Research Article / *Araştırma Makalesi*

Geliş tarihi: 21.07.2017
Kabul tarihi:29.11.2017

Harran Tarım ve Gıda Bilimleri Dergisi (2017) 21(4): 420-430
DOI: 10.29050/harranziraat.330112

Change in Weight and Dimensions of Cowpea (*Vigna unguiculata* L. walp.) during Soaking

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Abstract

The weight, dimensions, spericity and volumetric expansion of cowpea seeds during soaking at 30, 40 and 50 °C was studied. Weight (Wt), Length (L), width (W), thickness (T), equivalent diameter (D_{eq}) and volume (V) of seeds increased with the increase in time at all temperatures studied. The greatest increase was found in thickness. The sphericity values were determined between 0.71 and 0.77, which means they were independent of water gain and temperature. Peleg's model for the properties of cowpea was used for the determination of the peleg constants. Peleg's model was found to be suitable for describing the properties behavior of cowpea kernels during soaking. The activation energy results showed that the activation energy value of cowpea related to thickness was the highest and most affected with temperature while that of length was the lowest and less affected by temperature during soaking. The plots of the cowpea properties versus time at different temperatures and Peleg's model results were shown that properties increased with the temperature and time.

Key Words: Cowpea, Peleg model, Soaking, Dimension

Islatma Esnasında Börülcenin (*Vigna unguiculata* L. Walp.) Ağırlık ve Boyutlarındaki Değişim

Öz

Börülce tanelerinin ıslatma esnasında 30, 40 ve 50 °C'deki ağırlığı, boyutları, küresellik ve hacimsel genişlemesi incelenmiştir. Tanelerin ağırlık (Wt), uzunluk (L), genişlik (W), kalınlık (T), eşdeğer çap (D_{eq}) ve hacimleri (V) tüm çalışılan sıcaklıklarda sürenin uzamasıyla artmıştır. En fazla artış kalınlıkta bulunmuştur. Küresellik değerleri 0.71 ile 0.77 arasında tespit edilmiş, bu da su alımı ve sıcaklığından bağımsız olduğu anlamına gelmektedir. Börülcenin özellikleri için Peleg sabitlerinin hesaplanmasında Peleg modeli kullanılmıştır. Peleg modelinin ıslatma sırasında, Börülce tanelerinin özellik davranışlarının tanımlaması için uygun olduğu tespit edilmiştir. Aktivasyon enerjisi sonuçları, kalınlık ile ilgili börülcenin aktivasyon enerji değerinin en yüksek olduğu ve sıcaklıktan en fazla etkilendiğini, uzunluğun ise ıslatma sırasında sıcaklığın en düşük ve en az etkilenmiş olduğunu göstermiştir. Farklı sıcaklıklardaki zamana karşı börülce özelliklerinin grafikleri sıcaklık ve zamanla özelliklerin arttığını göstermiştir.

Anahtar Kelimeler: Börülce, Peleg model, Islatma, Boyut

Introduction

Cereals and legumes are potential ingredients for many processed foods due to their protein contents. Among these foods, cowpea is an important plant food that is widely produced and consumed. It is important source of carbohydrate (50-53%), protein (17-28%), fats (3%), ash (3%), fibre (6%), iron, vitamin B and minerals (Kaptso et al., 2008; Sobukola and Abayomi, 2011).

Cowpea (*Vigna unguiculata L.* Walp.), is a leguminous plant belonging to the fabaceae family. Cowpeas are one of the most important food pulse crops, which have been grown in the semi-arid tropics covering Asia, Africa, Southern Europe, Central and South America.

Cowpea seeds are processed into a variety of products before consumption. Soaking of dry seeds for around 14-16 h at room temperature followed by cooking in boiling water for 1-2 h is the main process to produce a tender edible product for both domestic use and industrial scale processes. These processes alter the physical and chemical structure of the seeds and govern the following processes: diffusion of water into the seed, gelatinisation of starch, geometrical and dimensional changes and leaching of soluble solid from seed through the soaking or cooking medium, that are major phenomena taking place in cowpea during soaking and cooking. Swelling, mainly linear and volumetric expansion, of the seed are important parameters for the analysis and design of the process and for designing and constructing the equipment.

The dimensional properties of cowpea seeds are essential for the design of equipment for handling, harvesting, processing and storing the grain, or determining the behavior of the grain for its handling and processings. Therefore, it is necessary to determine these properties (Baryeh, 2002; Karababa, 2006).

Many researchers conducted studies on the geometric changes of agricultural products due to water absorption and/or thermal processing (Leopold, 1983; Singh and Kulshrestha, 1987; Tang and Sokhansanj, 1993; Çarman, 1996; Bayram et al., 2004; Yadav and Jindal, 2007; Aydın et al., 2008;; Mendes et al., 2011; Perez et al., 2011; Aghkhani et al., 2012; Sayar et al., 2016).

The modeling moisture transfer in grains and legumes during soaking has attracted considerable attention (Jideani and Mpotokwana, 2009). There are a large number of research reports in which the authors investigated the hydration and/or cooking characteristics of cereals and legumes at various conditions (Taiwo et al., 1998; Maskan, 2001; Turhan et al., 2002; Kaptso et al., 2008; Kashiri et al., 2010; Sobukola and Abayomi, 2011). Change and modeling of the properties of Karagöz cowpea variety kernel (weight, dimensions, volume and spericity) during soaking has not previously reported. Therefore, the main objectives of this study were the followings: (1) to determine the properties of cowpea seeds during soaking; (2) investigate the effects of temperature and time on the moisture gain and physical properties of cowpea seeds; (3) develop the mathematical models representing the time dependence of the weight, length, width, thickness, equivalent diameter and volume of cowpea during soaking.

Materials and Methods

Material

Cowpeas samples (local name: Karagöz variety) with an initial moisture content of 10.20±0.87 was obtained from Çoker Seeding company, Manisa, Turkey. Dust, foreign materials, broken and small kernels were removed by hand picking.

Soaking operation

Measured initial dimensions (L; length, W; width and T; thickness) of selected 20 cowpea seeds were weighed and placed in a beaker containing 500 mL deionised water which was in a water bath (Model WUC-D10H, DAIHAN Scientific Co., Ltd., Gangwon-do, 220-821, KOREA) at the desired temperature (30, 40 and 50 ^oC). All seeds in a beaker were removed at the end of the predetermined time, superficially dried with a tissue paper, weighed (W_t, at any time), measured for size and returned to the beaker. The experiments were stopped at 390 min soaking time.

Determination of moisture content of cowpea

The initial moisture content of cowpea was determined by using oven method (105 ^oC) (AOAC, 2002).

Determination of dimensions, equivalent diameter, volume and spericity of cowpea kernel

The length, width and thickness of cowpeas were measured using a digital micrometer (Mutitoyo No. 505-633, Japan). Using the readings, the equivalent diameter, D_e, was calculated using the following relationship;

$$D_{eq} = [LWT]^{1/3} \quad (1)$$

Sphericity (ϕ) was determined by Eq. (3), according to the method given by Mohsenin (1980):

$$\phi = \frac{(LWT)^{1/3}}{L} \quad (2)$$

The volume of the seeds (*V*) was calculated from the following Eq. (4), assuming that the chickpea seed is a sphere:

$$V = \frac{4}{3}\pi\left[\frac{D_{eq}}{2}\right]^3 \quad (3)$$

Theory weight and expansion during soaking

Peleg (1988) proposed a two-parameter sorption equation and tested its prediction accuracy during water vapour adsorption of milk powder and whole rice, and soaking of whole rice. This equation has since been known as the Peleg's model:

$$M = M_o + \frac{t}{K_1 + K_2 * t} \quad (4)$$

where M is moisture content at time t in % (d.b.); M_o is initial moisture content in % (d.b.); K_1 is the Peleg rate constant in min % $(d.b.)^{-1}$; K_2 is the Peleg capacity constant in % $(d.b.)^{-1}$.

When we used Y and Y_o general notations instead of M and M_o in Eq. (4), we optained new equation for the properties of cowpea during soaking.

$$Y = Y_o + \frac{t}{K_1 + K_2 * t}$$

Y={Wt, L, W, T, D_{eq},V},

Y_o={Wt_o, L_o, W_o, T_o, $D_{eq(o)}$, V_o} (5)

where Wt, L, W, T, D_{eq} and V are weight (g), length (mm), width (mm), thickness (mm), equivalent diameter (mm) and volume (mm^3) at any time (min); Wt_o, L_o, W_o, T_o, $D_{eq(o)}$ and V_o are initial properties; K_1 is the Peleg rate constant in min $(g)^{-1}$, min $(mm)^{-1}$ and min $(mm^3)^{-1}$; K_2 is the Peleg capacity constant in $(g)^{-1}$, $(mm)^{-1}$ and $((mm^3)^{-1}$.

The Peleg capacity constant K_2 relates to maximum (or minimum) attainable weight (g), length (mm), width (mm), thickness (mm), equivalent diameter (mm) and volume (mm^3). As $t \to \infty$, Equation (5) give the relation between equilibrium or maximum properties (Wt_e, L_e, W_e, T_e, $D_{eq(e)}$ and V_e) and K_2:

Y_e={Wt_e, L_e, W_e, T_e, $D_{eq(e)}$,V_e},

Y_o={Wt_o, L_o, W_o, T_o, $D_{eq(o)}$, V_o} (6)

where, Wt_e, L_e, W_e, T_e, $D_{eq(e)}$ and V_e are the weight (g), length (mm), width (mm), thickness (mm), equivalent diameter (mm) and volume (mm^3) at the equilibrium or saturation.

K_1 could be compared to a diffusion coefficient and the Arrhenius equation could be used to describe the temperature dependence of the reciprocal of Peleg's constant K_1 in the following manner:

$$\ln(1/K_1) = \ln(K_o) - \frac{E_a}{RT} \qquad (7)$$

where E_a, R, K_o and T are activation energy for the hydration process in kJ mol^{-1}, universal gas constant in 8.314x10^{-3} kJ mol^{-1} K^{-1}, frequency factor or pre-exponential constant in % min^{-1}, the soaking temperatures (K), respectively.

When $\ln(1/K_1)$ is plotted against (1/T), a straight line with slope of $-E_a/R$ is obtained from which the activation energy can be calculated and sensitivity of the constant to temperature can be assessed.

Statistical analysis

Statistical analysis was performed by SPSS 16.0 (SPSS Inc., Chicago, U.S.A) program. Multivariate analysis was performed on the raw data obtained and the mean values of the data were compared with the Duncan Multiple Comparison Test at P ≤0.05 significance level. Sigma Plot 10 (Jandel Scientific, San Francisco, USA) was used to fit the models and to plot the data. The parameters were evaluated by the nonlinear least squares method of Marquardt-Levenberg until minimal error was achieved between experimental and calculated values. Correlation coefficient squared (R^2) and root mean standard error (RMSE) (Eq. 6) was used as the criteria for the accuracy of the fit.

$$RMSE = \sqrt{\frac{1}{n}\sum_{1}^{n}\left[\frac{Value_{\exp} - Value_{pre}}{Value_{\exp}}\right]^2} \qquad (8)$$

where n, $Value_{exp}$ and $Value_{pre}$ are the numbers of observations, the experimental values and predicted values, respectively. A value of lowest root mean standard error less than 0.10 was considered to be a good fit of the model.

Results and Discussion

Primary modeling of time dependence of cowpea weight, dimensions and volume

The mean values of Wt, L, W, T, D_e and V of soaked cowpeas at 30, 40 and 50°C were illustrated in Fig. 1. The weight (g), length (mm), width (mm), thickness (mm), equivalent diameter (mm) and volume (mm^3) of cowpea during soaking were significantly ($p \leq 0.05$) increased as the time increased (Fig. 1). Similar results were found for soybean (Singh and Kulshrestha, 1987; Bayram et al., 2004), chickpea (Sayar et al., 2016), lima bean (Aghkhani et al., 2012), lentil (Tang and Sokhansanj, 1993), rice (Yadav and Jindal, 2007), castorbean, mung bean, and cowpea (Leopold, 1983; Aydın et al., 2008). But, in the study of Sayar et al. (2016), the increase in the length of chickpea seed was the highest, followed by those in width and thickness. The highest % increase was obtained in weight values of this study (101, 108, 117 %) for 30, 40 and 50 ^oC during soaking, respectively. But, the lowest % increase was found in length values (15, 17 and 18.50 %) for the same temperatures (Fig. 1). The maximum % increase in volume was 70, 81 and 101 at the 30, 40 and 50 ^oC during soaking. In the case of soybean seed, Deshpande and Ojha (1993) found the expansion to be largest along their thickness in comparison with length and width. The variability in the expansion values of dimensions is attributed to the different cell arrangements along the dimensions of the seeds (Baryeh, 2002).

It was expected that, increasing the soaking temperature caused a decrease in the time to the sharp rise in dimensions of cowpea. Joint side was important for the cowpea kernel. Two half parts of the kernel combine to form the whole kernel, attached by the germ part. Bran layers determine the firmness of the whole kernel and act as a barrier to the water penetration and leaching. When the water diffused through these layers, it first passes between the two half parts and under the bran layers.

The change in sphericity of cowpea relation to soaking time was illustrated in Fig 2. The sphericity is a measure of a particle is the ratio of the surface area of a sphere (with the same volume as the given particle) to the surface area of the particle.

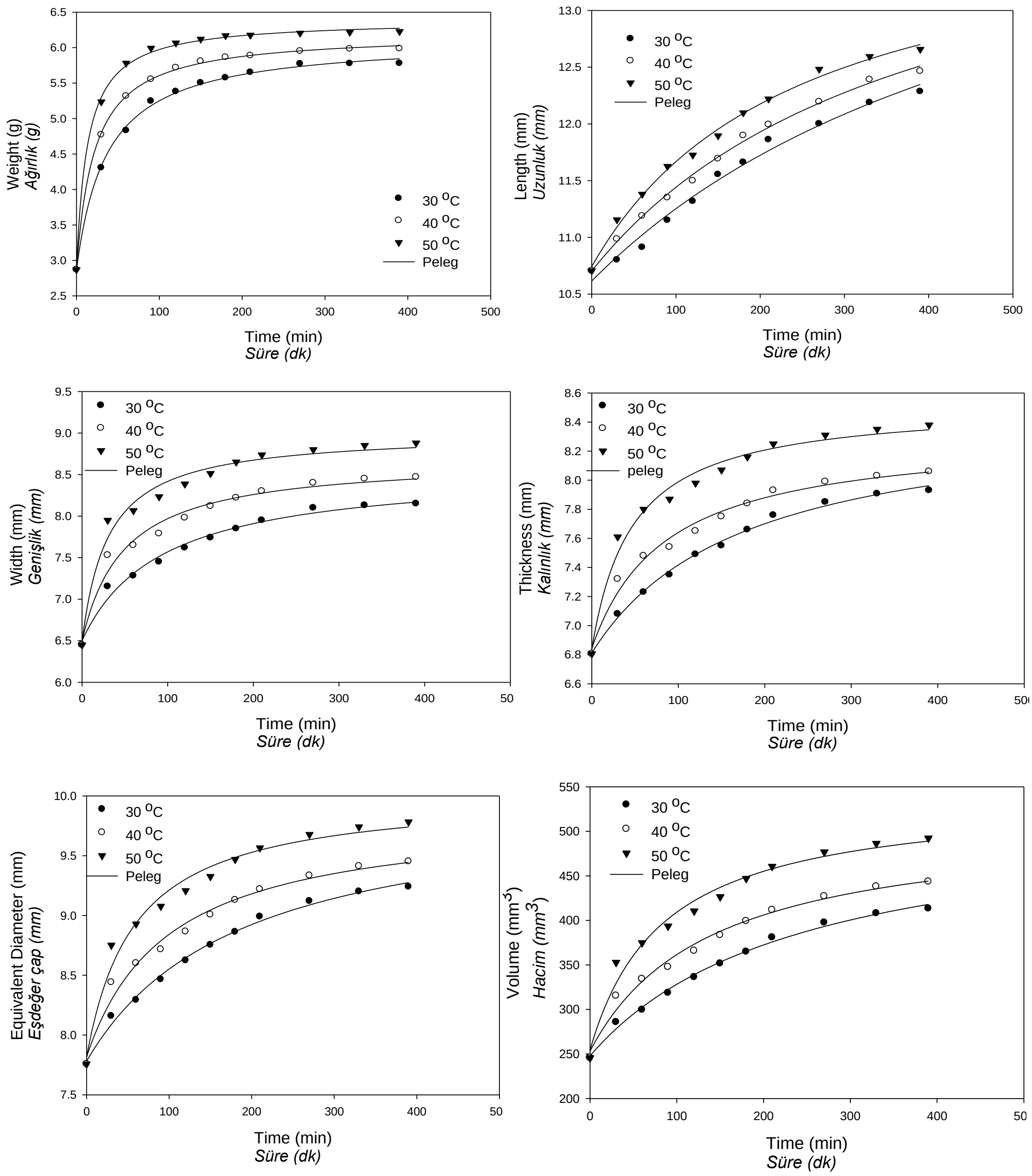

Figure 1. Means of experimental and predicted weight, length, width, thickness, equivalent diameter and volume of cowpea at different temperatures during soaking.

Şekil 1. Börülcenin ıslatma sırasında farklı sıcaklıklardaki deneysel ve hesaplanmış ağırlık, uzunluk, genişlik, kalınlık, eşdeğer çap ve hacim ortalama değerleri.

Sphericity values of cowpea seeds were calculated during soaking at the given temperatures. In this study, sphericity values were determined between 0.71 and 0.77, which means they were independent of water gain and temperature. The sphericity of cowpea seed changed between 0.74 and 0.72 during soaking (Aydın et al., 2008). In the study of Demirhan and Özbek (2015) carried out on cowpea seed, the sphericity value was also determined to be averagely 0.74. The sphericity values obtained in this study were close to 1, which supports the thesis that the cowpea seeds can be assumed as a sphere in Eq. (3).

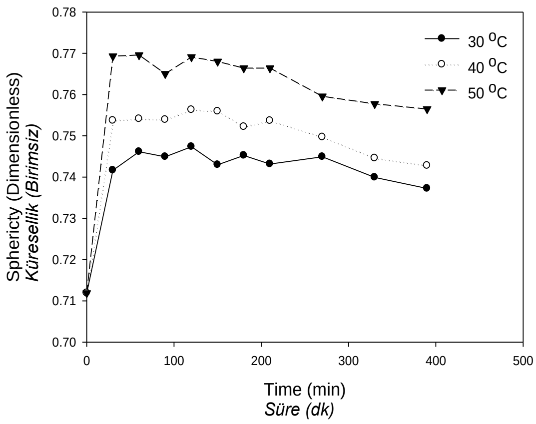

Figure 2. Change in mean sphericity values of cowpeas at different temperatures during soaking.

Şekil 2. Börülcenin Islatma esnasında farklı sıcaklıklardaki ortalama küresellik değerlerindeki değişim.

Rate of increase in properties was higher during the early stages of soaking but lower in the late soaking periods. Cowpea properties curves are characterized by an initial phase of rapid water pickup followed by an equilibrium phase, during which the cowpea approaches its full soaking capacity. Length, width, thickness, equivalent diameter and volume curves showed the similar characteristics as weight change curves during soaking.

Peleg's model (Eq. 5), for describing the water gain (weight change (g)), change of dimensions (mm) and volume (mm) behaviour of cowpea kernel during soaking, was investigated. Peleg's parameters (K_1, K_2), R^2 and RMSE of cowpeas for all properties at different soaking temperatures (30, 40 and 50^{o}C) were evaluated by using the non-linear regression analysis (Eq. 5). Fig. 1 and Table 1 represent the variation of experimental and predicted values of W_t, L, W, T, D_{eq} and volume using the Peleg's model with soaking time for cowpea at the different temperatures (30, 40 and 50 ^{o}C) with the R^2 between 0.9791 and 0.9995, RMSE between 0.003 and 0.027. Peleg's model was found to be suitable for describing the properties behavior of cowpea kernels.

The Peleg's constant K_1 is related to transfer or property rate and its reciprocal ($1/K_1$) can be linked to a diffusion coefficient, the values of K_1 decreased with increasing temperature, this corresponds to an increase in the initial property rate and $1/K_1$ values, significantly ($p \leq 0.05$) (Table 1). K_2 values also decreased while Wt_e, L_e, W_e, T_e, $D_{eq(e)}$ and V_e values increased with increasing temperature (30-50 °C), significantly ($p \leq 0.05$).

Table 1. Summary of constants fitted in Peleg's equation and Arrhenius equation for cowpea obtained for different temperatures.

Çizelge 1. Börülce için Peleg ve Arrhenius denklemlerine uyarlanmış sabitlerin farklı sıcaklıklardaki değerlerin özeti.

Property *Özellik*	Temp. *Sıcaklık* (°C)	K_1 min. value^{-1} *dak. değer^{-1}*	K_2 value^{-1} *değer^{-1}*	$1/K_1$	Equilib. values	R^2	RMSE	E_a kJ mol^{-1}	Equation for E_a E_a için eşitlik
Weight	30	11.22	0.307	0.0891	6.13	0.9980	0.007	43.81	y=14.97-5269.20x
Ağırlık	40	6.55	0.300	0.1527	6.20	0.9995	0.004		R^2=0.9996
	50	3.82	0.284	0.2617	6.40	0.9985	0.006		
Length	30	133.19	0.236	0.0075	14.95	0.9868	0.005	22.42	y=3.98-2696.13x
Uzunluk	40	107.77	0.228	0.0093	15.10	0.9966	0.003		R^2=0.9770
	50	76.65	0.214	0.0130	15.38	0.9946	0.004		
Width	30	45.18	0.480	0.0221	8.53	0.9857	0.008	53.79	y=17.55-6469.51x
Genişlik	40	22.33	0.450	0.0448	8.67	0.9791	0.010		R^2=0.9996
	50	12.05	0.400	0.0830	8.95	0.9791	0.012		
Thickness	30	105.24	0.600	0.0095	8.48	0.9956	0.003	54.38	y=16.90-6540.46x
Kalınlık	40	57.55	0.480	0.0174	8.89	0.9851	0.006		R^2=0.9944
	50	27.60	0.450	0.0362	9.03	0.9841	0.007		
Equivalent Diameter	30	84.39	0.453	0.0118	9.97	0.9946	0.004	47.50	y=14.40-5713.11x
Eşdeğer Çap	40	48.50	0.420	0.0206	10.14	0.9847	0.007		R^2=0.9977
	50	26.23	0.380	0.0381	10.39	0.9808	0.009		
Volume	30	0.88	0.0036	1.1364	523.54	0.9944	0.012	43.72	y=17.46-5259.06x
Hacim	40	0.54	0.0031	1.8519	568.34	0.9869	0.021		R^2=0.9949
	50	0.30	0.0030	3.3333	579.09	0.9809	0.027		

The order of magnitude of $1/K_1$ values of the present study for weight (g), Length (mm), width (mm), thickness (mm), equivalent diameter (mm) and volume (mm^3) were found to be in the range of 0.0891-0.217 min (g)$^{-1}$ (65.95 % increase), 0.0075-0.0130 min (mm)$^{-1}$ (42.31 % increase), 0.0221-0.0830 min (mm)$^{-1}$ (73.37 % increase), 0.0095-0.0362 min (mm)$^{-1}$ (73.76 % increase), 0.0118-0.0381 min (mm)$^{-1}$ (69.03 % increase) and 1.1364-3.3333 min (mm^3)$^{-1}$ (65.91 % increase) for 30-50 °C temperature range, respectively. From Table 1 and Fig. 1. % increase in $1/K_1$ values one can seen that length is the least effected while the thickness is the most effected by temperature.

Similarly, K_2 decreased as the temperature increased for all properties at different temperaturtes (Table 1). This clearly confirms the results that hydration rate and the dependence of K_2 on temperature indicated that different equilibrium (Equilib.) properties would be obtained for different soaking temperatures. As the soaking temperature increased, the equilibrium values of cowpea increased (Table 1). It may be due to the enhanced plasticity of grain cells at high temperatures during soaking. Therefore, the grain imbibed more water and resulted to change in dimensions at high temperatures.

Activation energy and effect of temperature on cowpea properties

In order to find the effect of temperature on cowpea properties, an Arrhenius type equation (Eq. 7) was used for modeling the dependence of Peleg rate constant (K_1) on temperature, which had been used previously to describe the temperature dependent hydration kinetics of Cowpea (Demirhan and Özbek. 2015). Arrhenius plots of weight, length, width, thickness, equivalent diameter and volume for cowpea seeds was represented in Fig. 3. The activation energy values of soaked cowpea seeds related to W_t, L, W, T, D_{eq} and V were found as 43.81, 22.42, 53.79, 54.38, 47.50 and 43.72 kJ mol^{-1}. respectively. The activation energy results showed that the activation energy value of cowpea related to thickness was the highest and most affected with temperature while that of length was the lowest and less afeccted by temperature during soaking. The previous section (change of K_1^{-1} with temperature) also correlated this lesults. The value of activation energy values obtained in the present study was in the range values reported by Sobukola and Abayomi (2011). Kaptso et al. (2008) and Demirhan and Özbek (2015) for cowpea 18.14-34.82 kJ mol^{-1}, 37.62-78.81 kJ mol^{-1} and 38.14 kJ mol^{-1}, respectively.

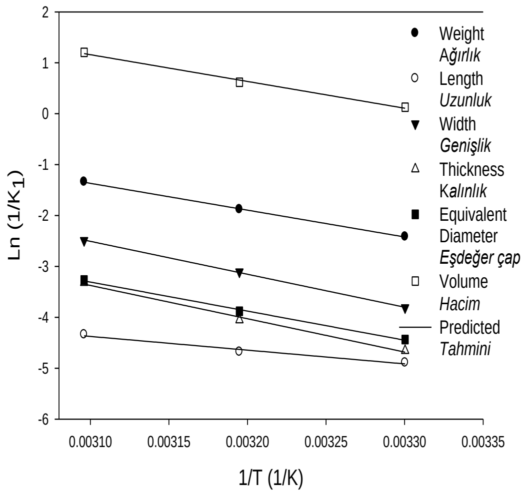

Figure 3. Arrhenius-type relationship between Peleg's constant. K_1 and reciprocal absolute temperature for different properties of cowpea.

Şekil 3. Börülcenin farklı özellikler için Peleg sabiti. K_1 ve mutlak sıcaklığın tersi arasındaki Arrhenius tipi ilişki.

Conclussion

As a conclusion, structural change in cowpea starts to take place during the soaking, due to water gain. Understanding the water gain in the cowpea during the soaking is of practical importance since it governs the subsequent operations and quality of the final product. Hence, modeling dimensional changes during the soaking has attracted considerable attention. Determination of the soaking mechanism and the prediction of the dimensional changes of the kernel are essential for the design of large-scale cowpea soaking equipment. Soaking temperature and time drastically affected the properties (weight, length, width, thickness, equivalent diameter and volume) of cowpea during hydration. Both Peleg's rate and capacity constants, K_1 and K_2 were significantly ($p \leq 0.05$) decreased with increasing temperature from 30 to 50 ^{o}C for all properties. The temperature dependence of K_1 and K_2 were adequately described by Arrhenius type relationship. Peleg's model adequately described the water gain and dimensional characteristics of cowpea.

Acknowledgment

We wish to thank the Scientific Research Projects Executive Council of University of Harran (HUBAK. Project No: 17007) for financial supports.

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