k_2=0.29910	0,984	0.014121	0.025642
First order rehydration kinetics equation	Salty Water	k_{R1}=0.24685	M_e=3.01250	0.984	0.200230	0.051552
	Hot Water	k_{R1}=0.18677	M_e=2.98696	0.960	0.177186	0.040369
	Natural	k_{R1}=0.32207	M_e=3.04064	0.972	0.186125	0.044545
Exponential related equation	Salty Water	k_{R2}=0.27154	M_e=3.04327	0.949	0.215671	0.059810
	Hot Water	k_{R2}=0.20423	M_e=3.07900	0.951	0.195593	0.049192
	Natural	k_{R2}=0.35355	M_e=3.13897	0.968	0.197452	0.050131

Table 7. Regression coefficient for model equations

	Model	A	B	C	R^2
Moisture loss percentage Natural Beans	Linear				
	Exponential	0,7665	-0,165	-	0,9611
	Power				
	Logarithmic	-0,066	0,3083	-	0,76
	Polynomial	0,0029	-0,1036	0,8998	0,9328
Moisture loss percentage Boiled Beans	Linear				
	Exponential	0,8689	-0,151	-	0,9932
	Power				
	Logarithmic	-0,064	0,3308	-	0,78
	Polynomial	0,0025	-0,0945	0,8915	0,9536
Moisture loss percentage Salty Beans	Linear				
	Exponential	0,8533	-0,154	-	0,99
	Power				
	Logarithmic	-0,065	0,3271	-	0,77
	Polynomial	0,0026	-0,0974	0,9	0,95
Natural Beans Rehydration 25 °C	Linear	0,153	0,9733		0,76
	Exponential	0,9437	0,108		0,70
	Power	0,7711	0,5271	-	0,8853
	Logarithmic	0,7088	0,7444	-	0,9582
	Polynomial	-0,0318	0,503	0,2733	0,9729
Boiled Beans Rehydration 25 °C	Linear	0,1627	1,36	-	0,8627
	Exponential	1,4054	0,0805	-	0,8165
	Power	1,2662	0,3623	-	0,9688
	Logarithmic	0,7112	1,1808	-	0,966
	Polynomial	-0,025	0,4377	0,81	0,993
Salty Beans Rehydration 25 °C	Linear	0,1988	1,0367	-	0,821
	Exponential	1,065	0,1148	-	0,74
	Power	0,8888	0,5377	-	0,9456
	Logarithmic	0,8911	0,784	-	0,967
	Polynomial	-0,0362	0,5967	0,2408	0,995
Natural Beans Rehydration 45 °C	Linear	0,2052	1,9267		0,8506
	Exponential	1,9827	0,074		0,8185
	Power	1,8097	0,3298	-	0,9537
	Logarithmic	0,8938	1,7049	-	0,9464
	Polynomial	-0,0322	0,5593	1,2183	0,9846
Boiled Beans Rehydration 45 °C	Linear	0,1418	1,67	-	0,7542
	Exponential	1,6687	0,0657	-	0,71
	Power	1,4969	0,3112	-	0,928
	Logarithmic	0,6556	1,4597	-	0,9448
	Polynomial	-0,0309	0,4814	0,9908	0,9829
Salty Beans Rehydration 45 °C	Linear	0,2006	2,0267	-	0,83
	Exponential	2,071	0,0708	-	0,80
	Power	1,8883	0,3188	-	0,9518
	Logarithmic	0,8838	1,7951	-	0,9464
	Polynomial	-0,0341	0,5756	1,2767	0,9856

Table 8. Regression coefficient for model equations

Model	Experimental	k	a	n	c	R^2
Lewis Model M = exp(-kt)	Moisture loss natural beans	5,822	-	-	-	0,961
	Moisture loss boiled beans	6,567	-	-	-	0,993
	Moisture loss salty beans	6,414	-	-	-	0,990
	Rehydration natural beans 25 °C	3,926	-	-	-	0,913
	Rehydration boiled beans 25 °C	4,153	-	-	-	0,929
	Rehydration salty beans 25 °C	4,088	-	-	-	0,914
	Rehydration natural beans 45 °C	3,58	-	-	-	0,906
	Rehydration boiled beans 45 °C	4,118	-	-	-	0,920
	Rehydration salty beans 45 °C	3,834	-	-	-	0,919
Page Model $M = \exp(-kt^n)$	Moisture loss natural beans	2,134	-	0,7	-	0,979
	Moisture loss boiled beans	4,706	-	0,9	-	0,996
	Moisture loss salty beans	3,283	-	0,8	-	0,995
	Rehydration natural beans 25 °C	14,911	-	1,4	-	0,925
	Rehydration boiled beans 25 °C	30,317	-	1,6	-	0,952
	Rehydration salty beans 25 °C	29,868	-	1,6	-	0,938
	Rehydration natural beans 45 °C	13,607	-	1,4	-	0,918
	Rehydration boiled beans 45 °C	30,123	-	1,6	-	0,946
	Rehydration salty beans 45 °C	24,103	-	1,55	-	0,940
Modifiye Page $M = \exp(-(kt)^n)$	Moisture loss natural beans	3,105	-	0,70	-	0,977
	Moisture loss boiled beans	5,392	-	0,88	-	0,996
	Moisture loss salty beans	4,776	-	0,83	-	0,997
	Rehydration natural beans 25 °C	1,293	-	0,5	-	0,964
	Rehydration boiled beans 25 °C	1,585	-	0,5	-	0,959
	Rehydration salty beans 25 °C	1,533	-	0,5	-	0,970
	Rehydration natural beans 45 °C	1,364	-	0,5	-	0,975
	Rehydration boiled beans 45 °C	1,590	-	0,5	-	0,961
	Rehydration salty beans 45 °C	1,603	-	0,5	-	0,974
Henderson and Pabis M = (a)exp(-kt)	Moisture loss natural beans	0,165	0,7665	-	-	0,961
	Moisture loss boiled beans	0,151	0,8689	-	-	0,993
	Moisture loss salty beans	0,154	0,853	-	-	0,99
	Rehydration natural beans 25 °C	-0,108	0,943	-	-	0,70
	Rehydration boiled beans 25 °C	-0,0805	1,4054	-	-	0,8165
	Rehydration salty beans 25 °C	-0,1148	1,065	-	-	0,74
	Rehydration natural beans 45 °C	-0,074	1,982	-	-	0,8185
	Rehydration boiled beans 45 °C	-0,0657	1,668	-	-	0,71
	Rehydration salty beans 45 °C	-0,0708	2,071	-	-	0,80

Table 9. Regression coefficient for account in experimental study

Experiments	Diffusion Coefficient (m^2/s)	R^2
Moisture loss natural beans	$5,313 \times 10^{-8}$	0,961
Moisture loss boiled beans	$5,993 \times 10^{-8}$	0,993
Moisture loss salty beans	$5,853 \times 10^{-8}$	0,990
Rehydration natural beans 25 ℃	$3,583 \times 10^{-8}$	0,913
Rehydration boiled beans 25 ℃	$3,790 \times 10^{-8}$	0,929
Rehydration salty beans 25 ℃	$3,730 \times 10^{-8}$	0,914
Rehydration natural beans 45 ℃	$3,267 \times 10^{-8}$	0,906
Rehydration boiled beans 45 ℃	$3,758 \times 10^{-8}$	0,920
Rehydration salty beans 45 ℃	$3,498 \times 10^{-8}$	0,919

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