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KINETICS OF WATER SORPTION BY EGUSI MELON (*Cucumeropsis edulis*) SEEDS

A. Addo and A. Bart-Plange
Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
E-Mail: addoahmad@yahoo.com

ABSTRACT

The kinetics of water absorption by *egusi* melon seeds was studied by the gravimetric method during soaking for a temperature range of 30 - 70°C to determine its moisture diffusivity. The water diffusion coefficient of the grain was in the range of 5.18×10^{-8} to 20.99×10^{-8} m^2/s. An Arrhenius-type equation described the strong temperature effect on the diffusion coefficient with activation energy of 28.38 kJ/mol. It was shown that a satisfactory prediction of water absorption during soaking of the *egusi* was possible by fitting experimental data to Becker's model.

Keywords: modeling, *egusi* melon, arrhenius-type equation, diffusion coefficient, soaking.

INTRODUCTION

Curcubit seeds such as *egusi* melon seeds are protein-rich and commonly used in sauces, soups, and other dishes in West African countries. The uses of cucurbit seeds as sources of oils and proteins have been reviewed by Jacks *et al*. (1972). After the hull is removed, cucurbit seeds contain about 50 percent oil and up to 35 percent proteins. Most of their oil is made up of non-saturated fatty acids, thus of high nutritional values. Conjugated fatty acids among some cucurbit oils make them highly useful as drying oils (i.e. they combine readily with oxygen to form an elastic, waterproof film). The proteins, on the other hand, are principally of the globulin type, and are deficient in lysine but also in sulfur-bearing amino acid. Protein efficiency ratios (PER) of about 30 to 70 (that of powdered skim milk is 80) have been measured in *egusi*. The PER improves with addition of lysine.

Processing of cereals and legumes often requires that the seeds be hydrated first to facilitate operations such as cooking or canning. Thus, absorption of water into these materials is of both theoretical and practical interest to processing industries (Hsu, 1983a; Taiwo *et al*., 1998). The absorption of moisture into the grain during soaking is influenced by the water temperature amongst other factors. From a processing and engineering point of view, one is interested not only in knowing how fast the absorption of water can be accomplished, but how it will be affected by processing variables such as temperature (Verma and Prasad, 1999), and also how one can predict the soaking time under given conditions. Thus, quantitative data on the effect of processing variables are necessary for practical applications to optimise and characterise the soaking conditions, design food processing equipment and predict water absorption as a function of time and temperature (Abu-Ghannam and McKenna, 1997; Bhattacharya, 1995; Taiwo *et al*., 1998).

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 de Silva, 1977; Kon, 1979; Sopade and Obekpa, 1990; Thakor *et al*., 1995; Abu-Ghannam and McKenna, 1997; Addo *et al*., 2006). Works dealing with the change of volume and weight of grains such as sorghum, wheat and maize soaked in water have been published (Becker, 1960). The problem of water diffusion into grain kernels was studied by Becker (1959), who found analytical expression for short times of immersion. As noted by Becker (1960), the absorption of liquid water by the wheat kernel proceeds by a heterogeneous mechanism. There is a very rapid initial absorption, followed by a subsequent absorption that is directly proportional to the square root of the time of immersion. Several researchers conducted soaking tests of grains and found that Becker's model fits best for the experimental data (Lu *et al*., 1994; Ali, 1974; Verma and Prasad, 1999; Addo *et al.*, 2006). Many studies (Hsu, 1983a, b; Resio *et al*., 2003; Addo *et al.*, 2006) have reported the influence of temperature on moisture diffusivity into soybean, amaranth grains and maize kernels to follow Arrhenius relation.

Literature search on moisture diffusion data of *egusi* melon seeds yielded scanty information. It was thus the purpose of this study to determine the moisture diffusivity and energy of activation of *egusi* melon seeds.

MATERIALS AND METHODS

Plant material

Egusi melon seeds were obtained from the local market. Foreign matter, broken, cracked, and damaged seeds were separated and discarded. Experimental samples were taken using the quartering procedures of Lees (1975) and the initial moisture content was 0.0626 kg water/kg dry matter. The volume (v) of each kernel was calculated from measurements of the volume of 50 *egusi* seeds measured with volume displacement of water and replicated thrice. The principal dimensions (L the length, mm; B the breadth, mm; and T thickness, mm) were measured with a vernier calliper (Addo *et al*., 2006), giving averaged values of 14.9, 6.3 and 1.5 mm for length, width and thickness, respectively.

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Soaking experiments

The *egusi* seeds samples of 10 g were placed in screen tubes and immersed in a constant temperature water bath maintained at ± 0.5°C for soaking experiments at five levels of temperature viz. 30°C, 40°C, 50°C, 60°C and 70°C for eight levels of soaking durations viz. 1, 2, 3, 5, 7, 10, 12 and 15 min. The initial moisture content of *egusi* seeds was determined by oven drying method of whole kernels in triplicate at 103°C for 24 h (AOAC, 1980) and expressed as kg/kg (db). The moisture gain was calculated from the gain in weight of the sample to an accuracy of 0.001 g using electronic precision balance.

During soaking experiments, the samples were removed at specific intervals ranging from 1 -15 min and the soaked seeds were quickly blotted with the paper towels to remove surface moisture (Becker, 1960; Fan *et al*., 1963; Lu *et al.*, 1994) and weighed.

Verma and Prasad (1999) calculated the volume-surface area ratio (v/s) by dividing the equivalent volume of sphere by surface area of seed as

$$\frac{v}{s} = \frac{4\pi r_e^3}{3s} \quad \text{Or} \quad \frac{v}{s} = \frac{r_e}{3}\left[\frac{4\pi r_e^2}{s}\right] \tag{1}$$

Where r_e is equivalent radius. The factor $((4\pi r_e^2/s)$ is the ratio of equivalent surface area of a sphere of equal volume to the surface area of the grain, and can be denoted as sphericity,ϕ.

Substituting ϕ, Eq. (1) gets reduced to

$$\frac{v}{s} = \frac{r_e}{3}\phi \quad \text{Or} \quad \frac{v}{s} = \frac{d_e}{6}\phi \tag{2}$$

Where, de is the equivalent diameter which can be expressed by a relationship as $d_e = (6v/\pi)$.

Substituting de, in Eq. (2) and further simplifying, we get Eq. (3) which describes the relationship between volume and surface area explicitly,

$$\frac{v}{s} = \left[\frac{6v}{\pi}\right]^{1/3}\phi \quad \text{or} \quad \frac{v}{s} = \frac{v^{1/3}\phi}{4.836} \tag{3}$$

Similar expression has also been reported by Fan *et al.* (1963). The sphericity of grains was computed from the following equation (Mohsenin, 1970):

$$\phi = \frac{(LBT)^{1/3}}{L} \tag{4}$$

Where, ϕ is sphericity.

Mathematical model (Verma and Prasad, 1999)

Moisture diffusion into the grains is primarily caused by concentration gradient. This gradient tends to move the water molecules to equalize concentration. Becker (1960), using Fick's law of molecular diffusion, proposed the following mathematical model for diffusion in solids of arbitrary shape to correlate the moisture gain by wheat kernel during soaking in water

$$\frac{c_s - c}{c_s - c_o} = 1 - \frac{2}{\sqrt{\pi}}X + BX^2 \tag{5}$$

Subject to the following initial and boundary conditions

$c = c_o$ *at* $\theta = 0;$

$c = c_s$ *at* $s = 0$ *and* $\theta > 0;$

where s is a general coordinate with origin at bounding surface, *c* the average concentration, c_s the concentration at the bounding surface and c_o the initial concentration and θ the diffusion time. After replacing the concentration term (*c*) by the moisture content (*m*) the equation can be rewritten as

$$MR = \frac{m_s - m}{m_s - m_o} = 1 - \frac{2}{\sqrt{\pi}}X + BX^2 \tag{6}$$

Where, *MR* is moisture ratio. *m*, mo and ms are average moisture contents at any given soaking duration, initial moisture content and moisture content at the bounding surface respectively. For small values of *X*, Eq. (6) can be approximated to

$$1 - MR = (2/\sqrt{\pi})X \tag{7}$$

Where,

$$X = (s/v)\sqrt{D\theta} \tag{8}$$

In which s/v is surface-to-volume ratio. Combining eqns. (5) - (7), resulting in

$$m - m_o = \alpha_b\sqrt{\theta} \tag{9}$$

Where

$$\alpha_b = \left(2/\sqrt{\pi}\right)(m_s - m_o)(s/v)\sqrt{D} \tag{10}$$

Or

$$D = [\alpha_b\sqrt{\pi} / \{2\{m_s - m_o) (s/v\}]^2 \tag{11}$$

In Eq. (11), m_s and m_o are constants for a particular type of grain and the ratio of volume-to-surface area (*v/s*) may be taken as constant irrespective of moisture content (Becker, 1960; Fan *et al.*, 1963).

A plot of (m - m_o) against $\sqrt{\theta}$ would give a straight line of slope (α_b) for a particular water temperature of soaking (Eq. 9). At different water temperatures the slope (α_b) would vary. Moisture diffusivity, *D*, can be determined at different temperatures using different (α_b) values in Eq. (11). The temperature dependence of the diffusion coefficient for *egusi* seeds was expressed by the following Arrhenius–type equation (Becker, 1960; Fan *et al*., 1963; Addo *et al*., 2006):

VOL. 4, NO. 6, NOVEMBER 2009 ISSN 1990-6145
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www.arpnjournals.com

$$D=D_o e^{-E/RT} \quad (12)$$

Where, D_o is constant, E activation energy for soaking process, R universal gas constant, 8.314 *kJ/ mol/K, T* absolute temperature of water, *K*.

RESULTS AND DISCUSSIONS

Experimental data of water soaking of *egusi* seed were plotted against the square root of soaking period for different water soaking temperatures (Figure-1). It was found that the moisture gain is positively correlated ($R \geq 0.98$) with the square root of the soaking period at all the water soaking temperatures.

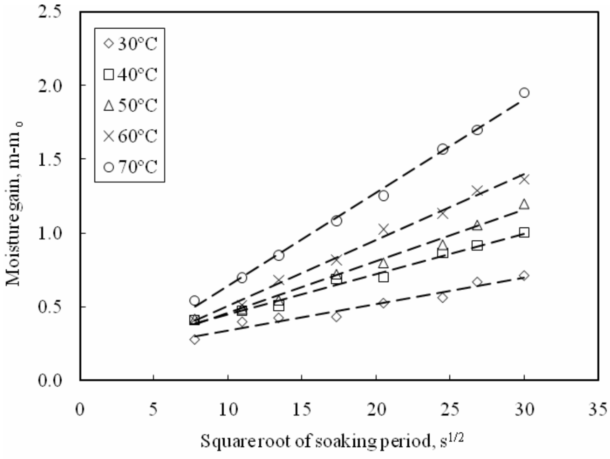

Fig. 1. Variation in moisture content gain in egusi with square root of soaking time at various temperatures.

The data represent Eq. (10) with good correlation coefficient validating Becker's equation for maize too (Becker, 1960). The slopes (α_b) of the straight lines in Eq. (10) were determined from Figure-1 for all the water soaking temperatures and they are shown in Table-1.

Table-1. Coefficients of soaking curves at different temperatures with the pertinent statistics and moisture diffusivity.

Temperature (ºC)	**Intercept**	**Slope** (α_b) ($\times 10^{-2}$)	**Correlation coefficient** (R)	**Moisture diffusivity** D ($\times 10^{-8}$ m²/s)
30	0.1636	1.79	0.98	5.19
40	0.1795	2.73	0.99	7.92
50	0.1077	3.50	0.99	10.15
60	0.0630	4.46	0.99	12.93
70	0.0199	6.32	0.99	20.99

Moisture diffusion into the *egusi* seed took place because of the moisture gradient between the surface and the centre. The diffusivity varied from 5.19×10^{-8} m^2/s to 20.99×10^{-8} m^2/s for corresponding temperature increase from 30 ºC to 70 ºC respectively (Table-1). No similar work on *egusi* has been found in the literature. Therefore literature on other legumes is reported in this study although direct comparison can not be made. Studies on the moisture diffusivity of other legumes by Seyhan-Gurtas *et al*. (2001) studied the moisture diffusivities of legumes in Turkey. The water diffusion coefficients of the legumes were in the range 9.71×10^{-11} - 5.98×10^{-10} m^2/s for the chickpeas, 3.53×10^{-10} - 1.33×10^{-9} m^2/s for the lentils and 4.35×10^{-11} - 3.79×10^{-9} m^2/s for a temperature range of 15 ºC to 40 ºC, giving nearly a 90 fold variation.

Figure-2 shows the Arrhenius relation for the diffusion coefficients of *egusi* seed. The constant (D_o) and the slope (E/R) in equation 12 were determined using the least squares method and these values were $D_o = 4.03 \times 10^{-3}$ (m^2/s) and $E/R = 3412.5$ (K). The value of the energy of activation (E) was determined by multiplying the value of the slope (E/R) by the gas constant value (8.314 J mol^{-1} K^{-1}) and found to be 28.38 kJ/mol. The Arrhenius equation was sufficient to describe the temperature effect on the moisture diffusivity, as the regression coefficient of fitting was 0.98 (Figure-2). The activation energy was lower than those obtained by Seyhan-Gurtas *et al*. (2001) for legumes studied.

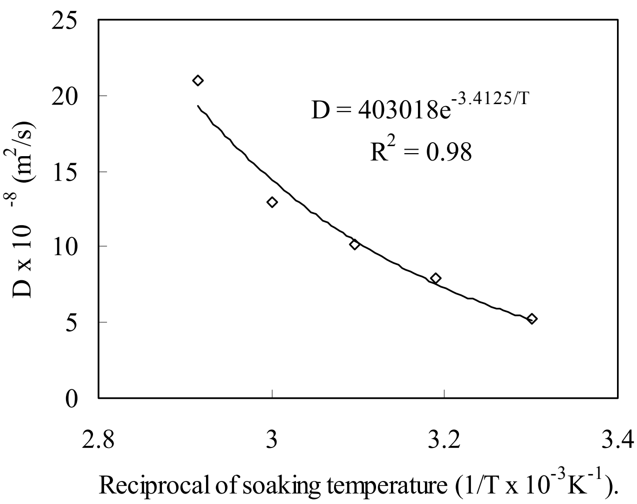

Fig. 2. Relationship between diffusion coefficient and the reciprocal of soaking temperature.

CONCLUSIONS

The following conclusions can be drawn from this study:

- Moisture gain in the *egusi* seed is linearly correlated with the square root of soaking period and followed Becker's equation in the temperature range of 30 to 70°C for soaking periods of 1-15 min;
- The water diffusion coefficient of the *egusi* seed increased exponentially from 5.18×10^{-8} to 20.99×10^{-8} m^2/s with increasing soaking temperature;
- An Arrhenius-type equation described the strong temperature effect on the diffusion coefficient with activation energy of 28.38 kJ/mol; and
- Data presented in this study on diffusivity and the temperature dependence of diffusivity for *egusi* seed can help in better design of sorption process and equipment.

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ARPN Journal of Agricultural and Biological Science

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