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Effect of Soaking Temperature on Water Absorption Characteristics of Selected Ghanaian Cowpea Varieties

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Abstract

The water absorption kinetics of three cowpea varieties (Asontem, Hewale and Asomdwee) was studied following the phenomenological models derived from Fick's law of diffusion. Soaking of seeds from each cowpea variety was carried out for 10 h at four temperatures (30˚C, 40˚C, 50˚C and 60˚C). The saturation moisture content was higher for Asontem (106.9 g water/1000 g dry weight) and Hewale varieties (108.7 g water/1000 g dry weight) and lower for Asomdwee hybrid (100.7 g water/1000 g dry weight), respectively. The proposed Fick's law of diffusion satisfactorily described the kinetics of water absorption regardless of the variety and temperature. The estimated values for water diffusion coefficient for Asontem, Hewale and Asomdwee varied from 5.12×10^{-10} m²/s to 6.64×10^{-10} m²/s, 3.96×10^{-10} m²/s to 5.12×10^{-10} m²/s, 4.93×10^{-10} m²/s to 6.08×10^{-10} m²/s, respectively. The strong influence of temperature on the water diffusion coefficient was adequately described by an Arrhenius-type equation with activation energy values for Asontem, Hewale and Asomdwee as 7.27 kJ/mol, 7.26 kJ/mol and 6.26 kJ/mol, respectively.

Keywords

Cowpea, Water Absorption, Diffusion Coefficient, Arrhenius-Type Equation, Modelling

1. Introduction

Cowpea (*Vigna unguiculata*) is an essential member of the legume family Fabaceae. It is widely consumed in many parts of the world including Ghana. It is considered one of the crops which have been in existence for many years. On average it contains 23.4%, 11%, 3.6%, 1.3% and 56.8% of protein, water, ash, fat, carbohydrate, respectively [1]. Generally, processing of cowpea seeds requires initial soaking of seeds in water to allow water absorption by seeds for a period of time before additional processing of the seeds takes place [2]. The rate of water absorption by the seeds largely depends on soaking temperature and soaking time [3]. An increase in soaking temperature results in an increase in the rate of water absorption [4]. The rate of water absorption also depends on the initial moisture content of seeds, variety of seeds, soaking duration, acidity level of soaking water and seed physical characteristics [5] [6]. From process optimization and engineering perspective, it is important to know the rate of water absorption by seeds and the effect of processing variables on the seeds with time during the soaking period [7]. Consequently, for industrial purposes, whether in designing food processing equipment or determining favorable conditions under which soaking can be carried out and how these conditions change with time and temperature, it is necessary to have measurable data which describe the effect of the processing variables on agricultural materials [8] [9] [10]. Several hydration models such as the exponential model, the Peleg's model, first-order kinetics, Becker's model among others have been developed by various researchers to predict rehydration of several legume seeds [11] [12] [13]. The Peleg model and the phenomenological models derived from Fick's diffusion are mostly used in the rehydration of legumes seeds [14] [15]. However, the rehydration model for effects of processing variables on the rate of water uptake and moisture diffusivity in some existing legumes grown in Ghana, such as Asontem, Hewale and Asomdwee cowpea varieties have not been established. Thus, this research was undertaken to study the influence of temperature on the water absorption characteristics of three newly-developed cowpea varieties grown in Ghana.

2. Materials and Methods

2.1. Preparation of Cowpea Seeds

Samples of three cowpea varieties (Asontem, Hewale and Asomdwee) were obtained from the Council for Scientific and Industrial Research-Crops Research Institute (CSIR-CRI) at Fumesua, Kumasi, Ghana. The seeds were cleaned manually to remove all foreign matter viz. dirt, stones fragments, weevil contaminated seeds and broken seeds. The cleaned seeds were sealed in labelled transparent low density polyethylene bags and stored at 4˚C to prevent moisture loss and recontamination.

2.2. Determination of Seed Moisture Content

The initial moisture contents of the samples of three cowpea varieties were determined in triplicate by oven drying method. 15 g of each sample was heated in an oven at 103˚C for 72 h according to [16] and expressed as kg/kg (dry basis). The following equation was used in determining the initial moisture content:

$$M_d = \frac{100 - M_w}{100 \times M_w} \quad (1)$$

M_d = moisture content (dry basis).

M_w = moisture content (wet basis).

2.3. Determination of Seed Dimensions

The basic dimensions (length (L), breadth (B) and thickness (T) all in millimeters) of sample seeds from each cowpea variety were determined in triplicate using a digital Vernier caliper with a least count of 0.02 mm for each single seed of 10 seeds sampling before soaking and average value was determined for each sample. A seed each was placed within the Vernier caliper measuring unit and the nob adjusted until the seed was just closely held before taking its reading [17].

2.4. Determination of Equivalent Radius

The equivalent radius (R) was determined for 50 seeds from each cowpea variety. The assumption was that the volume of the cowpea seed can be approximated by calculating the volume of a sphere with radius equal to half diameter of the seed. To determine the volume of the seed, 50 ml of distilled water was transferred into a measuring cylinder of 100 ml capacity. Afterward, 50 seeds of each cowpea variety were separately immersed in the water one variety at a time. The amount of water displaced was read on the measuring cylinder and recorded accordingly. The procedure was replicated five times and the true volume (V) was calculated in mm^3 and equivalent radius (R) is given by Equation (2):

$$R = \sqrt[3]{\frac{3V}{4\pi}} \tag{2}$$

V = volume of seed (mm^3).

2.5. Soaking Experiment

The water absorption characteristics of the three cowpea varieties were determined by soaking them at four different water temperatures (30˚C ± 2˚C, 40±2˚C, 50˚C ± 2˚C, and 60˚C ± 2˚C in a thermostatic water bath for 10 h. Three replicates of sample size of 10 g ± 0.02 g were separately placed in a mesh, tied and labelled before they were placed into the portable water bath. The samples were removed at predetermined time interval of 30 minutes. The samples were placed on soft moisture absorbing tissues after untying the nets. The seeds were blotted with tissue paper to absorb remaining water on the surface of the seeds before the seed samples were reweighed [18], as cited by [17].

2.6. Soaking Experiment

The water absorption capacity of seeds of each cowpea hybrid was determined using Equation (3) by [19]:

$$W_{ac} = \frac{W_f - W_i}{W_i} \tag{3}$$

W_{ac} = water absorption capacity (d.b. %) of seeds.

W_f = weight of seeds (g) after immersion into water.

W_i = weight of seeds (g) before immersion into water.

2.7. Modelling of Rehydration Kinetics

Many studies on water absorption and drying use the moisture ratio (MR) as the basis for achieving water absorption and drying models as a result of few data dispersion and optimize data [20]. Normally, when a diffusion process takes place at a temperature, which is constant, that process is believed to exhibit Fick's second law of diffusion. As stated by Fick, a diffusion process which is axisymmetric in nature can be expressed using an equation that is three-dimensional given by:

$$\frac{\partial M}{\partial t} = D\left(\frac{\partial^2 M}{\partial x^2} + \frac{\partial^2 M}{\partial y^2} + \frac{\partial^2 M}{\partial z^2}\right) \tag{4}$$

M = instantaneous moisture at specified time (kg/kg).

D = diffusion coefficient (m^2/s).

t = time (s).

[21], proposed a model to determine the diffusion coefficient, *D*. The model is an equation which shows the relationship between moisture concentration and time for particles of random shape as well as relative short immersion times. The equation is given as:

$$1-\left(\frac{U-U_s}{U_o-U_s}\right) = \frac{2}{\pi^{1/2}} F_o^{1/2} \tag{5}$$

$$F_o = \frac{D\theta}{R^2} \tag{6}$$

U = mean moisture concentration in dry weight (g/g).

U_s = saturation moisture concentration in dry weight (g/g).

U_o = initial moisture concentration in dry weight (g/g).

D = diffusion coefficient (m^2/s).

R = equivalent radius of the sphere with the same volume as that of particle under consideration.

θ = soaking or immersion time (s).

Temperature dependency of diffusion coefficient was described by Arrhenius Equation (7):

$$D = D_0 e^{-E/RT} \tag{7}$$

D_0 = diffusion constant (m^2/s).

E = activation energy (kJ/mol).

R = gas constant (8.314 kJ/molK).

T = absolute temperature (K).

Linear regression analysis of (D vs. 1/T) was used to determine activation energy values for the different cowpea varieties under consideration. The linear regression analysis gave slope value indicating (E/R). A product of the slope (E/R) value and gas constant (R) produced the activation energy values for Asontem, Hewale and Asomdwee cowpea seeds.

2.8. Experimental Design

The soaking experiment was performed in a factorial form in a completely randomized design with three replications to study the influence soaking temperature on water absorption capacity of samples of three cowpea varieties.

3. Results

3.1. Initial Physical Properties of Cowpea Varieties

The initial physical properties of the three cowpea varieties (Asontem, Hewale and Asomdwee) determined before soaking at different temperatures are given in Table 1.

3.2. Water Absorption Characteristics of Asontem, Hewale and Asomdwee

The water absorption characteristics of Asontem, Hewale and Asomdwee cowpea varieties are shown in Figures 1-3.

3.3. Saturation Moisture Content (U_s) and Diffusion Coefficient (D) of Asontem, Hewale and Asomdwee Cowpea Varieties

The saturation moisture contents and diffusion coefficients of Asontem, Hewale and Asomdwee cowpea varieties are shown in Tables 2-4.

3.4. Water Absorption Rate of Asontem, Hewale and Asomdwee cowpea

The water absorption rate of Asontem, Hewale and Asomdwee cowpea varieties during soaking at temperatures of 30˚C, 40˚C, 50˚C and 60˚C are given in Figures 4-6.

Table 1. Physical properties of Asontem, Hewale and Asomdwee cowpea varieties.

	Cowpea Variety		
Physical Property	Asontem	Hewale	Asomdwee
Moisture content (%d.b.)	16.53 ± 0.00	12.40 ± 0.01	13.63 ± 0.00
Length (mm)	7.19 ± 0.75	6.88 ± 0.72	7.20 ± 0.46
Breadth (mm)	6.01 ± 0.42	5.54 ± 0.43	5.44 ± 0.32
Thickness (mm)	4.78 ± 0.28	4.45 ± 0.34	4.63 ± 0.24
Radius (mm)	3.46 ± 0.38	3.26 ± 0.37	3.08 ± 0.64
Surface area (mm^2)	111.00 ± 18.30	96.44 ± 13.34	100.81 ± 9.32

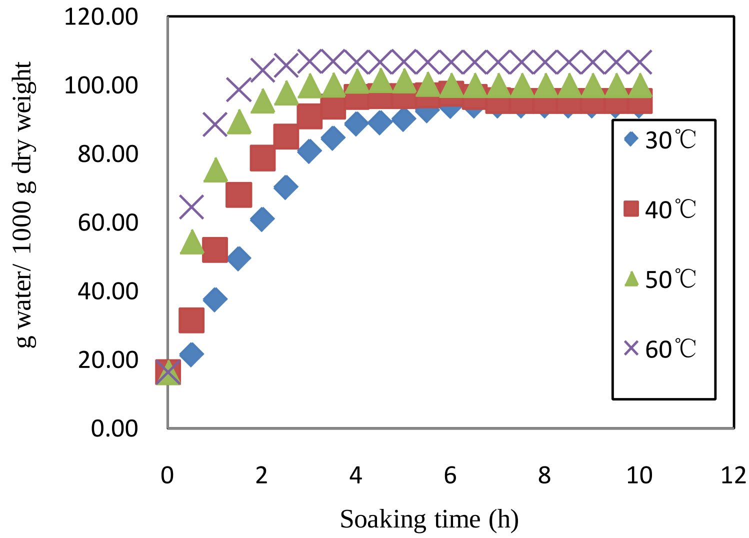

Figure 1. Water absorption characteristics of Asontem.

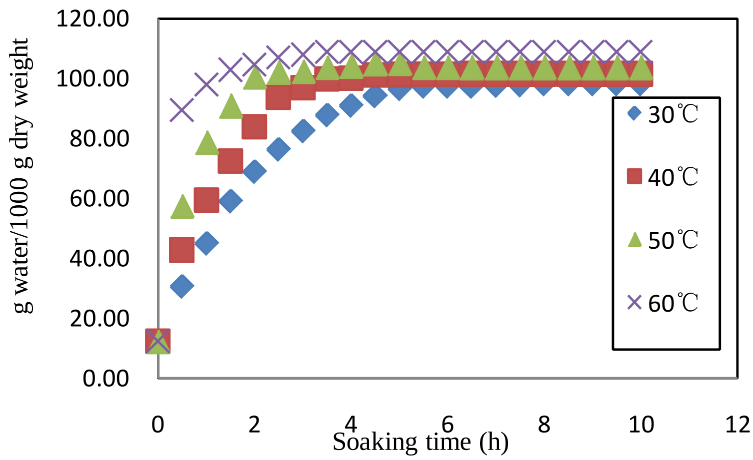

Figure 2. Water absorption characteristics of Hewale.

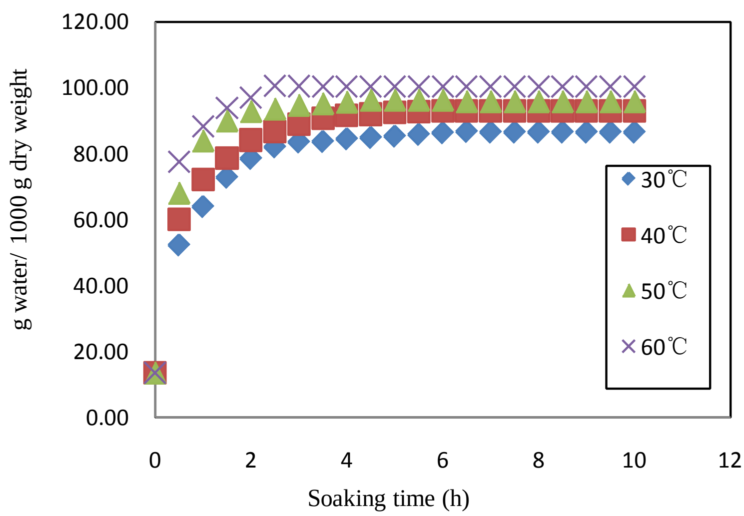

Figure 3. Water absorption characteristics of Asomdwe.

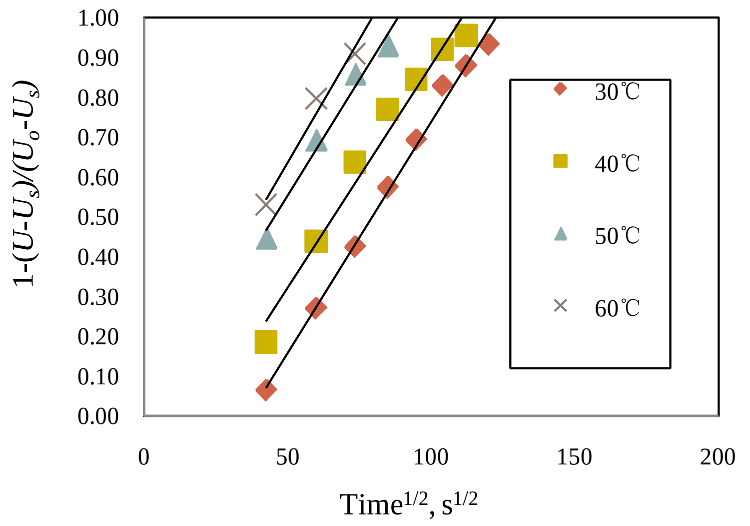

Figure 4. Water absorption rate for Asontem.

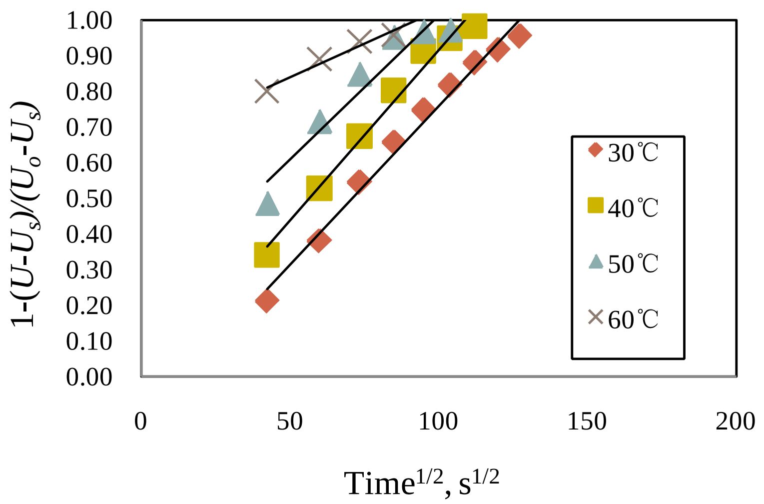

Figure 5. Water absorption rate for Hewale.

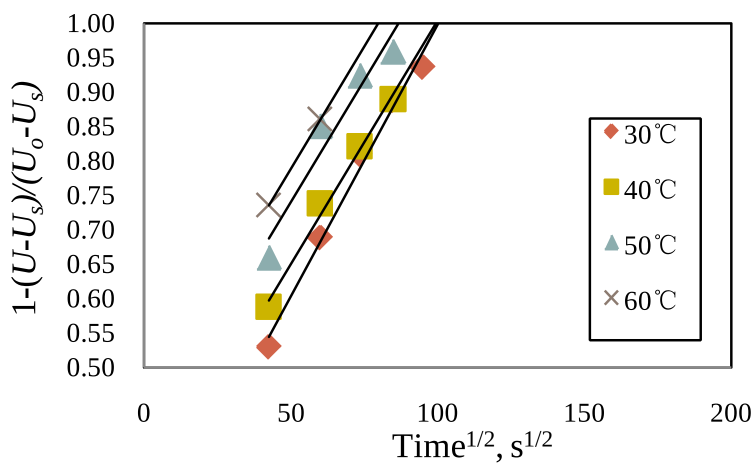

Figure 6. Water absorption rate for Asomdwee.

Table 2. Saturation moisture content (U_s) and diffusion coefficient (D) of Asontem cowpea variety at different soaking temperatures.

	Temperature (˚C)			
Parameter	30	40	50	60
U_s	93.9	97.6	101.5	106.9
D × (10^{-10} m^2/s)	5.12	5.69	6.19	6.64
R^2	0.93	0.89	0.88	0.87

Table 3. Saturation moisture content (Us) and diffusion coefficient (D) of Hewale cowpea variety at different soaking temperatures.

	Temperature (˚C)			
Parameter	30	40	50	60
U_s	98.3	101.5	104.9	108.7
D × (10^{-10} m^2/s)	3.96	4.38	4.85	5.12
R^2	0.95	0.91	0.84	0.96

Table 4. Saturation moisture content (U_s) and diffusion coefficient (D) of Asomdwee cowpea variety at different soaking temperatures.

	Temperature (˚C)			
Parameter	30	40	50	60
U_s	86.8	92.9	96.4	100.7
D × (10^{-10} m^2/s)	4.93	5.16	5.80	6.08
R^2	0.80	0.87	0.82	0.97

4. Discussions

4.1. Initial Physical Properties of Cowpea Varieties

The initial moisture content for Asontem cowpea was higher than that ofAsomdwee and Hewale cowpea varieties. The data presented in **Table 1** generally agree with those reported by [22], who reported values ranging from 0.73 cm - 0.92 cm for length, 0.55 cm - 0.73 cm for breadth and 0.38 cm - 0.58 cm for thickness of cowpea seeds. Furthermore, [23] reported similar range of values for length, breadth and thickness of cowpea seeds. Asontem also exhibited generally higher values for its principal dimensions with the exception of its average length which was slightly lower than that of Asomdwee. However, the values for equivalent radius and the surface area of Asontem were highest in comparison to Asomdwee and Hewale.

4.2. Water Absorption Characteristics of Asontem, Hewale and Asomdwee

It is seen from **Figures 1-3** that the rate of water absorption by cowpea seeds increased as the soaking temperatures increased. [11] [24] and [25] reported similar results from their studies on the water absorption characteristics of Soybean and chickpea. [26] Also made comparable observation when they studied on the water absorption characteristics of soybean seeds. During the soaking process, an initial instant rate of water absorption was observed after which the rate of water absorption gradually slowed down as the saturation moisture content was approached at all four temperatures. This was because the force driving the water absorption into the seeds decreased as the rate of water absorption neared saturation moisture content [27]. The time taken for saturation moisture content for all the cowpea varieties to be reached was longer during soaking at 30˚C but decreased with increasing temperatures. This is because the higher the temperature, the higher the rate of water diffusion into the seeds. Again higher temperatures mean faster gelatinization of starch content of seeds and faster denatured protein resulting in faster rate of water absorption. The time taken for saturation moisture content for Asontem cowpea to be reached was at 8 h during soaking at 30˚C, but it reduced to 6 h, 4.5 h and 3 h when soaking was carried out at 40˚C, 50˚C and 60˚C, respectively. The time taken for saturation moisture content to be achieved for Hewale cowpea during soaking at 30˚C was also 8 h but it also reduced to 6.5 h, 5 h and 3.5 h as the soaking temperature of the water was increased to 40˚C 50˚C and 60˚C, respectively. Similar results were obtained for Asomdwee cowpea variety whose saturation moisture content was reached at 6.5 h, 6 h, 4.5 h and 2.5 h during soaking at 30˚C, 40˚C 50˚C and 60˚C, respectively. Similar results were reported by [17] when they studied the water absorption characteristics of two maize varieties: Obatanpa and Mamaba.

4.3. Saturation Moisture Content (U_s) and Diffusion Coefficient (D) of Asontem, Hewale and Asomdwee Cowpea Varieties

The diffusion coefficients of the three cowpea varieties (Asontem, Hewale and Asomdwee) during water absorption were determined using Equation (5) and Equation (6). The factors from the linear regression analyses: the diffusion coefficient, saturation moisture content and the coefficient of determination are shown in **Tables 2-4**. The saturation moisture content for all the three cowpea varieties increased as the soaking temperatures increased, although the rates at which increment in saturation moisture contents occurred between the initial and final soaking temperatures were not the same for the three different cowpea varieties. The values obtained for the coefficient of determination ranged from 0.80 to 0.97 indicating an extremely good fit to the data obtained from the experiment. The water absorption rates for Asontem, Hewale and Asomdwee cowpea varieties are shown in **Figures 4-6**. From **Table 2**, the diffusion coefficient values of Asontem cowpea seeds ranged from 5.12×10^{-10} m^2/s to 6.64×10^{-10} m^2/s which were higher than those of Asomdwee cowpea seeds in **Table 4** ranging from 4.93×10^{-10} m^2/s to 6.08×10^{-10} m^2/s and Hewale cowpea in **Table 3** ranging from 3.96×10^{-10} m^2/s to 5.12×10^{-10} m^2/s, respectively. This outcome could be as a result of the variations in their seed characteristics since they are different varieties of cowpea [28]. According to [29], proteins and carbohydrates are the main constituents of seeds, which have the ability to absorb so much water, with proteins having a higher water absorption power than carbohydrates. Thus, the differences in the nutritional compositions of Asontem, Hewale and Asomdwee cowpea seeds could also be another reason for the diffusion coefficient values of Asontem cowpea seeds being higher than that of the other two cowpea varieties. It is therefore possible that Asontem cowpea seeds have higher protein content than that of Hewale and Asomdwee, making Asontem cowpea seeds absorb more water than the other two cowpea varieties under the same temperature treatments and the same soaking time. In contrast to the diffusion coefficient values (common treatment: 7.75×10^{-11} m^2/s to 1.99×10^{-10} m^2/s and microwave treatment: 2.23×10^{-9} m^2/s to 9.78×10^{-9} m^2/s) reported by [5], the diffusion values reported in this study were lower but similar to the values of 4.35×10^{-11} m^2/s to 3.79×10^{-9} m^2/s and 1.99×10^{-10} m^2/s to 39.16×10^{-10} m^2/s reported by [18] and [30].

4.4. Water Absorption Rate of Asontem, Hewale and Asomdwee Cowpea Varieties

The values of the diffusion coefficients of Asontem, Asomdwee and Hewale cowpea varieties were fitted to Arrhenius equation in order to describe the temperature effect on the moisture diffusivity of the three cowpea varieties, with the coefficient of determination, R^2, which ranged from 0.96 to 0.99. **Figure 7** shows the Arrhenius relation for the diffusion coefficients and temperature of Asontem, Hewale and Asomdweecowpea varieties. It shows the existence of a linear relationship between the diffusion coefficients and the reciprocal absolute temperatures used in the soaking experiment. In addition, the Arrhenius equation was extremely adequate in describing the effect or influence of temperature on the absorption of moisture by the seeds of all the three cowpea varieties. From **Table 5**, the temperature sensitivity of the diffusion coefficient, D, was highest for Asontem cowpea variety with activation energy of 7.27 kJ/mol, the second highest being Hewale cowpea variety with activation energy of 7.26 kJ/mol and lowest for Asomdwee cowpea variety with activation energy of 6.26 kJ/mol. The values of activation energy obtained for the three cowpea varieties were similar to those reported by [17] for two maize varieties: Obatanpa and Mamaba. Obatanpa maize variety had activation energy value of 6.54 kJ/mol while Mamaba maize variety had activation energy of 6.82 kJ/mol. However, in comparison to other studies, the activation energy values obtained for the three cowpea varieties were significantly smaller. [22], reported activation energy value of 11.20 kJ/mol for white bambara groundnut [7], also reported an activation energy value of 28.38 kJ/mol for Egusi melon seeds, whereas [18] reported higher activation energy values for soybean.

5. Conclusion

The water absorption kinetics of three cowpea varieties (Asontem, Hewale and Asomdwee) was studied following the phenomenological models derived from

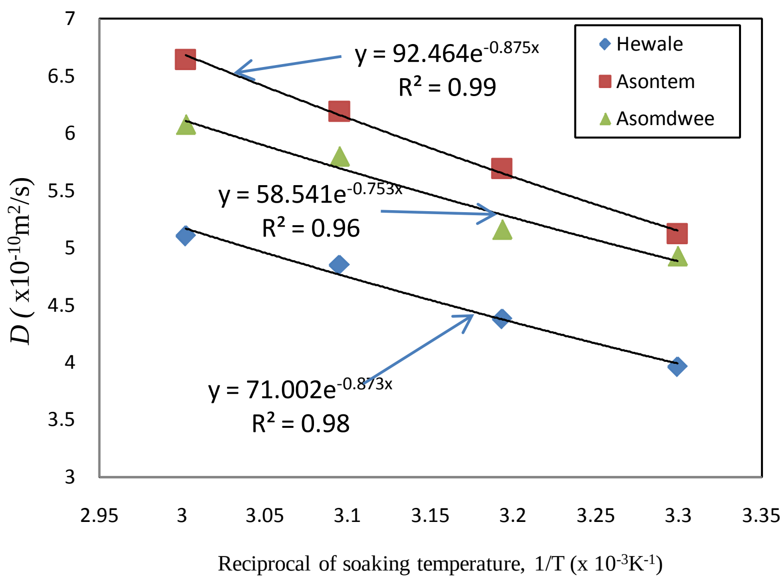

Figure 7. Relationship between Diffusion Coefficients And Temperature for Asontem, Hewale and Asomdwee.

Table 5. Activation energy values during soaking of Asontem, Hewale and Asomdwee cowpea varieties.

Cowpea variety	Activation energy (*E*)	R^2
Asontem	7.27	0.99
Hewale	7.26	0.98
Asomdwee	6.26	0.96

Fick's law of diffusion. The time taken for Asontem, Hewale and Asomdwee cowpea varieties to reach saturation moisture content during soaking decreased from 8 h to 3 h, 8 h to 3.5 h and 6 h to 5 h, respectively, by the increase in soaking temperature from 30˚C through to 60˚C. A reasonable forecast of water absorption by Asontem, Hewale and Asomdwee cowpea varieties during soaking was achieved by fitting of the experimental data to Fick's diffusion law. The water diffusion coefficients for Asontem, Hewale and Asomdwee cowpea varieties, within temperature variation from 30˚C to 60˚C, ranged from 5.12×10^{-10} m²/s to 6.64×10^{-10} m²/s, 3.96×10^{-10} m²/s to 5.12×10^{-10} m²/s and 4.93×10^{-10} m²/s to 6.08×10^{-10} m²/s, respectively. The intense influence of temperature on the water diffusion coefficient was adequately described by an Arrhenius-type equation giving activation energy values of Asontem, Hewale and Asomdwee cowpea varieties as 7.27 kJ/mol, 7.26 kJ/mol and 6.26 kJ/mol, respectively.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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