

INVESTIGATION OF DEHYDRATION AND REHYDRATION KINETICS OF PEAS SUBJECTED TO OPEN-AIR SUN DRYING

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Abstract— The aim of the present work was to investigate the kinetics of dehydration and rehydration of the open-air dried peas for untreated and pretreated samples. The models of Page, Wang & Singh, Parabolic and Midilli et al. were applied to experimental data during dehydration and the models of Peleg's, Weibull, first-order kinetic and exponential association were used in rehydration experiments and the corresponding parameters of the models were observed. The models of Midilli et al. and Weibull were found as the suitable models for dehydration and rehydration of the peas, respectively. The highest diffusion coefficients with the values of $6.98 \times 10^{-11} \text{ m}^2 \text{ s}^{-1}$ with the blanched peas in the dehydration and $9.98 \times 10^{-12} \text{ m}^2 \text{ s}^{-1}$ with the salted peas in the rehydration were achieved.

Keywords— Dehydration, Effective diffusivity, Kinetic models, Open-air sun drying, Peas, Rehydration.

I. INTRODUCTION

Green peas (*Pisum sativum*) is a leguminous vegetable and it has been widely used in the human diet for a long time because it is an excellent source of protein, vitamins, minerals and other nutrients and is low in fat, high in fiber, and contains no cholesterol (Doymaz and Kocayigit, 2011; Jadhav et al., 2010). Fresh peas contain about 78% moisture and are extremely perishable (Jadhav et al., 2010; Pardeshi et al., 2009). The major producer countries include China, India, the United States, France, and Egypt (Jadhav et al., 2010). Food preservation methods, such as drying, canning, freezing or cold storage, are applied to peas due to their seasonal nature (Doymaz and Kocayigit, 2011; Jadhav et al., 2010). Drying of peas is gaining popularity due to providing the advantages such as longer shelf life, palatability, and convenience during transport and handling (Jadhav et al., 2010; Pardeshi et al., 2009).

Drying is an ancient process used to preserve food. In order to benefit from the free and renewable energy source provided by sun, several attempts have been made in recent years to develop solar drying mainly for preserving various agricultural products (Chemkhi et al., 2004; Jadhav et al., 2010), such as apricot (Al-Juamili et al., 2007; Igual et al., 2012; Toğrul and Pehlivan, 2002), apple (Aktaş et al., 2009), basil (Akpınar, 2006; Özcan et al., 2005), bean (Al-Juamili et al., 2007; Hii et al., 2009), fig (Doymaz, 2005), grape (Al-Juamili et al., 2007), mulberry (Doymaz, 2004), pepper (Akpınar and Bicer, 2008; Arslan and Özcan, 2010; Tunde-Akintunde, 2011), red chili (Banout et al., 2011) and rosemary (Arslan and Özcan, 2008).

Dehydrated products before consumption or further processing need to be rehydrated (Oliveira and Oliveira, 1999). Although, the final product quality, such as structural and physicochemical modifications, is affected during dehydration process, the rehydrated product shows similar characterization to the fresh product and leads to restoration of the final product properties (Bilbao-Sainz et al., 2005; Krokida et al., 1999). The rehydration kinetics of different foods after drying has already been reported by some authors in the literature (Krokida and Philippopoulos, 2005; Madamba and Liboon, 2011; Marabi and Saguy, 2004; Maskan, 2000).

The aim of this study is to investigate the effect of pretreatment methods on open-air sun drying kinetics of the green peas and the water absorption kinetics of the dried green peas during rehydration, to compare the experimental data observed during both dehydration and rehydration processes with the predicted values obtained using various dehydration and rehydration models.

II. MATERIALS AND METHODS

Fresh green peas (*Pisum sativum*) were purchased from a local market in Thrace region of Greece and shelled prior to experiments. The pretreated and untreated peas range in diameter from 8 to 9.5 mm was dried under the sun. Pretreatment methods are given in Table 1.

Dry matter and moisture contents of the fresh samples were determined prior to dehydration process. The moisture contents of the samples were obtained by the Association of Official Analytical Chemists (AOAC, 1990). To determine the initial moisture content, 10 g of sample was dried in an oven (Memmert UM-400) at 105 °C for 24 h and this experiment was repeated four times. 17.88% dry matter and 82.12% moisture contents were observed for the peas. The pretreated and untreated peas were dried to 2.89% moisture content.

Open-air sun drying experiments were carried out during July 2011. A certain amount of natural and pre treated peas placed in sieve tray were put on the portable digital balance (Alfais, I2000-1, which has 0–300 g measurement range with an accuracy of ± 0.1 g) and ex-

Table 1. Pretreatment methods

Code	Description
Natural	Untreated samples
Blanched	Samples were immersed in hot water at 85 °C for 1 min and then immediately placed under running cold water for at least 3 min to cool to room temperature and finally drained
Salted	Samples were immersed in solution of 10% salt at room temperature for 1 min

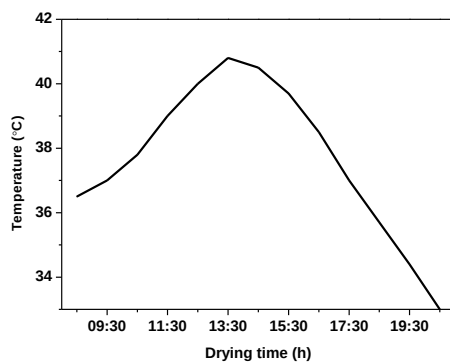


Fig. 1. Variation of ambient air temperature during open-air sun drying of peas on a typical day of July 2011 in Thrace region of Greece

posed to the sun. During dehydration, the weight loss and the temperature of the ambient air were measured and recorded at each hour from 8:30 am to 20:30 pm due to determine the dehydration curves. It was observed that the ambient day time temperature ranges from 33 °C to 41 °C. The highest air temperature was reached between 12:30 p.m. and 15:30 p.m. The variation of ambient temperature during open-air sun dehydration of the peas under natural convection on a typical day is shown in Fig. 1. Due to the dehydration process was completed in two days; the samples were kept in a sealed glass jar over the night. Dehydration process was proceeded until the samples reached a constant mass. Dried samples were packed in low density polyethylene (LDPE) bags, which were sealed thermally.

The moisture ratio of peas during dehydration (MR_d) was calculated using the following equation:

$$MR_d = \frac{M_t - M_e}{M_o - M_e} \quad (1)$$

where MR_d is the moisture ratio (dimensionless), M_t is the moisture content at a specific time (g water/g dry matter), M_o is the initial moisture content (g water/g dry matter), M_e is the equilibrium moisture content (g water/g dry matter). The equilibrium moisture content was assumed to be zero for sun drying because of the continuous fluctuation of the relative humidity of the drying air and MR_d equation was simplified as (Al-Juamili *et al.*, 2007; Soysal *et al.*, 2006):

$$MR_d = \frac{M_t}{M_o} \quad (2)$$

The peas dried in three different ways were kept in packages due to be used for the rehydration experiments in an oven at 40 °C. 5 g dried samples (m_o) were rehydrated in 1 L of distilled water at 40 °C. The samples were removed at regular time intervals (1 hour), and their weights were measured (m_t) until difference in successive weightings was insignificant. The moisture ratio of peas during rehydration (weight gain on rehydration) (MR_r) was calculated using the following equation:

$$MR_r = \frac{m_t - m_o}{m_o} \quad (3)$$

III. RESULTS AND DISCUSSIONS

A. Mathematical Modeling of Dehydration Kinetics

Figure 2 shows the dehydration ratio of the peas versus time for natural, blanched and salted samples. The dehydration ratio of the peas was calculated by Eq. 2. As seen in Fig. 2, moisture contents of the samples decrease by time and after a certain time, the samples reach a constant mass. While the dehydration time to reach a constant mass was found as 24 hours for natural samples, those for salted and blanched samples were observed as 20 and 17 hours, respectively. Pretreatment process obviously provides shorter dehydration times for the peas. This result can be attributed to that the pretreatment methods remove wax layer on the peas.

Doymaz and Kocayigit (2011) studied on drying of the natural and pretreated peas in a cabinet-type dryer at the temperature range in 55-70 °C. They observed 6.5 and 4.5 hour dehydration times at 55 °C for natural and pretreated (blanched) samples, respectively. The experimental data were fitted to four different moisture ratio (MR_d) models, namely Page, Wang and Singh, Parabolic and Midilli *et al.*, to determine the most suitable drying equation (Table 2).

B. Mathematical Modeling of Rehydration Kinetics

Figure 3 gives the rehydration ratios of the dried peas (natural, blanched and salted) versus time. It is seen that high rehydration rates were observed in all cases for the first six hours and then rehydration rates begin to decrease. That observation is in an agreement with the results previously reported by Maldonado *et al.* (2010). Even though the shortest dehydration time is observed with the blached peas, the best results are achieved with the salted samples in rehydration rates of the peas. It seems that shriveling of the blanched peas reduces the rehydration performance of the peas and the surface porosity of the salted peas improves that.

In order to determine the water content uptake as a function of rehydration time, Peleg's model, Weibull equation, first-order kinetic model and exponential association equation were used in this study. The selected four rehydration kinetic models are detailed shown in Table 3.

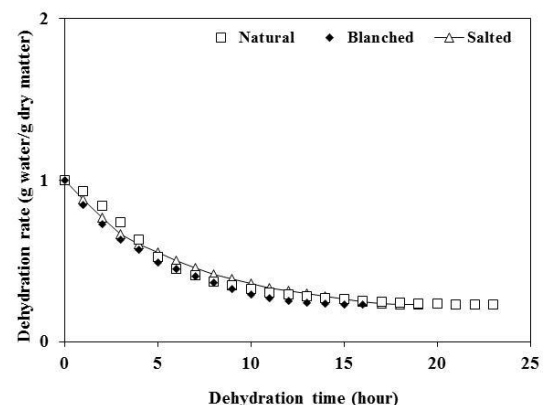


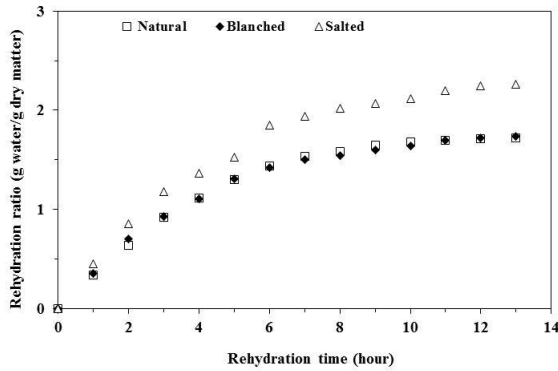
Fig. 2. Dehydration ratios of the peas versus dehydration time for □ natural, ◆ blached and Δ salted samples

Table 2. Mathematical models used for the dehydration kinetics of the peas

Model name	Model equation	Reference
Page	$MR = \exp(-kt^n)$	Cheevitsopon and Noomhorm, 2011; Hassan-Beygi, <i>et al.</i> , 2009; Page, 1949
Wang and Singh	$MR = 1 + at + bt^2$	Vega-Galvez <i>et al.</i> , 2008; Wang and Singh, 1978
Parabolic	$MR = a + bt + ct^2$	Daghighbandan <i>et al.</i> , 2006; Sharma and Prasad, 2004
Midilli <i>et al.</i>	$MR = a \exp(-kt^n) + bt$	Abano <i>et al.</i> , 2011; Midilli <i>et al.</i> , 2002

Table 3. Mathematical models used for the rehydration kinetics of the peas

Model name	Model equation	Reference
Peleg	$M = M_{ir} + \frac{t}{k_1 + k_2 t}$	Garcia-Pascual <i>et al.</i> , 2005; Kaptso <i>et al.</i> , 2008; Peleg, 1988; Turhan <i>et al.</i> , 2002
Weibull	$M = M_e + (M_o - M_e) \exp\left[-\left(\frac{t}{\beta}\right)^\alpha\right]$	Bantle <i>et al.</i> , 2011; Machado <i>et al.</i> , 1999; Uribe <i>et al.</i> , 2011
First-order rehydration kinetic	$M = M_e + (M_{ir} - M_e) \exp(-k_{R1}t)$	Apar <i>et al.</i> , 2009
Exponential association	$M = M_e [1 - \exp(-k_{R2}t)]$	Noshad <i>et al.</i> , 2012

**Fig. 3.** Rehydration ratios of the peas versus rehydration time for □ natural, ♦ blanched and Δ salted samples

Peleg proposed a two-parameter model to describe water absorption by grains:

$$M = M_o + \frac{t}{k_1 + k_2 t} \quad (4)$$

where, M_o is the initial moisture content at $t=0$ (g water/g dry matter), M is the absorbed water content at any time (g water/g dry matter), t is the rehydration time (h), k_1 and k_2 are the coefficients. The equilibrium moisture content (M_e) (g water/g dry matter) at sufficiently longsoaking time ($t \rightarrow \infty$), is expressed as:

$$M_e = M_{ir} + \frac{1}{k_2} \quad (5)$$

The probabilistic Weibull model has been widely applied to model rehydration of foodstuffs. Weibull can be represented, as follows:

$$M = M_e + (M_{ir} - M_e) \exp\left[-\left(\frac{t}{\beta}\right)^\alpha\right] \quad (6)$$

where, β (h) and α (dimensionless) are the scale and the shape parameters, respectively. The lower the value of α higher the uptake of water. β represents the time needed to reach 63% of the rehydration value.

$$M = M_e [1 - \exp(-k_{R2}t)] \quad (7)$$

where k_{R2} is the kinetic constant (h^{-1}).

$$M = M_e + (M_{ir} - M_e) \exp(-k_{R1}t) \quad (8)$$

where k_{R1} is the rehydration kinetic constant (h^{-1}).

C. Statistical Analysis

The statistical analysis of experimental data was determined using *Statistica 6.0 software* (Statsoft Inc., Tulsa, OK), which is based on the Levenberg–Marquardt algorithm. The three criteria of statistical analysis have been used to evaluate the adjustment of the experimental data to the different models: the coefficient of determination (R^2), reduced chi-square (χ^2) and RMSE. These parameters can be calculated as

$$\chi^2 = \frac{\sum_{i=1}^N (MR_{exp,i} - MR_{pre,i})^2}{N - z} \quad (9)$$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^N (MR_{pre,i} - MR_{exp,i})^2 \right]^{1/2} \quad (10)$$

where $MR_{exp,i}$ and $MR_{pre,i}$ are the experimental and predicted dimensionless MR , respectively, N is the number of data values, and z is the number of constants of the models. The best model describing the dehydration characteristics of samples was chosen as the one with the highest R^2 , the least χ^2 and RMSE (Doymaz, 2012; Lee and Kim, 2008; Uribe *et al.*, 2011).

Statistical analysis of dehydration process

Four models, namely Page, Wang & Singh, Parabolic and Midilli *et al.*, were used to explain the dehydration of peas in the decreasing dehydration rate period. Table 4 gives the model constants (a , k , n and b) calculated by the curve fitting models and the values of R^2 , RMSE and χ^2 observed using these model constants. The statistical data from the models were investigated and the model of Midilli *et al.* presented the removable moisture rate, with the lowest error rate at all three trials (Table 4). Thus, the model of Midilli *et al.* was defined to investigate the variation of the moisture content versus time for the peas.

$$MR = a \exp(-kt^n) + bt \quad (11)$$

It is possible to calculate the optimum removable moisture ratio (MR) for the peas at the specified operating conditions, using the constants from the model. In this model, RMSE values of the peas varied between 0.023183 and 0.073242, χ^2 values between 0.000053 and 0.000357 (very close to zero) and R^2 values between 0.9963 and 0.9994.

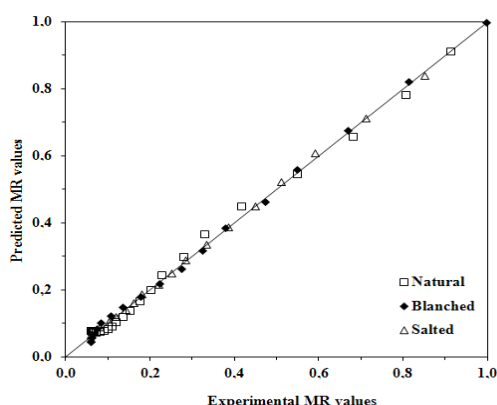
Figure 4 compares the experimental removable moisture ratios (MR_{exp}) and the predicted removable moisture ratios (MR_{pre}) calculated by the model of Midilli *et al.* for natural, blanched and salted peas. As seen in Fig.4, experimental and predicted values are in a good agreement, which proves the suitability of the model in describing dehydration characteristics of green

Table 4. Statistical results observed with different thin layer models during

Model	Code	Model constant				R ²	RMSE	χ ²
Page	Natural	k=0.14	n=1.08			0.9859	0.146	0.00125
	Blanched	k=0.20	n=0.99			0.9987	0.035	0.00011
	Salted	k=0.18	n=0.94			0.9993	0.023	0.00005
Wang and Singh	Natural	a=-0.12	b=0.0034			0.9665	0.213	0.00296
	Blanched	a=-0.15	b=0.0055			0.9852	0.118	0.00131
	Salted	a=-0.12	b=0.0039			0.9765	0.159	0.00191
Parabolic	Natural	a=0.96	b=-0.108	c=0.0032		0.9696	0.214	0.00258
	Blanched	a=0.94	b=-0.129	c=0.0048		0.9922	0.081	0.00065
	Salted	a=0.93	b=-0.104	c=0.0032		0.9867	0.120	0.00102
Midilli <i>et al.</i>	Natural	a=1.02	b=-0.033	k=0.1151	n=1.250	0.9963	0.073	0.00036
	Blanched	a=1.00	b=-0.0004	k=0.1196	n=0.982	0.9988	0.035	0.00012
	Salted	a=1.00	b=-0.0006	k=0.1827	n=0.919	0.9994	0.023	0.00005

Table 5: Estimated parameters and statistical results observed with the models during rehydration

Model	Code				R ²	RMSE	χ ²
Peleg	Natural	k ₁ =3.4585	k ₂ =0.3713	M _e =2.793	0.9678	0.26229	0.00933
	Blanched	k ₁ =3.4167	k ₂ =0.3627	M _e =2.751	0.9839	0.18741	0.00592
	Salted	k ₁ =3.1882	k ₂ =0.3166	M _e =3.259	0.9783	0.22636	0.00792
Weibull	Natural	α=0.8538	β=3498	M _e =2.590	0.9980	0.04685	0.00061
	Blanched	α=0.8254	β=3547	M _e =2.524	0.9961	0.09175	0.00064
	Salted	α=0.9232	β=3088	M _e =2.988	0.9956	0.11895	0.00192
First-order rehydration kinetic	Natural	k _{R1} :0.0003	M _e =2.461		0.9752	0.21771	0.00719
	Blanched	k _{R1} :0.0003	M _e =2.495		0.9884	0.14888	0.00442
	Salted	k _{R1} :0.0003	M _e =2.914		0.9838	0.18762	0.00510
Exponential association	Natural	k _{R2} :0.0003	M _e =2.417		0.9370	0.26229	0.00933
	Blanched	k _{R2} :0.0003	M _e =2.392		0.9837	0.12987	0.00681
	Salted	k _{R2} :0.0004	M _e =2.842		0.9751	0.12987	0.00590

**Fig. 4.** Experimental and predicted moisture ratios using Midilli *et al.* model for the natural, blanched and salted peas during dehydration

peas. The prediction using the model showed MR values banded along the straight line, which showed the suitability of this model in describing dehydration characteristics of green peas.

Statistical analysis of rehydration process

The constants of R², RMSE and χ² were calculated using Peleg's model, Weibull equation, first-order kinetic model and exponential association equation to describe the rehydration kinetics of the peas. The observed constants for natural, blanched and salted peas are given in Table 5. As it is seen from Table 5, the lowest kinetic rate and characteristic constants (k₁, k₂) of the Peleg's model were observed for the salted peas in comparison with the natural and blanched peas. As suggested (Solomon, 2007), k₁ parameter may be representative of water absorption rate in the early phase of rehydration pro-

cess. High water absorption capacity is correlated with the low k₂ value. Moreover, equivalent moisture content (M_e) increases by decreasing of k₂ parameter. Solomon (2007) demonstrated that k₂ parameter is inversely correlated with equivalent moisture content (M_e) in water absorption of food. In consideration of the Peleg model parameters (k₁, k₂ and M_e), it is seen that k₂ parameter is proportional to k₁ and inversely proportional to M_e parameters.

α and β parameters of Weibull model calculated for untreated and pretreated peas are given in Table 5. At the beginning of the process, α parameter, which is necessary for the determination of the water absorption rate, is observed as 0.85378, 0.82538 and 0.92323 for natural, blanched and salted peas, respectively. Goula and Adamopoulos (2009) reported that α parameter ranges between 0.2 -1.0. Low α parameter indicates high water absorption capacity. Referring to Table 5, the lowest β value of 3087.60 (s) is obtained with the salted peas. That value is found as 3498.43 and 3547.07 (s) for natural and blanched peas, respectively. Low β value indicates high rehydration rates. Apar *et al.* (2009) studied on rehydration of food and they reported that β value decreases by increasing temperature. Marabi and Saguy (2004) and Cunningham *et al.* (2007) suggested that β parameter represent the required time to accomplish the hydration process of approximately 63%. Marabi *et al.* (2003) used Weibull model in their study and found that mass transfer is related to capilarity for high porosity crops and to diffusion for low porosity crops.

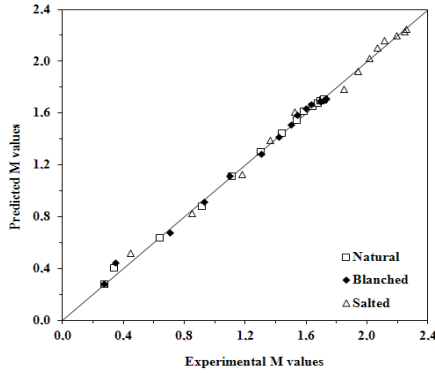


Fig. 5. Experimental and predicted absorbed water ratios using Weibull model for the natural, blanched and salted peas during rehydration

The highest k_{R1} and k_{R2} values of first-order and exponential association models is achieved with salted peas. The best model describing the thin-layer dehydration characteristics of peas was chosen as the one with the highest R^2 values and the lowest χ^2 and RMSE values. In all cases, the R^2 values for the models were greater than 0.96, indicating a good fit, except for that obtained by exponential association model for natural peas. As can be seen in Table 5, in the models used in rehydration experiments, R^2 values of the peas varied between 0.9370 and 0.9980, RMSE values between 0.26229 and 0.04685 and χ^2 values between 0.00061 and 0.00933. Considering the obtained values of R^2 , RMSE and χ^2 , the predicted results from Weibull model provide a good fit with experimental results. Figure 5. indicates the predicted moisture ratios from Weibull model versus the experimental moisture ratios and supports that the predicted results from the model are in a good agreement with the experimental results.

D. Determination of Effective Moisture Diffusivity

Diffusion coefficient (D_{eff}) is one of the most important parameters for the diffusion mass transfer and Fick's laws are the common laws used to explain water diffuses into the dried green peas and diffusion type of them (Ende and Peppas, 1997). Same equations in both dehydration and rehydration were used to determine the diffusion coefficients. The spherical peas were used in the dehydration experiment and one-dimensional Fick's diffusion equation (Eq. 12) was used to determine the diffusion coefficient.

$$\frac{\partial M(r,t)}{\partial t} = \frac{1}{r^n} \frac{\partial}{\partial r} \left(r^n D_{eff} \frac{\partial M}{\partial r} \right) \quad (12)$$

where, $n = \begin{cases} 0 \\ 1 \\ 2 \end{cases}$ refers to sphere-shaped crops.

Table 6. D_{eff} and R^2 values of the peas in the dehydration process

Code	Dehydration	
	$D_{eff} * 10^{11} \text{ m}^2 \text{ s}^{-1}$	R^2
Natural	5.65	0.949
Blanched	6.98	0.988
Salted	6.12	0.996

Determination of effective moisture diffusivity in dehydration

Initial and boundary conditions are given below:

$$M(t=0, 0 \leq r < R) = M_0$$

$$M(t \geq 0, R) = M_e$$

$$\left(\frac{\partial M}{\partial r} \right)_{r=0} = 0$$

Under these assumptions, Eq. (12) is dissolved by the separation variables method and simplified as Eq. (13), which gives the dehydration equation for sphere-shaped peas (Crank, 1975).

$$MR = \frac{M_t - M_e}{M_{id} - M_e} = \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp \left[-\frac{n^2 \pi^2 D_{eff}}{r^2} t \right] \quad (13)$$

where; M_t is the moisture content (g water/g dry matter) at a certain time (t), M_e is the equilibrium moisture content (g water/g dry matter), M_{id} is the initial moisture content (g water/g dry matter), t is a certain dehydration time (second), r is the radius of the sphere-shaped crops (m) and D_{eff} is the diffusion coefficient (m^2/s). For long drying periods, Eq. (14) is the logarithmic form of the Eq. 13 and can be further simplified to only the first term of the series Eq. (15).

$$\ln(MR) = \ln \left(\frac{6}{\pi^2} \right) - \left(\frac{\pi^2 D_{eff}}{r^2} t \right) \quad (14)$$

The effective moisture diffusivity is obtained by plotting the experimental dehydration data in terms of $\ln(MR)$ versus time (second).

$$K = \frac{\pi^2 D_{eff}}{r^2} \quad (15)$$

where D_{eff} value in Eq. 14 is the diffusion coefficient of the water in the solid and assumed as a constant. However, it is known that diffusion coefficient is a function of temperature and moisture content of solid (McCabe *et al.*, 1993). From Eq. 14, a plot of $\ln(MR)$ versus time gives a straight line and D_{eff} can be calculated using the slope (K) of that line in Eq. 15. Figure 6 indicates linear relationship between $\ln(MR)$ and dehydration time for the natural, blanched and salted peas.

Table 6 illustrates the diffusion and regression coefficients for untreated and pretreated peas in the dehydration process. The regression coefficients using determination of diffusion coefficient range between 0.949 and 0.996. The D_{eff} values of the samples are varied in the range of $5.65-6.98 * 10^{-11} \text{ m}^2 \text{ s}^{-1}$. As seen, the highest diffusion coefficient is achieved with the blanched peas. The D_{eff} values obtained from this study lie within general range of $10^{-12}-10^{-8} \text{ m}^2/\text{s}$ for dehydration of food materials and comparable with other reported values (Zogzas *et al.*, 1996).

Determination of effective moisture diffusivity in rehydration

Equation (8) changes in rehydration into an equation given below (Eq. 16):

$$M = \frac{M_s - M_t}{M_s - M_{ir}} = \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp \left[-\frac{n^2 \pi^2 D_{eff}}{r^2} t \right] \quad (16)$$

where; M_s is the saturation water content (g water/g dry matter), M_{ir} is the initial moisture content of the dried sample (g water/g dry matter), M_t is the instantaneous moisture content (g water/g dry matter) of sample after soaking for time t (second) and r is the radius of the peas (m).

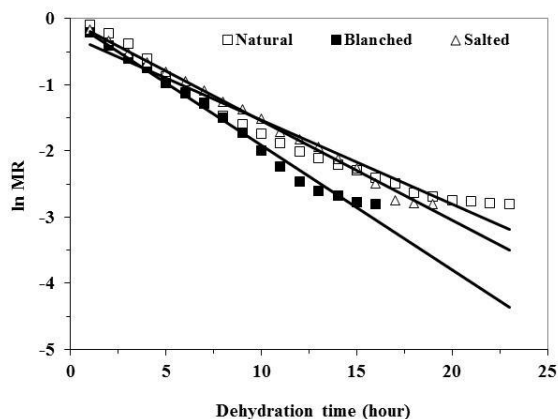


Fig. 6. Linear relationship between $\ln(MR)$ and dehydration time for the natural, blanched and salted peas

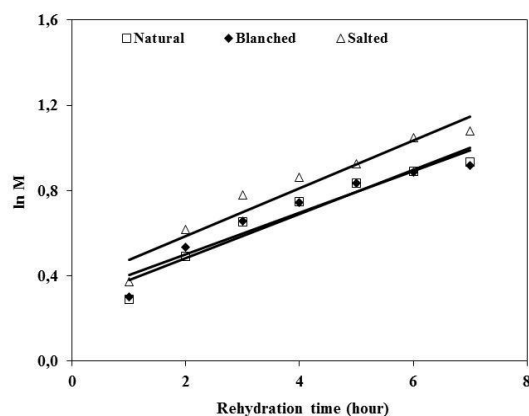


Fig. 7. Linear relationship between $\ln(M)$ and rehydration time for the natural, blanched and salted peas

Table 7. D_{eff} and R^2 values of the peas in the rehydration process

Code	Rehydration	
	$D_{eff} \cdot 10^{12} \text{ m}^2 \text{ s}^{-1}$	R^2
Natural	9.24	0.932
Blanched	7.58	0.916
Salted	9.98	0.931

The swelling kinetics of the dried peas having swelling properties is investigated by the Eq. 13. For that purpose, from Eq. (13), a plot of absorbed water ratio ($\ln M$) versus time gives a straight line and D_{eff} can be calculated using the slope (K) of that line in Eq. 16. Fig. 7. demonstrates linear relationship between $\ln(M)$ and rehydration time for the natural, blanched and salted peas.

Table 7 gives the diffusion and regression coefficients for untreated and pretreated peas in the rehydration process. While the regression coefficients range between 0.916 and 0.932, the diffusion coefficients are varied in the range of $7.58\text{--}9.98 \cdot 10^{-12} \text{ m}^2 \text{ s}^{-1}$. The highest diffusion coefficient is observed with the salted peas. As

seen in Table 7, the higher diffusion coefficients were observed in dehydration than rehydration. This result is in agreement with Neumann's findings which showed osmotic pressure was not effective at rehydration due to that the capillary system of the crops had been damaged during dehydration (Neumann, 1972).

IV. CONCLUSION

In this study, dehydration and rehydration kinetics of the peas is presented for untreated and pretreated peas. The results show that pretreatment methods affect the dehydration of the peas. The shorter dehydration time is obtained in the experiment with pretreated peas. Pretreatment of the peas decreases the dehydration time and the shortest dehydration time is achieved with the blanched peas. This event can be attributed that the soaking the peas in the hot water causes the surface shrinkages.

Besides, the salted peas give the relatively better results in rehydration. Salt water enhances the rehydration properties due to lead to formation of surface porosity. While the relatively shorter process time is obtained with the blanched peas during the dehydration, it can not be achieved with those during the rehydration. Moreover, lower rehydration capacity is seen for the blanched peas with respect to the others.

Four models from literature were chosen to investigate the each dehydration and hydration processes. The parameters of a , k , n , b , k_1 , k_2 , α , β , k_{R1} and k_{R2} for dehydration and rehydration of the peas were calculated and R^2 , RMSE and χ^2 values were figured out using these parameters in the models. The models of Midilli *et al.* and Weibull give the excellent fits for dehydration and rehydration of the peas, respectively. Therefore, the predicted results obtained by these models are close agreement with the experimental results.

The highest diffusion coefficients with the values of $6.98 \cdot 10^{-11} \text{ m}^2 \text{ s}^{-1}$ and $9.98 \cdot 10^{-12} \text{ m}^2 \text{ s}^{-1}$ are achieved with the blanched peas in the dehydration and the salted peas in the rehydration, respectively. In all cases, higher dehydration rates are found in comparison with the rehydration rates, as expected.

NOMENCLATURE

MR_d :	Dehydration ratio (g water /g dry matter)
M_t :	Moisture content at any time of dehydration or instantaneous moisture content (g water/g dry matter)
M_e :	Equilibrium moisture content (g water/g dry matter)
M_0 :	Initial moisture content during dehydration (g water/g dry matter)
MR_r :	Rehydration ratio (g water /g dry matter)
m_t :	Mass of the green peas at time of rehydration (g water/g dry matter)
m_0 :	Mass of the dry green peas at time 0 (g water/g dry matter)
M :	Absorbed water content at any time (g water/g dry matter)
α :	Weibull shape parameter (dimensionless)
β :	Weibull rate parameter (min)
χ^2 :	Reduced chi-square
$MR_{exp,i}$:	Experimental moisture ratio
$MR_{pre,i}$:	Predicted moisture ratio

R^2 : Determination of coefficient
 N : Constant, positive integer
 z : Number of coefficients and constants
 t : time
 $RMSE$: Root mean square error
 n : Number of observations
 D_{eff} : Effective moisture diffusivity (m^2/s)
 a, b, c : Dehydration coefficients
 dm : Dry matter
 k : Dehydration constants
 k_1 : Peleg rate constant $\min (kg\ dm)\ (kg\ water)^{-1}$
 k_2 : Peleg capacity constant $(kg\ dm)\ (kg\ water)^{-1}$
 k_{R1} : Rehydration kinetic constant (h^{-1})
 k_{R2} : Kinetic constant (h^{-1})
 r : Radius (m)
 K : Slope

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