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Modeling of the Water Uptake Process for Cowpea Seeds (*Vigna Unguiculata* L.) under Common Treatment and Microwave Treatment

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Summary: The water uptake kinetics of cowpea seeds were carried out at two different water absorption treatments - common treatment and microwave treatment - to evaluate the effects of rehydration temperatures and microwave output powers on rehydration. Water uptake of cowpea seeds during soaking in water was studied at various temperatures of 20 - 45ºC, and at various microwave output powers of 180 – 900 W. As the rehydration temperature and microwave output power increased, the water uptake of cowpea seeds increased and the rehydration time decreased. The Peleg's and Richards' Models were capable of predicting water uptake of cowpea seeds undergoing common treatment and microwave treatment, respectively. The effective diffusivity values were evaluated by fitting experimental absorption data to Fick's second law of diffusion. The effective diffusivity coefficients for cowpea seeds varied from 7.75×10^{-11} to 1.99×10^{-10} m^2/s and from 2.23×10^{-9} to 9.78×10^{-9} m^2/s for common treatment and microwave treatment, respectively.

Keywords: Cowpea; Water uptake; Physical properties; Effective diffusivity; Modeling

Introduction

Cereals and legumes are potential ingredients for many processed foods due to their protein contents. Among these foods, cowpea (*Vigna unguiculata* L.) is an important plant food that is widely produced and consumed. This agricultural material is important source of carbohydrate, protein, iron, vitamin B and minerals. On dry weight basis, these seeds contain mostly proteins 17-28%, fats 3%, and carbohydrates 50-53%, ash 3% and fibre 6%, and it is also an important item in the diet of most people [1, 2].

Hydration characteristics of cereals and legumes are important when preparing a product from them. Hydration is a complex process aimed at restoration of the properties of the raw product [3, 4]. The wide variety of dehydrated foods, and the concern for meeting quality specifications and conserving energy, emphasizes the need for a thorough understanding of the rehydration process [5].

Processing of cereals and legumes often requires that the seeds be hydrated first to facilitate operations such as cooking or canning. Understanding water absorption in seeds during soaking is of practical importance as it affects subsequent operations and quality of the final product. Thus, the penetration of water into these materials is of theoretical and practical interest to the processing industry. The rate of water absorption has a significant role in the formulation of foods. The absorption of water into seeds influenced by their intrinsic (physical and chemical) and extrinsic (temperature, soaking solutions time, etc.) factors. Hence, quantitative data on the effect of processing variables are necessary for practical applications to optimize and characterize soaking conditions, design food processing equipment and predict water uptake as a function of the time and temperature [1-3; 6, 7].

The physical properties of cowpea seeds, like those of other grains and 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. Various types of cleaning, grading and separation equipment are designed on the basis of the physical properties of grains or seeds. Physical properties affect the conveying characteristics of solid materials by air or water and cooling and heating loads of food materials. It is, therefore, necessary to determine these properties [8, 9].

The modeling moisture transfer in grains and legumes during soaking has attracted considerable attention [10]. 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 [1-3; 6, 7; 11, 12]. In the literature, there is no information was found on the effect of microwave treatment on the water uptake kinetics of cowpea seeds except the studies performed under common treatment.

Availability of empirical models will enable engineers to provide optimum solutions to the aspect of the rehydration process, such as influence of operating conditions, and chemical and physical properties on water transfer. Hence, there is a need for information on how these parameters affect rehydration characteristics of cowpea seeds which are

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important raw materials in many processing industries. Therefore, the main objectives of this study were the followings: (i) to determine the physical properties of cowpea seeds; (ii) investigate the effects of rehydration temperature and microwave output power on the water uptake kinetics of cowpea seeds; (iii) develop the mathematical models representing the time dependence of the moisture content during soaking; (iv) determine the effective moisture diffusivity coefficients; and (v) estimate the activation energy for kinetic constant of the Peleg's Model for cowpea seeds during soaking.

Experimental

Materials

Cowpea seeds were purchased from a local supplier in Istanbul, Turkey. The initial moisture content of the seeds was determined using the oven dry method at 105±1°C for about 24 h in hot air oven [13]. The initial moisture content for the cowpea seeds on dry basis (d.b.) was found as 0.16 g/g d.b.

Determination of Physical Properties of Seeds

The physical characteristics of the cowpea seeds were evaluated according to Baryeh [8]. Twenty-five randomly selected seeds were used to measure length (L), width (W) and thickness (T) from the three principal dimensions which are in the three mutually perpendicular directions using a micrometer gauge. Using the readings, the geometric mean diameter, D_m, was calculated using the following relationship;

$$D_m = (LWT)^{1/3} \tag{1}$$

The sphericity (φ) was calculated as a function of the three principal dimensions as shown below;

$$\varphi = \frac{(LWT)^{1/3}}{L} \tag{2}$$

The surface area, A (mm^2), of the seeds was calculated using the equation;

$$A = \pi \cdot D_m{}^2 \tag{3}$$

While the volume, V, was evaluated using the relationship;

$$V = \frac{\pi \cdot WT \cdot L^2}{6[2L - (WT)^{0.5}]} \tag{4}$$

The bulk density is the ratio of the mass sample of a seed to its total volume. It was determined by filling a 1000 ml container with seeds from a height of about 15 cm, striking the top level and then weighing the contents [9; 14].

The kernel density defined as the ratio of the sample mass of the seeds to its kernel volume, was determined using the water displacement method [9; 14]. Five hundred ml of water was placed in a 1000 ml graduated measuring cylinder and 25 g seeds were immersed in that water. The amount of displaced water was recorded from the graduated scale of the cylinder. The ratio of weight of seeds to the volume of displaced water gave the kernel density.

Following this, the porosity, ε, of the seeds which is the fraction of the space in the bulk seed which is not occupied by the grain was computed from the values of kernel density and bulk density using the relationship as follows [15, 16];

$$\varepsilon = \frac{(\rho_k - \rho_b) \cdot 100}{\rho_k} \tag{5}$$

Water Uptake Studies

To understand the effect of soaking temperatures on water uptake kinetics for common treatment, the cowpea seeds were rehydrated at different rehydration temperatures of 20, 25, 30, 35, 40 and 45°C (±0.2°C). On the other hand, to understand the effect of microwave output power on water uptake kinetics for microwave treatment, the cowpea seeds were rehydrated at different microwave output powers of 180, 360, 540, 720 and 900 W.

For both situations, water uptake of the seeds was determined by soaking about 10 g samples in 250 mL beakers containing 200 mL of distilled water. At specific time intervals, the seeds were removed from the water and then weighed. Before weighing the sample, it was removed and allowed to drain over a mesh for 60 s in order to eliminate the superficial water. At each interval, the water content of the seeds was calculated as the difference between the weight of the dry solids and the soaked seeds. All experiments were duplicated, and the reproducibility of the experiments was within the range of ±5%.

Modeling of Water Uptake

In the present study, in order to determine the water uptake as a function of soaking time for different soaking temperatures for common treatment, Peleg's equation (Equation 9) and the Weibull equation (Equation 11) [20; 23; 16-18] were used, respectively;

$$W = W_0 + \frac{t}{K_1 + K_2 t} \tag{6}$$

where; W is the moisture content at a specific time (g/(g d.b.)) during rehydration, W_0 is the initial moisture content (g/(g d.b.)) before rehydration, t is the rehydration time (s), K_1 is a kinetic rate constant of the model (s.(g d.b./g)) and K_2 is a characteristic constant of the model (g d.b./g). If the time of rehydration is long enough [19, 20], equilibrium moisture content (W_e) is given by;

$$W_e = W_0 + \frac{1}{K_2} \tag{7}$$

In the rehydration process unlike the drying process, equilibrium moisture content (W_e) cannot be measured independently, because many changes can occur at long soaking times, making it difficult to establish when equilibrium is attained. Hence, equilibrium moisture content (W_e) is considered as an additional parameter to be identified in the Weibull Model (Equation 11) [17, 18, 21]. Then, by using this estimated equilibrium moisture content value (W_e), the Weibull Model is described as;

$$W = W_e + (W_0 - W_e)\exp\left[-\left(\frac{t}{\beta}\right)^{\alpha}\right] \tag{8}$$

where; β and α are the scale and the shape parameters, respectively. The scale parameter β which is a behavior index, defines the rate of the moisture uptake process, represents the time needed to accomplish approximately 63% of the moisture uptake process and depends on the process mechanism [22].

On the other hand, in order to determine the water uptake kinetics as a function of soaking time at different microwave output powers for microwave treatment, the sigmoidal mathematical models were used as follows:

Gompertz Model ($y = ae^{-e^{b-cx}}$)

Logistic Model ($y = \dfrac{a}{1 + be^{-cx}}$)

Richards Model ($y = \dfrac{a}{(1 + e^{b-cx})^{1/d}}$)

MMF Model ($y = \dfrac{ab + cx^d}{b + x^d}$)

Determination of effective moisture diffusivity coefficients

In order to predict moisture diffusivity coefficients during soaking of cowpea seeds, the second Fick's law solution for diffusion out of sphere was used. For this purpose, the following assumptions were made:

(i) the effective diffusion coefficient is independent of moisture concentration,
(ii) the volume of grain does not change during water absorption,
(iii) the surface of grain reaches the equilibrium moisture content instantaneously upon immersion in absorption media.

General series solution of Fick's second law in spherical coordinates is given below [23]:

$$\mathrm{MR} = \frac{W_i - W_e}{W_o - W_e} = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left(-\frac{n^2 . D_{eff} . \pi^2}{r^2} . t\right) \tag{9}$$

where; MR is the moisture ratio, W_i is the moisture content at a specific time (g/g d.b.), W_o is the initial moisture content (g/g d.b.), W_e is the equilibrium moisture content (g/g d.b.), D_{eff} is the effective moisture diffusivity coefficient (m^2/s), r is the equivalent radius of cowpea seed (m) and t is the rehydration time (s).

Statistical Analysis

The software package MATLAB 5.0 was used in the numerical calculations. The parameters were evaluated by the nonlinear least squares method of Marquardt-Levenberg until minimal error was achieved between experimental and calculated values. The residual (SSR) is defined as the sum of the squares of the differences between experimental and calculated data and is given by Equation 10;

$$SSR = \sum_{m=1}^{N_d}\left(C_m^{obs} - C_m^{cal}\right)^2 \tag{10}$$

where; m is observation number and N_d is total number of observations. The estimated variance of the error (population variance) is calculated by the SSR at its minimum divided by its degrees of freedom;

$$\sigma^2 \approx s^2 = \frac{(SSR)_{\min}}{(m-p)} \tag{11}$$

Results and Discussions

Physical Properties

The physical properties of the cowpea seeds are shown in Table-1. The seed weight was determined as 0.17 g and this value was in the range of values obtained from the study performed by Olapade *et al.* [24], Kaptso *et al.* [2] and Sobukola and Abayomi [1]. As can be seen from the Table-1, the values of L, W, T and geometric mean diameter were found as 9.31, 6.54, 5.46 and 6.92 mm, respectively. These values were similar with the values obtained from the studies performed by Taiwo [6], Olapade *et al.* [24], Kaptso *et al.* [2] and Sobukola and Abayomi [1].

Table-1: Calculated physical properties of cowpea seeds.

Parameters	Values
Weight (g)	**0.17±0.03**
Length (mm)	**9.31±0.29**
Width (mm)	**6.54±0.41**
Thickness (mm)	**5.46±0.29**
Geometric mean diameter (mm)	**6.92±0.28**
Sphericity	**0.74±0.02**
Surface area (mm^2)	**150.86±12.18**
Volume (mm^3)	**128.77±9.88**
True density (g/ml)	**1.24±0.04**
Bulk density (g/ml)	**0.83±0.01**
Porosity (%)	**34.39±2.37**

Surface area, volume and sphericity were determined as a function of the linear dimensions and were calculated as 150.86 mm^2, 128.77 mm^3 and 0.74, respectively. The bulk and true densities of cowpea seeds were found as 0.83 and 1.24 g/ml, respectively. There are slight differences observed when compared with the values reported in literature studied by Taiwo [6], Olapade *et al.* [24] and Kaptso *et al.* [2]. These differences could be due to the differences in moisture content, variety and growing conditions.

Porosity of seeds is very important in water uptake as seeds with low porosity may find it difficult to take up water compared with seeds of high porosity [1; 22]. The porosity of cowpea seeds was determined as 34.39%. The porosity value of cowpea seeds is similar to the value obtained from the study performed by Kaptso *et al.*[2].

Effect of rehydration temperature on water uptake kinetics of cowpea seeds for common treatment

To investigate the effect of soaking temperature on water uptake during rehydration undergoing common treatment, the cowpea seeds were rehydrated at various rehydration temperatures; 20, 25, 30, 35, 40 and 45°C. The data of moisture content uptake during rehydration versus rehydration time of cowpea seeds was shown in Fig. 1.

The shapes of these curves are typical of water absorption in legumes [25-27]. The rate of water absorption was initially rapid and slowed down as equilibrium was approached. The rate of water absorption depends on the difference between the water content at saturation and at a given time, protein and sugar content [28, 29]. From all the experiments with cowpea seeds investigated, high temperature of soaking resulted in high water absorption rate as compared with low temperature. This could be linked to a high rate of water diffusion at higher temperatures as reported for cereal grains [30, 31] and different peas and beans [2; 7; 32].

For the experiments performed at different rehydration temperatures, the water uptake kinetics was described by using two empirical models. Among these models, Peleg's Model was observed as the most appropriate one for all the experimental data with the values for the higher coefficient of determination and the lower standard error values. The constants, standard error (σ) and R^2 values for the model were estimated and given in Table-2. Also the fitness of the experimental data to the Peleg's Model is illustrated in Fig. 1.

Table-2: The estimated parameters and statistical analysis of Peleg's Model at different rehydration temperatures

		Peleg Model		
Temperature (°C)	**K_1[a]**	**K_2[b]**	**σ**	**R^2**
20	**2734.27**	**0.6782**	**0.0217**	**0.9983**
25	**2244.93**	**0.6818**	**0.0134**	**0.9993**
30	**1755.59**	**0.6855**	**0.0313**	**0.9968**
35	**1429.09**	**0.6891**	**0.0159**	**0.9991**
40	**1102.59**	**0.6927**	**0.0230**	**0.9985**
45	**776.09**	**0.6963**	**0.0188**	**0.9989**
		Weibull Model		
Temperature (°C)	**1/β[c]**	**α[d]**	**σ**	**R^2**
20	**0.000368**	**0.5687**	**0.0357**	**0.9959**
25	**0.000261**	**0.9499**	**0.0276**	**0.9973**
30	**0.000279**	**1.1696**	**0.0375**	**0.9956**
35	**0.000125**	**2.8008**	**0.0283**	**0.9976**
40	**0.000409**	**1.0559**	**0.0371**	**0.9964**
45	**0.000303**	**1.7160**	**0.0288**	**0.9981**

[a]K_1: g d.b. s/g; [b]K_2:g d.b./g; [c]1/β: s^{-1}; [d]α: none

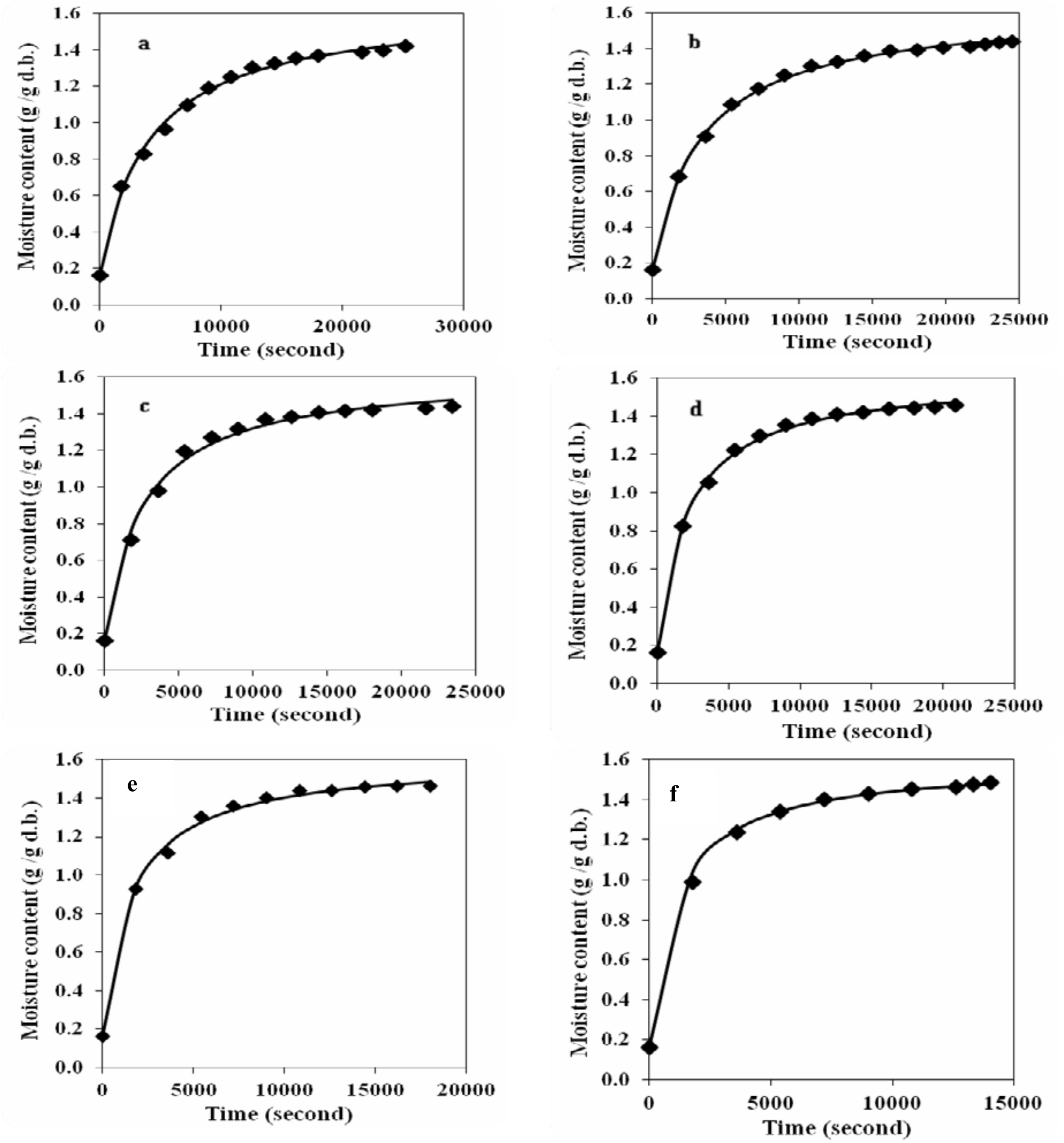

Fig. 1: Water uptake data of cowpea seeds during rehydration at different temperatures; (a) 20°C; (b) 25°C; (c) 30°C; (d) 35°C; (e) 40°C; (f) 45°C; (—) Models.

It has been shown that K_1 is a function of temperature and K_2 is a constant for a food material [7; 32-34]. The Peleg's constant K_1 is related to mass transfer rate. Therefore, it would be more appropriate to say that the reciprocal of K_1 characterizes the diffusion coefficient. As can be seen from Table-3, K_1 values of Peleg's Model decreased with increase in rehydration temperature. This result is in agreement with the earlier studies performed for soybean, cowpea and peanuts by Sopade and Obekpa [33], for chickpea by Turhan *et al.* [7], for wheat products by Maskan [34], for cowpea by Kaptso *et al.* [2] and for cowpea and maize by Sobukola and Abayomi [1].

The constant K_2 has been related to maximum water absorption capacity of the seeds. In the literature, there are mixed reports about the relationship between K_2 and temperature. As can be seen from Table-3, K_2 values of Peleg's Model increased with increase in rehydration temperature. The constant K_2 was reported to decrease with increase in temperature for soybean [35], whole hazelnut and hazelnut kernels [36], amaranth grain

[37] and wheat products [34]. However, Turhan *et al.* [7] reported that K_2 increases linearly with increase in temperature for chickpea as obtained from this study for cowpea seeds. The dependence of the K_2 on the rehydration temperature was represented with linear equation given below (Eq. 12);

$$K_2 = a_1 + b_1 \cdot T \tag{12}$$

where; a_1 and b_1 are the constants and T is the rehydration temperature (K) applied during water uptake process. The values of K_2 versus T shown in Fig. 2 accurately fit to Eq. (1) with the statistical values of standard error (σ) and coefficient of determination (R^2) of 0.00003 and 0.9999, respectively. Then, a_1 and b_1 values were estimated as 0.4659 and $7.25\text{x}10^{-4}$.

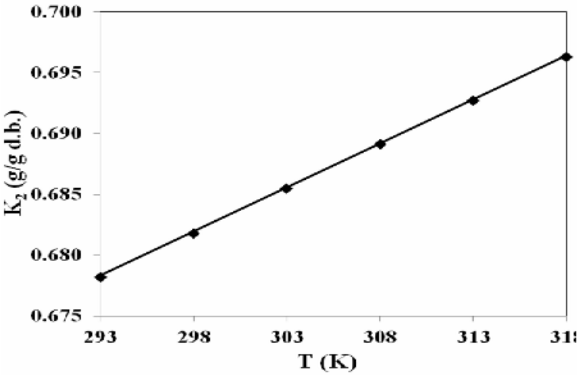

Fig. 2: Effect of temperature on K_2 during soaking of cowpea seeds.

Estimation of activation energy for kinetic constant of the Peleg's Model

In order to find the effect of temperature on water absorption of cowpea, an Arrhenius type equation was used for modeling of the dependence of Peleg's rate constant (K_1) on temperature, which had been used previously to describe the temperature dependent rehydration kinetics of legumes [7; 16]. The temperature dependence of the reciprocal of K_1 could be expressed by an Arrhenius type relationship (Eq. 13) as:

$$\frac{1}{K_1} = K_0 \exp\left(\frac{-E_a}{RT}\right) \tag{13}$$

where E_a is the activation energy (kJ/mol), R is the universal gas constant and T is the soaking temperature. Arrhenius plot for cowpea seeds was represented in Fig. 3. The activation energy value of soaked cowpea seeds was found as 38.14 kJ/mol. The value of activation energy obtained in the present study was in the range values reported by Sobukola and Abayomi [1] for cowpea (18.14-34.82 kJ/mol), by Kaptso *et al.* [2] for cowpea (37.62-78.81 kJ/mol) and by Gowen *et al.* [11] for chickpea (42.45 kJ/mol).

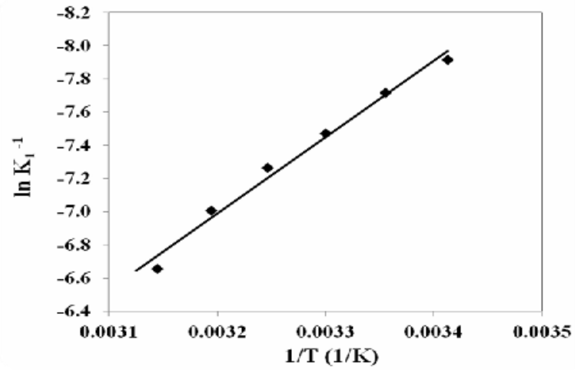

Fig. 3: Arrhenius plot for the Peleg's rate constant K_1 during soaking of cowpea seeds.

Effect of microwave output power on water uptake kinetics of cowpea seeds for microwave treatment

In order to understand the effect of microwave output power on water uptake kinetics, the cowpea seeds were rehydrated under microwave treatment at different microwave output powers of 180, 360, 540, 720 and 900 W.

The data of moisture content uptake during rehydration versus rehydration time of cowpea seeds were shown in Fig. 4. As can be seen from this figure, the moisture content uptake of cowpea seeds increased as the microwave output power increased.

On the other hand, the rehydration times for cowpea seeds at common treatment and microwave treatment were given in Table-3. The rehydration times obtained for cowpea seeds with microwave treatment were enormously lower than the rehydration time obtained for common treatment. This result indicates that the microwave treatment can be successfully used to rehydrate cowpea seeds.

Table-3: The rehydration times and calculated effective diffusivity values for cowpea seeds at common treatment and microwave treatment.

	Rehydration Time (min)	Effective Diffusivity Values (m^2/s)
Temperature (°C)		
20	420	$7.75\text{x}10^{-11}$
25	408	$8.68\text{x}10^{-11}$
30	390	$1.04\text{x}10^{-10}$
35	348	$1.21\text{x}10^{-10}$
40	300	$1.54\text{x}10^{-10}$
45	234	$1.99\text{x}10^{-10}$
Microwave Output Power (W)		
180	30	$2.23\text{x}10^{-9}$
360	10	$5.29\text{x}10^{-9}$
540	7.5	$7.20\text{x}10^{-9}$
720	6.2	$7.92\text{x}10^{-9}$
900	5.3	$9.78\text{x}10^{-9}$

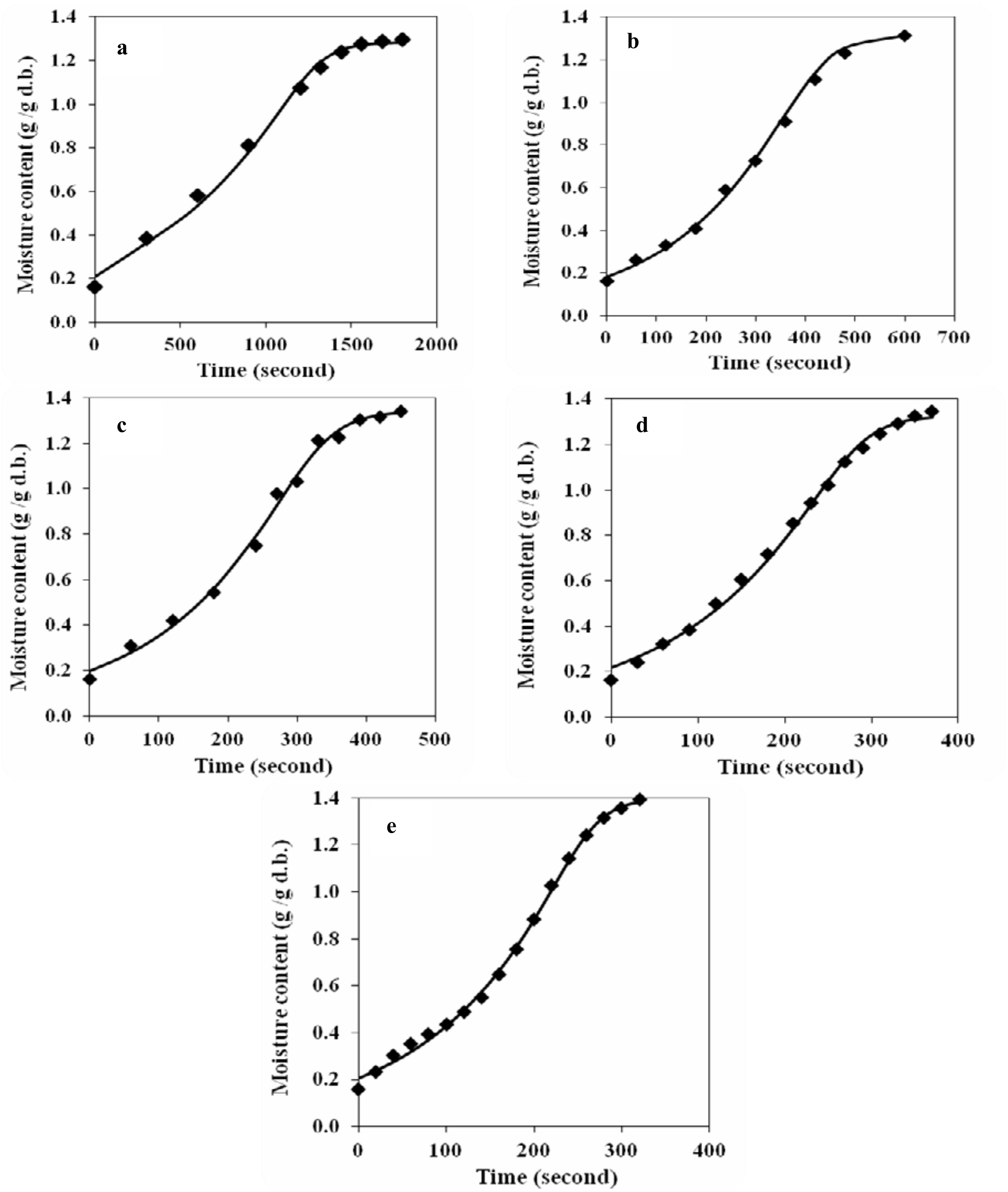

Fig. 4: Water uptake data of cowpea seeds during rehydration at different microwave output powers undergoing microwave treatment; (a) 180 W; (b) 360 W; (c) 540 W; (d) 720 W; (e) 900 W; (—) Models.

The water uptake kinetics of cowpea seeds undergoing microwave treatment were described by using sigmoidal mathematical models, and among these models, Richards' Model was observed as the most appropriate one for all the experimental data with the values for the higher coefficient of determination and the lower standard error values. The constants, standard error (σ) and R^2 values for the model were estimated and given in Table-4. Also the fitness of the experimental data to the Richards' Model is illustrated in Fig. 4. As can be seen from the Table-4, the kinetic rate constant, c (s^{-1}), increased with the increase in microwave output power.

Table-4: The estimated parameters and statistical analysis of Richards' Model at various microwave output powers

Richards' Model						
Microwave Output Power (W)	**a**	**b**	**c**	**d**	**σ**	**R^2**
180	1.2832	12.3277	0.0096	7.5066	0.0429	0.9959
360	1.3189	9.4013	0.0224	4.7476	0.0329	0.9977
540	1.3403	9.7533	0.0298	5.0678	0.0358	0.9972
720	1.3266	10.8139	0.0385	6.0087	0.0270	0.9982
900	1.3961	12.1228	0.0463	6.3489	0.0207	0.9990
MMF Model						
Microwave Output Power (W)	**a**	**b**	**c**	**d**	**σ**	**R^2**
180	0.1693	72075.5	2.0136	1.5693	0.0443	0.9943
360	0.1619	41215.2	2.3928	1.6890	0.0559	0.9941
540	0.2020	37875.9	1.8799	2.2533	0.0636	0.9923
720	0.1719	32096.1	1.8307	2.3085	0.0453	0.9952
900	0.1962	46988.6	3.3859	1.7902	0.0396	0.9967
Gompertz Model						
Microwave Output Power (W)	**a**	**b**	**c**	**σ**	**R^2**	
180	1.5764	0.8416	0.00148	0.0357	0.9952	
360	1.8196	0.9835	0.00375	0.0523	0.9940	
540	1.8722	0.9806	0.00497	0.0636	0.9910	
720	1.7945	1.0989	0.00665	0.0502	0.9937	
900	2.8605	1.0787	0.00459	0.0404	0.9963	
Logistic Model						
Microwave Output Power (W)	**a**	**b**	**c**	**σ**	**R^2**	
180	1.4132	6.6431	0.00256	0.0388	0.9942	
360	1.4902	9.0210	0.00746	0.0351	0.9972	
540	1.5346	9.0710	0.00984	0.0517	0.9941	
720	1.5005	10.6473	0.01260	0.0426	0.9954	
900	1.8098	9.8971	0.01140	0.0302	0.9979	

The relationship between the kinetic rate constants of the Richards' Model and the microwave output power

The aim of this study is to predict the relationship between the kinetic rate constants of the Richards' Model and the microwave output power. After evaluation of the data, it was observed that, the dependence of the kinetic rate constant on the microwave output power was represented with linear equation given below (Eq. 14);

$$c = a_2 + b_2 \cdot P \qquad (14)$$

where; c represents the kinetic rate constants of the Richards' Model, a_2 and b_2 are the constants, and P is microwave output power (W) applied during water uptake process. The values of kinetic rate constant versus P shown in Fig. 5 accurately fit to Eq. (3) with the statistical values of standard error (σ) and coefficient of determination (R^2) of 0.0017 and 0.9947, respectively. Then, a_2 and b_2 values were estimated as 0.0025 and $5x10^{-5}$.

Calculation of effective diffusivity coefficients for common treatment and microwave treatment

To calculate the effective diffusivity coefficients by using the method of slopes, the logarithm of moisture ratio values, ln(MR), was plotted against drying time (t) according to the experimental data obtained at various rehydration temperatures and microwave output powers. The effective diffusivity values (D_{eff}) of cowpea seeds are presented in Table-3 for various rehydration temperatures and microwave output powers. The effective diffusivity values for the cowpea seeds increased from 7.75×10^{-11} to 1.99×10^{-10} m^2/s and from 2.23×10^{-9} to 9.78×10^{-9} m^2/s as the soaking temperature and microwave output power increased, respectively. The increase in effective moisture diffusivity with the temperature was also determined in the study performed by Verma and Prasad [38]. Diffusivity values obtained in this study were in the range values published in the literature for different grains such as cowpea seed ($2.16x10^{-10}$– $5.95x10^{-9}$ m^2/s) [2]; rice (0.16 - $0.49x10^{-10}$ m^2/s) [21]; sorghum (2.22- $8.38x10^{-12}$ m^2/s) [12] and chickpea (1.99 – $39.16x10^{-10}$ m^2/s) [39].

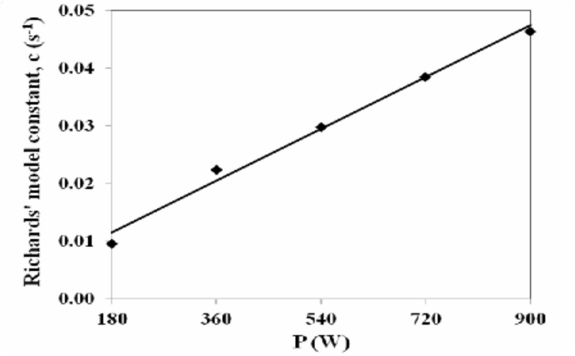

Fig. 5: Effect of microwave output power on the constant of Richards' Model during soaking of cowpea seeds.

Conclusions

As a result of the experiments performed on the water uptake kinetics of cowpea seeds, it was observed that the moisture content uptake of cowpea seeds increased as the rehydration temperature and microwave output power increased. On the other hand, the rehydration time obtained for cowpea seeds with microwave treatment was enormously lower than the rehydration time obtained for common treatment. This result indicates that the microwave treatment can be successfully used to rehydrate cowpea seeds.

In order to determine the moisture content uptake as a function of rehydration time at various rehydration temperature, two different models were examined, and both of them provided a good agreement with experimental data, but the Peleg's Model was chosen as appropriate model to represent the water uptake kinetics of cowpea seeds because of the high coefficient of the determination of R^2 value. On the other hand, to determine the moisture content uptake as a function of rehydration time at various microwave output powers undergoing microwave treatment, four different models were examined, and the Richards' Model was chosen as appropriate model to represent the water uptake kinetics of cowpea seeds because of the high coefficient of the determination of R^2 value.

The dependence of the kinetic rate constants of the model used on the microwave output power were represented with linear equation. The benefit of this study is that by choosing the microwave output power, the value of the kinetic constants could be calculated. Moreover, for estimation of the activation energy of rehydration, the data obtained from the Peleg's Model were fitted to the Arrhenius equation, and the activation energy was calculated as 38.14 kJ/mol.

Nomenclature

φ	**Sphericity**
A	**Surface area (mm^2)**
V	**Volume (mm^3)**
ε	**Porosity**
ρ_k	**Kernel density**
ρ_b	**Bulk density**
W	**Moisture content at a specific time (g/(g d.b.))**
W_0	**Initial moisture content before rehydration (g/(g d.b.))**
W_e	**Equilibrium moisture content (g/(g d.b.))**
K_1	**Kinetic rate constant of the Peleg's Model (s.(g d.b./g))**
K_2	**Characteristic constant of the Peleg's Model (g d.b./g)**
MR	**Moisture ratio**
D_{eff}	**Effective moisture diffusivity coefficient (m^2/s)**
T	**Rehydration temperature, K**
E_a	**Activation energy (kJ/mol)**
P	**Microwave output power (W)**

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