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FULL LENGTH ARTICLE

Analysis of water absorption of bean and chickpea during soaking using Peleg model

S.M. Shafaei [a,*], **A.A. Masoumi** [b], **H. Roshan** [b]

[a] *Department of Biosystem Engineering, College of Agriculture, Shiraz University, Shiraz 71441-65186, Iran*
[b] *Department of Mechanics of Biosystem Engineering, Faculty of Agriculture, Isfahan University of Technology, Isfahan 84156-83111, Iran*

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Abstract Peleg model was used to determine the instance moisture content of three varieties of bean (Talash, Sadri and Mahali Khomein) and three varieties of chickpea (Desi, small Kabuli and large Kabuli) during soaking. The experiments were carried out at three different temperatures (5, 25 and 45 °C) in triplicate using distilled water. The moisture content versus time curves were plotted at different experimental temperatures, for six varieties. The results indicated that water absorption increased as the temperature increased. The obtained Peleg model constants were investigated relative to temperature. Activation and free activation energy, as well as entropy and enthalpy changes for the three studied varieties of both chickpea and bean were calculated at three temperatures using Peleg model constants and regression analysis. In the case of bean, the results showed a linear decrease in the coefficients k_1 and k_2. Furthermore for chickpea, the coefficient of k_1 decreased linearly and the effect of temperature on the coefficient k_2 was partial and decreasing. Likewise, the results indicated that the seeds enthalpy enhanced significantly as soaking temperature increased from 5 to 45 °C, the raising trend in entropy and released energy was not significant, however ($P < 0.05$). Maximum and minimum free activation energy in soaking process were observed in chickpea variety of Chico (301.28 kJ mol^{-1}) and bean variety of Mahali Khomein (86.77 kJ mol^{-1}), respectively. In addition, negative values of enthalpy changes of varieties demonstrated that the changes in moisture content during soaking process were associated with exothermic and energetically favorable transformation.

1. Introduction

Legumes are economical sources of protein, energy, vitamins and minerals. Food legumes diminish the incidence of several diseases, such as cancer, cardiovascular diseases, obesity and diabetes (Bhathena and Velasquez, 2002). Compared to whole eggs, dairy products or meat, legumes contain relatively low quantities of the essential amino acid methionine. This means

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[*] Corresponding author. Tel.: (+98) 09132040158; fax: (+98) 07116280913.
E-mail address: smshafaei@shirazu.ac.ir (S.M. Shafaei).

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that a smaller proportion of the plant proteins, compared to proteins from eggs or meat, may be used for the synthesis of protein in humans.

Chickpea (*Cicerarietinum L.*) is an important protein source in many developing countries. It is the third most commonly consumed legume in the world. There are two main varieties of chickpeas namely Desi and Kabuli. The Kabuli variety has a thin, white seed coat and Desi variety has a thick, colored seed coat, being smaller than Kabuli in size (Thushan Sanjeewa et al., 2010).

Bean (*Phaseolus vulgaris L.*) is an important member of the legume group. In the new world, it is one of the main sources of protein and calories in the human nutrition (Graham and Ranalli, 1997). Unlike the chickpea, bean is a summer crop that needs warm climate to grow. Maturity is typically achieved within 55–60 days after planting. Thus, the area under bean is increasing on the planet earth (Hungria et al., 2000).

In Iran, bean and chickpea have been widely grown as legumes production for a long time. High shelf life, the ease of transport, and the added value are attractive to farmers. Three famous varieties of bean are Talash, Sadri and Mahali Khomein (Shafaei and Masoumi, in press).

Since soaking is usually done before dehulling and cooking grains, investigation of water absorption characteristics of different seeds during soaking has been considered by researchers. Grains in different soaking conditions, show different water absorption rates and water absorption capacities (Shafaei and Masoumi, 2013a; Shittu et al., 2012; Bello et al., 2010; Kashiri et al., 2012; Montanuci et al., 2013). Understanding water absorption in legumes during soaking is of particular importance since it affects succeeding processes and the quality of the final product (Turhan et al., 2002). Water absorption of seed during soaking mainly depends on soaking time and water temperature. Throughout the immersion, water spreads slowly into the seeds and eventually reaches a constant level of moisture content (Ranjbari et al., 2011; Shafaei and Masoumi, 2013c, 2013d). Using warm water is a typical method to diminish the soaking time, because higher temperatures increase moisture diffusivity leading to a higher hydration rate (Kashaninejad et al., 2009; Shafaei and Masoumi, 2013b; Khazaei and Mohammadi, 2009).

The relationship between moisture content of seeds in soaking and time is usually expressed by different models. Many theoretical and empirical approaches have been employed and occasionally empirical models were preferred because of their relative ease of use (Shafaei and Masoumi, 2014b; Yildirim et al., 2013; Da Silva et al., 2013; Ghafoor et al., 2014). Water absorption of rice was studied by researchers. The results were indicated that the proper model for predicting the behavior of water uptake was 'Page' model (Kashaninejad et al., 2007). Some researchers reported Binomial model is the best model for modeling hydration of chickpea seeds (Shafaei and Masoumi, 2014c).

Within many theoretical, empirical and semi empirical models, the most popular model which has been used to model the water absorption kinetics of agricultural products is the Peleg model (Jideani and Mpotokwana, 2009). Using short time experimental data for predicting equilibrium moisture content of foods and grains is the major advantage of the Peleg model. Besides that, the model is a popular empirical non exponential model and parameters are of immense practical significance in hydration kinetics applied to weight gain during rehydration (Peleg, 1988). The model is commonly used to describe absorption characteristics of various materials within soaking (Vasudeva et al., 2010; Salimi Hizaji et al., 2011; Montanuci et al., 2013; Ranjbari et al., 2013; Botelho et al., 2013; Oliveira et al., 2013).

The Peleg model is shown as:

$$M_t = M_o \pm \frac{t}{k_1 + k_2 t} \tag{1}$$

where M_t is moisture content at time t (d.b. %), M_o is initial moisture content (d.b. %), t is time (h), k_1 and k_2 are the Peleg rate ($h\%^{-1}$) and Peleg capacity constant ($\%^{-1}$), respectively. In Eq. (1), "$\pm$" becomes "$+$" if the process is absorption or adsorption and "$-$" if the process is drying or desorption (Corzo et al., 2012).

The rate of sorption (R) can be gotten from the first derivative of the Peleg equation:

$$R = \frac{dM}{dt} = \pm \frac{k_1}{(k_1 + k_2 t)^2} \tag{2}$$

The Peleg rate constant k_1 relates to sorption rate at the beginning (R_0), R at $t = t_0$:

$$R = \frac{dM}{dt}\bigg| t = 0 = \pm \frac{1}{k_1} \tag{3}$$

The Peleg coefficient constant k_2 relates to maximum (or minimum) possible moisture content. As $t = \infty$, Eq. (1) gives the relation between equilibrium moisture content (M_e) and k_2.

$$M|_{t=\infty} = M_e = M_0 \pm \frac{1}{k_2} \tag{4}$$

The Peleg model has been used to describe sorption processes in various foods. Oliveira et al. (2013) studied simultaneous water desorption and sucrose absorption of adzuki beans using the model. Prasad et al. (2010) used it to describe water desorption of sago chickpea. Moreira et al. (2008) applied the model for studying water absorption of chestnuts. The Peleg model was also employed to model the water absorption process of many starchy and oily kernels (Abu-Ghannam and McKenna, 1997; Waezi-Zadeh et al., 2010; Gowen et al., 2007). In these reports, the model mostly fitted below the gelatinization temperature (conditioning step) rather than above the gelatinization temperature (cooking step) of the starchy grains.

Enthalpy is a thermodynamic quantity equivalent to the internal energy of a system plus the product of pressure and volume. In other words, the observed heat in a reaction occurring at constant pressure equals enthalpy change. Enthalpy, like internal energy, is a function of system state, independent of the way it is reached. Entropy indicates automatic dispersal of energy. It also shows that how much to what extent the energy dissipates in a process with certain temperature. Thus, entropy is a thermodynamic quantity for degree of disorder in the system. The higher the degree of disorder, the higher the entropy. (Jideani et al., 2002).

The objective of this study was to determine the Peleg constants (k_1 and k_2) for different varieties of chickpea (large Kabuli (Kabuli), small Kabuli (Chico) and Desi) and bean (Talash, Sadri and Mahali Khomein) at three experimental temperatures (5, 25 and 45 °C). Using the constants to review change in thermodynamic parameters of seeds during soaking.

2. Materials and methods

2.1. Sample preparation

Each variety of bean and chickpea was prepared from Legumes seed collection center, agricultural organizations Khomein, Markazi, Iran. Before testing, the broken seeds and external materials were removed. Seeds of bean and chickpea were categorized as three groups by size of their large dimension. In order to eliminate the effect of seed size on the soaking trials, medium-size grains were used. The initial moisture content of samples was determined using AACC 44-15A method for chickpea (AACC, 1999) and ASAE S352.2 DEC97 for bean (ASAE, 1999).

2.2. Soaking tests

Experiments were conducted in distilled water at 5, 25 and 45 °C for different durations. Before each experiment, the containers and distilled water were kept in desired temperature for a few hours to reach the same temperature.

Ten seeds of favorite type were randomly selected and weighed, then placed in glass beakers containing 200 ml distilled water for each duration included in the timetable. Amount of water absorption by various seeds was determined 5, 10, 15, 30, and 60 min after immersion. The tests were continued at intervals of one hour to reach equilibrium moisture content. After reaching certain times, the samples were removed from the beakers and placed on a paper to eliminate the excess water, the soaked samples were then weighed. A digital chronometer and a precision electronic balance (AND, Model GF400, accuracy ± 0.001 g Japan) were respectively used to record soaking duration and to measure weight of sample before and after immersion. In order to reduce error, all tests were performed in triplicate. The water absorption capacity was determined using the Eq. (5) (McWatters et al., 2002):

$$W_a = \frac{W_f - W_i}{W_i} \times 100 \tag{5}$$

where, W_a is water absorption (d.b. %), W_f is weight of seeds after immersion (g) and W_i is weight of seed before immersion (g).

According to Vishwakarm et al. (2013), data obtained after loss of soluble solids of more than 1% of the samples initial mass were not included. Therefore, at each step, amount of solid material dissolved in water was controlled by measuring density of distilled water and drained water in the experiment.

2.3. Analysis of soaking data and soaking model

Since the seeds absorbed just a little amount of water before two hours, the recorded data were not used to fit to the Peleg model. Also, the soluble solid loss of more than 1% of the initial mass of the samples was not desired, the recorded data after this time were not used to determine the Peleg constants (Vishwakarm et al., 2013). Some researchers such as Sayar et al. (2001), used soaking times of 11 and 7 h for chickpea at 20 °C and 40 °C, respectively; and Turhan et al. (2002), predicted this time to be about 7 h for chickpea at 20 °C.

The experimental data were fitted to Peleg model for the time between two hours and equilibrium moisture content time for six varieties of seeds, using MATLAB software. After determining the coefficients of Peleg model in three temperatures for different varieties of bean and chickpea, the relationship between them and test temperatures was examined. The effect of temperature, time and variety on the water absorption of seeds was determined by analysis of variance (ANOVA) within a completely randomized design. Means were compared with Duncan's multiple range test in confidence of 0.05, using SAS software. To evaluate Peleg model prognostication, predicted data were plotted against test data for six studied varieties at three temperatures and determined the coefficient of determination (R^2), by following Eq. (6):

$$R^2 = \frac{\sum_{i=1}^{n}\left(M_{\exp,i} - M_{\exp\ \text{ave}}\right)^2 - \sum_{i=1}^{n}\left(M_{\exp,i} - M_{\text{pre},i}\right)^2}{\sum_{i=1}^{n}\left(M_{\exp,i} - M_{\exp\ \text{ave}}\right)^2} \tag{6}$$

where, $M_{\exp,i}$ is the ith experimentally observed moisture content, $M_{\text{pre},i}$ the ith predicted moisture content, M_{expave} is average moisture content observed and n the number of observations. The goodness of fit between the experimental and predicted water absorption values was calculated using the mean relative percentage deviation modulus (E), which is defined as:

$$E = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{M_{\exp,i} - M_{\text{pre},i}}{M_{\exp,i}}\right| \times 100 \tag{7}$$

2.4. Determination of equilibrium moisture content

According to the Peleg model, the rate of absorption reaches to zero when water absorption becomes constant. By this method and using Eq. (4), equilibrium moisture was measured from experimental data of sample at each temperature and the obtained equilibrium moisture contents were compared at confidence level of 5% with Duncan's multiple ranges test.

2.5. Thermodynamic parameter determination

Some researchers indicated that, by combining moisture diffusion equation and Eq. (1), the dependence of the Peleg model's coefficient on the temperature can be shown according to Eq. (8) (Jideani and Mpotokwana, 2009):

$$\frac{1}{K_1} = K_{\text{ref}f}\exp\left[\frac{-E_a}{R}\left(\frac{1}{T} - \frac{1}{T_{\text{ref}}}\right)\right] \tag{8}$$

Where: K_{ref}, is coefficient of hydration at reference temperature; E_a, is activation energy (kJ mol^{-1}); R, is universal gas constant ($=8.314\ \text{J mol}^{-1}\ \text{K}^{-1}$); T, is the experience temperature (K); and T_{ref}, is reference temperature (K). To reduce the co-linearity of K_{ref} and activation energy, the reference temperature was selected as the average temperature of the experiment (Gowen et al., 2007). Taking the logarithm of both sides of the Eq. (8), the linear Eq. (9) is obtained:

$$\ln\left(\frac{1}{K_1}\right) = \ln K_{\text{ref}f} + \left(\frac{E_a}{R}\right)\left(\frac{1}{T_{\text{ref}}} - \frac{1}{T}\right) \tag{9}$$

If $\ln(1/k_1)$ is plotted versus $((1/T_{\text{ref}}) - (1/T))$, a line with the gradient of (E_a/R) is obtained from which the activation energy can be calculated. Using activation energy, changes in enthalpy, entropy and the free energy of activation are obtained based on Eqs. (10)–(12), respectively.

$$H = E_a - RT \tag{10}$$

$$\Delta S = R\left(LnA - Ln\frac{K_B}{h_p} - LnT\right) \tag{11}$$

$$\Delta G = \Delta H - T\Delta S \tag{12}$$

where R, is universal gas constant; LnA, is intercept of the curve from Eq. (12); K_B, is Boltzmann constant ($=1.38 \times 10^{-23}$ J K^{-1}); h_p, is Planck's constant ($=6.626 \times 10^{-34}$ J s); and T is absolute temperature (K).

3. Results and discussion

3.1. Water absorption curves

The initial moisture content values of seeds were less than 9% (d.b. %). The increment of moisture content of samples during soaking time is shown in Figs. 1 and 2. These 3D charts were plotted based on simultaneous effect of time and temperature on water absorption kinetics of seeds during soaking. The charts give an opinion of how the seeds moisture content in response to the two input variables. It is clear that the absorption curves show the rate of water absorption increased with increasing temperature. Varieties of bean reached to saturation moisture content at the same time. However, the time needed to reach saturation moisture content was shorter in higher water temperatures, in the case of chickpea. The reason of these phenomena was the increment of water diffusivity in seeds. Thus, high temperatures could cause the seeds to soften and expand. The moisture absorption rate was higher, when the soaking temperature was closer to gelatinization temperature of seeds (Shafaei and Masoumi, 2013e; Shafaei et al., 2013). Therefore, applying higher temperatures at short time resulted in the equilibrium moisture to be mailed at shorter time of soaking, compared to lower temperature along with longer time of immersion.

In general, the water absorption rate was fast at the beginning of soaking and slow at the end of soaking process. More extraction of solid matter from seeds at the end of soaking time was a negative factor of water absorption. Similar results have been reported for various agricultural products such as pasta, sorghum, milled rice, chick peanuts and barley seeds (Cunningham et al., 2007; Kashiri et al., 2012; Yadav and Jindal, 2007; Pan and Tangratanavalee, 2003; Shafaei et al., 2014).

3.2. Effect of variety on water absorption

The results indicated that, regarding bean varieties, water absorption values were significantly different ($P < 0.05$) since, morphological and physiological properties of the varieties were different. Talash variety is the most popular variety of bean which is cultivated in warm and dry areas. Despite Talash, Sadri variety is an improved cultivar which is why it is cultivated in cold climate (Beyzaei et al., 2012) and Mahali Khomein variety is a genetically modified variety based on Kheomin (Markazi – Iran) region.

The result indicated that, water absorption values were not significantly different for chickpea samples ($P > 0.05$). It is due to same condition of cultivation and partial difference among morphological and physiological properties of these varieties of chickpea in Iran.

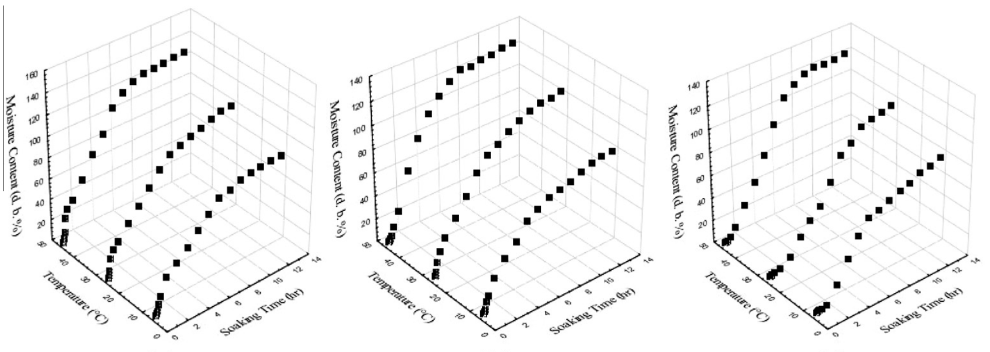
In general, moisture content of each type of chickpea was lower than each type of bean in the same conditions of time and temperature. Thus it can be resulted resistance of chickpea to water penetration is more than that of bean.

3.3. Equilibrium moisture content

The results of determined equilibrium moisture content of varieties at three temperatures are shown in Table 1. It shows that the equilibrium moisture content of bean varieties increased significantly ($P < 0.05$), when the soaking temperature increased from 5 to 45 °C. But for chickpea samples, equilibrium moisture content had no significant difference ($P > 0.05$). It was due to the difference between morphological and physiological properties of bean and chickpea.

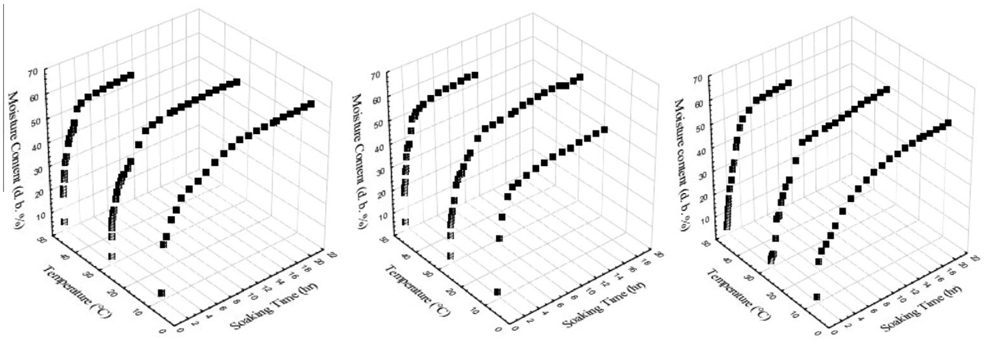
3.4. Evaluation of Peleg model

Fig. 3 shows the Peleg model fitted on data for Talash variety and Kabuli variety. Other verity fitted models same as those. Coefficient of determination (R^2) and mean relative percentage



(a) (b) (c)

Figure 1 Moisture absorption characteristics of three studied varieties of bean during immersion, (a) Talash, (b) Sadri, (c) Mahali Khomein.



(a) (b) (c)

Figure 2 Moisture absorption characteristics of three varieties of chickpea during immersion, (a) Kabuli, (b) Chico, (c) Desi.

Table 1 Equilibrium moisture content (d.b %) of bean and chickpea varieties.

Samples	Equilibrium moisture content (d.b. %)		
	5 °C	25 °C	45 °C
Bean			
Talash	97.15^{c}	113.60^{b}	135.08^{a} *
Sadri	92.31^{c}	115.85^{b}	131.46^{a}
Mahali Khomein	89.24^{c}	108.02^{b}	127.66^{a}
Chickpea			
Kabuli	55.96^{b}	59.61^{a}	59.60^{a}
Chico	56.67^{b}	60.53^{a}	59.64^{a}
Desi	55.94^{b}	59.50^{a}	59.13^{a}

* Means with the same letter are not significantly different ($P < 0.05$) according to Duncan's multiple ranges test.

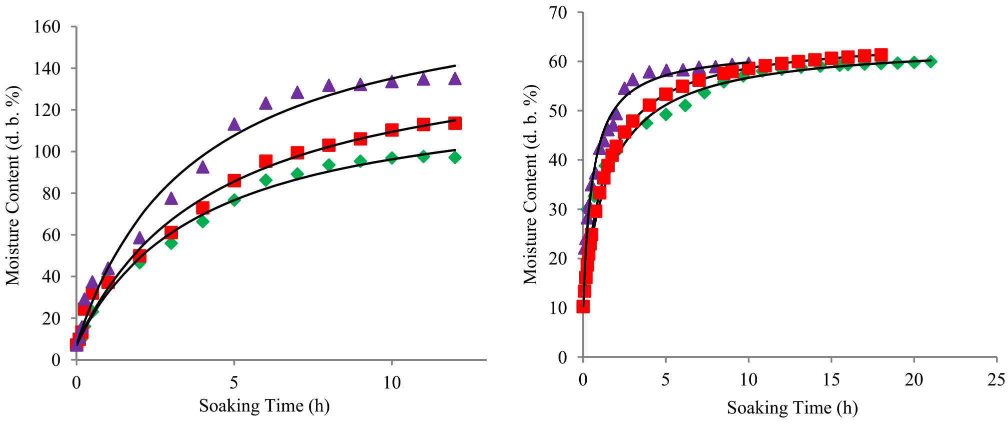
deviation modulus (E) shown in Tables 2 and 3, are more than 0.9 and less than %10, respectively. It indicates that Peleg model was reliable enough to predict moisture content of bean and chickpea. Predicted values were plotted versus measured values for Talash variety of bean and Kabuli variety of chickpea variety at 25 °C (Fig. 4). For other varieties, predicted values versus measured value same as those at each temperature.

3.5. Peleg constant k_1

Tables 2 and 3 show the constant k_1 at three different temperatures for bean and chickpea varieties, respectively. The results showed that the Peleg's rate constant (k_1) for bean decreased linearly as the temperature increased from 5 to 45 °C ($P < 0.05$) (Fig. 5). Almost the same result was observed in the case of chickpea (Fig. 6). The decrement of Peleg's rate constant (k_1) with temperature shows that water transfer, being reversely related to k_1 is promoted by increased temperature. Since, higher temperatures result in the grain gelatinization and subsequently the expansion and softening of grain. Therefore, more pores and cracks are opened and finally the transmission of water through the seed is increased (Ranjbari et al., 2011). Same results have been reported by other researchers (Solomon, 2007; Karacabey et al., 2013; Montanuci et al., 2013; Botelho et al., 2013).

3.6. Peleg constant k_2

Tables 2 and 3 show the constant k_2 at three different temperatures respectively for bean and chickpea varieties. The constant k_2 is related to maximum water absorption capacity (Turhan et al., 2002; Peleg, 1988). Peleg's constant k_2 depends on the type of seed and the loss of soluble solids during soaking (Toma et al., 2001; Abu-Ghannam and McKenna, 1997).



(a) (b)

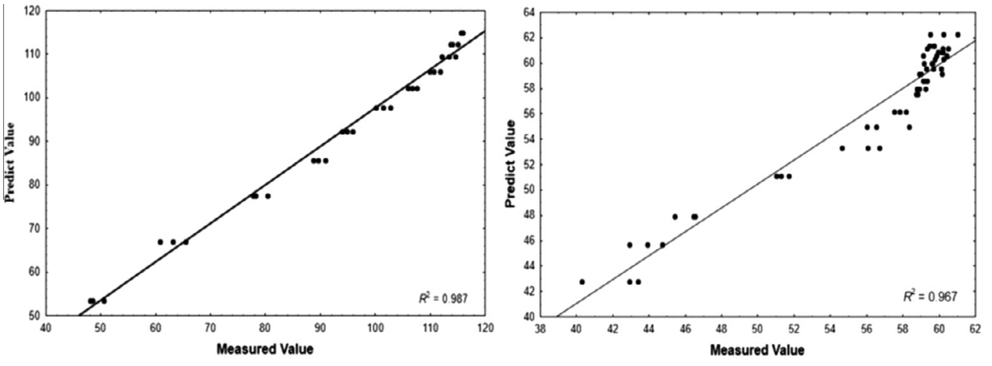
Figure 3 Peleg model fitted on bean (Talash) – (a) and chickpea (Kabuli) data – (b) during immersion 5°◆, 25°■, 45°▲.

Table 2 The coefficients of Peleg model, coefficient of determination (R^2) and mean relative percentage deviation modulus (E) for moisture content of bean varieties during immersion at different temperatures.

Type	Temperature (°C)	$K_1 \times 10^{-4}$ (h × %$^{-1}$)	$K_2 \times 10^{-4}$ (%$^{-1}$)	R^2	E (%)
Talash					
	5	34.03	7.74	0.975	3.04
	25	23.19	6.38	0.987	0.95
	45	13.04	5.47	0.977	1.87
Sadri					
	5	34.39	8.75	0.990	1.58
	25	26.83	6.29	0.987	2.89
	45	19.20	4.11	0.967	4.45
Mahali Khomein					
	5	58.45	6.86	0.983	2.78
	25	52.15	5.29	0.989	1.45
	45	42.07	4.09	0.988	3.94

Table 3 The coefficients of Peleg model, coefficient of determination (R^2) and mean relative percentage deviation modulus (E) for moisture content of chickpea varieties during immersion at different temperatures.

Type	Temperature (°C)	$K_1 \times 10^{-2}$ (h × %$^{-1}$)	$K_2 \times 10^{-2}$ (%$^{-1}$)	R^2	E (%)
Kabuli					
	5	3.5	2	0.986	1.45
	25	2.4	1.9	0.967	0.98
	45	2.19	1.9	0.996	1.98
Chico					
	5	2.5	2	0.986	2.86
	25	1.6	1.9	0.997	2.17
	45	0.8	1.9	0.996	3.15
Desi					
	5	4.4	1.9	0.959	4.45
	25	2.9	1.9	0.981	3.47
	45	2.6	1.7	0.987	2.17



(a) (b)

Figure 4 Predicted value of moisture content against experimental value for Talash variety of bean at 25 °C (a) and Kabuli variety of chickpea at 25 °C (b).

The decrease of Peleg model constant k_2 with increasing temperature is due to absorption of possible moisture content. Thus, in higher temperatures of soaking, the k_2 decrease is due to increasing water absorption capacity. For bean varieties Peleg's constant k_2 decreased with increasing temperature (Fig. 5). However, it was not affected by temperature in the case of chickpea, resulting in the same saturation moisture contents of the three varieties at each temperature. Similar results have been reported for chickpea (Sayar et al., 2001; Toma et al., 2001), soybean (Toma et al., 2001), bean (Abu-Ghannam and McKenna, 1997), and wheat products (Maskan, 2002).

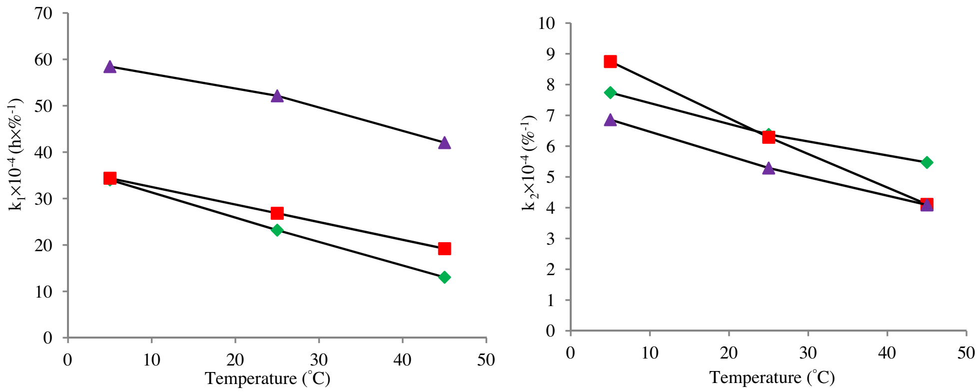


Figure 5 Effect of immersion temperature on Peleg rate constant k_1 and k_2 for bean, ▲, MahaliKhomein; ■, Sadri; ♦, Talash.

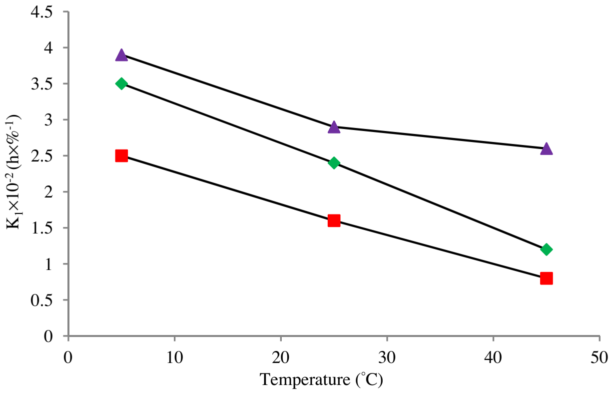


Figure 6 Effect of immersion temperature on Peleg rate constant k_1 for chickpea, ♦, Kabuli; ■, Chico, ▲, Desi.

Table 4 Activation energy during heat transfer from 5 to 45 °C.

Variety	Absorbed energy (kJ/mol)	R^2	$K_{\mathrm{ref}} \times 10^{-4}$
Talash	253.717	0.977	23.19
Sadri	154.354	0.985	26.83
Mahali Khomein	86.773	0.955	52.15
Kabuli	126.269	0.913	240
Chico	301.275	0.974	160
Desi	141.123	0.920	290

3.7. Activation energy

Fig. 7 shows the values of $\ln(1/k_1)$ plotted against $((1/T_{\mathrm{ref}})$ - – $(1/T))$, forming a line with the gradient of (E_a/R), for Sadri variety of bean. The same behavior was observed in case of other varieties. Maximum and minimum activation energy in soaking process were obtained in chickpea variety of Chico ($301.28\ \mathrm{kJ\ mol^{-1}}$) and bean variety of Mahali Khomein ($86.77\ \mathrm{kJ\ mol^{-1}}$), respectively. The values of activation energy for each variety are presented in Table 4. The values of activation energy for various varieties of bean and chickpea were significantly different ($P < 0.05$). It expresses the different physical properties of varieties with regard to heat transfer and activation energy. Positive values of energy suggest that the seeds have gained energy during soaking, in order to absorb moisture and increase their volume. The increment of experiment temperature from 5 to 45 °C only led to some changes in seed texture loosening and faster diffusion of moisture throughout the seeds. Some investigator reported the similar results in the same way about barley seeds (Montanuci et al., 2013). Other researchers also reported similar results of activation energy with respect to temperature changes for four bean varieties grown in South Africa (Jideani and Mpotokwana, 2009).

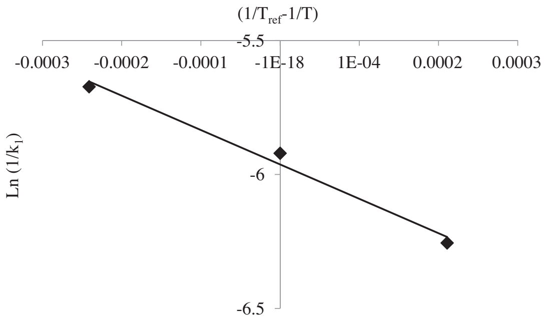


Figure 7 Activation energy during soaking of Sadri bean at 5, 25 and 45 °C.

3.8. Effect of temperature on system enthalpy, entropy and released energy

Tables 5 and 6 present the effects of temperature changes on enthalpy, entropy and released energy of the soaking process of bean and chickpea varieties, respectively. In whole varieties, negative values of enthalpy indicate that during soaking, the moisture content of the seeds has changed within an exothermic and energetically favorable transformation (Reusch, 2007). Increment of soaking temperature led to the enthalpy for each variety to increase ($P < 0.05$). It occurred due to absorbed heat at constant pressure along with seed volume expansion. The volume expansion is in fact further moisture sorption at equal times due to temperature increase.

In soaking process, entropy increased with negative values as the soaking temperature increased, showing no significant

Table 5 Thermodynamic parameters of water absorption of bean varieties.

Variety	Temperature (°C)	ΔH (Cal/mol)	ΔS (Cal/Kmol)	ΔG (kcal/mol)
Talash				
	5	−2058.823	−244.286	65.890
	25	−2225.104	−245.461	68.574
	45	−2391.386	−246.333	75.979
Sadri				
	5	−2158.187	−245.431	66.108
	25	−2324.463	−245.958	68.623
	45	−2490.741	−246.458	75.602
Mahali Khomein				
	5	−2225.779	−234.821	63.090
	25	−2392.055	−236.752	70.283
	45	−2558.332	−237.452	72.987

Table 6 Thermodynamic parameters of water absorption of chickpea varieties.

Variety	Temperature (°C)	ΔH (Cal/mol)	ΔS (Cal/Kmol)	ΔG (kcal/mol)
Kabuli				
	5	−2186.276	−243.253	65.474
	25	−2352.551	−246.695	71.869
	45	−2583.832	−251.682	77.553
Chico				
	5	−2011.269	−245.935	66.395
	25	−2177.542	−248.353	71.869
	45	−2343.823	−249.389	73.489
Desi				
	5	−2171.428	−241.204	64.919
	25	−2337.700	−242.168	71.776
	45	−2503.987	−248.589	74.541

difference ($P > 0.05$). The free energy of activation rose with positive values as the temperature increased, with neither significant difference in a probability ($P > 0.05$). Positive values of free energy of activation express the absorption of energy from surrounding area (Reusch, 2007). The same results have been reported by other researchers for four bean and five barley varieties respectively (Jideani and Mpotokwana, 2009; Montanuci et al., 2013).

4. Conclusions

Summarized results obtained in present study are:

1. The Peleg model could satisfactorily predict the moisture content of different bean and chickpea varieties during soaking.
2. The water absorption capacity of legumes increased with the increment of both soaking temperature and time.
3. During the soaking process, moisture content increased rapidly at the beginning of immersion. However, the rate of water absorption slowed down and quiet as the time passed and the moisture content reached to saturation point.
4. In the case of bean, the variety significantly affected the water absorption, however, indicating no effect in the case of chickpea.
5. The Peleg rate constant k_1 decreased with increasing temperature for a piece variety of bean and chickpea.
6. For the bean varieties, the Peleg moisture capacity constant k_2 declined as the temperature increased while it was not affected by temperature, in the case of chickpea.
7. Changes in thermodynamic parameters during moisture sorption process of chickpea and bean seeds suggested that an exothermic and energetically favorable transformation reaction has occurred. Enthalpy, entropy and free energy of activation of chickpea and bean seeds increased as soaking temperature increased from 5 to 45 °C.

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