



Moisture-dependent Physical Properties and Hydration Kinetics of Peanut Kernel

By Shubhra Shekhar, Manoj Singh & Kamlesh Prasad

Abstract- The physical properties of agricultural objects affected by moisture are essential for effective postharvest unit operations. Raw peanut in India is used in a wide variety of forms, and the process involved often soaking in water before being used as an ingredient in the preparation of different delicacies. Soaking and grinding in preparation of seasonings are commonly used to garnish the most traditional fermented foods such as *idly*, *dosa*, *vada*, and *uttapam* with several other breakfast items in the Indian subcontinent. The effect of moisture content (6.57 to 35.07%) on physical properties and the temperature (5 to 35°C) dependent soaking behavior of peanut kernel of GG-20 genotype were assessed. The increase in moisture content of peanuts has affected the dimensional characteristics linearly, whereas most of the gravimetric and frictional properties followed a nonlinear trend. The feasibility of different models describing the hydration behavior was assessed for the peanut kernel. The adequacy of fitted models was determined using the coefficient of determination (R^2), chi-square (χ^2), and root mean square error (RMSE). The values of these parameters as higher R^2 (≥ 0.96) and lower χ^2 (≤ 0.005) and RMSE (≤ 0.020) reflect the applicability of models in describing the soaking behavior of the peanut kernel.

Keywords: peanut, physical properties, soaking, diffusion, models, hydration.

GJRE-C Classification: DDC Code: 551.571 LCC Code: QC915



Strictly as per the compliance and regulations of:



Moisture-dependent Physical Properties and Hydration Kinetics of Peanut Kernel

Shubhra Shekhar ^α, Manoj Singh ^σ & Kamlesh Prasad ^ρ

Abstract- The physical properties of agricultural objects affected by moisture are essential for effective postharvest unit operations. Raw peanut in India is used in a wide variety of forms, and the process involved often soaking in water before being used as an ingredient in the preparation of different delicacies. Soaking and grinding in preparation of seasonings are commonly used to garnish the most traditional fermented foods such as *idly*, *dosa*, *vada*, and *uttapam* with several other breakfast items in the Indian subcontinent. The effect of moisture content (6.57 to 35.07%) on physical properties and the temperature (5 to 35°C) dependent soaking behavior of peanut kernel of GG-20 genotype were assessed. The increase in moisture content of peanuts has affected the dimensional characteristics linearly, whereas most of the gravimetric and frictional properties followed a nonlinear trend. The feasibility of different models describing the hydration behavior was assessed for the peanut kernel. The adequacy of fitted models was determined using the coefficient of determination (R^2), chi-square (χ^2), and root mean square error (RMSE). The values of these parameters as higher R^2 (≥ 0.96) and lower χ^2 (≤ 0.005) and RMSE (≤ 0.020) reflect the applicability of models in describing the soaking behavior of the peanut kernel. The rate of moisture uptake at different temperatures during hydration depicts the process as diffusion-controlled in the primary phase, with a higher absorption rate followed by a slower absorption rate during the secondary phase of hydration. Effective diffusivity in the endothermic process of moisture absorption varied from 2.905×10^{-10} to 10.754×10^{-10} ($\text{m}^2/\text{sec.}$) over the studied temperature range with the activation energy of 32.175 KJ/mol.
Keywords: peanut, physical properties, soaking, diffusion, models, hydration.

1. INTRODUCTION

Peanut (*Arachis hypogaea*) is the 3rd most crucial oilseed crop after soybean and cotton. Being a legume crop, it is rich in protein. This tropical cash crop is often referred to as "The king of oilseeds," groundnut, earth nut, wonder nut, or poor men's cashew nut. India is the pioneer producer of peanuts with a production of 6.48 MMT and contributed more than 18% of world production for 2020 (FAOSTAT 2022)^[1]. The chief peanut-producing states in India are Gujarat, Rajasthan, Andhra Pradesh, Tamil Nadu, and Madhya

Pradesh. These five states account for around 90% of the total area under peanut cultivation, mainly as the *Kharif* season crop (June - September). As a leguminous crop, it is grown in crop rotation mainly to maintain soil health and reduce soil erosion.

Eighty percent of the total peanut produced in India undergoes processing for oil extraction through either mechanical or solvent extraction in a batch or continuous process. The high temperature in most efficient mechanical extractors damages the edible quality of obtained defatted materials and is unsuitable for human consumption (BADWAIK, PRASAD, DEKA 2012)^[2]. Residual solvent associated with solvent-extracted defatted peanut meal creates problems in its utilization for various value-added products (BADWAIK, PRASAD, SETH 2014)^[3], therefore affecting the loss of valuable resources.

Peanut may be considered a functional food, as it contains numerous functional and health-promoting compounds, including arginine, mono, and polyunsaturated fatty acids, dietary fiber, folate, niacin, vitamin E, and most of the vital minerals (GOPALAN, RAMA SASTRI, BALASUBRAMANIAN 1971)^[4] beneficial for human health. The presence of bioactive phenolic compounds provides this valuable biomaterial with a rich source of antioxidants (FRANCISCO, RESURRECCION 2008)^[5]. Raw peanut in India is used in a wide variety of forms. The process involved often soaking in water before being used as an ingredient in the preparation of different delicacies. Soaking and grinding in preparation of seasonings are commonly used to garnish the most traditional fermented foods such as *idly*, *dosa*, *vada*, and *uttapam* with several other breakfast items in the Indian subcontinent (ACHAYA 1984)^[6].

The physical properties of peanut kernels, like those of other seeds, become helpful in designing equipment, especially for handling, processing, and storing. The moisture content of grain affects the efficiency of cleaning, grading, and separation processes (YALÇIN, ÖZARSLAN, AKBAŞ 2007)^[7]. The author has made investigations the determination of the physical properties of various leguminous splits, such as chickpeas, lentils, black gram, and green gram (BHATIA, SHARMA, PRASAD, PRASAD 2009)^[8]; PRASAD, VAIRAGAR, BERA 2010)^[9]; KAUR, SHEKHAR, KUMAR, PRASAD 2021)^[10]; KAUR, PRASAD 2022)^[11]; KAUR, PRASAD 2022)^[12]; KAUR, PRASAD 2021)^[13].

Author α: Department of Food Process Engineering, National Institute of Technology, Rourkela, Odisha, India. e-mail: scholarshekhar@gmail.com

Author σ: Department of Food Engineering and Technology, SLIET, Longowal, Punjab, India. e-mail: manoj Singh85@gmail.com

Author ρ: Department of Food Engineering and Technology, SLIET, Longowal, Punjab, India. e-mail: profkprasad@gmail.com

Limited studies on water absorption kinetics for peanuts were carried out. The present study aims to investigate the moisture-dependent physical properties of temperature-dependent water absorption kinetics to assess the adequacy of mathematical models in describing the process of water absorption kinetics.

II. MATERIALS AND METHODS

a) Sample Preparation

The dried whole peanut pods of genotype GG-20 were procured from the Central Institute of Postharvest Engineering and Technology (CIPHET), Punjab Agricultural University Campus (PAU), Ludhiana (Punjab). The whole peanut pods were cleaned and dehulled. The kernels were manually sorted to separate damaged and shrunk kernels. The sorted sound kernels (Fig. 1) were stored in air-tight glass containers and under refrigerated conditions. The samples were taken out as per the experimental requirements. The initial moisture contents of the kernels were determined using the hot air oven method (GUPTA, DAS 2000)^[14]. The predetermined weight of moisture was impregnated to obtain the four levels of moisture content for the peanut kernels as $5.57 \pm 0.56\%$, $15.09 \pm 0.65\%$, $24.98 \pm 0.51\%$, and $35.07 \pm 0.61\%$ (wet basis), conditioned and stored at $5 \pm 1^\circ\text{C}$. The samples for the study were taken out and kept in the ambient environmental condition in sealed pouches to equilibrate quickly and without any change of moisture content.

b) Determination of Physical Properties

The geometrical shape consisting of a cylinder and two hemispheres at the ends has been found to be quantitative appropriateness for peanuts (AKCALI, INCE, GUZEL 2006)^[15]. The physical dimensions were determined randomly measured for three major perpendicular dimensions, length (L), width (W), and thickness (T), of 100 seeds of each variety using a digital vernier caliper (Mitutoyo Corporation, Japan) having the precision of 0.01mm. The geometric mean dimension (D_g) of peanut kernels was found using the relationship as given (MOHSENIN 2020)^[16]:

$$D_g = \sqrt[3]{LWT} \quad (1)$$

The criteria used to describe the shape of the seed are sphericity. Thus, the sphericity (Φ) was accordingly computed (MOHSENIN 2020)^[16] as:

$$\Phi = \left[\frac{D_g}{L} \right] 100 \quad (2)$$

The surface area (S_a) was calculated (Eqn. 3) considering the geometrical properties of the kernel as:

$$S_a = \pi \times L \times T \quad (3)$$

Electronic balance (Ishida Co. Ltd., Japan) was used to measure the weight of the sample to an accuracy of 0.001 g. The true density of a peanut kernel

is defined as the ratio of the mass of the seed to the solid volume occupied (DESHPANDE, BAL, OJHA 1993)^[17]. The liquid displacement technique determined the seed volume and its true density. The immersion time was maintained below 10 sec, which was considered too small to absorb water. The amount of displaced water was recorded from the graduated scale of the measuring cylinder (AMIN, HOSSAIN, ROY 2004)^[18]. The porosity (ϵ) of bulk seed was computed from the values of true density (ρ_t) and bulk density (ρ_b) using the relationship (Eqn. 4) given (MOHSENIN 2020)^[16]:

$$\epsilon = \left[1 - \left(\frac{\rho_b}{\rho_t} \right) \right] 100 \quad (4)$$

To determine the angle of repose (ϕ), a cylinder of 50 mm diameter was used. The height and diameter of the formed heap of peanut kernels were measured to determine the angle of repose (ϕ) using the relationship:

$$\phi = \arctan \frac{(2H)}{D} \quad (5)$$

Where H is the height of the heap (mm), and D is the diameter of the heap (mm) at its base.

The static coefficient of friction (μ) was determined for three structural surfaces, namely galvanized steel sheets, glass, and plywood. A plastic cylinder of 50 mm diameter and 60 mm height was placed on an adjustable tilting flat plate faced with the test surface and filled with a sample of about 100 g. The cylinder was raised slightly to ensure complete contact with the peanut kernel and the experimenting surface and to avoid any error being induced by the test cylinder. The setup was then inclined gradually until the cylinder started sliding down. The angle of tilt was noted from a graduated scale (DUTTA, NEMA, BHARDWAJ 1988)^[19]; SHEPHERD, BHARDWAJ 1986)^[20].

$$\tan \alpha = \mu \quad (6)$$

All the experiments were replicated at least ten times, and average values were reported.

c) Water Absorption during Soaking

The hydration behavior of peanut kernel was determined by soaking a 50g sample in cylindrical glass containers containing 250 ml of distilled water (1:5 w/v) (ABD EL-HADY, HABIBA 2003)^[21]. Soaking water temperatures were 5, 15, 25, and 35°C . Before each experiment, the sample, containers, and distilled water were kept at the desired temperature for a few hours. Hydration behavior was precisely observed for up to 24 hours using an electronically controlled water bath to an accuracy of $\pm 0.2^\circ\text{C}$ (RESIO, AGUERRE, SUAREZ 2005)^[22]. The moisture content of the sample during hydration was determined based on the sample's weight increase. Soaked kernels were immediately blotted with the muslin cloth to remove any chance of the presence

of surface water before taking the reading (VERMA, PRASAD 1999)^[23].

d) Modeling of Water Absorption of Peanut Kernels

The kinetics of hydration of peanut kernels was assessed using selected models presented in Table 1. Analysis of absorption behavior through selected models, the time-dependent data of moisture content, and moisture ratio (MR) of peanut kernels is essential. The moisture ratio was calculated as follows:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (7)$$

These parameters can be calculated as follows:

$$R^2 = \frac{\left[\sum_{i=1}^N (MR_{exp,i} MR_{pre,i}) - \frac{(\sum_{i=1}^N MR_{exp,i})(\sum_{i=1}^N MR_{pre,i})}{N} \right]^2}{\left(\sum_{i=1}^N MR_{exp,i}^2 - \frac{(\sum_{i=1}^N MR_{exp,i})^2}{N} \right) \left(\sum_{i=1}^N MR_{pre,i}^2 - \frac{(\sum_{i=1}^N MR_{pre,i})^2}{N} \right)} \quad (8)$$

$$\chi^2 = \frac{1}{N-n} \sum_{i=1}^N (MR_{exp,i} - MR_{pre,i})^2 \quad (9)$$

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (MR_{pre,i} - MR_{exp,i})^2} \quad (10)$$

where $MR_{exp,i}$ is the i^{th} experimentally observed moisture ratio, $MR_{pre,i}$ the i^{th} predicted moisture ratio, N is the number of observations, and n is the number of constants in the model (YALÇIN, ÖZARSLAN, AKBAŞ 2007)^[7]; TOĞRUL, PEHLIVAN 2003)^[25].

III. RESULTS AND DISCUSSION

a) Physical Properties

An increase in moisture content from 5 to 35% has shown a linear change in length (L), width (W), thickness (T), and geometric mean diameter (GMD) of peanut kernels (Fig. 2) from 14.52 to 16.37 mm, 8.40 to 9.61 mm, 7.41 to 8.79 mm, and 9.67 to 11.14 mm, respectively (Table 2). A linear dimensional increase in peanut kernels with an increase in moisture content was mainly due to the absorption of moisture that resulted in the swelling of peanut cells and thus affected kernel's dimensional properties. The linear increase in width and thickness has also been reported for popcorn kernel (KARABABA 2006)^[26] and pistachio nut (KASHANINEJAD, MORTAZAVI, SAFEKORDI, TABIL 2006)^[27]. A minor initial decrease in the sphericity (ϕ) of peanut kernel with further increase as the increase in moisture content is evident (Fig 2). The initial decrease in sphericity may be attributed to the initial higher rate of lateral expansion in comparison to the change in the width and thickness. However, at later stages of moisture gain, the rate of expansion in width and thickness increased more and caused to increase in sphericity. The high sphericity value suggests that the kernel tends towards a spherical shape (OMOBUWAJO, SANNI, OLAJIDE 2000)^[28], being cylindrical. The surface area (S_a) of peanut kernels increased linearly from 3.38

Where M_0 , M_e , and M_t are the initial equilibrium, and moisture at any time t , respectively. The moisture ratio data were then fitted to the different models (exponential model and Weibull model). The parameters in each model were estimated by using the nonlinear regression analysis. Adequacy of the fitted model was assessed in terms of coefficient of multiple determination (R^2), Chi-square (χ^2), and root mean square error (RMSE) to ascertain the quality fit with a condition of higher R^2 value and lower χ^2 and RMSE values (KASHANINEJAD, MAGHSOUDLOU, RAFIEE, KHOMEIRI 2007)^[24].

to 4.52 cm^2 with increased moisture content. It was of overall 33.73% increase (Fig. 2). A surface area is a relevant tool in determining the shape of the kernel and indicating the material behavior on oscillating surfaces during processing (ALONGE, ADIGUN 1999)^[29].

The unit mass (UM) of peanut kernel was found to be increased from 0.462 to 0.724 gm with an increase in moisture content (Table 2). Differential sphericity, surface area, and unit mass of materials serve in designing aerodynamic cleaning systems. Bulk density (ρ_B) decreased from 560 to 496 kg/m^3 with an increase in moisture (Fig. 3). This decrease in the bulk density on change of moisture content is probably due to higher volume expansion in kernel in comparison to weight change on change in moisture content (Fig. 3). A decrease in bulk density was found for chickpea seeds from 800 to 741.4 kg/m^3 with an increase in moisture content from 4.9 to 14.1% (AMIN, HOSSAIN, ROY 2004)^[18]. A similar relation between moisture content and bulk density was reported for Soybean (DESHPANDE, BAL, OJHA 1993)^[17], sunflower seed (GUPTA, DAS 1997)^[30], and popcorn kernel (KARABABA 2006)^[26]. Porosity increased linearly from 39.58 to 46.77% with an increase in moisture content, and similar trends were reported for gram (DUTTA, NEMA, BHARDWAJ 1988)^[31], sunflower kernel (GUPTA, DAS 1997)^[30], green gram (NIMKAR, CHATTOPADHYAY 2001)^[32], chickpea seed (KONAK, CARMAN, AYDIN 2002)^[33], and popcorn kernel (KARABABA 2006)^[26].

The angle of repose and coefficient of friction as frictional properties are essential in designing equipment for solid flow and storage structures. The coefficient of friction between the seed and wall is an essential

parameter in predicting seed pressure on walls (GUMBE, MAINA 1990)^[34]. The angle of repose of peanut kernels increased from 39.01 to 50.48° with an increase in moisture content in the range of 5 to 35% (Table 2). The static coefficient of friction at various moisture levels reflects the increase in moisture content for all the analyzed surfaces (Fig. 4). This is due to the increased adhesion properties between the seed and the material surfaces at higher moisture levels.

b) Soaking Kinetics

The behavior of moisture uptake during time-dependent soaking by peanut kernel at temperatures 5, 15, 25, and 35°C is shown in Fig. 5. An early rapid hydration rate in the primary phase with a slower hydration rate in the second phase was observed (Fig. 5). The time needed for the transition of phase was found by applying the creep deformation properties in the water absorption process, observed to be temperature-dependent, and were 2.80, 2.56, 1.89, and 1.24 hrs at 5, 15, 25, and 35°C, respectively. The diffusion process governs the rapid initial water uptake in the primary phase was probably due to the filling of capillaries on the surface of the seed coats. A decrease in water absorption rate further in the relaxation phase may be attributed to the reason that water filling decreased the driving force. At any time, the moisture content of the kernels increased with temperature, indicating that the amount of water absorbed during hydration was a function of both soaking time and temperature (Fig. 5). Similar results were found in the case of rice (KASHANINEJAD, MAGHSOUDLOU, RAFIEE, KHOMEIRI 2007)^[24]. The water gain increases with the temperature increase of soaking water (Fig. 5). This increase is due to changes in diffusion resistance. Higher temperatures are known to expand and soften the material, which has affected the intactness and lowered the diffusion resistance to water transfer. Due to this, water gain cannot follow the pace of increased temperature. Temperature-induced softening has been reported for soybean (SINGH, KULSHRESTHA 1987)^[35], chickpea (SAYAR, TURHAN, GUNASEKARAN 2001)^[36], and kidney bean (ABU-GHANNAM, MCKENNA 1997)^[37].

c) Fitting of the Model Equation

i. Empirical Models

Table 3 presents the fitted Peleg, Exponential, and Weibull models as nonlinear regression models to describe the water absorption characteristic of peanut kernels at hydration temperatures of 5 to 35°C. All selected models accurately described peanut kernel's water absorption at the hydration temperatures from 5 to 35°C. The selected models gave accurate predictions and satisfactorily described soaking characteristics as R^2 values were equal to or higher than 96.36%, RMSE values were lower than 0.005 with χ^2 valued lower than 0.005 (Table 3).

Appraisal of the Peleg rate constant (K_1) reflects a linear decrease in its value from 0.065 to 0.017 hr/%mc (db) with the increasing temperature from 5 to 35°C (Table 3). The term "inverse of K_1 " is called the initial rate of absorption; thus, at a given temperature, as K_1 decreases, the amount of water absorbed becomes greater (PRASAD, VAIRAGAR, BERA 2010)^[9]. This resulted in a lower K_1 at 35°C compared to a lower temperatures depicting a higher initial water absorption rate for peanut kernel. Further, the water absorption process proceeded at a slower pace and ceased attaining the equilibrium water content. The Peleg capacity constant, K_2 , as the absorption ability of foods showed a marginal increase with temperature (Table 3), reflecting the property of peanut kernel towards water absorption capacity.

The probabilistic Weibull model describes a system's behavior with some degree of variability (CUNHA, OLIVEIRA, OLIVEIRA 1998)^[38]. Weibull shape parameter (α) is a behavior index that depends on the process mechanism, and the higher its value, the slower the process in the initial phase of absorption (CUNHA, OLIVEIRA, OLIVEIRA 1998)^[38]; MACHADO, OLIVEIRA, GEKAS, SINGH 1998)^[39]. Thus, the inverse of the Weibull shape parameter was thus considered an indicator of the initial rate of the hydration process. An increase in the temperature of soaking thus reduced the value of α from 5.609 to 1.546, further justifying the obtained temperature-dependent soaking behavior for peanut kernel (Table 3).

Weibull scale parameter (β) represents the time needed to accomplish approximately 63% of total absorbed water (CUNNINGHAM, MCMINN, MAGEE, RICHARDSON 2007)^[40]. Table 3 shows the effect of temperature change on relative rates of moisture diffusion and thus affecting the overall absorption process. This implies that with an increase in temperature from 5 to 35°C, the absorption rate in the primary phase of soaking was accelerated significantly (Fig. 5).

Fitting the exponential model to the experimental data at four different temperatures for the hydration process (Fig. 6) depicts an increasing trend of hydration rate constant (K) with the soaking temperature (Table 3). The high observed value of the coefficient of determination (R^2) confirmed the applicability in the prediction of the soaking process of the peanut kernel.

A large amount of absorbed water is present in the first phase of the process and further reaches equilibrium in the relaxation phase of soaking. However, at lower temperatures, the absorbed water in the primary soaking phase is less, and the absorption continues in the second phase. The values for the parameters K_1 , K_2 , K , and α & β in Peleg, Exponential, and Weibull models, respectively, supported the findings.

ii. *Diffusivity Model and Activation Energy*

To predict moisture diffusivity during the soaking of peanut kernels, the second Fick's law solution for diffusion out of an infinite cylinder being length of more than twice the width was used. For this purpose, the assumptions considered were (i) the effective diffusion coefficient is independent of moisture concentration, (ii) the volume of the kernel does not change during water absorption, and (iii) the surface of the kernel reaches the equilibrium moisture content instantaneously upon immersion in absorption media. The general series solution of Fick's second law in the infinite cylinder is given below (CRANK 1975)^[41]:

$$MR = \sum_{n=1}^{\infty} \frac{4}{\beta_n^2} \exp\left[-\frac{\beta_n^2}{R^2} \times D_e t\right] \quad (11)$$

D_e is the effective diffusivity ($m^2/sec.$) and R is the characteristics radius of the cylinder. Eqn calculated the effective diffusion coefficient. (11) using slopes derived from the linear regression of $\ln(MR)$ against time data. The effective diffusion coefficient during the soaking of peanut kernels varied from 2.9053×10^{-10} to 10.753×10^{-10} ($m^2/sec.$) over the temperature range studied $5-35^\circ C$ (Table 4).

A similar result was also obtained with other agricultural seeds. The effectiveness of diffusivity during soaking of rice varied from 5.58×10^{-11} to 3.57×10^{-11} ($m^2/sec.$) in the temperature range from 25 to $70^\circ C$ (KASHANINEJAD, MAGHSOUDLOU, RAFIEE, KHOMEIRI 2007)^[24], in case of soybean, varied from 1.08×10^{-10} to 2.00×10^{-10} $m^2/sec.$ in the temperature range from 40 to $60^\circ C$ (HSU 1983)^[42], and 1.632×10^{-9} to 3.237×10^{-9} ($m^2/sec.$) in case of splits chickpea at the hydration temperature range of 40 to $60^\circ C$ (PRASAD, VAIRAGAR, BERA 2010)^[9].

The effect of temperature on effective diffusivity is generally described using the Arrhenius-type relationship to obtain a better agreement of the predicted curve with experimental data:

$$D_e = D_0 \exp\left(-\frac{E_a}{RT_a}\right) \quad (12)$$

D_0 is a diffusivity-constant equivalent to the diffusivity at infinitely high temperatures, E_a is the activation energy (K J/mol), R is the universal gas constant (8.314 J/mol. K), and T_a is the absolute temperature. The logarithm of D_e as a function of the reciprocal of absolute temperature (T_a) is plotted in Fig.7. The results show a linear relationship between ($\log D_e$) and ($1/T_a$) or an Arrhenius-type relationship (Eqn. 12). The diffusivity constant (D_0) and activation energy (E_a) calculated from the linear regression is 8.010 ($m^2/sec.$) and 32.175 (KJ/mol), respectively. This value is comparable to those reported in the literature for water absorption in some legumes. This activation energy is in reasonable agreement with the data presented by several author's for other grains. Activation energy (E_a)

value of 30.0 KJ/mol in the case of whole rice grains (BELLO, TOLABA, SUAREZ 2004)^[43] and 22.49 to 22.70 KJ/mol in the case of hydration of chickpea splits of different shapes (PRASAD, VAIRAGAR, BERA 2010)^[9].

IV. CONCLUSIONS

The hydration kinetics of peanut kernel (GG-20) in plain water at different temperatures was examined. The soaking process exhibited an initial faster rate of water absorption followed by a slower pace during the secondary absorption phase. The transition from primary absorption phases occurred approximately between 1.23 to 2.80 hrs, depending on the soak water temperature, which may be used as the deciding time for soaking of peanut. The moisture absorption was an endothermic process with heat absorption of 32.175 KJ/mol.

REFERENCES RÉFÉRENCES REFERENCIAS

1. FAOSTAT *FAOSTAT statistics database*. Edition ed. Rome: FAO, 2022.
2. BADWAIK, L., PRASAD, K. DEKA, S. Optimization of extraction conditions by response surface methodology for preparing partially defatted peanut. *International Food Research Journal*, 2012, 19(1), 341.
3. BADWAIK, L. S., PRASAD, K. SETH, D. Optimization of ingredient levels for the development of peanut based fiber rich pasta. *Journal of Food Science and technology*, 2014, 51(10), 2713-2719.
4. GOPALAN, C., RAMA SASTRI, B. BALASUBRAMANIAN, S. Nutritive value of Indian foods 1971.
5. FRANCISCO, M. L. D. RESURRECCION, A. Functional components in peanuts. *Critical reviews in food science and nutrition*, 2008, 48(8), 715-746.
6. ACHAYA, K. T. *Everyday Indian processed foods* 1984.
7. YALÇIN, İ., ÖZARSLAN, C. AKBAŞ, T. Physical properties of pea (*Pisum sativum*) seed. *Journal of Food Engineering*, 2007, 79(2), 731-735.
8. BHATIA, T., SHARMA, R., PRASAD, K. PRASAD, K. Studies on some physical properties of protein-rich legume (*Lens esculantus*) splits. *Asian Journal of Chemistry*, 2009, 21(10), S103-107.
9. PRASAD, K., VAIRAGAR, P. BERA, M. Temperature dependent hydration kinetics of *Cicer arietinum* splits. *Food Research International*, 2010, 43(2), 483-488.
10. KAUR, R., SHEKHAR, S., KUMAR, P. PRASAD, K. Image Analysis as a Non-Destructive Approach in Selective Characterization of Promising Indian Chickpea Cultivars. In *Biology and Life Sciences Forum*. 2021, vol. 6, p. 112.
11. KAUR, R. PRASAD, K. Characterization and classification of selective Indian Chickpea cultivars based on physical and hydration properties, using

- Image and Multivariate analysis. *Legume Science*, 2022, 4(3), e168.
12. KAUR, R. PRASAD, K. Elucidation of chickpea hydration, effect of soaking temperature, and extent of germination on characteristics of malted flour. *Journal of Food Science*, 2022, 87(5), 2197-2210.
 13. KAUR, R. PRASAD, K. Effect of hydrothermal exposure on physical properties of Cicer Arietinum seeds. *AIP Conference Proceedings*, 2021, 2352, 1-8.
 14. GUPTA, R. DAS, S. Fracture resistance of sunflower seed and kernel to compressive loading. *Journal of Food Engineering*, 2000, 46(1), 1-8.
 15. AKCALI, I., INCE, A. GUZEL, E. Selected physical properties of peanuts. *International Journal of Food Properties*, 2006, 9(1), 25-37.
 16. MOHSENIN, N. N. *Physical properties of plant and animal materials: v. 1: physical characteristics and mechanical properties*. Edition ed.: Routledge, 2020. ISBN 1000122638.
 17. DESHPANDE, S., BAL, S. OJHA, T. Physical properties of soybean. *Journal of Agricultural Engineering Research*, 1993, 56(2), 89-98.
 18. AMIN, M., HOSSAIN, M. ROY, K. Effects of moisture content on some physical properties of lentil seeds. *Journal of Food Engineering*, 2004, 65(1), 83-87.
 19. DUTTA, S., NEMA, V. K. BHARDWAJ, R. Physical properties of gram. *Journal of Agricultural Engineering Research*, 1988, 39(4), 259-268.
 20. SHEPHERD, H. BHARDWAJ, R. Moisture-dependent physical properties of pigeon pea. *Journal of Agricultural Engineering Research*, 1986, 35(4), 227-234.
 21. ABD EL-HADY, E. HABIBA, R. Effect of soaking and extrusion conditions on antinutrients and protein digestibility of legume seeds. *LWT-Food Science and Technology*, 2003, 36(3), 285-293.
 22. RESIO, A. N. C., AGUERRE, R. J. SUAREZ, C. Analysis of simultaneous water absorption and water–starch reaction during soaking of amaranth grain. *Journal of Food Engineering*, 2005, 68(2), 265-270.
 23. VERMA, R. PRASAD, S. Kinetics of absorption of water by maize grains. *Journal of Food Engineering*, 1999, 39(4), 395-400.
 24. KASHANINEJAD, M., MAGHSOUDLOU, Y., RAFIEE, S. KHOMEIRI, M. Study of hydration kinetics and density changes of rice (Tarom Mahali) during hydrothermal processing. *Journal of Food Engineering*, 2007, 79(4), 1383-1390.
 25. TOGRUL, I. T. PEHLIVAN, D. Modelling of drying kinetics of single apricot. *Journal of Food Engineering*, 2003, 58(1), 23-32.
 26. KARABABA, E. Physical properties of popcorn kernels. *Journal of Food Engineering*, 2006, 72(1), 100-107.
 27. KASHANINEJAD, M., MORTAZAVI, A., SAFEKORDI, A. TABIL, L. Some physical properties of Pistachio (*Pistacia vera* L.) nut and its kernel. *Journal of Food Engineering*, 2006, 72(1), 30-38.
 28. OMOBUWAJO, T., SANI, L. OLAJIDE, J. Physical properties of ackee apple (*Blishia sapida*) seeds. *Journal of Food Engineering*, 2000, 45(1), 43-48.
 29. ALONGE, A. ADIGUN, Y. Some physical and aerodynamic properties of sorghum as related to cleaning. In *21st annual conference of the Nigerian society of agricultural engineers (NSAE). Federal Polytechnic Bauchi, Nigeria*. 1999.
 30. GUPTA, R. DAS, S. Physical properties of sunflower seeds. *Journal of Agricultural Engineering Research*, 1997, 66(1), 1-8.
 31. DUTTA, S., NEMA, V. BHARDWAJ, R. Thermal properties of gram. *Journal of Agricultural Engineering Research*, 1988, 39(4), 269-275.
 32. NIMKAR, P. CHATTOPADHYAY, P. PH—Postharvest Technology: some physical properties of green gram. *Journal of Agricultural Engineering Research*, 2001, 80(2), 183-189.
 33. KONAK, M., CARMAN, K. AYDIN, C. PH—Postharvest Technology: Physical properties of chick pea seeds. *Biosystems engineering*, 2002, 82(1), 73-78.
 34. GUMBE, L. MAINA, C. Friction coefficient of cereal grains on various surfaces. *AMA, Agricultural Mechanization in Asia, Africa and Latin America*, 1990, 21(4), 61-64.
 35. SINGH, B. KULSHRESTHA, S. Kinetics of water sorption by soybean and pigeonpea grains. *Journal of Food Science*, 1987, 52(6), 1538-1541.
 36. SAYAR, S., TURHAN, M. GUNASEKARAN, S. Analysis of chickpea soaking by simultaneous water transfer and water–starch reaction. *Journal of Food Engineering*, 2001, 50(2), 91-98.
 37. ABU-GHANNAM, N. MCKENNA, B. Hydration kinetics of red kidney beans (*Phaseolus vulgaris* L.). *Journal of Food Science*, 1997, 62(3), 520-523.
 38. CUNHA, L. M., OLIVEIRA, F. A. OLIVEIRA, J. C. Optimal experimental design for estimating the kinetic parameters of processes described by the Weibull probability distribution function. *Journal of Food Engineering*, 1998, 37(2), 175-191.
 39. MACHADO, M. D. F. T., OLIVEIRA, F. A., GEKAS, V. SINGH, R. P. Kinetics of moisture uptake and soluble-solids loss by puffed breakfast cereals immersed in water. *International Journal of Food Science & Technology*, 1998, 33(3), 225-237.
 40. CUNNINGHAM, S., MCMINN, W., MAGEE, T. RICHARDSON, P. Modelling water absorption of pasta during soaking. *Journal of Food Engineering*, 2007, 82(4), 600-607.
 41. CRANK, J. *The Mathematics of Diffusion*. Edition ed.: Oxford University Press, New York, 1975.

42. HSU, K. H. Effect of temperature on water diffusion in soybean. *Journal of Food Science*, 1983, 48(4), 1364-1365.
43. BELLO, M., TOLABA, M. P. SUAREZ, C. Factors affecting water uptake of rice grain during soaking. *LWT-Food Science and Technology*, 2004, 37(8), 811-816.



Fig. 1: Charged coupled device snapshot showing shelled peanut kernels of GG-20 variety

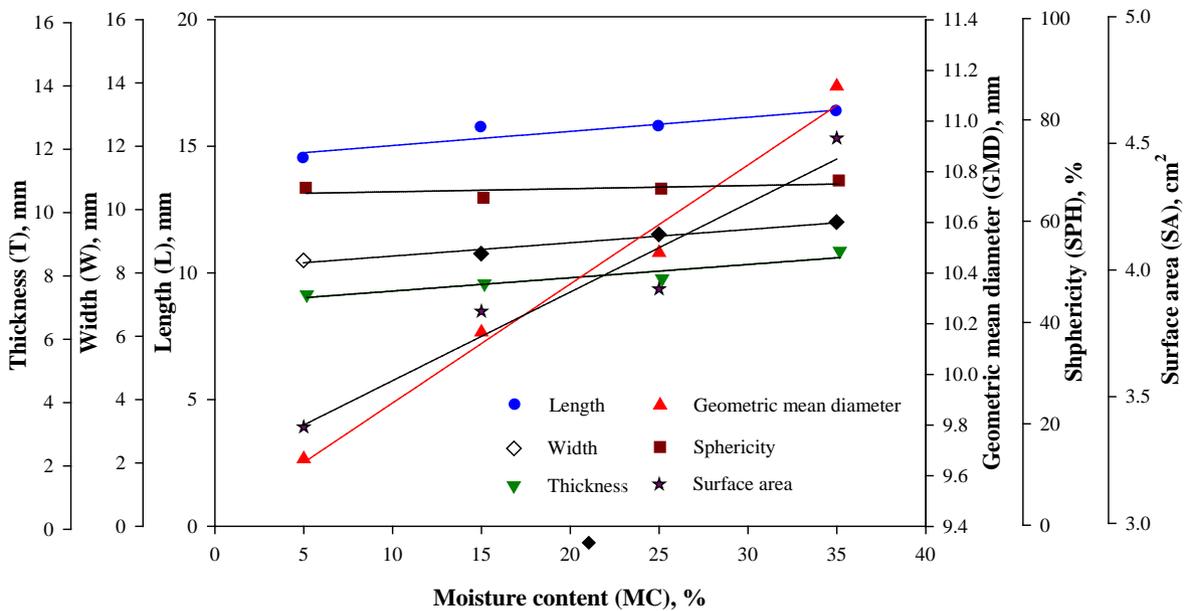


Fig. 2: Moisture dependent dimensional characteristics of peanut kernels

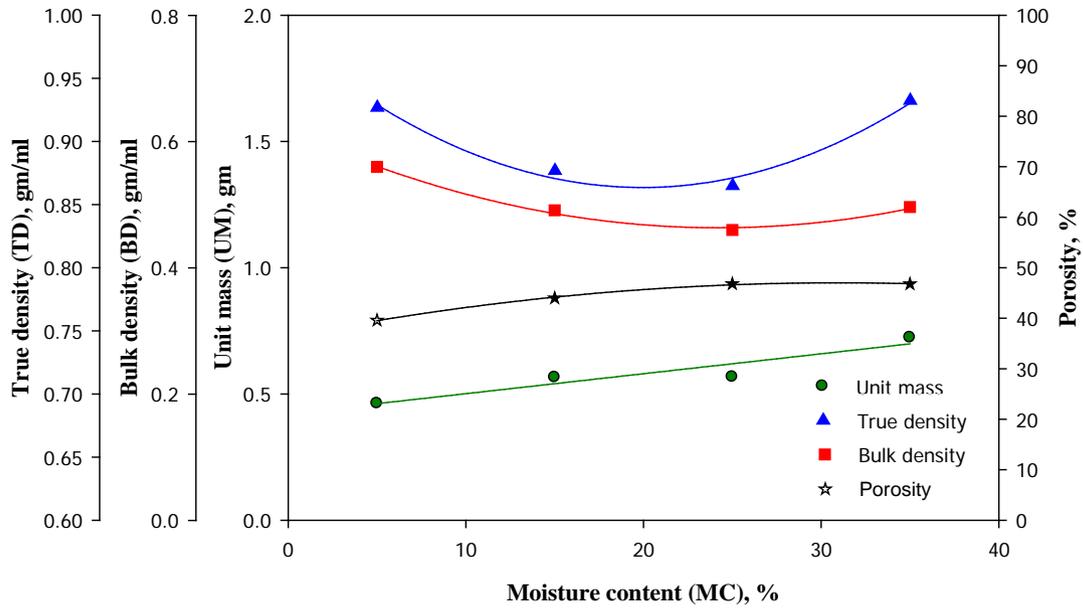


Fig. 3: Moisture dependent gravimetric characteristics of peanut kernels

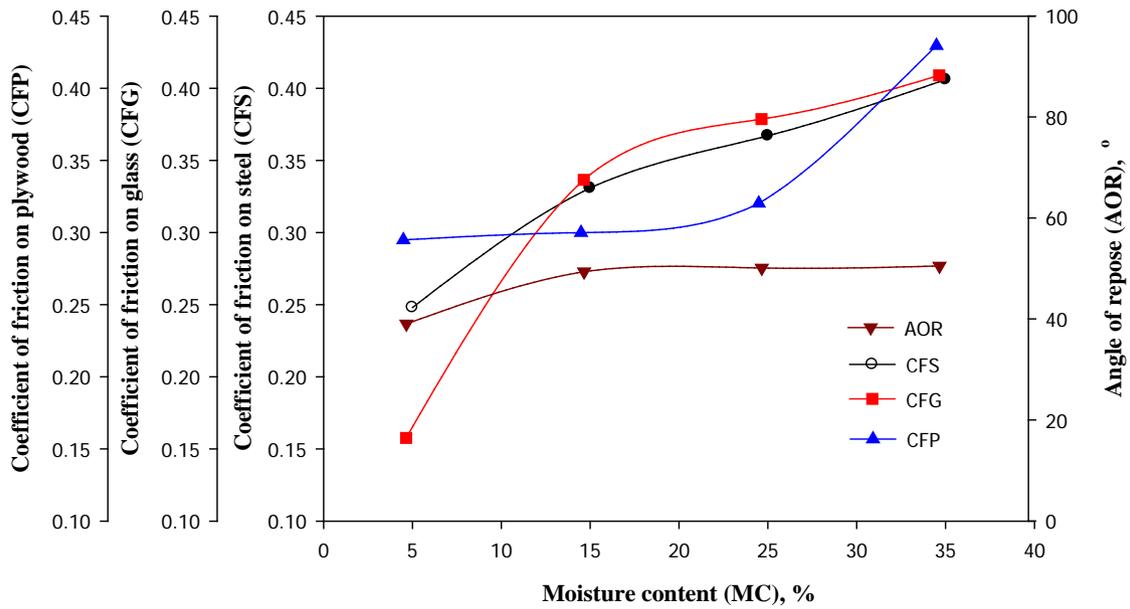


Fig. 4: Moisture dependent frictional characteristics of peanut kernels



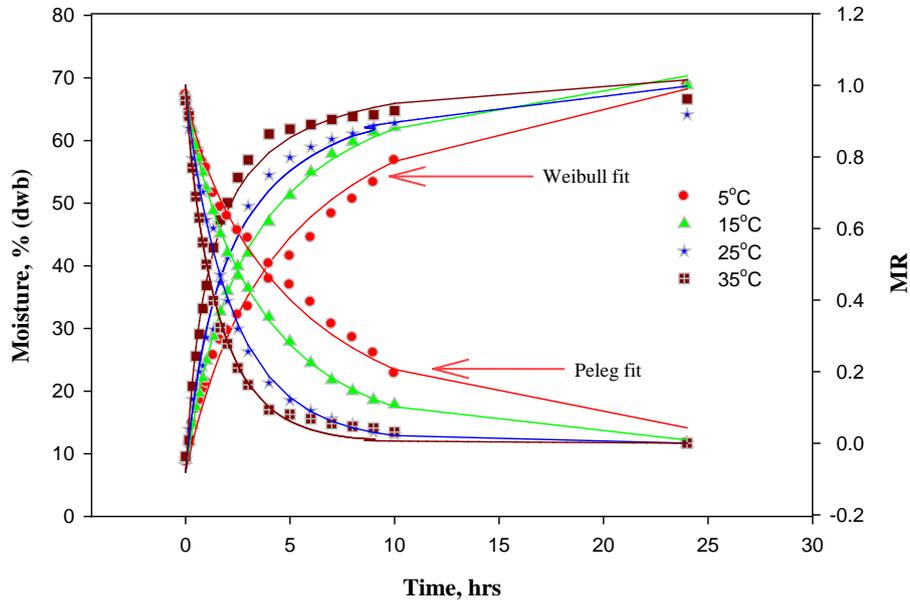


Fig. 5: Temperature dependent hydration characteristics of peanut kernel (Peleg and Weibull fit)

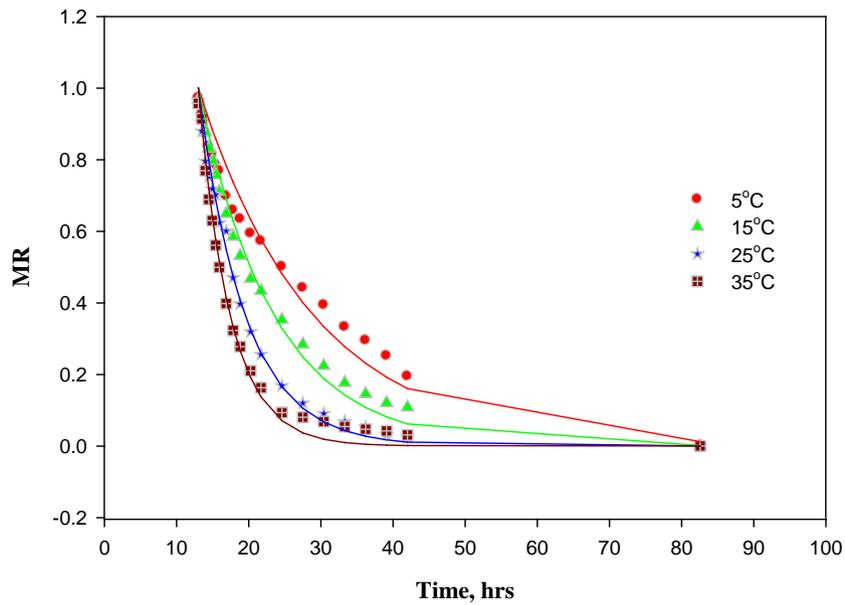


Fig. 6: Temperature dependent hydration characteristics of peanut kernel (Exponential fit)

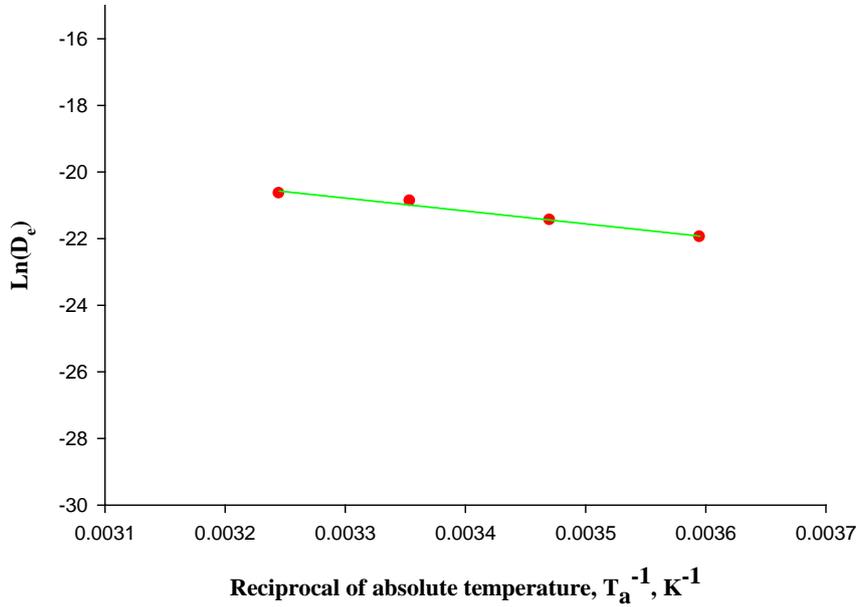


Fig. 7: Arrhenius plot of effective diffusivity of peanut kernels

Table 1: Models used for describing the peanut kernel hydration data

Model Name	Equation
Peleg	$M = M_0 + \frac{t}{(K_1 + K_2 t)}$
Exponential	$MR = \exp(-kt)$
Weibull	$MR = \text{Exp}(- (t/\alpha)^\beta)$

Table 2: Moisture dependent physical properties of peanut kernel (GG-20)

Parameters	Moisture Levels of shelled peanut (% wwb)			
	6.57±0.44%	15.74±0.01%	25.21±0.03%	35.07of ±0.09%
Length, mm	14.52±1.48	15.74±1.41	15.78±1.52	16.37±1.20
Width, mm	8.40±0.72	8.61±0.44	9.22±0.49	9.61±0.47
Thickness, mm	7.41±0.43	7.76±0.58	7.92±0.65	8.79±0.70
GMD, mm	9.67±0.66	10.17±0.56	10.48±0.54	11.14±0.50
Sphericity, %	66.60±4.20	64.61±3.66	66.44±4.97	68.03±4.56
Surface Area, cm ²	3.38±0.45	3.84±0.50	3.93±0.47	4.52±0.43
Unit Mass, gm	0.462±0.161	0.565±0.127	0.567±0.139	0.724±0.143
Bulk Density, kg/m ³	560.0±10	491.0±7.0	460.0±12.0	496.0±17.0
True Density, gm/ml	0.927±0.010	0.877±0.016	0.865±0.019	0.932±0.026
Porosity, %	39.58±0.95	43.98±1.63	46.81±1.09	46.77±0.97
Angle of Repose, degree	39.01±1.87	49.35±1.55	50.09±1.06	50.48±0.68
CSF (Steel)	0.248±0.004	0.331±0.014	0.367±0.008	0.406±0.006
CSF (Glass)	0.158±0.007	0.337±0.020	0.379±0.010	0.409±0.006
CSF (Plywood)	0.295±0.004	0.300±0.008	0.320±0.013	0.430±0.028

Table 3: Estimation of the parameters and goodness of fit for Peleg, Exponential and Weibull models

Temperature (°C)	Peleg Model					Exponential Model					Weibull Model				
	K ₁	K ₂	R ²	χ ²	RM SE	K	R ²	χ ²	RM SE	α	β	R ²	χ ²	RM SE	
5	0.0	0.0	0.98	0.00	0.01	0.1	0.96	0.00	0.05	5.6	0.7	0.98	0.00	0.03	
	65	14	04	07	15	83	36	31	46	09	89	54	13	46	
15	0.0	0.0	0.99	0.00	0.00	0.2	0.98	0.00	0.03	3.6	0.8	0.99	0.00	0.01	
	42	14	84	01	77	78	63	46	63	83	26	89	01	05	
25	0.0	0.0	0.98	0.00	0.02	0.4	0.99	0.00	0.02	2.2	0.9	0.99	0.00	0.02	
	29	15	74	05	04	50	21	08	84	56	05	46	06	34	
35	0.0	0.0	0.99	0.00	0.01	0.6	0.99	0.00	0.02	1.5	0.8	0.99	0.00	0.02	
	17	15	05	04	79	62	09	09	94	46	73	47	06	24	

Table 4: Temperature dependent effective diffusion coefficient of peanut kernel

Temperature (°C)	Effective diffusivity (m ² /sec)
5	2.905×10^{-10}
15	4.833×10^{-10}
25	8.581×10^{-10}
35	10.753×10^{-10}