RESEARCH ARTICLE

HYDRATION KINETICS OF ULTRASOUND TREATED CHICKPEAS (C*ider arietinum L.*) DURING SOAKING

Ali YILDIRIM[a*], Mustafa BAYRAM[b], Mehmet Durdu ÖNER[b]

ABSTRACT

In this study, effect of ultrasounds with high energy on water absorption capacity of chickpea was examined during soaking process. Asimptotik first order model was applied to experimental results and water hydration rate constant (k_H) was calculated. Normal soaking process was applied to chickpea samples at 20, 30, 40, 50, 60, 70 and 80 ^oC temperatures. In order to determining the effects of ultrasound in chickpea, soaking process was made with two different ultrasounds such as 25 kHz 100 W and 25 kHz 300 W. Increase in temperature from 20 to 80 ^oC increased the predicted water hydration rate constant (k_H) from $7.33x10^{-5}$ s^{-1} to $39.54x10^{-5}$ s^{-1}. When 25 kHz 100 W ultrasound applied, water hydration constan (k_H) for the same temperature range were found as $10.18x10^{-5}$ s^{-1} - $43.71x10^{-5}$ s^{-1}. Application of high power ultrasound such as 25 kHz 300 W at the same temperature interval was much more affected the water hydration rate constants (k_H values $12.33x10^{-5}$ - $47.80x10^{-5}$ s^{-1}). Gelatinization temperature of chickpea for this study was found as 60.80 ^oC. Activation energy values using hydration rate constant below and above 60 ^oC was found 32.01 and 5.89 kJ/mol, respectively. Increase in hydration rate constant increase the water absorption rate which provides chickpea to soften and cookin a shorter time.

Key words: Chickpeas, ultrasound, hydration kinetics, soaking

ULTRASON UYGULANMIŞ NOHUTLARIN (C*ider arietinum L.*) HİDRASYON KİNETİĞİ

ÖZET

Bu çalışmada, yüksek enerjiye sahip ultrasonik ses dalgalarının suda bekletme sırasında nohutun su emme kapasitesine etkisi incelenmiştir. Elde edilen deneysel sonuçlara, Asimptotik birinci derece modeli uygulanmış ve hidrasyon katsayıları (k_H) hesaplanmıştır. Nohut numunelerine, 20, 30, 40, 50, 60, 70 ve 80 ^oC sıcaklıklarında normal ıslatma işlemi uygulanmıştır. Nohutta ultrasonik ses dalgalarının etkisinin belirlenmesi amacıyla belirtilen ıslatma işlemi 25 kHz 100 W ve 25 kHz 300 W'lik 2 farklı ultrasonik ses dalgası uygulaması ile birlikte yapılmıştır. Sıcaklığın 20^oC'den 80 ^oC artırılmasıyla, hidrasyon katsayısı (k_H) $7.33x10^{-5}$ s^{-1} den $39.54x10^{-5}$ s^{-1}'ye arttığı belirlenmiştir. 25 kHz 100 W'lık ultrasonik ses dalgası kullanıldığında, model için hidrasyon katsayısı (k_H) aynı sıcaklık aralığında $10.18x10^{-5}$ s^{-1} ve $43.71x10^{-5}$ s^{-1} olarak bulunmuştur. Yüksek güçteki ultrasonik ses dalgalarının (25 kHz 300 W) kullanılmasının, bu etkiyi daha çok arttırdığı (k_H değerleri, $12.33x10^{-5}$ - $47.80x10^{-5}$ s^{-1}) gözlenmiştir. Yapılan çalışmada jelatinizasyon sıcaklığı 60.80 ^oC olarak bulunmuştur. Aktivasyon enerji değerleri 60 ^oC'nin altında ve üzerinde sırasıyla 32.01 ve 5.89 kJ/mol olarak bulunmuştur. Hidrasyon katsayılarının artması, su absorpsiyon hızının artmasını, böylelikle nohutun daha kısa sürede yumuşamasını ve pişmesini sağlamaktadır.

Anahtar kelimeler: Nohut, ultrason, hidrasyon kinetiği, suda bekletme

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INTRODUCTION

Chickpea is a staple food crop in many tropical and subtropical countries, have been grown in Turkey since about 7000 B.C, and has been produced in semi-arid zones of India and Middle Eastern countries. It is the second most important pulse crop in the world. Chickpeas are sources of complex carbohydrates, protein and dietary fibre, having significant amounts of vitamins and minerals, and high energetic value (Chavan et al., 1986; Tharanathan and Mahadevamma, 2003). Several reports claim that inclusion of chickpeas in the daily diet has many beneficial physiological effects in controlling and preventing various metabolic diseases such as diabetes mellitus, coronary heart disease and colon cancer (Simpson et al., 1981; Shehata et al., 1988; Chavan et al., 1989).

Soaking allows water to be distributed among starch and protein fractions within the legume. The water thus imbibed is utilised during cooking to facilitate chemical reactions such as starch gelatinisation and protein denaturation. As soaking proceeds, water penetrates the seed coat, travelling through the cotedylons and towards the centre of the bean. Such water absorption causes the bean to become softer and uniform in texture (Abu-Ghannam, 1998; Deshpande & Bal, 2001). Soaking process is generaly applied to legumes before cooking or during cooking in order to decrease the cooking time and increase the leached materials. Whether used at home to prepare a variety of dishes or in commercial practice, dry legumes need to be rehydrated by soaking in water or other pre-treatments before further processing. Researchers have already demonstrated that increasing the temperature of the soaking medium is an effective way to accelerate water uptake by various seeds and hence, to shorten the soaking time (Quast and da Silva, 1977; Ekpenyong and Borchers, 1980; Davis and Gordon, 1982). The soaking process has been characterised as a time consuming step and many attempts have been directed towards shortening it (Rockland and Metzler, 1967; Kon et al., 1973). As soaking conditions vary depending upon the particular legume under study, it is necessary for practical applications to characterise and optimise these conditions. Hence, water hydration during soaking needs to be predictable as a function of time and temperature.

Kinetics in grains and legumes during soaking has attracted considerable attention. The hydration kinetics of dry legumes during soaking has been described by a three-parameter asymptotic model (Abu-Ghannam and Mckenna, 1997; Ibarz et al., 2004; Gowen et al., 2007). There have been many attempts directed towards analysing the hydration data and the modes of water transport in many legume varieties (Hsu et al., 1983; King & Ashton, 1985). Additionally, it is a basic model to describe the hydration, that moisture absorption can be described easily. To select the most suitable model, degree of fit to the experimental data and simplicity of the model should be considered.

Presoaking of chickpeas alone may not be enough for decreasing the cooking time. Ultrasonic waves can cause a rapid series of alternative compressions and expansions, in a similar way to a sponge when it is squeezed and released repeatedly. Ultrasound cavitations can result in the occurrence of microstreaming which is able to enhance heat and mass transfer (Jayasooriya et al., 2004; Zheng & Sun, 2006). Ultrasonic is a rapidly growing field of research, which is finding increasing use in the food industry for both the analysis and modification of food products (Zbigniew et al., 2007). In this study, it was aimed to examine hydration kinetics of ultrasound applied chickpeas during soaking and to characterise the kinetic constants and to determine suitable conditions for rehydration.

MATERIALS AND METHODS

Legume source

Dry kabuli certified chickpeas (inci) obtained from Çukurova Agricultural Research Institute (Adana, Turkey) with initial moisture content of 11.58% (d.b.) (±0.04) and an average diameter of 8.00 (±0.27) mm (measured with Mutitoyo No. 505-633, Japan, digital micrometer) , Turkey), were used throughout this study. After removing foreign materials and damaged seeds, they were sieved to standardize the sizes, 7.5 –9 mm. An analytical balance (with a sensitivity of ±0.0001, Shimadzu, Japan) was used to determine the weight of chickpea samples.

Dry moisture content determination
The moisture contents of randomly selected grains (5 g) were determined in dry basis at 105 °C for 48 h using oven drying method (AOAC, 2002). Average moisture content was subsequently calculated on a percentage dry basis (% d.b.). The experiments were replicated twice and measurements were duplicated.

Determination of water intake during soaking
Chickpeas was soaked at 20, 30, 40, 50, 60, 70 and 80 °C without, and with 25 kHz 100 W (acoustic energy density (EAD) of 0.025Wcm^3) and 25 kHz 300W (EAD of 0.017W cm^3) ultrasound treatments. One hundred grams of chickpea seeds were immersed in 2000 ml deionized water (1:20); conventional and ultrasonic soaking were both performed in thermostatically controlled ultrasonic (US) tanks (Intersonik Co., Turkey) until seeds were fully hydrated. Four grams of chickpea and 80 ml soaking water (1:20) were quickly removed from the tanks for the moisture content determination within 30 min intervals. Chickpea seeds were gently wiped with clean paper towel to remove excess water and ground for the moisture content determination.

Statistical analysis
Calculated parameters for modeling and plots were compared using Statgraphics 10 (SIGMAPLOT 10 software, Jandel Scientific, San Francisco, USA) and Excel 2003 (Microsoft, USA) software. ANOVA and Duncan's multiple-range tests at $P < 0.05$ were performed to predict optimum process conditions (SPSS version 16 statistical software, SPSS Inc., USA). Models validation was performed by R^2, $P<0.05$ and RMSE (%) = Root mean square error. All measurements were made with a minimum of duplicate replications.

RESULTS AND DISCUSSION
Water hydration (absorption) characteristics of chickpea
Soaking to hasten the gelatinization of starch in the seed, is the first step during processing of edible seeds and grains. Seeds are usually soaked before cooking. The most important property for soaking of chickpea is the moisture content to achieve the proper cooking operation. It can be achieved either through conditioning below the cooking temperature and then cooking above the cooking temperature, or through direct cooking above the cooking temperature. Understanding water absorption in legumes during soaking is of practical importance since it affects subsequent processing operations and the quality of the final product.

The water absorption characteristics of chickpea were analyzed using moisture content (% g/g, d.b.) values. Mean moisture contents (% g/g, d.b.) of soaked chickpeas at 20, 30, 40, 50, 60, 70 and 80 °C without and with ultrasounds with respect to soaking time were illustrated in Figures 1-2. The moisture content (% g/g, d.b.) of chickpea during soaking were significantly ($P<0.05$) increased as the temperature, time and power of ultrasounds increased. Rate of increase in moisture content was higher during the early times of soaking whereas lower in the late soaking periods. Chickpea water absorption curves, illustrated in Figures 1-2 are characterised by an initial phase of rapid water pickup followed by an equilibrium phase, during which the chickpea approaches its full soaking capacity. Results indicated that increasing soaking temperature enhanced water pickup in the initial phase, increasing the slope of the water absorption curve, thereby leading to faster attainment of the equilibrium phase, and this was in agreement with previously published data (Turhan et al., 2002). The rate of water absorption increased with increasing temperature (Figures 1-3). The behavior of material during moisture absorption depends on the heat and mass transfer characteristics of the product (Fasina et al., 1993).

Kinetics of Hydration of Chickpeas

Chickpea hydration as a function of time
Many theoretical, empirical, and semi-empirical models have been employed for the kinetics of the water absorption behaviour of chickpeas during soaking (Hung et al., 1993; Sayar et al., 2001; Turhan et al., 2002; Patane et al., 2004; Ibarz et al., 2004; Pinto and Esin, 2004; Sabapathy et al., 2005; Wood and Harden, 2006; Gowen et al., 2006; Gowen et al., 2007).

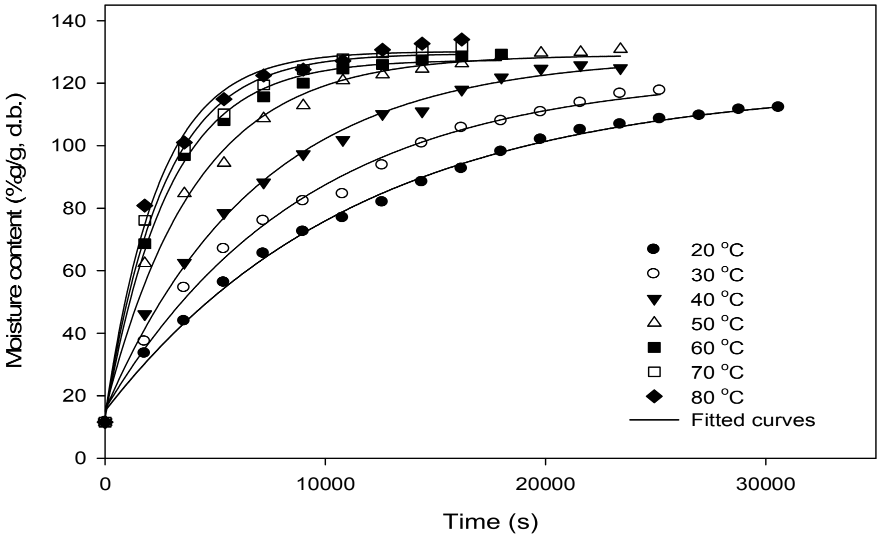

Figure 1. Means of experimental and predicted hydration values (% g/g, d.b.) of chickpeas during soaking at different temperatures.

When chickpeas are submerged in a sufficient amount of water adsorb the liquid to a point of saturation or until equilibrium is reached, at which point no additional water can be retained.

Variation of the content in water of chickpeas with time may be described as

$$\frac{dM}{dt} = k_o - k_H M \qquad \text{(Eq.1)}$$

where M is the moisture content of chickpea in % (g water/100 g dry solid), t is the soaking time, k_o and k_H (or k_1) are the zero-order and first-order (hydration) kinetic constants, respectively. This equation can be integrated with the boundary limit, which for initial time (t=0) the water content of the sample (referred to as the dry solids, %) is M_o. We can obtain;

$$\frac{k_o / k_H - M}{k_o / k_H - M_o} = \exp(-k_H * t) \qquad \text{(Eq.2)}$$

For very large times (t=∞), equilibrium (saturation) is reached, and $M=M_s$(% saturation moisture content in d.b.) = k_o/k_H. In this way, equation is obtained as follows:

$$M = M_s + (M_o - M_s)\exp(-k_H * t) \qquad \text{(Eq.3)}$$

$k_o = M_s * k_H$, which indicates the velocities of the two steps, of retention and liberation of water, are equalized. This is a three-parameter asymptotic model. This model was also applied to chickpeas for soaking by Gowen et al., (2007). Such asymptotic model have been previously employed to describe the soaking process in kidneybeans (Abu-Ghannam and McKenna, 1997) and faba beans (Haladjian et al., 2003).

For mathematical modeling of variation of moisture content of chickpea during soaking at each temperature without and with ultrasound, the model was tested. The parameters in the model such as M_s and k_H were estimated by using the non-linear regression analysis of Equation 3 (Table 1). The performance of the model was tested according to their coefficient of determination (R^2), residuals of either moisture content and percentage of root mean square error (% RMSE (Table 1).

Data on the amount of water absorbed (moisture content) during soaking are illustrated in Figures 1-2 for this model. The course of the hydration, adequately fitted by a nonlinear equation with coefficients, shows that the seed water content increases with soaking time at all temperatures and

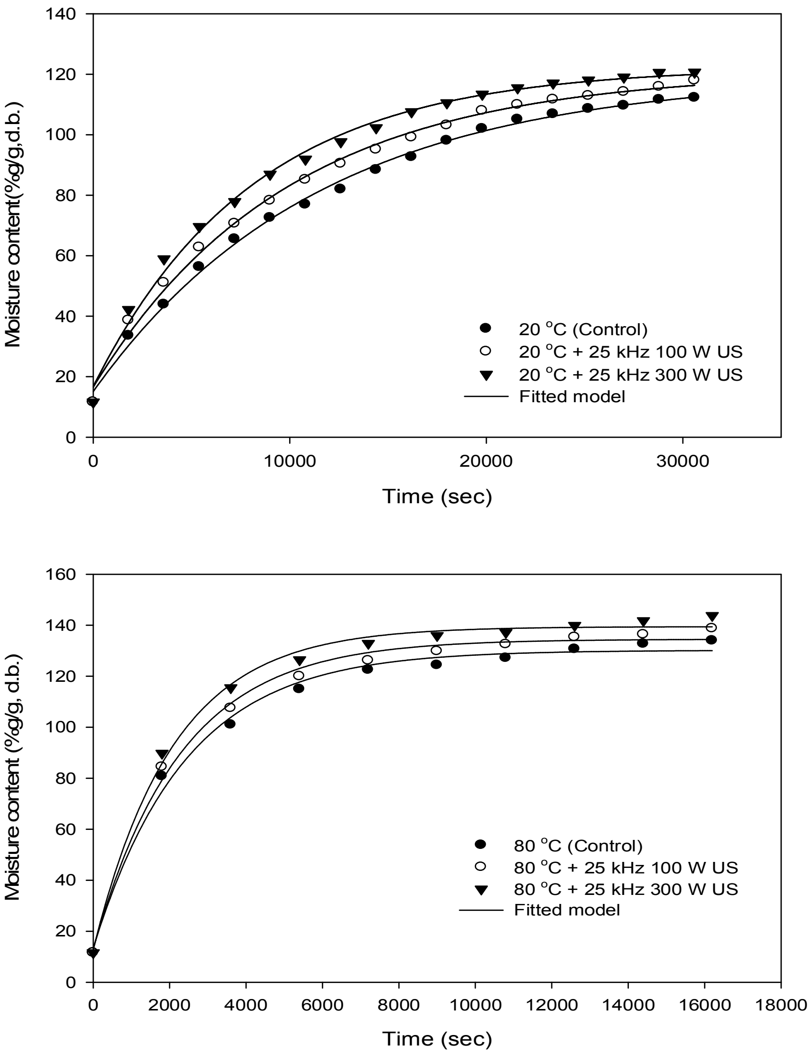

Figure 2. Means of experimental and predicted hydration values (% g/g, d.b.) of chickpeas during soaking at different temperatures without and with ultrasound treatments.

treatments such as ultrasounds. Water absorption ceased when the grains attained the saturation water content. The rate of water intake increased with increasing temperature as suggested by the slopes of the absorption curves getting steeper with increased temperature. Earlier studies reported that the water hydration rate by whole beans is influenced by seed size (Hung et al., 1993), initial water content (Smith and Nash, 1961), thickness and structure of seed coat (Abu-Ghannam and McKenna, 1997; Singh and Kulsherstha, 1987). Table 1 and Figure 1 show that the water hydration, calculated by this model was a thermally activated process and was sensitive to temperature and ultrasound.

The predicted parameters, M_S and k_H values, from this model are given in Table 1. M_S (% g/g, d.b.) increased (123.55 to 139.46) with increasing soak temperature (20 to 80 °C) for chickpeas ($P<0.05$) (Table 1). Similar temperature dependence was found in the literature for both kidneybeans (Abu-Ghannam and McKenna, 1997) and chickpeas (Turhan et al., 2002). It has been postulated that increasing soak temperature promotes leaching of water-soluble components, resulting in lower asymptotic moisture content (Abu-Ghannam and McKenna, 1997).

Representative of the rate of water intake during soaking, k_H increased from 7.33 x 10^{-5} to 39.54 x 10^{-5} s^{-1} with temperature increased from 20 to 80 °C, as was expected from visual inspection of the water absorption curves in this study (Table 1 and Figure 1). The k_H values for Red kidney beans had been found between 4.03 x 10^{-5} s^{-1} and 79.30 x 10^{-5} s^{-1} for 20-60 °C temperature range in a previous study (Abu-Ghannam and McKenna. 1997). Thus, hydration rate constants for that study were similar to those found in the present study. The goodness of fit for his model was coraleted with R^2 and RMSE that were found in the range of 0.9915-0.9972 and 2.83-9.03 for temperature of 20- 80 °C, respectively.

Table 1. Predicted parameters of Asymptotic first order model during soaking of chickpeas at different temperatures without and with ultrasound treatments.

PROCESS	M_S (%, d.b.)	k_Hx10^5 (s^{-1})	R^2	RMSE (%)
20 °C	123.55±0.37	7.33±1.5x10^{-6}	0.9951	9.01
20 °C + 25 kHz 100 W	120.93±0.05	10.18±2.6x10^{-6}	0.9954	10.09
20 °C + 25 kHz 300 W	122.37±0.45	12.33±2.2x10^{-6}	0.9945	10.39
30 °C	122.97±0.29	11.07±1.4x10^{-6}	0.9931	9.03
30 °C + 25 kHz 100 W	123.20±0.33	12.76±2.8x10^{-6}	0.9915	10.33
30 °C + 25 kHz 300 W	125.11±0.35	16.73±3.5x10^{-6}	0.9941	9.05
40 °C	128.17±0.30	15.80±3.1x10^{-6}	0.9972	6.39
40 °C + 25 kHz 100 W	129.10±0.21	18.76±1.5x10^{-6}	0.9936	8.12
40 °C + 25 kHz 300 W	132.29±0.28	22.61±1.3x10^{-6}	0.9959	5.80
50 °C	129.01±0.06	24.56±2.8x10^{-6}	0.9927	8.20
50 °C + 25 kHz 100 W	132.34±0.49	29.15±1.9x10^{-6}	0.9972	3.42
50 °C + 25 kHz 300 W	137.42±0.25	36.44±2.5x10^{-6}	0.9930	3.37
60 °C	127.46±0.16	35.06±1.3x10^{-6}	0.9972	2.83
60 °C + 25 kHz 100 W	131.24±0.21	38.98±1.8x10^{-6}	0.9961	2.62
60 °C + 25 kHz 300 W	136.74±0.14	43.47±1.6x10^{-6}	0.9937	3.00
70 °C	129.48±0.24	37.87±1.1x10^{-6}	0.9947	4.86
70 °C + 25 kHz 100 W	132.85±0.18	42.80±1.2x10^{-6}	0.9931	4.45
70 °C + 25 kHz 300 W	137.88±0.11	45.71±1.1x10^{-6}	0.9961	3.07
80 °C	132.46±0.30	39.54±0.8x10^{-6}	0.9931	5.53
80 °C + 25 kHz 100 W	134.52±0.13	43.71±1.4x10^{-6}	0.9939	4.13
80 °C + 25 kHz 300 W	139.46±0.21	47.80±1.3x10^{-6}	0.9954	2.97

RMSE (%) = Root mean square error: $100*\sqrt{\frac{1}{n}\sum_{1}^{n}\left[(M_{exp}-M_{pre})/M_{exp}\right]^2}$

Chickpea hydration as a function of soaking time and temperature

Previous studies showed that temperature is one of the most important factors affecting the hydration of agricultural products (Kashaninejad et al., 2007; Turhan et al., 2002). In order to find the cooking temperature of chickpeas and effect of temperature, an Arrhenius type equation was applied to soaking temperatures for hydration rate constant (k_H) found from Asymptotic first order model.

The dependence of k_H of the this model on temperature was modelled using the Arrhenius equation (Equations 4), which had been used previously to describe the temperature dependent hydration kinetics of legumes (Abu-Ghannam and McKenna, 1997; Turhan et al., 2002):

$$ln(k_H) = ln(k_{ref}) - (\frac{E_a}{R}) * (\frac{1}{T}) \quad \text{(Eq.4)}$$

where k_H and T are hydration rate constant, the soaking temperature (in Kelvin), respectively. E_a is the activation energy for the hydration process and R is the ideal gas constant (8.314 x10^{-3} kJ/mol °K). k_{ref} is reference hydration rate constants for the this model.

The rate of water transfer and/or starch gelatinization in whole cereal and legume grains during soaking were investigated in a number of studies (Bakshi and Singh, 1980; Lin, 1993; Sayar et al., 2001; Turhan et al., 2002; Sağol et al., 2006). In these studies a coefficient for water transfer rate and/or starch gelatinization rate changed linearly versus temperature and every curve brakes at a spesific temperature which is close to cooking temperature. Arrhenius plots (natural logarithm of rate constants versus the inverse of T (in Kelvin)) for chickpeas are superposed in Figure 3. The activation energy, E_a, is related to the slope of these graphs, and is indicative of the temperature dependence of k_H. For soaked chickpeas, a break seemed to occur at a certain soak temperature in the Arrhenius curve. To locate the temperature at which the break in the Arrhenius curve for soaked chickpeas occurred, the estimated natural log of rate constants (k_H) were fitted to a linear model with break point (Muggeo, 2003), and the break temperature were estimated to be 60.80 ^oC. To confirm the validity of applying a linear model with a break to the soaked chickpea data, the following approach was taken. A linear model with a break at 60.80 ^oC was applied (R^2 = 0.9793-0.9970). The model was compared by the correlation coefficient, and inclusion of the break was shown to significantly improve the model ($P < 0.05$). Such a discontinuity in the Arrhenius curve had been observed during the soaking of rice (Bakshi and Singh, 1980) and chickpeas (Sayar et al., 2001; Turhan et al., 2002), and it has been suggested that the break is linked to the early onset of starch gelatinization. However, it has been suggested (Sayar et al., 2001; Turhan et al., 2002) that chickpea gelatinization may actually commence between the lower temperatures of 55 and 60 ^oC. This observed temperature range is fairly close to the reported cooking temperature of 63-70 ^oC for chickpea (Fernandez & Berry, 1989). It is possible that the break in the Arrhenius curve for soaked chickpeas was due to partial gelatinization and/or structural changes, promoted soaking at temperatures above 60 ^oC. So, the cooking temperature of chickpeas studied in the present study was 60.80 ^oC. The cooking temperature was around 60 °C for whole soybean (Kubota, 1979). This implies a significant change in chickpeas affecting the hydration and reactivity of starch. This observed cooking temperature is fairly close to the reported cooking temperature of 55-70 ^oC for chickpea (Fernandez and Berry, 1989; Sayar et al., 2001).

To estimate the model parameters such as M_o (initial m.c), M_e (equilibrium m.c), T (temperature in Kelvin) and t (time in second), a generalized non-linear regression of Equation 3 can be performed on the entire dataset. It may be interesting to compare the activation energy resulting from the variation of the values of k_H with temperature, with the value obtained from the hydration process. The dependence of constant (k_H) on temperature was modeled using the Arrhenius equation, which has been used previously to describe the temperature dependent hydration kinetics of other grains and seeds (Maskan, 2002; Turhan et al., 2002).

Incorporating temperature break at 60.80 ^oC for the model, time and temperature dependence of moisture content for soaked chickpeas, and dependence of initial and equilibrium moisture contents, the following general models were derived to describe the water absorption kinetics of chickpeas:

For temperature ≤60 ^oC

$$M = M_e + (M_o - M_e)\exp\left[-[3623 * \exp(\frac{-3849.88}{T})] * t\right] \quad \text{Eq.5}$$

For temperature >60^oC

$$M = M_e + (M_o - M_e)\exp\left[-[0.00297 * \exp(-\frac{70879}{T})] * t\right] \quad \text{Eq.6}$$

The k_H values decreased as temperature increased suggesting a corresponding increase in the initial hydration rate. When Arrhenius equation was applied to the k_H values for temperatures bellow and above break point (60.80), the activation energy values were predicted. The activation energy values of soaked chickpeas bellow 60 ^oC for Asymptotic first order model was found as 32.01 (R^2=0.9970) kJ/mol. The activation energy for the model at soaking temperatures above 60 ^oC was also predicted and found as 5.89 (R^2=0.9793) kJ/mol. This value agrees well with the literature value of 19.50 kJ mol^{-1} for the activation energy of osmotic hydration of chickpeas at 5-50 ^oC (Pinto and Esin, 2004). The activation energies of chickpea were found as 41.79 kJ mol^{-1} and 8 kJ mol^{-1} for 25-37 ^oC and 37-60 ^oC temperature ranges by Gowen et al. (2007). In another study, the activation energy for chickpea was 48 and 18 kJ mol^{-1} for temperature bellow and above 55 ^oC, respectively (Sayar et al., 2001).

When the activation energy of chickpea found in present study was compared with respect to bellow and above the cooking temperatures it can be seen that a 82 % decrease was obtained after cooking temperature. Therefore, the lower activation energy for the rate of water transfer above the cooking temperature implies that it travels faster in cooked chickpea than in uncooked chickpea.

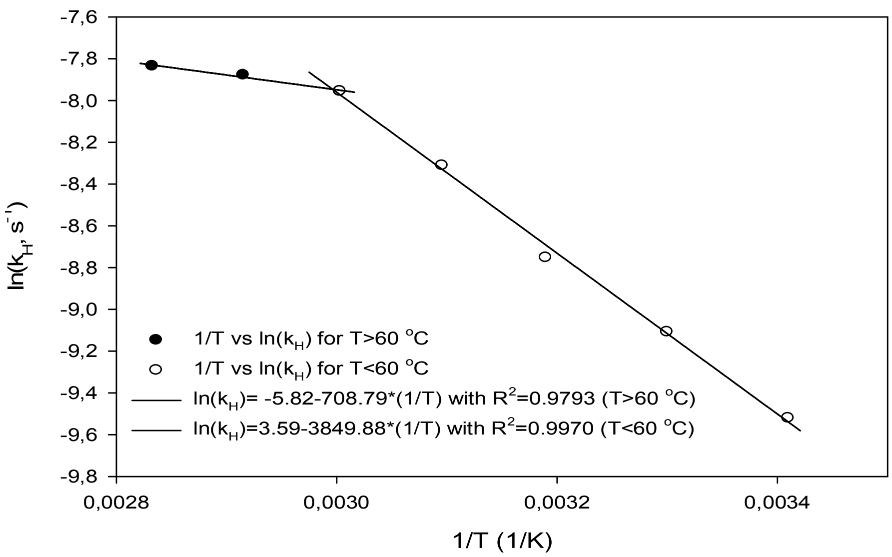

Figure 3. Arrhenius plot for Asymptotic first order model of hydration rate constant, k_H, over the soaking temperature range 20-80 ^oC.

Effect of ultrasounds on hydration during soaking of chickpeas

One emergent application of power ultrasound in food industry is the enhancement of mass transfer in processes where hydration takes place. The application of ultrasounds on drying has been studied before in some researches (Gallego-Juarez, 1998). Power ultrasound introduces pressure variations at solid/liquid interfaces, and therefore increases the moisture absorption rate. Acoustic energy also causes oscillating velocities and microstreaming at the interfaces which may affect the diffusion boundary layer (Gallego-Juarez et al., 1999). Furthermore, ultrasonic waves also produce rapid series of alternative contractions and expansions (sponge effect) of the material in which they are travelling (Gallego-Juarez, 1998; Mulet et al., 2003); this alternating stress creates microscopic channels which may make the moisture gain easier. In addition, acoustic waves may produce cavitation of water molecules inside the solid matrix, which may be beneficial for the gain of strongly attached moisture (Mulet et al., 2003). Therefore, external and internal resistance may be seriously affected during drying by the effects associated to acoustic energy, thus increasing mass transfer.

Ultrasound has been used to enhance mass transfer in solid/liquid systems like meat (Carcel et al., 2007a), cheese (Sanchez et al., 1999) brining and osmotic dehydration of apple (Simal et al., 1998a; Carcel et al., 2007b). Different applications in conventional extraction processes (Romdhane and Gourdon, 2002) and solid/supercritical fluid systems, mass transfer have also been found in the literature (Fuente et al., 2004; Riera et al., 2004). Han and Baik (2006) reported the effect of ulrasounds in reduction soaking and cooking time of legumes. Wambura et al. (2008) has reported that use of ultrasound made to reduce in cooking time of rice by 70%. These studies show that thermosonication can be used to icrease the water absorption during soking operation.

The effects of ultrasounds are illustrated in Figure 2. The moisture contents at each temperature without US (ultrasound) were used as control. Aplication of 25 kHz ultrasounds significantly ($P<0.05$) increased the water absorption of chickpea for all temperatures (20-80 ^oC). The moisture content (% g/g, d.b.) values of chickpea increased from 76.91 to 85.14 (% g/g, d.b.) with 25 kHz 100 W US application for 20 ^oC and 180 min soaking. A similar increase was observed for other soaking times at constant temperatures. Increase in power of US (from 100 to 300 W) significantly ($P<0.05$) increased the moisture content (from 85.14 to 91.89) of chickpea during soaking at 20 ^oC. When the higher US powers such as 300 W at 20 ^oC and 180 min was compared with control, moisture content of chickpea was found to be increase from 76.91 to 91.89 (% g/g, d.b.). Similarly, 25 kHz US and increase in power (100 to 300 W) increased the moisture content of soaked chickpea at all temperatures. Ultrasound applications affected the water absorption capacity of chickpea during soaking at different temperatures and times due to create a more effective cavitation that cause the chickpea grain as porous or sponge.

k_H values found from this model were main parameters for the ultrasonic assisted process of diffusion which were compared with the conventional soaking at different temperatures (Figure 2). Ultrasound application changed k_H values that means the hydration of chickpea was effected during soaking. When the ultrasound such as 25 kHz 100 W was applied to chickpeas during soaking at 20 ^oC, k_H values increased from $7.33x10^{-5}$ to $10.18\ x10^{-5}\ s^{-1}$ (41.61% increase). Also, increase in power of ultrasound (from 100 to 300 W) increased k_H values from $7.33x10^{-5}$ to $12.33x10^{-5}\ s^{-1}$ (68.21% increase) at the same soaking temperature (20 ^oC) (Table 1). Similarly, for soaking at 60 ^oC, k_H values changed from $35.06x10^{-5}$ to $38.98x10^{-5}$ and to $43.47\ x10^{-5}\ s^{-1}$ for non-ultrasound, 25 kHz 100 W and 25 kHz 300 W ultrasound treatments, respectively. A significant ($P<0.05$) change in k_H values was observed for other soaking temperatures (20-80 ^oC) when ultrasound was applied to chickpeas during soaking. The ultrasound increased the water absorption of chickpea during soaking due to increasing of mass diffusion rate (Fuente et al., 2004).

CONCLUSION

Hydration rate of chickpea significantly increased ($P<0.05$) with increasing temperature and power of ultrasound (100–300 W). Hydration coefficient (k_H) for a temperature range of 20–80 ^oC increased from $7.33x10^{-5}$ to $47.80x10^{-5}\ s^{-1}$ with ultrasound application. Kinetics model (Asymptotik first order) where Arrhenius relationship inserted for k_H can be used to determine moisture content of chickpeas as a function of soaking time and temperature. Average gelatinization temperature of chickpea from the water absorption model was found as 60.80 ^oC. Activation energy (E_a) values of chickpea for below and above gelatinization temperature of 60.80 ^oC were found to be 32.01 and 5.89 kJ mol^{-1}, respectively. The ultrasound enhanced soaking described in this study will facilitate the advancement in the study of the mechanisms involved for the aim of extending the application of this technology.

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