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PEA GRAINS IN DRYING: UNRAVELING THE KINETICS OF HOT-AIR DRYING AND EXPLORING MATHEMATICAL MODELS FOR MOISTURE DIFFUSION

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Abstract: Pea drying studies were assessed to learn more about the kinetics and properties of drying in a hot-air dryer. Research was done on impact of temperatures and pre-treatments on drying behaviours. The drying rate graphs demonstrated that the entire drying procedure took place when rates were declining. To properly understand the experimental data, four mathematical models (Henderson & Pabis, Page, Wang & Singh, and Aghbashlo et al.) were used. The Page model was discovered to be the ideal one to depict peas' curves of drying. The identification of the Page model as the most suitable for depicting pea drying curves underscored the applicability in modeling drying behaviors in similar agricultural products. With Fick's second law of diffusion, effective moisture diffusivity (D_{eff}) sorted from $2.45x10^{-10}$ to $6.55x10^{-10}$ m^2/s at given temperature. D_{eff} was expressed as a function of temperature with an Arrhenius type equation. For samples from Potas, Blanch, and Control codes, the activation energy for moisture diffusion was computed as 21.48, 22.82, and 22.32 kJ/mol, respectively. The computation of activation energy for moisture diffusion for different samples offered practical information for optimizing drying processes under various conditions. The results showed the importance of pea drying kinetics and practical implications for industry on drying efficiency and product quality.
Keywords: Drying kinetics, pea, effective moisture diffusivity, Page model

BEZELYE TANELERİNİN KURUTULMASI: SICAK HAVA KURUTMA KİNETİĞİNİN ÇÖZÜMLENMESİ VE NEM DİFÜZYONU İÇİN MATEMATİKSEL MODELLERİN İNCELENMESİ

Özet: Sıcak hava kurutucusunda kurutmanın kinetiği ve özellikleri hakkında daha fazla bilgi edinmek için bezelye kurutma çalışmaları değerlendirilmiştir. Sıcaklıkların ve ön işlemlerin kurutma davranışları üzerindeki etkisi üzerine araştırma yapılmıştır. Kurutma hızı grafikleri, kurutma prosedürünün tamamının hızlar düşerken gerçekleştiğini göstermiştir. Deneysel verileri doğru bir şekilde anlamak için dört matematiksel model (Henderson & Pabis, Page, Wang & Singh, ve Aghbashlo vd.) kullanılmıştır. Page modelinin, bezelyelerin kuruma eğrilerini tasvir etmek için ideal model olduğu keşfedilmiştir. Page modelinin bezelye kuruma eğrilerini tasvir etmek için en uygun model olarak tanımlanması, benzer tarım ürünlerinde kuruma davranışlarının modellenmesinde uygulanabilirliğin altını çizmiştir. Fick'in ikinci difüzyon yasasına göre, efektif nem difüzivitesi (D_{eff}), belirli sıcaklıkta $2.45x10^{-10}$ to $6.55x10^{-10}$ m^2/s arasında sıralanmıştır. D_{eff}, Arrhenius tipi bir denklemle sıcaklığın bir fonksiyonu olarak ifade edilmiştir. Potas, Blanch ve Kontrol kodlarından alınan numuneler için nem difüzyonuna yönelik aktivasyon enerjisi sırasıyla 21.48, 22.82 ve 22.32 kJ/mol olarak hesaplanmıştır. Farklı numuneler için nem difüzyonuna yönelik aktivasyon enerjisinin hesaplanması, çeşitli koşullar altında kurutma proseslerinin optimize edilmesi için pratik bilgiler sunmuştur. Sonuçlar, bezelye kurutma kinetiğinin önemini ve endüstri için kurutma verimliliği ve ürün kalitesi üzerindeki pratik sonuçlarını göstermiştir.
Anahtar Kelimeler: Kurutma kinetiği, bezelye, efektif nem difüzivitesi, Page modeli

INTRODUCTION

Due to great amount of high fiber content, protein, vitamins, minerals, and other nutrients, low fat and absence of cholesterol, the pea (Pisum sativum L.) is one of the most widely farmed edible legumes in the world (An et al., 2010). Turkey has produced 107344 tons of peas in 2018 on an area of 10917 acres (FAO, 2020). Peas must be preserved in some way, such as canning, freezing, or cold storage, because they are both seasonal and perishable, making them unavailable for immediate use. An alternative method of preserving peas is drying technique. Because they have a longer shelf life, they are more palatable and easier to transport and handle. Thus, dried peas become more and more popular (Pardeshi et al., 2009).

In the food industry, drying is a conventional or industrial preservation technique. To minimize the growth of bacteria, enzymatic processes, and other biochemical activities, it is frequently utilized to reduce the moisture content and water activity of food (Doymaz, 2011; Li et al., 2016). Drying is an intricate and unsteady thermal process. It is essential from an engineering perspective to maintain control over the variables of this complex process. Numerous mathematical models are employed to control the drying process or to improve new or existing drying systems (Demirpolat et al., 2022). According to Doymaz (2013), the models can be divided into various categories. Recent mathematical modeling studies and experimental research on the drying properties of peas have been conducted (Pardeshi et al., 2009; Jadhav et al., 2010; Pandey et al., 2019; Taşova, 2019; Kaveh et al., 2021; Skulinová et al., 2011). Due to waxy layer covering the pea's surface, drying of peas requires a long time. However, by applying a specific chemical pre-treatment that increases the moisture diffusivity of the waxy layer, the drying method's effectiveness can be improved (Brar et al., 2020). Additionally, they provide a high-quality dried product and speed up drying by loosening tissue structure. Some of the most common and widely used as pre-treatments are citric acid, sodium chloride etc. In the literature, there have been several research for drying peas using chemical pre-treating (Burande et al., 2008; Jadhav et al., 2010; Doymaz and Kocayigit, 2011). One pre-treatment technique used to halt several physiological processes before drying fruits and vegetables is blanching. Enzymes that cause undesirable reactions, like enzymatic browning and oxidation during processing and storage, are revealed when the enzymes are inactivated. Additionally, drying time is shortened. Additionally, the elimination of intercellular air from tissues, which softens the tissue and causes the retention of carotene and ascorbic acid, are factors that affect storage (Jadhav et al., 2010).

The major goals of this study are to find out how green pea drying, and rehydration behaviors are impacted by drying temperature and pre-treatments. Other objectives of this study include computing activation energy and the effective moisture diffusivity of green peas, as well as fitting experimental results to four mathematical models. By assessing how different temperatures and pre-treatments influence the drying process, the research shed light on optimizing drying conditions for peas, which can have implications for industrial drying processes. Among the four mathematical models, the study identifies the Page model as the most suitable for depicting the drying curves of peas. This finding provides valuable guidance in selecting the appropriate model for modeling and predicting drying behavior in similar subjects. By applying Fick's second law of diffusion, the study estimates the effective moisture diffusivity at different temperatures.

The study calculates the activation energy for moisture diffusion for samples from different treatments (Potas, Blanch, and Control codes). Additionally, this study advances the understanding of pea drying kinetics and properties offering valuable insights and methodologies that can be applied in the optimization of drying processes not only for peas but also for other agricultural products. The findings contribute to the broader literature on drying kinetics, modeling, and process optimization in the field of food engineering and agricultural sciences. While previous research may have examined drying processes in general on other crops, this study delves into the intricacies of pea drying including the impact of temperature variations and pre-treatments on drying behaviors. The utilization of multiple mathematical models and the identification of the Page model as the most suitable for depicting pea drying curves contribute novel insights to the literature. Overall, the unique focus on peas, coupled with the comprehensive approach to analyzing drying kinetics and properties, distinguishes this study from existing literature in the field of agricultural drying.

MATERIAL AND METHODS

Sample Preparation

In Istanbul, Turkey, fresh green peas (Pisum sativum) are bought at a neighboring market. After a visual inspection, the dry, immature, and fractured pods are manually removed. Hand-shelled pea pods are used. Average diameter for peas is 1.0±0.1 cm. Before drying, the pea samples are split into three sample lots. 4% potassium carbonate (Potas code) (Sigma-Aldrich, ACS reagent 99.0%) is added to an aqueous solution that is used to soak one batch of pea samples for three minutes. The second batch of pea samples is placed in boiling water for three minutes (Blanch code). The other lot (Control code) is left untreated. The initial moisture content of peas is assessed utilizing a standard approach (AOAC 1990), which involve vacuum drying them during 24 hours at 70°C over a desiccant consisting of magnesium sulfate. To get a reliable average, this is done as three times. The samples' original moisture content is determined to be 72.70% on a wet basis (2.663 kg water/kg dry matter). Standard deviation is found as approximately 0.0082%.

Drying Procedure

The cabinet dryer (APV & PASILAC, UK) is used to dry the pea samples (Figure 1). To create steady-state conditions, the dryer is started around 30 minutes before experimental part. At constant air speeds of 2 m/s and air temperatures of 50, 60, 70, and 80°C, the drying experiments are carried out. A Testo 440 vane probe anemometer (Lutron, AM-4201, Taiwan) is used to measure air velocity. The surfaces of the samples are crossed by horizontal airflow. The sample, which weighed roughly 50 g, is then put in the dryer. The weight loss of the peas is monitored with a digital scale (model

BB3000, Mettler-Toledo AG, Grefensee, Switzerland) for a measuring range of 0-3000 g and a reading precision of 0.1 g. When samples have a moisture level of roughly 0.17 kg water/kg dry matter (d.b), drying is completed. The dry peas' low-density polyethylene bags are then chilled and heat-sealed. Two-way analysis of variance is carried out to examine drying data with a 0.05 level of significance.

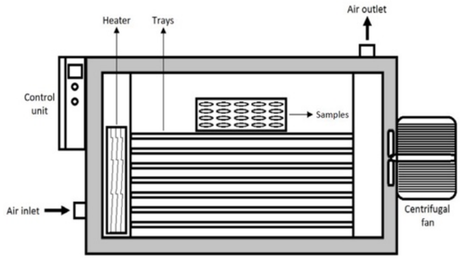

Figure 1. Experimental set up

Determination of Drying Parameters

The following formula (Eq. 1) is used to determine the experimental moisture content of pea pod waste over a specified period:

$$M = \frac{W_t - W_d}{W_d} \quad (1)$$

where W_t is the mass at time t (in kg), W_d is the mass at which a solid is bone-dry (also in kg), and M is the moisture content at that time (in kg water/kg dry matter). Following equation (Eq. 2) is utilized to calculate the moisture ratio (MR) for green peas:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (2)$$

where t is the drying time in minute unit and M_t, M_e and M_0, are the moisture contents at any time, equilibrium moisture content (kg water/kg dry matter) and starting moisture content, respectively. M_e can be equal to zero without a substantial M_0 since M_e values are relatively modest in comparison to M_0 (Pandey et al., 2019). Consequently, MR can be condensed to (Eq. 3):

$$MR = \frac{M_t}{M_0} \quad (3)$$

Eq. (4) is used to compute the drying rate (DR):

$$DR = \frac{M_{t1} - M_{t2}}{t_2 - t_1} \quad (4)$$

where M_{t1} and M_{t2} are the moisture contents (d.b) at those times, and t_1 and t_2 are the drying times (min).

Mathematical Modelling

Four drying models, which are often used to simulate drying curves, are employed to fit the data from the drying of peas (Table 1). Statistica 8.0.550 (StatSoft Inc., Tulsa, OK, USA) are used to analyze the data. A non-linear regression method based on the Levenberg-Marquardt method is used to estimate model parameters. The coefficient of determination (R^2) and root mean square error (RMSE) are utilized to define how well each model fit the experimental data. The following formulas are used to determine these parameters (Eq. 5, Eq. 6):

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^{N}(\overline{MR_{pre}} - MR_{exp,i})^2} \quad (5)$$

$$RMSE = \left[\frac{1}{2}\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2\right]^{\frac{1}{2}} \quad (6)$$

where $MR_{exp,i}$ and $MR_{pre,i}$, respectively, are the observed and predicted dimensionless moisture ratios, and N is the total observation number, z is the total number constant, and z is the total constant number. Higher R^2 and lower RMSE values demonstrate a better fit of the experimental data to the model (Pandey et al., 2019; Zhu, 2018).

Table 1. The drying models utilized to determine the drying curves

Model name	Model [1)]
Henderson & Pabis	$MR = a\exp(-kt)$
Page	$MR = \exp(-kt^n)$
Wang & Singh	$MR = 1 + at + bt^2$
Aghbashlo et al.	$MR = \exp\left(-\frac{k_1 t}{1 + k_2 t}\right)$

[1)] *Empirical constants and coefficients in drying models are a, b, k, k_1, k_2, and n.*

Determination of Effective Moisture Diffusivity

The following equation, which is a mass-diffusion equation in a period of falling rate, illustrates Fick's second law of diffusion:

$$\frac{\partial MR}{\partial t} = D_{eff}\nabla^2 . MR \quad (7)$$

For unstable state diffusion in spherical coordinates, Fick's second rule (Eq. 7) can be analytically solved under the following circumstances, according to Crank (1975): Low shrinkage, consistent effective diffusivity, diffusion-based moisture migration, and drying process temperature:

$$MR = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left(-n^2\pi^2\frac{D_{eff}t}{r^2}\right) \quad (8)$$

For lengthy drying intervals, Eq. (8) can be simplified even further by only using the first component in the series. As a result, Eq. (9) is given as follows in a logarithmic form:

$$ln(MR) = ln\left(\frac{6}{\pi^2}\right) - \left(\pi^2\frac{D_{eff}t}{r^2}\right) \quad (9)$$

Plotting the experimental drying data as ln (MR) vs time (min) reveals the effective moisture diffusivity. A plot of ln MR versus time using Eq. (9), which has the following slope (Eq. 10):

$$Slope = \frac{\pi^2 D_{eff}}{r^2} \quad (10)$$

Computation of Activation Energy

It is believed that an Arrhenius-style equation can adequately capture the link between effective moisture diffusivity and air temperature (Eq. 11):

$$D_{eff} = D_0 exp\left(-\frac{E_a}{R(T+273.15)}\right) \quad (11)$$

Here, T is the temperature in degrees Celsius, E_a is the activation energy in kilojoules per mole, R is the universal gas constant in kilojoules per mole per kilogram, and D_0 is the preexponential factor in m^2/s. The slope and intercept of the plot of ln (D_{eff}) vs 1/(T+273.15) can be used to compute both kinetic parameters (E_a and D_0).

Rehydration Experiments

The samples are dried at various temperatures before being rehydrated at 20°C. Dried samples weighing 1.5 g of sample is put into glass beakers with distilled water in a ratio of 1:160 (w/w). After 300 minutes, the samples are taken out and weighed with an electronic digital scale (Precisa, model XB220A, Precisa Instruments AG, Dietikon, Switzerland) with a sensitivity of 0.001 g. According to Eq. (12), the rehydration capacity (RC) is determined.

$$RC = \frac{W_1}{W_2} \quad (12)$$

In this case, W_1 is the weight before rehydration, and W_2 is the weight after.

RESULTS AND DISCUSSION

Drying Curves

Figure 2 illustrates how drying peas' drying curves are affected by temperature. For vegetables of a similar type, the drying curves are typical. The moisture content decreases over the course of drying in every case study, and at higher air temperatures, it does so more quickly.

As the temperature increases, the moisture content decreases. At 50, 60, 70, and 80°C, the drying times necessary to estimate the end moisture content of the peas are 465, 405, 285 and 240 min for control samples, respectively. From 50 to 80°C, the samples' average drying rates increase by 1.937 times.

At higher temperatures, the increased heat absorption causes a greater driving force for mass transfer, a faster drying rate, and subsequently, a shorter drying time. Similar results are obtained, which support previous findings about peas (Doymaz and Kocayigit, 2011; Taskin et al., 2016; Pandey et al., 2019).

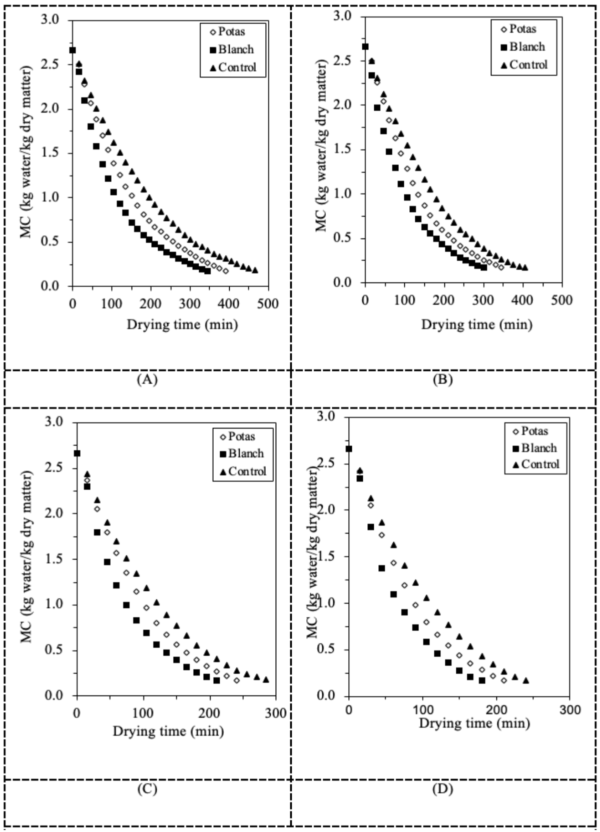

Figure 2. Pea drying curves at various temperatures, with and without pre-treatments (A: 50°C, B: 60°C, C: 70°C, D: 80°C)

Impact of Pre-Treatment Solution

Findings in Figure 2 show that pre-treatment is a key factor that influences drying time. In comparison to the other Potas and Control samples, the samples that are immersed in hot water before drying takes less time. In comparison to control samples, which requires 465 min for drying at 50°C to obtain a final water content of 0.17 kg water/kg dry matter, peas pre-treated with hot water blanching (Blanch code) and potassium carbonate solution (Potas code) take 345 and 390 min, respectively, to reach this water content. For samples of Blanch and Potas codes, the difference in drying periods is roughly 25.81% and 16.13%, respectively. These findings demonstrate that the pre-treatment solution increases the permeability of pea cell membranes, increasing water diffusivity. Similar patterns are seen while drying at 60, 70, and 80°C. Previous investigations on pea drying (Simal et al., 1996; Burande et al., 2008; Doymaz and Kocayigit 2011; Pandey et al., 2019) have documented the observed pre-treatment features.

Drying Rate

Figure 3 depicts the pea drying rate curves. In certain instances, a constant-rate period is not seen. The warming-up and falling-rate periods can be seen as two distinct periods in Figure 3, respectively. The existence of falling-rate drying behavior, according to Darvishi (2017), shows that the internal barrier to mass and heat transport is always increasing. The drying rate and moisture content are seen to be decreasing over time in Figure 3. Additionally, as the temperature rises, the rate of drying accelerates. When the peas' moisture content drops during the drying process, the drying rates gradually fall from their initial levels. The outcomes are in line with the findings of several authors who have observed the drying of different products (Pardeshi et al., 2009; Ponkham et al., 2012).

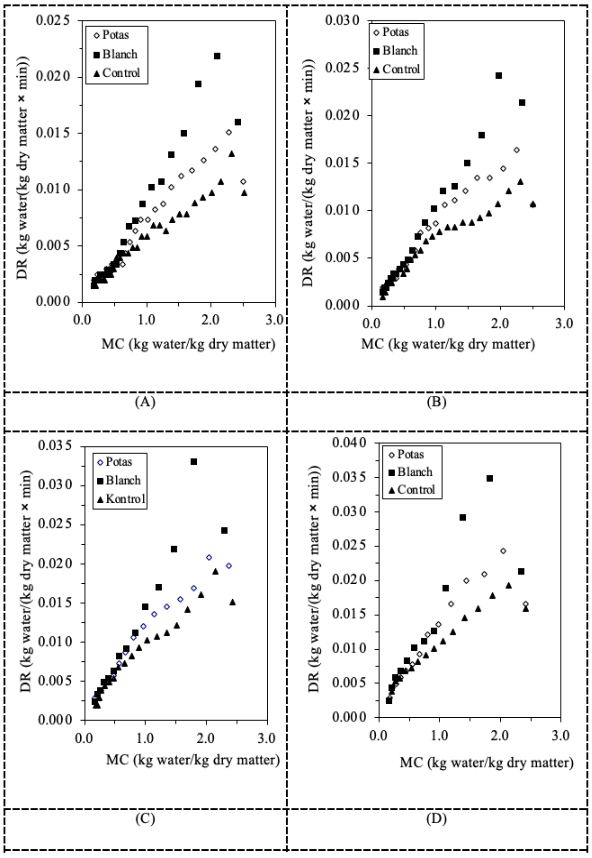

Figure 3. Moisture content vs drying rate for A: 50°C, B: 60°C, C: 70°C, D: 80°C

Assessment of Models

Four drying models are utilized to fit the moisture content data from the MR that is gathered at various temperatures (Table 1). The Page model, one of the thin-layer drying models, accurately predicts the kinetics of pea drying at all drying temperatures and coefficients different from other models (Table 2).

The model with the highest R^2 and lowest RMSE values is deemed to be the best. Table 3 displays the outcomes of the statistical calculation. Each model has an R^2 value greater than 0.98.

The models are given if the average R^2 values determined by applying the models are ranked highest to lowest: Page > Wang & Singh > Henderson & Pabis > Aghbashlo et al. The models are listed as follows if the average RMSE values are ranked from lowest to highest: Aghbashlo et al., Page, Wang & Singh, Henderson & Pabis, and others. This assessment led to the Page model being determined as the best representative model. In that situation, the data points on the plots have a common focal point that is a 45° straight line. Additional proof that the program can accurately predict how peas will dry is provided by this pattern by comparing predicted and experimental values (Figure 4). Different studies have reported similar findings in the literature (Senadeera et al., 2003; Yang et al., 2018).

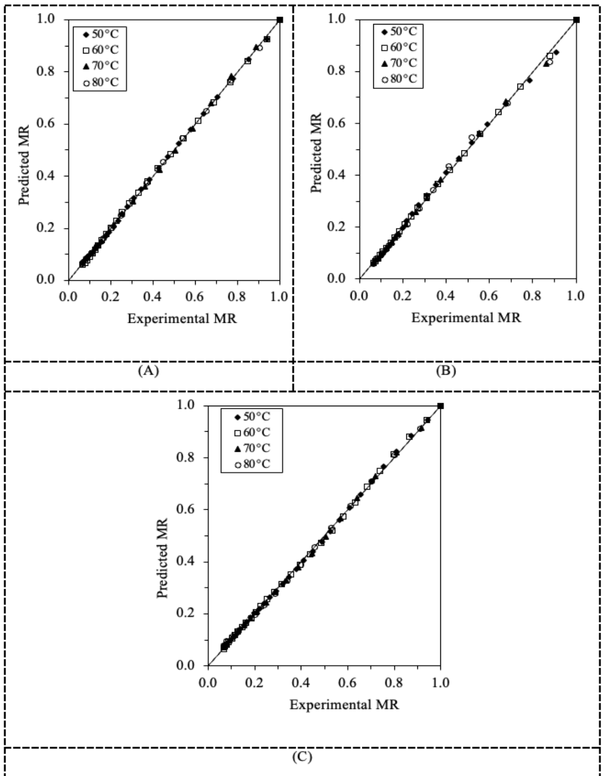

Figure 4. Comparison of experimental and predicted moisture ratio values using Page model (A: Potas, B: Blanch, C: Control)

Table 2. Coefficients of pea drying models at various temperatures

T (°C)	Code	Models	Coefficient-1	Coefficient-2
50	Potas	Henderson & Pabis	a=1.033200	k=0.006620
		Page	k=0.004176	n=1.082660
		Wang & Singh	a=-0.005090	b=0.000007
		Aghbashlo et al.	k_1=0.005899	k_2=-0.00039
	Blanch	Henderson & Pabis	a=1.000601	k=0.008403
		Page	k=0.009833	n=0.967951
		Wang & Singh	a=-0.006542	b=0.000012
		Aghbashlo et al.	k_1=0.008919	k_2=0.000390
	Control	Henderson & Pabis	a=1.032609	k=0.005307
		Page	k=0.002836	n=1.110415
		Wang & Singh	a=-0.004064	b=0.000005
		Aghbashlo et al.	k_1=0.004502	k_2=-0.000502
60	Potas	Henderson & Pabis	a=1.051832	k=0.007665
		Page	k=0.003482	n=1.146526
		Wang & Singh	a=-0.005745	b=0.000009
		Aghbashlo et al.	k_1=0.006343	k_2=-0.000732
	Blanch	Henderson & Pabis	a=0.996229	k=0.009503
		Page	k=0.010834	n=0.973517
		Wang & Singh	a=-0.007415	b=0.000015
		Aghbashlo et al.	k_1=0.009938	k_2=0.000296
	Control	Henderson & Pabis	a=1.049279	k=0.006171
		Page	k=0.002333	n=1.176208
		Wang & Singh	a=-0.004584	b=0.000006
		Aghbashlo et al.	k_1=0.004832	k_2=-0.000829
70	Potas	Henderson & Pabis	a=1.036354	k=0.010211
		Page	k=0.004958	n=1.145214
		Wang & Singh	a=-0.007735	b=0.000016
		Aghbashlo et al.	k_1=0.008367	k_2=-0.001173
	Blanch	Henderson & Pabis	a=1.012128	k=0.013032
		Page	k=0.011851	n=1.018354
		Wang & Singh	a=-0.010088	b=0.000028
		Aghbashlo et al.	k_1=0.012774	k_2=-0.000071
	Control	Henderson & Pabis	a=1.041003	k=0.008612
		Page	k=0.003878	n=1.154493
		Wang & Singh	a=-0.006461	b=0.000011
		Aghbashlo et al.	k_1=0.006914	k_2=-0.001073
80	Potas	Henderson & Pabis	a=1.055277	k=0.011777
		Page	k=0.004456	n=1.199866
		Wang & Singh	a=-0.008735	b=0.000021
		Aghbashlo et al.	k_1=0.009166	k_2=-0.001585
	Blanch	Henderson & Pabis	a=1.037488	k=0.014843
		Page	k=0.008894	n=1.108724
		Wang & Singh	a=-0.011211	b=0.000034
		Aghbashlo et al.	k_1=0.013020	k_2=-0.000982
	Control	Henderson & Pabis	a=1.050422	k=0.009713
		Page	k=0.003541	n=1.201108
		Wang & Singh	a=-0.007152	b=0.000014
		Aghbashlo et al.	k_1=0.007366	k_2=-0.001519

Table 3. Predicted statistical data from various models

Coefficient	T (°C)	Code	Models			
			Henderson & Pabis	Page	Wang & Singh	Aghbashlo et al.
R^2	50	Potas	0.9989	0.9996	0.9959	0.9989
		Blanch	0.9978	0.9982	0.9818	0.9988
		Control	0.9972	0.9995	0.9983	0.9998
	60	Potas	0.9969	0.9994	0.9978	0.9977
		Blanch	0.9993	0.9995	0.9846	0.9997
		Control	0.9940	0.9993	0.9996	0.9995
	70	Potas	0.9958	0.9996	0.9991	0.9997
		Blanch	0.9988	0.9987	0.9897	0.9987
		Control	0.9950	0.9993	0.9992	0.9997
	80	Potas	0.9940	0.9996	0.9981	0.9979
		Blanch	0.9958	0.9970	0.9928	0.9956
		Control	0.9924	0.9991	0.9994	0.9996
Average R^2			**0.9963**	**0.9990**	**0.9946**	**0.9988**
RMSE	50	Potas	0.0326	0.0247	0.0803	0.0353
		Blanch	0.0557	0.0432	0.1532	0.0297
		Control	0.0734	0.0275	0.0528	0.0168
	60	Potas	0.0605	0.0285	0.0565	0.0563
		Blanch	0.0298	0.0181	0.1330	0.0120
		Control	0.1022	0.0290	0.0236	0.0257
	70	Potas	0.0669	0.0160	0.0282	0.0161
		Blanch	0.0231	0.0235	0.0949	0.0197
		Control	0.0781	0.0284	0.0275	0.0142
	80	Potas	0.0751	0.0142	0.0390	0.0396
		Blanch	0.0475	0.0384	0.0759	0.0417
		Control	0.0896	0.0293	0.0237	0.0145
Average RMSE			**0.0612**	**0.0267**	**0.0657**	**0.0268**

Effective Moisture Diffusivity

D_{eff} values at various temperatures range from $2.45x10^{-10}$ to $6.55x10^{-10}$ m^2/s are shown in Figure 5. It is evident that as air temperature rises, D_{eff} values rise significantly as well. Drying at 80°C results in the highest D_{eff} value, while drying at 50°C results in the lowest value. Higher drying temperatures will ultimately result in more heating energy and more active water molecules, which means higher moisture diffusivity. Pre-treated samples have greater effective diffusion coefficient values than untreated samples (Control code). Therefore, it can be said that the pretreatment solutions alter the sample's structure to speed up drying. Samples that have been pre-treated with hot water and subsequently dried are where the substance with the highest effective diffusion coefficient is discovered. According to Zogzas et al. (1996), the range of D_{eff} values for drying food items is often between 10^{-12} and 10^{-8} m^2/s. The D_{eff} values are close to those for peas published in literature: $3.52x10^{-11}$-$5.66x10^{-10}$ m^2/s (Tao et al., 2018); $3.95x10^{-10}$-$6.23x10^{-10}$ m^2/s (Pardeshi et al., 2009); $4.05x10^{-11}$-$1.51x10^{-10}$ m^2/s (Jadhav et al., 2010); $8.05x10^{-11}$-$1.97x10^{-10}$ m^2/s (Doymaz and Kocayigit, 2011). The differences between the results can be explained by effect of type, pre-treatment solution, composition of peas and proposed model used for calculation.

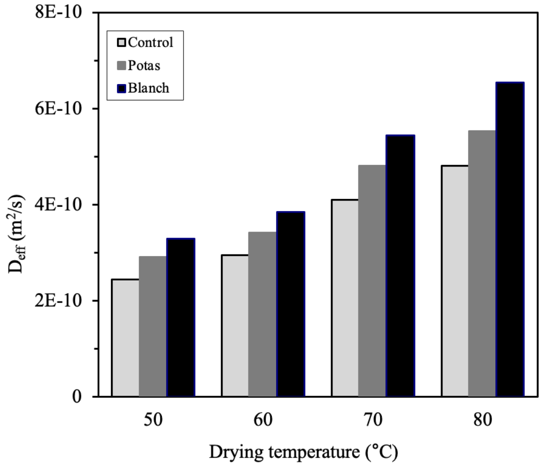

Figure 5. Effective moisture diffusivity versus temperature

Activation Energy

The activation energy represents the energy threshold necessary to initiate the drying process by surpassing the barrier. Since ln (D_{eff}) plotted as a function of 1/(T+273.15) generates a line with a slope equal to ($-E_a/R$), it is simple to calculate E_a (Figure 6). The pre-treated and control samples' D_{eff} are affected by temperature in Eqs. (13), (14) and (15), with the following coefficients:

Potas:

$$D_{eff} = 8.492 \times 10^{-7} exp\left(-\frac{2584.5}{(T+273.15)}\right) (R^2 = 0.9719) \quad (13)$$

Blanch:

$$D_{eff} = 1.564 \times 10^{-6} exp\left(-\frac{2745.8}{(T+273.15)}\right) (R^2 = 0.9751) \quad (14)$$

Control:

$$D_{eff} = 9.817 \times 10^{-7} exp\left(-\frac{2685.7}{(T+273.15)}\right) (R^2 = 0.9836) \quad (15)$$

For the Potas, blanch, and Control code samples, the activation energies are 21.48, 22.82, and 22.32 kJ/mol, respectively. According to Zogzas et al. (1996), the activation energy levels for elements associate to food generally sequence from 12.7 to 110 kJ/mol. A considerable amount of agreement exists between the activation energy estimations reported in this experiment and the activation energy predicts for drying peas in published studies: 28.40 kJ/mol (Simal et al., 1996); 22.48 kJ/mol (Pardeshi et al., 2009); 25.45-28.40 kJ/mol (Honarvar et al., 2011); 22.01-30.99 kJ/mol (Doymaz and Kocayigit, 2011); and 29.76-30.23 kJ/mol (Tao et al., 2018).

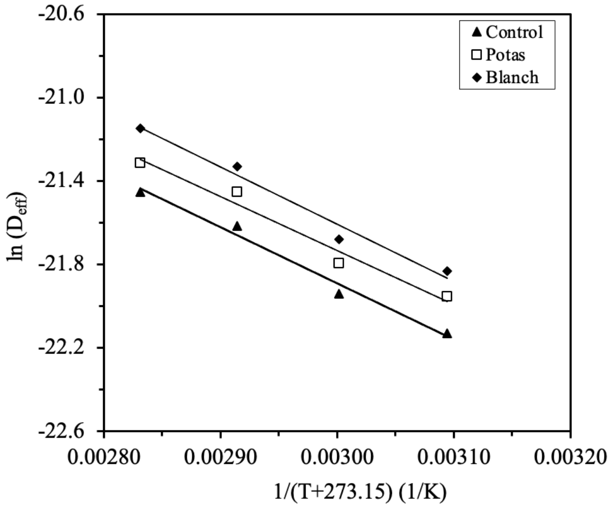

Figure 6. Arrhenius-type relationship between effective moisture diffusivity and temperature

Rehydration Capacity

Rehydration capacity (RC) is a commonly used dry product quality measure. According to Karacabey et al. (2016), rehydration values give information on the physical and chemical modifications to a dried sample's composition that are brought on by drying and other treatments utilized before dehydration. Rehydration capacity diminishes as drying temperature rises, as shown in Figure 7, with greater RC values at 50°C. Additionally, following drying at the same temperatures, the RC values of samples that has been pre-treated with potassium carbonate solution are higher than those that have been blanched with hot water and control samples. It can be claimed that during the drying process, the samples suffer only minor physical damage from the potassium carbonate solution. As a result, it is possible to say that the capacity for rehydration has improved. Kaur and Bawa (2002), and Burande et al. (2008) obtain comparable results.

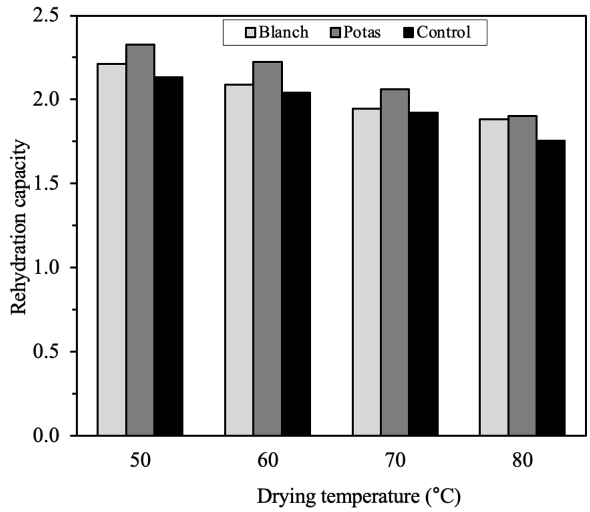

Figure 7. Effect of pre-treatment and air-drying temperature on rehydration capacity of peas

CONCLUSIONS

At various temperatures, the hot-air dryer is used to test the green pea's drying qualities. Peas dry during the periods of rising and falling rates for each infrared power. Temperature and pre-treatments have a big impact on drying speed. Drying time is decreased by pre-treatment and an increase in temperature. The Page model produces the best findings and is most compatible with the experimental data from the pea drying trials when compared to the other three thin-layer drying models. For temperature investigation in range of 50-80°C, the D_{eff} values range from $2.45x10^{-10}$ to $6.55x10^{-10}$ m^2/s. The effective moisture diffusivity rises as the temperature increases. Drying at 80°C shows in the highest D_{eff} value, while drying at 50°C results in the lowest value. Each model from experiments has an R^2 value greater than 0.98. For samples of Blanch and Potas codes, the difference in drying periods is nearly 25.81% and 16.13%, respectively. Using an Arrhenius type equation, the activation energies for the Potas, Control, and Blanch samples are identified as 21.48, 22.82, and 22.32 kJ/mol, respectively.

Author contributions

İ.D: Conceptualization, Methodology, Writing–review & editing.
N.A: Investigation, Writing–review & editing.

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Conflicts of interest: The author declares there is no conflicts to declare.

Ethics approval

This article does not contain any studies with human or animal subjects.

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