Hydration kinetics and physical properties of split chickpea as affected by soaking temperature and time

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Abstract In this study, some physical properties (principal dimensions, mean diameters, sphericity, area, density and electrical conductivity) of split chickpea were measured as function of soaking time (up to 360 min) and temperature (25–65 °C). Initially, the water absorption rate was high and then it showed a progressive decrease at all temperatures, whereas solid loss exhibited a power function of temperature ($P < 0.05$). The Peleg model was predicted well the kinetic of split chickpea soaking. No significant difference ($P < 0.05$) was observed in Peleg rate constant (K_1) and Peleg capacity constant (K_2) at all temperatures except for K_1 at 25 °C. The discrepancy for K_1 was in relation to permeability characteristics of split chickpea at temperature of 25 °C. As temperature increased from 25 to 65 °C, the K_1 value decreased from 0.04620 to 0.00945 g h⁻¹, whereas the K_2 value increased from 0.08597 to 0.11320 g⁻¹. Plot for K_1 exhibited a slope changes around 45 °C corresponding to gelatinization temperature of split chickpeas. The effect of temperature and time on physical properties of split chickpea during soaking was monitored by regression equations. It was concluded that physical properties of split chickpea affected by its water absorption especially at higher temperatures.

Keywords Chickpea · Kinetic · Physical properties · Solid loss · Water absorption

Introduction

Beans are valuable sources of protein, energy, vitamins and minerals economically. Chickpea (*Cicer arietinum* L.), member of the bean family, is a good source of essential amino acids (except types containing sulfur), sterols, vitamins, dietary fiber and it also has a small amount of fat, mainly from unsaturated fatty acids (Jukantil et al. 2012). The chickpea on average contains a 20.9 %, 1.3 %, and 43.4 % of protein, fat and carbohydrates, respectively (Sanchez-Vioque et al. 1999). According to statistics released by the FAO in 2013, in terms of output, India is allocated ranks first in production and then in the next positions are the Pakistan, Turkey, Iran and Mexico, respectively (Food and Agriculture Organization 2011). According to the world production statistics in 2011, it was reported that Iran's share is equal to 290,243 t, 2.50 % of total production in the world (Food and Agriculture Organization 2011).

Desi (India origin) and Kabuli (Mediterranean and Middle Eastern origin) chickpeas are two major varieties. In comparison, Desi variety has smaller size, darker color, thicker cover and higher fiber (Singh et al. 2010; Thushan Sanjeeva et al. 2010). These are commonly used as split chickpea in some traditional foods and processed canned foods in Iran. It is clear that, soaking is applied before cooking to move out some undesirable materials (like oligosaccharides which known as Flatulence-causing agents) present in the chickpea and reduce the cooking time (Singh et al. 2010). It is reported that the highest quality of protein is achieved when the samples cook at lesser time (Uebersax Mark 2006). According to the literature, in order to achieve a better-quality product, in terms of protein digestion and economic benefits resulting from reduced cooking time, presoaked product is recommended for temperatures above than ambient temperature (Bello et al. 2004).

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Water transport modeling is very important to understand the effect of grain/seed moisture content on the quality of the final product. The Peleg equation was generally used to describe the water absorption of various food products during soaking such as red kidney beans (Abu-Ghannam and McKenna 1997), sorghum grains (Kashiri et al. 2010), dehydrated Dasheen leaves (Maharaj and Sankat 2000) and spring and winter chickpeas (Turhan et al. 2002). In this study, the effect of soaking time and temperature on the water absorption, solid loss and physical properties of split chickpea was investigated. In addition, the kinetics of water uptake at different temperatures was analyzed by the Peleg model.

Materials and methods

Materials

The split chickpeas were obtained from a local market in Tabriz, Iran and separation of damaged split chickpeas and impure materials were manually carried out. They were packaged in polyethylene bags and kept at 4 °C before experiments.

Water absorption measurement

To investigate the water absorption of split chickpea, 10 g of samples with 60 ml of distilled water (pH = 7) were poured into a plastic container of 100 ml. Water absorption of the sample at different temperatures (25, 35, 45, 55 and 65 °C) were measured at intervals of 5 min to 360 min. The end point was introduced as the saturation point of water absorption, which occurs when the weight of adsorbed water was constant. Water absorption (W_t , %) was calculated according to the following equation:

$$W_t(\%) = \frac{M_t - M_o}{M_o} \times 100 \quad (1)$$

Where, M_o and M_t are the mass of split chickpeas before soaking and at different soaking intervals, respectively.

The results of water absorption were plotted against time. Then, the Peleg empirical relationship was used to model the kinetic of water absorption of split chickpea as follows (Hung et al. 1993):

$$M_t = M_o + \frac{t}{K_1 + K_2 t} \quad (2)$$

Where, $M_t - M_o$ is water uptake (g), K_1 is the Peleg rate constant (h.g^{-1}) and K_2 is the Peleg capacity constant (g^{-1}).

Solids loss measurement

The solid loss content was determined by AOAC method (AOAC 1980) in which 10 g sample weighted in plate and placed in air oven at temperature 110 ± 1 °C for 24 h. The solid loss (SL, %) was determined using the following formula:

$$SL(\%) = \frac{m_p}{m_o} \times 100 \quad (3)$$

Where, m_p and m_o are sample weight after and before drying in an oven, respectively. The results of solids loss were plotted against time the solid loss was analyzed using regression equations at different temperatures.

Physical properties determination

To characterize the physical properties, 10 split chickpeas were randomly selected at different soaking times and temperatures and the main dimensions including length (L, mm), width (W, mm) and thickness (T, mm) were measured using a digital micrometer (QLR, China) to an accuracy of 0.001 mm. Arithmetic mean diameter (D_a), geometric mean diameter (D_g), sphericity (ϕ) and surface area (S) were calculated using the following equations (Milani et al. 2007):

$$D_a = (L + W + T)/3 \quad (4)$$

$$D_g = (LWT)^{1/3} \quad (5)$$

$$\phi = D_g/L \quad (6)$$

$$S = \pi D_g^2 \quad (7)$$

The true volume (V_t) was determined using the liquid displacement method. Toluene (C_7H_8) was used instead of water because it is absorbed by the split chickpea to a lesser content. Moreover, its surface tension and dissolution power is low. The values of true volume (V_t) and density (ρ_t) of split chickpea at different soaking times and temperatures were calculated by the following relationships (Razavi 2008):

$$V_t = \frac{M_{td}}{\rho_{to}} = \frac{(M_{to} - M_p) - (M_{ptos} - M_{ps})}{\rho_{to}} \quad (8)$$

$$\rho_t = \frac{M_{ps} - M_p}{V_t} \quad (9)$$

Where V_t is the volume of toluene displaced; M_{td} is the mass of toluene displaced; ρ_{to} is toluene density; M_{to} is the mass of the pycnometer filled with toluene; M_p is the mass of the empty pycnometer; M_{ptos} is the mass of the pycnometer filled with toluene and grain; M_{ps} is the mass of the pycnometer and grain.

Due to leaching the materials from chickpea to water during of soaking, the water conductivity at different time and

temperature intervals of soaking were measured using a conductivity meter (JENWAY, 4010 μs) (Fosgate et al. 2013).

Data analysis

All experiments were performed triplicates. Means, standard deviation, regression equation, coefficient of determination (R^2) and mean-square-error (MSE), root-mean-square-error (RMSE) and all charts were prepared by Microsoft Excel Software (2010) and Matlab software (2010). ANOVA tests were performed by SPSS software version 16.0. Significant differences between means were determined by Duncan's multiple range tests; p values less than 0.05 were considered statistically significant.

Results and discussion

Water absorption

The water absorption of split chickpea at different temperatures is shown in Fig. 1. It can be seen that split chickpea represented typical sorption behavior as logarithmic with increasing water content during soaking time at all temperatures. Initially, the water absorption rate was increased, which is probably due to filling free capillaries and inter-micellar spaces on the seed coat and hilum. As the process continued, with decreasing concentration difference between soaking medium and the split chickpeas, the extraction of soluble solids in the reverse direction to the water movement suggests excess resistance to the water transfer so that the water absorption rate decreased (Sayar et al. 2001). Moreover, as temperature increased from 25 to 65 °C, the water absorption of split chickpea increased and it was reached to a saturation point

earlier from 360 to 75 min. But increasing the temperature from 25 to 65 °C caused the maximum water absorption to decrease from 11.123 to 8.820 g, respectively. This was in accordance with the results observed by Abu-Ghannam and McKenna (1997). They reported that the plasticity of seed coat of red kidney beans reaches to its maximum value as temperature increases, whereby the equilibrium moisture content decreases.

The Peleg model ($t/M-M_0 = K_1 + K_2t$) was used to model water absorption of split chickpea during the soaking time at different temperatures of 25, 35, 45, 55 and 65 °C (Jideani and Mpotokwana 2009). The results of modeling showed that this model was fitted well with $R^2 \geq 0.995$ at all temperatures. Table 1 shows the values of K_1 and K_2 obtained from fitting of Peleg model at mentioned temperatures. K_1 is a constant related to the mass transfer rate and the lowest K_1 has the highest initial water absorption rate. The results showed that the reduction in K_1 values was not significant i.e., from 0.04625 to 0.00945 h.g^{-1} ($P > 0.05$) as temperature increased from 25 to 65 °C except for 25 °C that was significantly different ($P < 0.05$). Several investigators also reported that K_1 decreased with increasing temperature (Cunningham et al. 2007; Resio et al. 2006; Wardhani et al. 2008). This result is very important in soaking process especially for cooking split chickpea. Because of lower water absorption rate by split chickpea at room temperature, it should be soaked at higher temperatures before cooking to save time. The following linearized Arrhenius equation was used to describe the effect of temperature on K_1 (Elbert et al. 2001):

$$\ln K = \ln C_K - \frac{E_a}{R_g T} \quad (10)$$

Where C_K is a constant (h.g^{-1}), E_a is the activation energy (KJmol^{-1}), R_g is the universal gas constant ($8.314 \text{ KJmol}^{-1} \text{ K}^{-1}$),

Fig. 1 Water absorption of split chickpea as function of soaking time and temperature

Table 1 The Peleg model constants determined for water absorption of split chickpea at different temperatures^a

T (°C)	$K_1 \times 10^3$ (h.g ⁻¹)	$K_2 \times 10^3$ (g ⁻¹)	RMSE	R ²
25	46.20 ± 0.015b	85.97 ± 0.022a	0.011	0.995
35	27.87 ± 0.006a	87.93 ± 0.021a	0.005	0.999
45	17.90 ± 0.001a	89.87 ± 0.023a	0.003	0.998
55	15.60 ± 0.004a	101.65 ± 0.029a	0.004	0.998
65	9.45 ± 0.003a	113.20 ± 0.031a	0.004	0.998

^a Means ± SD (standard deviation) within a column with the same lower-case letters are not significantly different at $p > 0.05$

and T is absolute temperature (K). Arrhenius plot exhibited structural changes of chickpea split around 45 °C that affect the initial water absorption rate, which is probably a result of approaching the gelatinization temperature of split chickpea. The E_a values for K_1 were 37.40 KJ mol⁻¹ and 28.39 KJ mol⁻¹ below and above 45 °C, respectively. The lower activation energy at above 45 °C expressed faster water migration in gelatinized split chickpea than ungelatinized split chickpea.

K_2 is a constant associated with water absorption capacity. The lowest K_2 has the highest water absorption capacity. With increasing temperature from 25 °C to 65 °C, the K_2 values was increased ($P < 0.05$) from 0.08597 to 0.11320 g⁻¹ (Table 1). Therefore, the highest and the lowest water absorption capacity for chickpea split were observed for soaking temperatures of 25 °C and 65 °C, respectively. Turhan et al., (2002) also observed that during soaking of spring and winter chickpeas, K_2 were increased by increasing temperature from 20 to 100 °C. On the contrary, Yildirim et al. (2010) reported that during soaking of chickpea at temperatures 20–97 °C, the K_2 value decreases as temperature rises.

Solid loss

During soaking of split chickpea, soluble solids leach out from split chickpea to water, so cause in reducing the nutrition value of substance. Solid loss as function of soaking time and temperature is presented in Fig. 2. It can be seen that initially, the content of transferred soluble solid to water was a greater slope because of more water diffusion and curve slope was decreased progressively. Solid loss can be estimated by a power type equation as follows (Yadav and Jindal 2007):

$$SL = t^u \quad (11)$$

Where, SL is the percent of solid loss (d.b. %), t is the soaking time (min) and u is a constant representing the power of solid leaching into the water medium. The results showed that solid loss data fitted well by Eq. (11) (Table 2). It can be also found that u value increased significantly with increasing the temperature from 25 to 65 °C ($P < 0.05$). In the production process of split chickpea from chickpea, the parts of grain go coatless, whereby the substances of split chickpea are in contact with water directly. Therefore, the soluble solids diffusion is mostly affected by temperature of water.

Physical properties

Electrical conductivity

Electrical conductivity determined for split chickpea soaked in water is shown in Fig. 3. As is seen, electrical conductivity during soaking process increased logarithmic at all temperatures. In addition, as temperature increases, electrical conductivity changes more intensely. In this case, electrical conductivity changed

Fig. 2. Solid loss of split chickpea as function of soaking time and temperature

Table 2 Results of regression analysis for estimating solid loss during soaking of split chickpea^a

T (°C)	u	SSE × 10 ⁻³	R ²	RMSE × 10 ⁻³
25	0.1537 ± 0.008a	13.22	0.983	25.09
35	0.2670 ± 0.036b	27.84	0.986	38.28
45	0.3259 ± 0.020c	72.96	0.956	74.91
55	0.4492 ± 0.007d	208.7	0.927	131.9
65	0.5211 ± 0.056e	28.53	0.991	50.93

^a Means ± SD (standard deviation) within a column with the different lowercase letters are significantly at $p < 0.05$

initially with greater slope and then decreased progressively. It can be probably due to migration of some compounds such as iron, zinc, calcium, etc. from split chickpea to water that change the electrical conductivity of water. Sarang et al. (2008) measured electrical conductivity of six fresh fruit (red apple, golden apple, peach, pear, pineapple and strawberry) and three kind of meat (chicken, pork and beef) at temperatures of 20–140 °C. They found that raising temperature increases the electrical conductivity.

Geometrical attributes and density

Table 3 show the regression relationships between physical parameters (main dimensions, mean diameters, surface area, sphericity and density) and soaking time at temperatures of 25, 35, 45, 55 and 65 °C. According to Table 3, the height (H), width (W), thickness (T), geometric diameter (D_g), arithmetic diameter (D_a) and surface area (S) values increased in longer periods of time and temperature with mean square error (MSE) values lower than 1.19 that confirms the equations precisely describes water absorption of split chickpea within the studied times and temperatures. Similar results were found for Caper seed (Dursun and Dursun 2005) and Millet (Baryrh 2002).

Fig. 3. Electrical conductivity of split chickpea as function of soaking time and temperature**Table 3** The regression relationships between physical parameters and soaking time determined for split chickpea at different temperatures

Temperature (°C)	Regression equation	MSE	R ²
25	H = 0.3048ln(x) + 5.5347	0.68	0.94
	W = 0.2789ln(x) + 4.4376	0.64	0.96
	T = 0.1307ln(x) + 2.5892	0.20	0.92
	D _a = 0.2381ln(x) + 4.1872	0.50	0.95
	D _g = 0.0382ln(x) + 2.3351	0.02	0.96
	S = 0.5991ln(x) + 17.048	1.19	0.95
	φ = -0.011ln(x) + 0.4124	0.004	0.96
	ρ _P = -0.03ln(x) + 1.3139	0.02	0.99
35	H = 0.3212ln(x) + 5.6073	0.67	0.98
	W = 0.2488ln(x) + 4.6237	0.46	0.96
	T = 0.1701ln(x) + 2.4423	0.31	0.98
	D _a = 0.2467ln(x) + 4.2244	0.48	0.98
	D _g = 0.0395ln(x) + 2.3415	0.02	0.98
	S = 0.6199ln(x) + 17.145	1.08	0.98
	φ = -0.011ln(x) + 0.4093	0.004	0.99
	ρ _P = -0.025ln(x) + 1.3006	0.01	0.98
45	H = 0.3051ln(x) + 5.9298	0.39	0.96
	W = 0.2445ln(x) + 4.8733	0.29	0.99
	T = 0.2022ln(x) + 2.4515	0.31	0.98
	D _a = 0.2506ln(x) + 4.4182	0.33	0.99
	D _g = 0.0397ln(x) + 2.3743	0.01	0.99
	S = 0.626ln(x) + 17.646	0.59	0.99
	φ = -0.01ln(x) + 0.3942	0.002	0.95
	ρ _P = -0.029ln(x) + 1.298	0.01	0.97
55	H = 0.2304ln(x) + 6.1309	0.20	0.98
	W = 0.1956ln(x) + 5.0201	0.17	0.99
	T = 0.2036ln(x) + 2.5	0.29	0.96
	D _a = 0.2099ln(x) + 4.5503	0.23	0.99
	D _g = 0.0334ln(x) + 2.3947	0.01	0.99
	S = 0.5255ln(x) + 17.972	0.37	0.99
	φ = -0.007ln(x) + 0.3877	0.001	0.98
	ρ _P = -0.027ln(x) + 1.2802	0.01	0.96
65	H = 0.2069ln(x) + 6.1837	0.15	0.95
	W = 0.1915ln(x) + 4.9918	0.15	0.99
	T = 0.1438ln(x) + 2.6347	0.14	0.95
	D _a = 0.1808ln(x) + 4.6034	0.14	0.99
	D _g = 0.0289ln(x) + 2.4027	0.01	0.99
	S = 0.4535ln(x) + 18.102	0.24	0.90
	φ = -0.007ln(x) + 0.3862	0.001	0.99
	ρ _P = -0.024ln(x) + 1.2667	0.01	0.87

On the contrary, the sphericity (φ) decreased by increasing soaking time and temperature from 25 to 65 °C ($R^2 > 0.95$) (Table 3). It can be due to differences in water absorption in different parts of split chickpea because the different parts of split chickpea are not similar in terms of coat, and therefore water diffusivity rate varies in different parts of the product.

Due to the water uptake and solid loss by the chickpeas, the density of splits also decreased as the soaking time and temperature increased (Table 3). It is in agreement with studies by Konak et al. (2002). As temperature increased from 25 °C to 65 °C, the percent of density changes (at time of equilibrium state of moisture uptake) decreased from 10.190 % to 6.504 %, respectively. It may be due to the more water absorption capacity at lower temperature, whereby more water absorption happened at 25 °C than 65 °C.

Conclusion

The water absorption of split chickpea increased faster at the beginning of soaking process and decreased progressively after filling the capillaries on seed coat and hilum. It was observed that the water absorption of split chickpea can be expressed by logarithmic behavior at all temperatures. The Peleg model can be used to describe successfully water absorption of split chickpea by using short-term data. By increasing the temperature of soaking medium, K_1 and K_2 increased and decreased, respectively. It demonstrates that the water absorption rate increased and the water absorption capacity decreased as the temperature rose from 25 to 65 °C. K_1 can be used to describe the gelatinization temperature by an Arrhenius-type model. The solid loss during soaking was obeyed a power function of temperature. The physical properties of split chickpea were affected by the water absorption and solid loss during soaking. These findings have a crucial importance in designing equipments and machines for handling, sorting, cooking and packaging processes of split chickpea.

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