

Research Article

Modelling Water Absorption of Four Varieties of Jack Beans During Soaking

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Abstract

The hydration kinetics of four different jack bean cultivars were systematically investigated to understand their water absorption behavior under controlled soaking conditions. The samples were immersed in water for soaking periods ranging from 10 to 40 minutes, while the soaking temperature varied between 31.68 and 53.3°C. These conditions were selected to simulate typical processing environments and to evaluate the influence of temperature and time on hydration behavior. To analyze the experimental data, five established mathematical model equations were applied to describe the water absorption process of the jack bean cultivars. The performance of the models was assessed using two statistical parameters: the coefficient of determination (R^2) and the root mean square error (RMSE). A higher R^2 value combined with a lower RMSE indicated a stronger agreement between the experimental and predicted water absorption values. Among the models tested, the Page model demonstrated the best fitting performance based on these statistical criteria, effectively capturing the hydration characteristics of the jack bean samples. The effective moisture diffusivity values increased from $3.067 \times 10^{-10} \text{m}^2/\text{s}$ to $9.40 \times 10^{-10} \text{m}^2/\text{s}$ with increasing soaking time and temperature, reflecting enhanced diffusion rates under warmer conditions. This increase is attributed to reduced water viscosity and structural softening of the bean matrix. Additionally, the moisture ratio curves revealed a consistent decrease with rising temperature across all cultivars, confirming the significant role of temperature in accelerating water absorption during soaking.

Keywords

Jack Beans, Water Absorption, Modelling, Diffusivity

1. Introduction

The jack bean (*Canavalia ensiformis*) seed is an oblong-shaped, white legume that is often overlooked and underutilised [11]. The tropical climber jack bean yields long pendant green beans, which are members of the Leguminales family. Native to the West Indies and Central America, jack beans can be found sporadically in tropical and subtropical regions [11]. All jack bean types have an oblong form and are white in colour [7]. The 2cm-long, silky seeds of the jack bean [4]. The most nutrient-dense portion is the jack bean seed, which is

high in protein, minerals, and vitamins. Potential nutritional [6, 20] and medicinal benefits for people and livestock [4] can be obtained from jack beans. Jack beans are grown for their aesthetic value [6].

Jack bean has nutritional profile of high amounts of carbohydrate (58.4%) and protein (25.2%) while low in fat content (5.21%) [19] which has led to jack bean potency as fermented food (tempeh-like product) [18] and a soybean substitute in

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animal feed production [21]. A recent study by [22] also discovered jack bean to contain a bioactive compound called kaempferol glycoside that could inhibit α -glucosidase activity that links to anti-diabetic properties. These characteristics further address the potential of the jack bean to be further developed into plant-based milk with functional properties.

Physical qualities of constituent colloids of grains and the permeability characteristics of the hull (pericarp) are related to the process of hydration [1]. Research has examined the impact of temperature on the volume of water absorbed by agricultural goods, such as parboiled rice [3], canary seedlings [10], soybeans [8], and beans [12]. An essential functional feature of agricultural crops is their ability to absorb water by imbibition [8]. The goal of this work is to simulate the kinetics of water absorption by jack bean seeds at various temperatures.

2. Materials and Methods

2.1. Material

The International Institute of Tropical Agriculture (IITA) in Ibadan, Oyo State, Nigeria, provided four types of jack bean seeds. Seed samples were physically cleaned to get rid of immature or broken seeds, as well as foreign objects like dust, dirt, stones, and chaff. They were then stored in a clean nylon bag with clear labels.

2.2. Water Absorption Procedure

A modified approach [15] was employed to conduct experiments on the water absorption of certain types of dried seeds, namely Jack beans. Samples were chosen at random, excluding out foreign objects and seeds that were cracked, fractured, or otherwise damaged. Using an electronic weighing balance (OHAUS scale, Cambridge, England), approximately 5g of each dried sample was weighed. It was then soaked in 100 ml of distilled water in a 250 ml beaker, with temperatures ranging from 31.68 to 53.3 oC for duration of 10 to 40 minutes. For every experimental run, the experiment was carried out in three replicates.

A digital chronometer (AND GF-6000, manufactured in Japan) was used to measure the amount of water absorbed by different samples over a period of 10 to 40 minutes following immersion. Once the designated sampling period had passed, each sample was taken out of the beaker and any extra water was dried off using dried wipes. Following cleaning, dried samples were weighed once more to ascertain how much water they had absorbed. The data gathered was then utilized to compute the water absorption capacity of seed samples using an equation.

$$\text{Water absorption capacity WAC} = (W_f - W_i) / W_i \times 100\% \quad (1)$$

W_f is weight of seeds after immersion. W_i is weight of seeds before immersion.

2.3. Modeling the Kinetics of Hydration

Five models were utilised to determine the parameters of each model's fitted moisture uptake of soaked jack beans. Table 1 lists the models and corresponding equations used in this investigation. The model that performed the best was the one with the highest coefficient of determination (R^2) and the lowest root mean square error (RMSE) between the experimental and predicted findings [5].

Table 1. Mathematical model selected for water absorption capacity.

Model Name	Empirical Expression
Wang and Singh	$MR = 1 + at bt^2$
Henderson and Pabis	$MR = aexp(-kt)$
Page	$MR = \exp(-kt)^n$
Logarithmic	$MR = aexp(-kt) + b$
Werma	$MR = \exp(-kt) + (1 - a) \exp(-gt)$

2.4. Effective Diffusivity (Deff)

Deff was determined with this equation [2]

$$C - (\pi^2 \text{Deff}) / r^2 \quad (2)$$

Where Deff (m^2/s) is effective diffusivity, c (s^{-1}) is rate constant of water absorption of mathematical model with best fit and r (m) is value of radius of equivalent sphere.

2.5. Statistical Analysis

MATLAB software is a statistical tool used for statistical analysis, including regression and generalised linear models. The coefficient of determination (R^2) and relative mean square error (RMSE) magnitude were taken into consideration while choosing the optimal model to forecast the equilibrium water content of jack bean seeds.

3. Results and Discussion

Water absorption during soaking is a critical pre-processing step that significantly influences the cooking quality, texture, and nutritional characteristics of legumes such as jack beans. Understanding the kinetics of water uptake is essential for optimizing soaking conditions and improving subsequent processing operations. The rate and extent of water absorption depend on factors such as seed variety, seed coat permeability, size, and internal structure.

In this study, the water absorption behaviour of four varieties of jack beans during soaking was investigated and mathematically modelled. Empirical and semi-empirical models

commonly used for hydration kinetics were applied to describe the relationship between moisture content and soaking time. These models provide valuable insight into the hydration mechanism and allow for comparison of soaking characteristics among different jack bean varieties.

Modelling water absorption kinetics helps to predict soaking time required to achieve desired moisture levels and supports process design and optimization in food and agro-processing industries. The outcomes of this modelling approach form the basis for evaluating varietal differences and discussing the suitability of the models in accurately representing the soaking behaviour of jack beans, which is further presented in the results and discussion section.

3.1. Water Absorption Curve of Seed Samples

Figure 1 displayed the percentage increase in moisture content for each of the four Jack bean types. The absorption curve indicates that as time increases, the rate of water absorption

increases. Consequently, as temperature rises, the moisture ratio decreases and approaches zero more quickly. Temperature and soaking time have an impact on the rate of water absorption. Comparable outcomes have been documented for a number of legume grains, including peanuts, soybeans, cowpeas, and chickpeas [14, 18]. In comparison to later soaking times, the intensity of water absorption was faster during the initial 30 minutes of soaking, as seen in Figure 1. While several types prefer to absorb water under these conditions at varying rates, TCE-2 showed the highest rate of absorption. Selected types of Jack beans had their moisture levels gradually increased over a period of 30 to 999 minutes, although at a decreasing rate. All of the chosen Jack bean varieties reached equilibrium at nearly identical moisture contents at the conclusion of the soaking period, therefore there were no discernible increases in moisture content. Different types of Jack beans reached their equilibrium moisture content around 700–850 minutes.

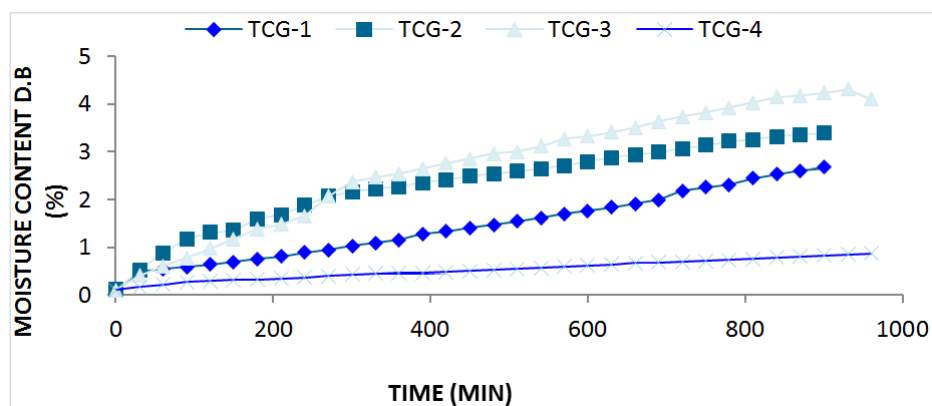


Figure 1. Water absorption curve for four varieties of Jack beans.

3.2. Moisture Diffusivity of Four Varieties of Seed Samples

The slope approach was used to plot $\ln(MR)$ versus time in order to quantify the effective diffusivity of seed samples. Table 2 displays the moisture diffusivity values for Jack beans. Plotting the natural logarithm of moisture ratio data against time was done while testing the Jack bean's ability to absorb water. Jack beans Deff values ranged from $3.216 \times 10^{-10} \text{ m}^2/\text{s}^2$

to $6.45 \times 10^{-10} \text{ m}^2/\text{s}^2$. Because the rate of diffusion increases with time spent in the water, there was an increase in the effective moisture diffusivity of the chosen jack bean cultivars. Because of the water's rapid flow at high times, effective diffusivity increases with time [9]. The order of magnitude of moisture diffusivity of this research work agrees with previously reported values for other seeds and grains. Bean seeds have Deff values of $1.778 - 5.141 \times 10^{-10}$ [2, 9, 14, 17], whereas chick pea seeds have Deff values of $2.43 \times 10^{-10} - 39.17 \times 10^{-10} \text{ m}^2/\text{s}^2$ [13, 14, 16].

Table 2. Moisture diffusivity for four varieties of Seed Samples.

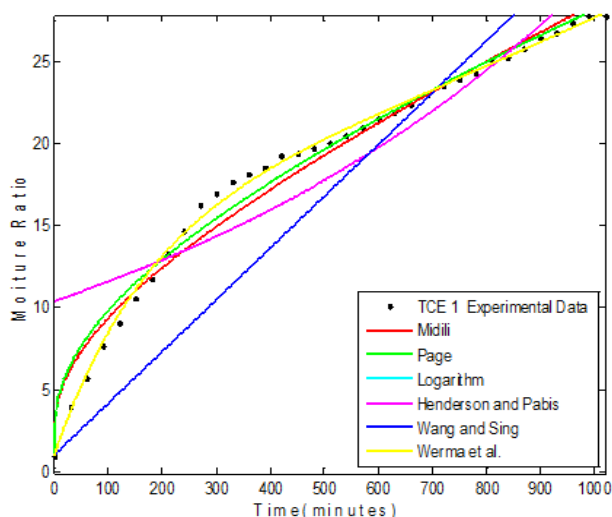
Seed	Samples	Temperature	R ²	Deff (10 ⁻¹⁰) (m ² /s)
Jack bean	TCE-1	54	0.759	3.216
	TCE-2	55	0.801	6.45

Seed	Samples	Temperature	R ²	Deff (10 ⁻¹⁰) (m ² /s)
	TCE-3	55	0.878	6.297
	TCE-4	54	0.646	5.779

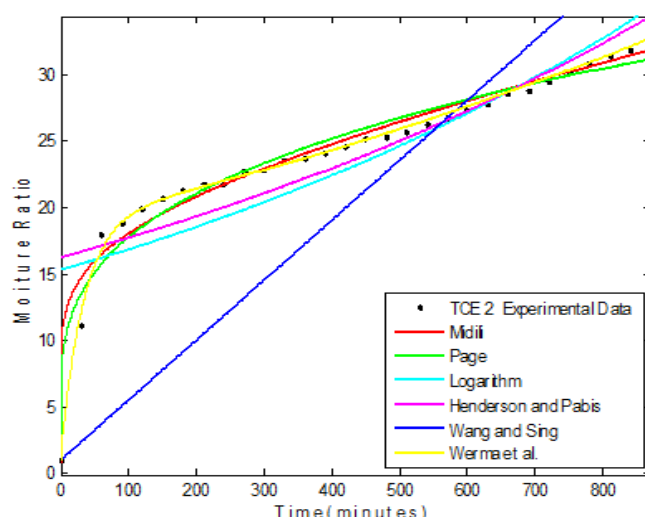
3.3. Mathematical Modeling of Water Absorption Capacity of Seed Samples

Six models in mathematics Fits to the collected experimental data included Midilli, Page Wang and Singh, Logarithmic, Werma, Henderson, and Pabis of water absorption capacity (Figure 2). Table 3 listed the models' respective R² and

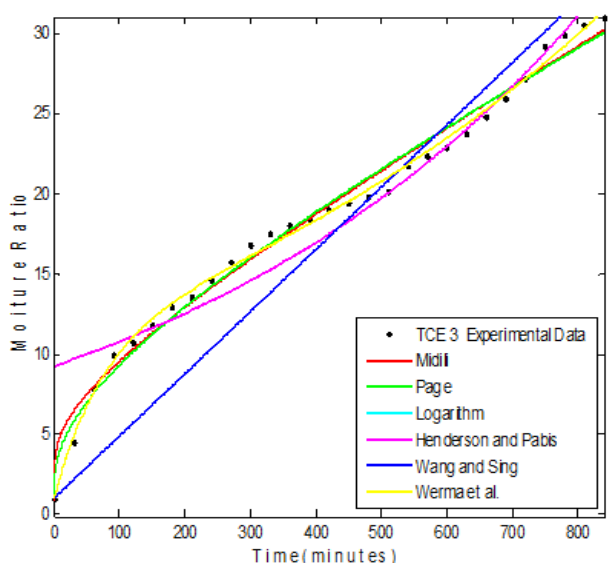
RMSE values. Based on the greatest value of the coefficient of determination (R²) and the lowest value of the root mean square error (RMSE), the best model was selected [17]. The page model is most suited to forecast changes in moisture ratio as a function of soaking time for four different types of jack beans, according to the results. The Page model has the lowest RMSE of 0.9979 and the greatest R² values of 0.1201.



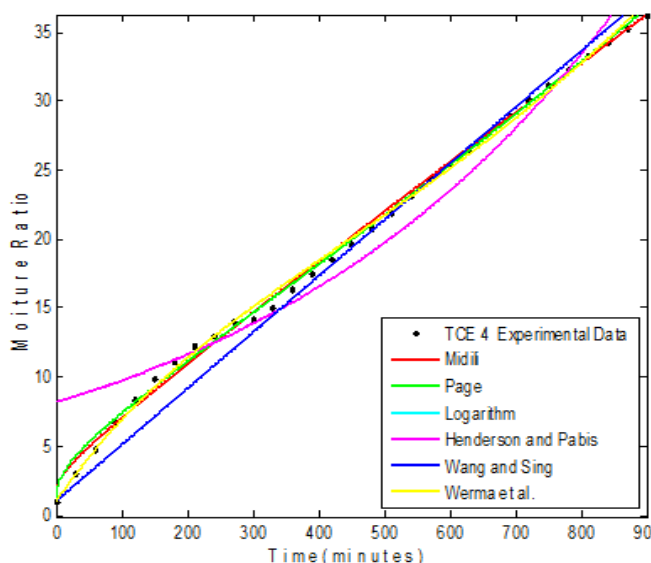
TCE-1



TCE-2



TCE-3



TCE-4

Figure 2. Water absorption curve for four varieties of Jack beans.

Table 3. The Coefficient of models along with statistical analysis of models of water absorption of four varieties of Jack seeds.

Models	TCE-1		TCE-2		TCE-3		TCE-4	
	R ²	RMSE	R ²	RMSE	R ²	RMSE	R ²	RMSE
Midilli	0.9763	2.1762	0.9734	1.1237	0.9644	1.5415	0.9954	0.7265
Henderson and Pabis	0.8318	2.9618	0.7443	3.3579	0.9187	2.2409	0.9444	2.4382
Page	0.9810	0.9965	0.9686	1.1775	0.9869	0.9001	0.9979	0.1201
Logarithmic	0.9115	2.1823	0.7838	0.1442	0.9634	1.5326	0.9951	0.7380
Wang and Singh	0.9536	1.5564	0.4551	4.9017	0.9324	2.0430	0.9921	0.9191
Werma	0.9974	0.3737	0.9947	0.4921	0.9963	0.4878	0.9975	0.5283

4. Conclusions

The study on the hydration kinetics of four jack bean cultivars demonstrated that temperature and soaking time significantly influence water absorption behavior. As temperature increased from 31.68°C to 53.3°C, the effective moisture diffusivity rose from 3.067×10^{-10} m²/s to 9.40×10^{-10} m²/s, indicating that higher temperatures enhance the rate of water diffusion within the seed matrix. The observed decrease in moisture ratio with increasing temperature further confirms the positive effect of thermal conditions on hydration rate.

Among the five mathematical models evaluated, the Page model provided the best fit for describing the hydration behavior of jack beans, as shown by its high coefficient of determination (R²) and low root mean square error (RMSE) values. This suggests that the Page model can accurately predict the moisture uptake characteristics of jack beans under varying conditions.

5. Recommendation

Based on the findings of this study, it is recommended that the Page model be adopted for accurately describing and predicting the hydration behaviour of jack beans under various temperature and soaking conditions. Since temperature was found to significantly influence the rate of water absorption and effective moisture diffusivity, optimal soaking temperatures between 40°C and 50°C are suggested for efficient hydration without compromising seed integrity. Further research should be conducted to investigate the hydration kinetics of jack beans at higher temperature ranges and under different pre-treatment methods, such as dehulling or enzymatic soaking, to better understand their effects on diffusion rate and water uptake efficiency.

Additionally, the results of this study can serve as a foundation for industrial-scale processing and food formulation, where proper hydration control is essential for improving

cooking quality, texture, and nutrient retention. Incorporating these findings into jack bean processing could enhance its utilization as a sustainable and nutritious legume in both human and animal nutrition.

Abbreviations

WAC	Water Absorption Capacity
RMSE	Root Mean Square Error
R ²	Coefficient of Determination
DEFF	Moisture Diffusivity Coefficient

Author Contributions

Esther Awotona is the sole author. The author read and approved the final manuscript.

Data Availability Statement

The data supporting the outcome of this research work has been reported in this manuscript.

Conflicts of Interest

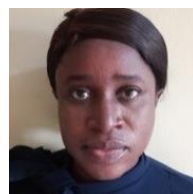
The author declares no conflicts of interest.

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Biography



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Research Field

Esther Awotona: Dehydration of Agricultural produce, Hydration of Agricultural produce, Wastewater treatment, Coagulation- flocculation process, Mathematical Modelling and Separation Process