Original Research Article

Modelling of Hydration Characteristics of Five Varieties of Cowpea Grains

ABSTRACT

Introduction: The hydration of grains is a process that consists of soaking them in water in order to increase their moisture content and this is a crucial step in industrialized processing and provides several beneficial effects on their physicochemical and nutritional qualities

Aims: This study focused on modeling of hydration characteristics of five varieties of cowpea which are: *Gombe*, *Oloyin* white, Drum, *Oloyin* brown and *Sokoto* cultivated in Nigeria.

Methodology: The experiments were carried out using electronic water bath at five temperatures (30, 40, 50, 60, and 70°C) in three replications. The amount of water absorption by five selected varieties of cowpea grains was calculated by measuring the increase in the mass of soaked grains per time. Five standard models of water absorption were fitted to the experimental data. Coefficient of determination (R^2), chi-square (x^2) and root mean square error (*RMSE*) were used to evaluate the models.

Results: The initial moisture content of the saturated cowpea was estimated as 13.56 ±1.15, 15.05 ±2.27, 13.30 ±0.37,10.85 ±0.13, 12.40 ±0.13 for *Gombe*, *Oloyin* white, Drum, *Oloyin* brown and *Sokoto* varieties respectively. The water uptake of the cowpea was faster at the initial stage and gradually slow down until the equilibrium moisture content was attained for all the varieties.

Conclusions: Weibull model was adjudged as the best fitted model for describing the water absorption property of all the varieties of the cowpea and the Activation energy of *Gombe, Oloyin* white, Drum, *Oloyin* brown and *Sokoto* varieties are 42.26 ± 4.65, 40.36 ±8.90, 39.47 ±8.62, 43.08 ±5.25 and 39.66 ±6.72 respectively.

Keywords: Cowpea varieties, Physical properties, Hydration, Thermodynamics, Modelling

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].The possible contribution of dry beans to improving the lives of subsistence farmers and his family in Africa is obvious. The excellent flavour of the cooked seeds makes it superior to other pulses in Southern Nigeria [3]. It was remarked to be exceptionally nutritious by Rachie [4]. Different forms of local recipes are prepared from the crop to meet the dietary needs of the people. In most West African communities, the seed grains are boiled and eaten with other staples such as yam, plantain, cassava, corn/maize, etc. A popular snack is produced from the grains through roasting particularly in Enugu/Nsukka area of Nigeria. Owing to the presence of the ANFs in various quantities in dry beans (like other legumes), the consumption of the bean will require processing for safety as human meals [5]. Cooked seeds of dry beans have higher fibre content, high efficiency of protein digestibility, higher amino acid availability, high gross and metabolizable energy and good fatty acid profile [2]

The hydration of grains is a process that consists of soaking them in water in order to increase their moisture content. This is a crucial step in industrialized processing and provides several beneficial effects on their physicochemical and nutritional quality [6, 7, 8, 9, 10]. Soaking is widely used in processing different grains for many reasons, as hydration is necessary for processes like cooking, extraction, fermentation, germination and malting. The hydration of grains before cooking helps to soften the bean structure and so, reducing the cooking time [11]. This process promotes the activation of cell-wall enzymes, decreases the degree of polymerization of rhamnogalacturonan and increases the solubility of poly galacturonan and galactan, which results in better polysaccharide solubility and shorter cooking time [12]. In addition, hydration enhances the homogeneous gelatinization of the starch and the homogeneous denaturation of proteins during cooking [13]. Therefore, a similar texture is obtained in the whole grain.

Moreover, the heat transfer through the grain during cooking is enhanced by the absorbed water, thus improving the inactivation of anti-nutritional factors [14] such as protease inhibitors, lectins, saponins, vicine, convicine, phytates, alkaloids, and indigestible oligosaccharides [15]. Hydration also improves component extraction from grains, which in this case is sometimes called the steeping process. The most commonly-extracted component from grains is starch, especially from cereal grains, and is conducted by wet milling. Softening the grains by hydration improves their wet grinding and so facilitates starch purification [16]. In addition, the hydration process is used to extract toxic components from beans. For instance, the Andean lupin (*Lupinus mutabilis* Sweet) has a high level of toxic alkaloids (lupanine), which needs to be extracted before being consumed. This extraction is performed in water; thus, the grains need to be hydrated [17]. In addition, during the hydration process, some anti-nutritional compounds, such as phytic acid, tannins, phenols, α-amylase, and trypsin inhibitors, are extracted [18].
The grain hydration process is mainly a mass transfer unit operation, in which the water activity difference acts as the driving force. In other words, the water is transported from a substance with a high effective water concentration (soaking water) to a substance with a low effective water concentration (grain), a phenomenon called diffusion. In addition, the complex structure and different tissues and cells of the grains form channels of many sizes, structure, composition, zones with varied permeability through which the water can flow. Therefore, the water does not only enter the grains by diffusion, but also by capillary flow. Thus, the hydration process is not as simple as it seems and involves not only mass transfer mechanisms, but also those of fluid flow. Consequently, the hydration process is of significant importance in the industrialization of

grains. However, this step is a batch process, which can take many hours and uses a substantial quantity of water. For that reason, its study, description and optimization are very desirable [19].

The water uptake of the grains can show two forms of behaviour, which are differentiated by the mass transfer rate at the beginning of the process. In the downward concave shape (DCS) behaviour, the water influx rate is a maximum at the beginning of the process and falling to zero after enough time has elapsed at the product equilibrium moisture content (*M*eq). Among many models, the Peleg Model [20] is the most widely used equation to describe this behaviour. The sigmoidal behaviour is described by an initial lag phase, i.e., an initial phase with a low water uptake rate. In this case, the water influx rate firstly increases, until an inflexion point is reached. After which the rate decreases to zero when the product reaches its equilibrium moisture content (*M*eq). This behaviour can be described by the Kaptso *et al*. model. The sigmoidal behaviour is of higher interest, since it is the lag phase that slows the process. All the grains that presented this behaviour are from *Leguminosae* or *Fabacea* family, like cow-pea [2], common bean [21], lima bean [22], Adzuki beans [23] and Andean lupin beans [15].

Many studies have reported the influence of temperature on water absorption property which includes soybean, amaranth grain and maize kernel [24, 25, 26] and many other grains. However, effect of varietal variations and processing variable on the rate of water uptake and moisture absorption property of cowpea grown in Nigeria, and it processed form have not been fully and thoroughly established.The aim of this work is to study the hydration behavior of cowpea as influenced by varieties and temperature

MATERIALS AND METHODS

Sample Collection

The five varieties of cowpea grains were obtained from a local market in Akure, Southwest Nigeria. The material was cleaned to remove foreign materials such as stones, broken grains, weevil damaged grains and dirt, sealed in an airtight container and kept in cool and dry place prior to its usage. Other material used for the study of water absorption characteristics include; Electronic Water bath, Beakers, measuring cylinder, weighing balance, venier callipers, distil water, Sample holder, Blotting paper, Hand towel.

Initial Moisture Content Determination

The initial moisture content of the seeds was determined using the oven dry method, the sample was placed in the laboratory oven at 105±1°C for about 24 h in hot air oven. Average moisture content was subsequently calculated on a percentage dry basis (% d.b) as shown in equation 1

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

Where Mc is moisture content on dry basis (%), M_w is mass of wet sample (g) andM_d is the mass of dry sample (g)

Determination of Physical Properties of Grains

The physical characteristics of the cowpea seeds were evaluated according to Baryeh [27]. 100 randomly selected seeds were used to measure length (L), width (W) thickness (T), from the three principal dimensions which are in the three mutually perpendicular directions using a vernier caliper and the mass (M) of the seeds was measured using digital weighing balance. Using the readings, the geometric mean diameter (Dm), arithmetic mean diameter (Da)sphericity (φ), surface area(A),volume (V)and mass (ρ) was calculated using the relationship shown in the equation 1-8 respectively;

$$D_m = \sqrt[3]{(LWT)} \tag{2}$$

$$D_a = \frac{L+W+T}{3} \tag{3}$$

$$\varphi = \frac{(LWT)^{1/3}}{L} \tag{5}$$

$$A = \pi D_m{}^2 \tag{6}$$

$$V = \frac{\pi.WT.L^2}{6[2L-(WT)^{0.5}]} \tag{7}$$

$$\rho = \frac{M}{V} \tag{8}$$

Soaking Experiment

The moisture content change of the cowpea grains during soaking in water were measured at five different water temperatures (30, 40, 50 60, and 70^0C) for five different varieties of cowpea; *Gombe, Oloyin* white, Drum, *Oloyin* brown and *Sokoto* varieties. Beakers (200 ml) containing 120 ml of distilled water were placed in thermostatically-controlled water baths (WBH 14-420 PEC MEDICAL USA) at the predetermined temperatures. Three replicates of 20±0.5g samples were weighed into the beakers giving a volumetric water-grain ratio of 5:1.

Throughout the soaking period, the samples were fully immersed in water and removed from the water bath after 15 minutes. The soaked samples were drained and transferred to a filter cloth and blotted carefully to remove excess surface water [28, 29]. The weight of the samples was then determined using a digital balance (A & D Co. Ltd., 14000176, Japan).The procedure was repeated at intervals of 15 minutes for first hour, 30min interval for the second hour and 60 min interval until equilibrium is attained to obtain the water absorption data, the experiments were terminated when the incremental change in sample weight was less than 0.05g when measured after 1hr of soaking, or up to a total soaking time of 10hrs. The increase in sample mass during soaking in water was considered to be an increase in sample moisture content [30].

Modeling of Absorption Characteristics

For fitting the moisture uptake of soaked five varieties of cowpea, five models were used to estimate the parameters associated with each model. The list of the empirical models and the respective equations used in this study is presented in Table 1. The best fitted model was determined based on the highest coefficient of determination (R^2) and the lowest values of the root mean square error (RMSE) and chi-square (χ^2) between the predicted and experimental results (COX *et al*., 2012).The standard error of estimate (SEE) indicates the fitting ability of a model to a set of data and represents the deviation of the dependent variable Mt,

$$\mathrm{SEE} = \sqrt{\sum_{i=1}^{n} \frac{(\mathrm{M}_{\mathrm{exp},i} - \mathrm{M}_{\mathrm{prep},i})^2}{\mathrm{d_f}}} \tag{5}$$

$$X^2 = \sum_{i-1}^{N} \frac{(M_{exp,i} - M_{prep,i})^2}{N-n} \quad (7)$$

$$R^2 = \sum_{i=1}^{n} \frac{(M_{exp,i} - M_{exp,ave})^2 - \sum_{i=1}^{n}(M_{exp,i} - M_{pre,i})^2}{\sum_{i}^{n}(M_{exp,i} - M_{exp\ ave})^2} \quad (8)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N} (M_{pre,i} - M_{exp,i})^2} \quad (9)$$

Where, $M_{exp,i}$ is the ith experimentally observed moisture content (%d.b), $M_{pre,i}$ the ith predicted moisture content (%d.b), $M_{exp,ave}$ is average moisture content observed (d. b. %), N is the number of data, d_f is degree of freedom and n is the number of the constant coefficient of model.

Table 1: Models used to describe the moisture uptake by soaking

Model	Equation	Reference
First Order	$\frac{m_{t-m_\infty}}{m_{o-m_\infty}} = \exp(-K.t)$	[31]
Peleg	$M_t = M_o + \frac{t}{K_1 + K_2}$	[20]
Page	$\frac{m_t - m_\infty}{m_o - m_\infty} = \exp(-\mathrm{Kt})$	[32]
Weibull	$\frac{M_t}{M_\infty} = 1 - \exp\left(-\left(\frac{t}{\beta}\right)^{\alpha}\right)$	[33]
Kaptso	$M_t = \frac{M_\infty}{1 + \exp[-Kt].(t - \tau)}$	[34]

MR is the rate of moisture uptake, and is given by the equation: $MR = \frac{M_{o-M_t}}{M_{o-M_e}}$

M_o is the initial moisture content of the bean, M_t is the moisture content of bean at time t, and M_e is the final moisture content at equilibrium.t is the hydration duration (in min), and the variables k_1, k_2, k, τ, α and β are the coefficients of the empirical models which was solve using nonlinear regression analysis on Microsoft excel version 2016 microsoft.inc

RESULTS AND DISCUSSION

Physical Properties

Table 2 shows the initial moisture content of five selected varieties of cowpea and there corresponding physical appearance. The initial moisture content estimated using standard oven dry method as 13.56 ± 1.15, 15.05 ± 2.27, 13.30 ± 0.37, 10.85 ± 0.13 and 12.40 ± 0.13 for *Gombe, Oloyin* white, Drum, *Oloyin* brown and *Sokoto* varieties respectively

Table 2: Initial moisture content of the selected varieties of cowpea

Varieties	Mean	SD	Coat colour	Eye colour
Gombe	13.56168	1.151601	white	White
*Oloyin*white	15.04894	2.268778	White	White

Drum	13.29697	0.371018	Darkish brown	brown
*Oloyin*brown	10.84599	0.125566	Brown	white
Sokoto	12.40178	0.125566	White	Black

Table3 shows the summary statistic of the physical properties of the different varieties of cowpea; *Gombe*, Drum, *Sokoto*, *Oloyin* white, and *Oloyin* brown. The weight of the seed was measured as 0.19 ± 0.04, 0.30 ± 0.07, 0.34 ± 0.05, O.25 ± 0.04 and 0.25 ± 0.04g for *Gombe*, Drum, *Sokoto*, *Oloyin* white, and *Oloyin* brown respectively. The highest mass was recorded in the *Sokoto* variety and lowest wat recorded in the *Gombe* variety. The seed mass of cowpea obtained in the present study fall within the same range (0.10–0.24 g) reported by Olapade [35] for eight varieties of Nigerian cowpeas and less than the seed weight of bambara (0.50–0.80 g) obtained by Baryeh [36]. The length (L), width (W) and thickness (T) shown Table 3 for all the selected varieties of cowpea are 0.89 ± 0.11, 0.70 ± 0.07 and 0.58 ± 0.08 respectively for Gombe variety, 1.15 ± 0.10, 0.82 ± 0.09 and 0.61 ± 0.07 for Drum variety respectively, 1.15 ± 0.14, 0.8 ± 0.15 and 0.68 ± 0.07 for Sokoto variety respectively, 1.02 ± 0.21, 0.75 ± 0.10 and 0.60 ± 0.06 for Oloyin white variety respectively and 1.12 ± 0.12, 0.81 ± 0;10 and 0.56 ± 0.06 for Oloyin brown respectively. This result is lesser than the findings of [35] who reported on cowpea seeds the range values of L, W and T, to be 0.73–1.00 cm, 0.49–0.73 cm and 0.33–0.57 cm, respectively and in tandem with the corresponding range values reported by Baryeh [36] on bambara seeds were 1.01–1.52 cm, 0.95–1.15 cm and 0.82—1.10 cm, respectively.

Table 3: Summary statistics of the physical properties of five selected varieties of cowpea

Varieties	Physical properties	Maximum	Minimum	Mean	SD	CV(%)
Gombe	Length (cm)	1.1700	0.7250	0.8932	0.1079	12.0775
	Width (cm)	0.7800	0.5250	0.7016	0.0668	9.5259
	Thickness (cm)	0.8600	0.5150	0.5826	0.0825	14.1566
	Arithmetic mean diameter (cm)	0.8367	0.6403	0.7258	0.0471	6.4901
	Geometric mean diameter (cm)	0.8059	0.6349	0.7112	0.0440	6.1805
	Sphericity	0.9697	0.6888	0.8037	0.0753	9.3669
	Surface area (cm^2)	2.0402	1.2663	1.5951	0.1976	12.3870
	Volume (cm^3)	0.4076	0.1005	0.1603	0.0589	36.7296
	Mass (g)	0.3000	0.1100	0.1916	0.0430	22.4325
	Density (g/cm^3)	1.8905	0.6311	1.2583	0.3085	24.5205
Drum	Length (cm)	1.2800	0.9250	1.1462	0.1040	9.0696
	Width (cm)	0.9550	0.6200	0.8160	0.0868	10.6322
	Thickness (cm)	0.7600	0.5000	0.6090	0.0658	10.8092
	Arithmetic mean diameter (cm)	0.9517	0.7283	0.8571	0.0683	7.9744
	Geometric mean diameter (cm)	0.9233	0.7043	0.8273	0.0675	8.1546
	Sphericity	0.8253	0.6334	0.7238	0.0451	6.2257
	Surface area (cm^2)	2.6780	1.5585	2.1641	0.3476	16.0637
	Volume (cm^3)	0.3317	0.1436	0.2273	0.0565	24.8628
	Mass (g)	0.4200	0.1900	0.3020	0.0743	24.6127
	Density (g/cm^3)	1.2925	0.4138	0.7677	0.1743	22.6997
Sokoto	Length (cm)	1.7050	1.0100	1.1523	0.1421	12.3336
	Width (cm)	0.9800	0.3200	0.8002	0.1519	18.9803

	Thickness (cm)	0.8400	0.5200	0.6890	0.0790	11.4665
	Arithmetic mean diameter (cm)	1.0800	0.6983	0.8805	0.0915	10.3926
	Geometric mean diameter (cm)	1.0002	0.6231	0.8549	0.0955	11.1689
	Sphericity	0.8516	0.5851	0.7457	0.0747	10.0123
	Surface area (cm²)	3.1426	1.2199	2.3233	0.4990	21.4779
	Volume (cm³)	0.3820	0.1339	0.2603	0.0760	29.2089
	Mass (g)	0.4400	0.2500	0.3408	0.0509	14.9360
	Density (g/cm³)	0.9935	0.4616	0.7555	0.1557	20.6062
Oloyin white	Length (cm)	1.3500	0.1700	1.0256	0.2066	20.1424
	Width (cm)	0.8650	0.3400	0.7520	0.1019	13.5558
	Thickness (cm)	0.6600	0.5150	0.5972	0.0555	9.2920
	Arithmetic mean diameter (cm)	0.9350	0.5117	0.7916	0.0815	10.2942
	Geometric mean diameter (cm)	0.8897	0.4226	0.7638	0.0927	12.1332
	Sphericity	2.4861	0.5468	0.8075	0.3564	44.1412
	Surface area (cm²)	2.4866	0.5611	1.8586	0.3858	20.7571
	Volume (cm³)	0.2517	0.1345	0.1887	0.0303	16.0748
	Mass (g)	0.3600	0.2000	0.2532	0.0364	14.3635
	Density (g/cm³)	0.9168	0.5518	0.7428	0.0796	10.7203
Oloyin brown	Length (cm)	1.3500	0.9500	1.1163	0.1194	10.6976
	Width (cm)	0.9700	0.6250	0.8108	0.0956	11.7915
	Thickness (cm)	0.7200	0.4400	0.5619	0.0636	11.3136
	Arithmetic mean diameter (cm)	0.9417	0.7167	0.8296	0.0608	7.3320
	Geometric mean diameter (cm)	0.8910	0.6914	0.7952	0.0554	6.9671
	Sphericity	0.9085	0.6297	0.7171	0.0629	8.7664
	Surface area (cm²)	2.4939	1.5018	1.9960	0.2787	13.9651
	Volume (cm³)	0.2969	0.1255	0.1879	0.0424	22.5482
	Mass (g)	0.3600	0.1600	0.2504	0.0436	17.4058
	Density (g/cm³)	1.0238	0.4364	0.7576	0.1418	18.7138

Water Uptake Characteristics

Figure 1 shows the evolution of water uptake isotherms at different temperatures for the five varieties of cowpea; *Gombe*, *Oloyin* white, Drum, *Oloyin* brown, and *Sokoto*. It was observed that water uptake was faster in the initial stages at all temperatures, especially in the first 30 minutes, and gradually slowed down as the moisture content approached saturation point known as equilibrium moisture content. According to Hsu [24], it had been demonstrated that diffusion in the solid endosperm is the main mechanism that controls the rate of absorption in seeds regardless of the process conditions. There was a noticeable effect of temperature on the grain moisture, mainly on the dynamic of hydration characteristics and also on the equilibrium moisture of the five varieties

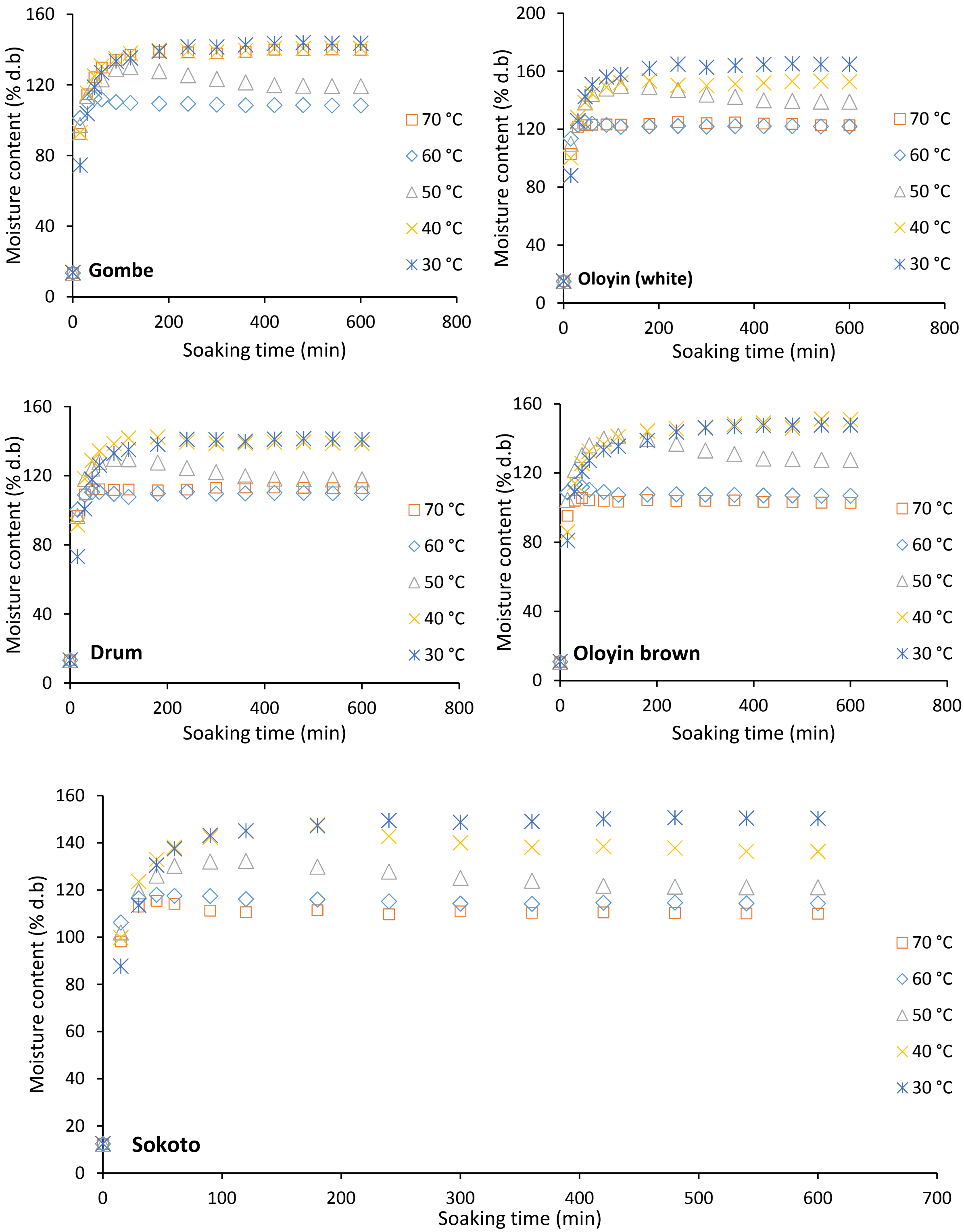

Figure 1: Moisture content vs soaking time at different temperature

Modelling of Absorption Characteristics

The data of gravimeteric based water absorption of five (5) varieties of cowpea at the different soaking temperatures were converted into the moisture content. Then these data were fitted to the selected models which include the Peleg model, page model, kaptso model, Weibul model and first order model (Table 1).The results of nonlinear regression analyses and statistical analyses of the different models including the constants of the models and the comparison criteria were used to evaluate goodness of fit namely, R^2, χ^2, RMSE and SEE. These results are presented in Table 4-8fordescribing water absorption for *Gombe*, *Oloyin* white drum, *Oloyin* brown and *Sokoto* varieties respectively. Base on the criteria of the highestR^2 and the lowestχ^2, RMSE and SEE values, the best model for describing the water absorption of the five varieties of cowpea was selected. Statistical results of semi-theoretical models show that theR^2,χ2, RMSE and SEE values varied between 0.9663 and 0.9997, 1.0×10^{-4} and 4.3×10^{-3}, 0.0066 and 0.0818, and 0.0004 and 0.1003, respectively, This indicated that some models provided a good representation of the experimental results. However, statistical results show that the Weibull model gave the highestR^2 in accordance with the lowest vales of χ^2, RMSE and SEE for all the five varieties at all temperature. Therefore, the Weibull model was considered the best model for describing both the water absorption of cowpea during soaking within the experimental range of study disagree with the findings of [37] who suggested Page model has the best model for describing the soaking behaviour of white rice, and [38] at room temperature claims to investigate the effect of soaking temperature on the constant and coefficient values of the Page model, namely, k and n, However, the variation in this result can be attribute to the class of the seed, which might directly affect the performance of the model. Nevertheless, the Weibull model can be used to estimate with great accuracy of the moisture content of the selected cowpea at any time during the soaking process.

Table 4: Model parameter for modelling of *Gombe* variety

Temperature	Model	Model constant	Goodness of fit parameter			
			SEE	R^2	RMSE	χ^2
70 °C	Peleg	K1 = 6.6249, K2 = 0.7712	0.0049	0.9968	0.0181	0.0004
	Page	K = 0.6877, n = 0.1546, Me = 139.2172	0.0006	0.9996	0.0065	0.0001
	Kaptso	K = 0.1491, T = 11.5658, Me = 135.9337	0.0519	0.9677	0.0588	0.0043
	Weibul	a = 15.0951, b = 0.6877, Me = 139.2172	0.0006	0.9996	0.0065	0.0001
	First order	K = 0.0591, me = 137.8261	0.0110	0.9930	0.0270	0.0008
60 °C	Peleg	K1 = 0.8334, K2 = 1.0371	0.0062	0.9928	0.0203	0.0005
	Page	K = 2.154, n = 0.0071, Me = 109.5936	0.0021	0.9975	0.0119	0.0002
	Kaptso	K = 0.2971, T = 6.5901, Me = 109.5998	0.0021	0.9975	0.0120	0.0002
	Weibul	a = 9.9303, b = 2.163, Me = 109.5969	0.0021	0.9975	0.0119	0.0002
	First order	K = 0.1651, me = 109.6278	0.0023	0.9973	0.0124	0.0002
50 °C	Peleg	K1 = 3.2718, K2 = 0.8934	0.0336	0.9709	0.0473	0.0026
	Page	K = 0.8592, n = 0.1381, Me = 123.5391	0.0169	0.9854	0.0336	0.0014
	Kaptso	K = 0.2211, T = 9.1316, Me = 122.6927	0.0236	0.9796	0.0396	0.0020
	Weibul	a = 10.0097, b = 0.8592, Me = 123.5391	0.0169	0.9854	0.0336	0.0014
	First order	K = 0.0922, me = 123.3369	0.0175	0.9849	0.0341	0.0013
40 °C	Peleg	K1 = 8.6704, K2 = 0.7526	0.0186	0.9898	0.0352	0.0014

Temperature	Model	Model constant	SEE	R^2	RMSE	χ^2
	Page	K = 0.7407, n = 0.1099, Me = 141.166	0.0148	0.9926	0.0314	0.0012
	Kaptso	K = 0.1483, T = 11.5312, Me = 136.7293	0.0520	0.9678	0.0589	0.0043
	Weibul	a = 15.0322, b = 0.6863, Me = 140.0151	0.0007	0.9996	0.0066	0.0001
	First order	K = 0.0593, me = 138.6096	0.0112	0.9930	0.0273	0.0009
30 °C	Peleg	K1 = 6.6243, K2 = 0.7712	0.0244	0.9884	0.0403	0.0019
	Page	K = 0.6875, n = 0.1546, Me = 139.2214	0.0178	0.9917	0.0345	0.0015
	Kaptso	K = 0.0825, T = 17.3501, Me = 139.6012	0.0579	0.9692	0.0621	0.0048
	Weibul	a = 24.5777, b = 0.8064, Me = 142.2912	0.0038	0.9979	0.0160	0.0003
	Firs order	K = 0.0399, me = 141.1934	0.0095	0.9948	0.0252	0.0007

Table 5: Model parameter for modelling of *Oloyin* white variety

Temperature	Model	Model constant	Statistical parameter			
			SEE	R^2	RMSE	χ^2
70 °C	Peleg	K1 = 2.5325, K2 = 0.9043	0.0093	0.9916	0.0249	0.0007
	Page	K = 1.2431, n = 0.057, Me = 123.5988	0.0006	0.9995	0.0064	0.0001
	Kaptso	K = 0.2379, T = 8.2783, Me = 123.4815	0.0008	0.9993	0.0072	0.0001
	Weibul	a = 10.0053, b = 1.2432, Me = 123.5987	0.0006	0.9995	0.0064	0.0001
	First order	K = 0.1117, me = 123.7377	0.0009	0.9992	0.0076	0.0001
60 °C	Peleg	K1 = 0.8294, K2 = 0.9258	0.0048	0.9955	0.0179	0.0004
	Page	K = 2.16, n = 0.0071, Me = 122.4769	0.0010	0.9990	0.0084	0.0001
	Kaptso	K = 0.3004, T = 6.5426, Me = 122.4839	0.0011	0.9990	0.0084	0.0001
	Weibul	a = 9.8676, b = 2.1735, Me = 122.4768	0.0010	0.9990	0.0084	0.0001
	First order	K = 0.1671, me = 122.519	0.0012	0.9989	0.0089	0.0001
50 °C	Peleg	K1 = 3.5211, K2 = 0.7599	0.0439	0.9724	0.0541	0.0034
	Page	K = 0.7923, n = 0.1502, Me = 143.9786	0.0219	0.9862	0.0382	0.0018
	Kaptso	K = 0.2076, T = 9.5356, Me = 142.3389	0.0450	0.9719	0.0548	0.0037
	Weibul	a = 10.9378, b = 0.7923, Me = 143.9785	0.0219	0.9862	0.0382	0.0018
	First order	K = 0.0814, me = 143.5201	0.0252	0.9842	0.0410	0.0019
40 °C	Peleg	K1 = 7.0208, K2 = 0.6714	0.0506	0.9865	0.0581	0.0039
	Page	K = 0.8471, n = 0.083, Me = 157.7889	0.0372	0.9942	0.0498	0.0031
	Kaptso	K = 0.1525, T = 11.6329, Me = 149.3876	0.0450	0.9767	0.0548	0.0038
	Weibul	a = 15.418, b = 0.7976, Me = 152.0426	0.0015	0.9992	0.0100	0.0001
	First order	K = 0.0606, me = 151.26	0.0061	0.9968	0.0201	0.0005
30 °C	Peleg	K1 = 6.6243, K2 = 0.7712	0.0620	0.9853	0.0643	0.0048
	Page	K = 0.6875, n = 0.1546, Me = 139.2214	0.0407	0.9940	0.0521	0.0034
	Kaptso	K = 0.098, T = 15.9966, Me = 161.117	0.0577	0.9770	0.0620	0.0048
	Weibul	a = 22.1878, b = 0.9007, Me = 163.5391	0.0052	0.9978	0.0185	0.0004
	First order	K = 0.0444, me = 163.0231	0.0067	0.9972	0.0212	0.0005

Table 6: Model parameter for modelling of Drum variety

Temperature	Model	Model constant	Statistical parameter			
			SEE	R^2	RMSE	χ^2
70 °C	Peleg	K1 = 2.4364, K2 = 0.9919	0.0037	0.9960	0.0157	0.0003
	Page	K = 0.8931, n = 0.163, Me = 112.5775	0.0004	0.9996	0.0051	0.0000
	Kaptso	K = 0.254, T = 7.8713, Me = 112.292	0.0012	0.9987	0.0089	0.0001
	Weibul	a = 7.6209, b = 0.8931, Me = 112.5775	0.0004	0.9996	0.0051	0.0000
	First order	K = 0.1213, me = 112.5042	0.0004	0.9995	0.0055	0.0000
60 °C	Peleg	K1 = 1.3507, K2 = 1.0267	0.0028	0.9968	0.0136	0.0002
	Page	K = 2.0938, n = 0.008, Me = 109.7671	0.0007	0.9992	0.0069	0.0001

	Kaptso	K = 0.2899, T = 6.8337, Me = 109.7784	0.0007	0.9992	0.0068	0.0001
	Weibul	a = 6.8302, b = 1.0722, Me = 109.8274	0.0007	0.9992	0.0066	0.0001
	First order	K = 0.1551, me = 109.8427	0.0007	0.9992	0.0066	0.0001
50 °C	Peleg	K1 = 2.6496, K2 = 0.8969	0.0533	0.9544	0.0596	0.0041
	Page	K = 1.2057, n = 0.0542, Me = 123.1242	0.0250	0.9787	0.0408	0.0021
	Kaptso	K = 0.2244, T = 9.2603, Me = 122.8658	0.0261	0.9777	0.0417	0.0022
	Weibul	a = 11.2171, b = 1.2058, Me = 123.1242	0.0250	0.9787	0.0408	0.0021
	First order	K = 0.0972, me = 123.273	0.0257	0.9781	0.0414	0.0020
40 °C	Peleg	K1 = 8.3219, K2 = 0.7559	0.0435	0.9765	0.0539	0.0033
	Page	K = 0.8452, n = 0.0802, Me = 140.0091	0.0237	0.9895	0.0397	0.0020
	Kaptso	K = 0.1534, T = 11.7596, Me = 137.7025	0.0336	0.9798	0.0473	0.0028
	Weibul	a = 15.6295, b = 0.8644, Me = 139.7626	0.0017	0.9989	0.0107	0.0001
	First order	K = 0.0612, me = 139.3415	0.0034	0.9979	0.0152	0.0003
30 °C	Peleg	K1 = 6.8988, K2 = 0.7712	0.0376	0.9834	0.0500	0.0029
	Page	K = 0.6875, n = 0.1546, Me = 139.2214	0.0240	0.9904	0.0400	0.0020
	Kaptso	K = 0.0812, T = 17.7354, Me = 138.2399	0.0504	0.9730	0.0580	0.0042
	Weibul	a = 24.9156, b = 0.8541, Me = 140.4639	0.0018	0.9990	0.0109	0.0001
	First order	K = 0.0395, me = 139.7282	0.0051	0.9972	0.0185	0.0004

Table 7: Model parameter for modelling of *Oloyin* brown variety

Temperature	Model	Model constant	Statistical parameter			
			SEE	R^2	RMSE	χ^2
70 °C	Peleg	K1 = 1.1269, K2 = 1.0681	0.0036	0.9955	0.0155	0.0003
	Page	K = 5.4884, n = 2397.713, Me = 103.2242	0.0074	0.9908	0.0222	0.0006
	Kaptso	K = 0.3044, T = 7.0578, Me = 103.8377	0.0007	0.9992	0.0067	0.0001
	Weibul	a = 13.893, b = 11.3828, Me = 103.8308	0.0007	0.9992	0.0067	0.0001
	First order	K = 0.1607, me = 103.8791	0.0008	0.9990	0.0072	0.0001
60 °C	Peleg	K1 = 1, K2 = 1.0121	0.0139	0.9845	0.0304	0.0011
	Page	K = 3.0353, n = 0.0086, Me = 108.5042	0.0054	0.9940	0.0190	0.0004
	Kaptso	K = 2.4689, T = 0.8901, Me = 108.5042	0.0054	0.9940	0.0190	0.0004
	Weibul	a = 2.5073, b = 1.8337, Me = 108.5042	0.0054	0.9940	0.0190	0.0004
	First order	K = 4.7984, me = 108.5042	0.0054	0.9940	0.0190	0.0004
50 °C	Peleg	K1 = 2.8539, K2 = 0.8012	0.0547	0.9623	0.0604	0.0042
	Page	K = 0.864, n = 0.136, Me = 133.6083	0.0310	0.9786	0.0455	0.0026
	Kaptso	K = 0.24, T = 9.698, Me = 132.6118	0.0411	0.9718	0.0523	0.0034
	Weibul	a = 10.0636, b = 0.864, Me = 133.6082	0.0310	0.9786	0.0455	0.0026
	First order	K = 0.0919, me = 133.3993	0.0318	0.9781	0.0461	0.0024
40 °C	Peleg	K1 = 9.0144, K2 = 0.707	0.0092	0.9968	0.0248	0.0007
	Page	K = 0.6421, n = 0.1427, Me = 147.2689	0.0103	0.9963	0.0263	0.0009
	Kaptso	K = 0.1056, T = 14.8035, Me = 143.7714	0.0884	0.9560	0.0768	0.0074
	Weibul	a = 19.6205, b = 0.6668, Me = 147.9545	0.0060	0.9969	0.0200	0.0005
	First order	K = 0.0475, me = 145.7286	0.0231	0.9881	0.0393	0.0018
30 °C	Peleg	K1 = 6.8988, K2 = 0.7712	0.0077	0.9977	0.0226	0.0006
	Page	K = 0.6875, n = 0.1546, Me = 139.2214	0.0119	0.9954	0.0282	0.0010
	Kaptso	K = 0.0919, T = 16.0945, Me = 141.5887	0.1003	0.9491	0.0818	0.0084
	Weibul	a = 22.0161, b = 0.6199, Me = 146.6721	0.0076	0.9960	0.0224	0.0006
	First order	K = 0.0432, me = 143.4818	0.0322	0.9833	0.0463	0.0025

Table 8: Model parameter for modelling of *Sokoto* variety

Temperature	Model	Model constant	Statistical parameter			
			SEE	R^2	RMSE	χ^2
70 °C	Peleg	K1 = 1.3074, K2 = 1.0034	0.0132	0.9856	0.0297	0.0010
	Page	K = 3.0353, n = 0.0086, Me = 110.444	0.0197	0.9785	0.0363	0.0016
	Kaptso	K = 2.3947, T = 0.8633, Me = 110.444	0.0197	0.9785	0.0363	0.0016
	Weibul	a = 2.5073, b = 1.8337, Me = 110.444	0.0197	0.9785	0.0363	0.0016
	First order	K = 4.7984, me = 110.444	0.0197	0.9785	0.0363	0.0015
60 °C	Peleg	K1 = 0.8442, K2 = 0.9642	0.0072	0.9928	0.0219	0.0006
	Page	K = 3.0353, n = 0.0086, Me = 114.9667	0.0105	0.9895	0.0264	0.0009
	Kaptso	K = 2.4207, T = 0.8727, Me = 114.9667	0.0105	0.9895	0.0264	0.0009
	Weibul	a = 2.5073, b = 1.8337, Me = 114.9667	0.0105	0.9895	0.0264	0.0009
	First order	K = 4.7984, me = 114.9667	0.0105	0.9895	0.0264	0.0008
50 °C	Peleg	K1 = 2.3926, K2 = 0.8672	0.0416	0.9663	0.0527	0.0032
	Page	K = 1.0023, n = 0.1021, Me = 126.1313	0.0209	0.9831	0.0373	0.0017
	Kaptso	K = 0.2413, T = 9.0303, Me = 125.6975	0.0235	0.9810	0.0396	0.0020
	Weibul	a = 9.74, b = 1.0023, Me = 126.1313	0.0209	0.9831	0.0373	0.0017
	First order	K = 0.1028, me = 126.1334	0.0209	0.9831	0.0373	0.0016
40 °C	Peleg	K1 = 6.1186, K2 = 0.7297	0.0636	0.9661	0.0651	0.0049
	Page	K = 0.8144, n = 0.1039, Me = 144.7903	0.0370	0.9828	0.0497	0.0031
	Kaptso	K = 0.1956, T = 10.6706, Me = 138.8383	0.0354	0.9781	0.0486	0.0029
	Weibul	a = 12.9528, b = 0.865, Me = 140.5344	0.0136	0.9915	0.0301	0.0011
	First order	K = 0.073, me = 140.2024	0.0150	0.9907	0.0316	0.0012
30 °C	Peleg	K1 = 6.8988, K2 = 0.7712	0.0371	0.9862	0.0498	0.0029
	Page	K = 0.6875, n = 0.1546, Me = 139.2214	0.0261	0.9913	0.0417	0.0022
	Kaptso	K = 0.1009, T = 14.9642, Me = 146.7307	0.0681	0.9669	0.0674	0.0057
	Weibul	a = 19.9692, b = 0.7814, Me = 149.4733	0.0018	0.9991	0.0110	0.0002
	First order	K = 0.0477, me = 148.3688	0.0092	0.9954	0.0248	0.0007

Thermodynamic Approach

Arrhenius equation was used for the evaluation of the temperature dependence of K_1 in peleg model. The activation energy is a function of temperature and therefore represents the influence of temperature on K_1. Table 9shows the activation energy obtained by nonlinear regression of K_1 as an exponential function of inverse temperature. The average values of Ea obtained for the five varieties of cowpea; *Gombe, Oloyin* white, Drum, *Oloyin* brown and *Sokoto* varieties are 42.26 ± 4.65, 40.36 ±8.90, 39.47 ±8.62, 43.08 ±5.25 and 39.66 ±6.72 respectively. The lower value of Ea and the negatives values of entropy indicate that the seeds were more thermally stable and hydration changes was less influenced by temperature[40].

The values of enthalpy (ΔH*) in Table 9 were negative at all temperature and varieties, indicating that cowpea hydration is associated with exothermic (energetically favourable) transformations. The values of enthalpy vary from one variety to the other. The negative values of enthalpy in the hydration was also verified [40] for Bambara seeds and [41] for barley.

Gibbs free energy is the driving force at constant temperature and pressure. Changes in free energy are generally coupled with enthalpy and entropy changes. The sign of ΔG informs about the spontaneity of the reaction. If ΔG < 0, the reaction is spontaneous [42]. In this study, positive values of ΔG were obtained, showing that the process was not spontaneous. A noticeable difference was found in ΔG for all the varieties at different temperatures. The ΔG* decreased with increasing temperature was observed, indicating that hydration was influenced by temperature.

Table 9: Thermodynamic parameters of the hydration of *Gombe* variety

Varieties	Temperature (K)	Ea (kJ/mol)	ΔH (cal/mol)	ΔS (cal/kmol)	ΔG (kcal/mol)
Gombe	343	38.51	-2813.2	-230.46	76.23
	333	39.28	-2729.28	-236.04	75.87
	323	40.34	-2645.08	-236.28	73.67
	313	43.21	-2559.07	-220.71	66.52
	303	49.94	-2469.2	-212.27	61.85
Oloyin white	343	25.67	-2826.03	-220.14	72.68
	333	49.43	-2719.14	-210.58	67.4
	323	40.44	-2644.98	-217.75	67.69
	313	44.45	-2557.83	-218.83	65.94
	303	41.79	-2477.35	-213.93	62.34
Drum	343	25.16	-2826.54	-219.73	72.54
	333	40.68	-2727.89	-213.82	68.47
	323	40.44	-2644.98	-215.39	66.92
	313	48.45	-2553.83	-219.85	66.26
	303	42.65	-2476.49	-214.1	62.39
Oloyin brown	343	36.37	-2815.33	-215.34	71.05
	333	45.73	-2722.83	-211.79	67.8
	323	40.44	-2644.98	-216	67.12
	313	50.21	-2552.07	-220.34	66.41
	303	42.66	-2476.49	-214.09	62.39
Sokoto	343	33.78	-2817.92	-216.11	71.31
	333	48.9	-2719.66	-210.68	67.44
	323	40.44	-2644.98	-214.54	66.65
	313	32.52	-2569.77	-218.87	65.94
	303	42.66	-2476.49	-214.09	62.39

CONCLUSION

The following information were drawn based on the finding of the study of hydration characteristics of five different varieties of cowpea as function of temperature;

1. The initial moisture content of the saturated cowpea was estimated as 13.56 ±1.15, 15.05 ±2.27, 13.30 ±0.37, 10.85 ±0.13, 12.40 ±0.13 for *Gombe*, *Oloyin* white, Drum, *Oloyin* brown and *Sokoto* varieties respectively.
2. The weight of the seed was measured as 0.19 ± 0.04, 0.30 ± 0.07, 0.34 ± 0.05, O.25 ± 0.04 and 0.25 ± 0.04g for *Gombe*, Drum, *Sokoto*, *Oloyin* white, and *Oloyin* brown respectively.
3. The length (L), width (W), and thickness (T) was measured as 0.89 ± 0.11, 0.70 ± 0.07 and 0.58 ± 0.08 respectively for *Gombe* variety; 1.15 ± 0.10, 0.82 ± 0.09 and 0.61 ± 0.07

for Drum variety respectively, 1.15 ± 0.14, 0.8 ± 0.15 and 0.68 ± 0.07 for *Sokoto* variety respectively, 1.02 ± 0.21, 0.75 ± 0.10 and 0.60 ± 0.06 for *Oloyin* white variety respectively and 1.12 ± 0.12, 0.81 ± 0;10 and 0.56 ± 0.06 for *Oloyin* brown respectively.

4. The water uptake of the cowpea was faster at the initial stage and gradually slow down until the equilibrium moisture content is attained for all the varieties.
5. Weibull model was adjudged as the best fitted model for describing the water absorption property of all the selected varieties of the cowpea.
6. The Activation energy of the selected five varieties of cowpea; *Gombe, Oloyin* white, Drum, *Oloyin* brown and *Sokoto* varieties are 42.26 ± 4.65, 40.36 ± 8.90, 39.47 ± 8.62, 43.08 ± 5.25 and 39.66 ± 6.72 respectively and drum varieties will be more stable during processing as it has the lowest Activation energy of 39.47 ±8.62.
7. The information provided on the physical property can be used to facilitate the design of handling and processing equipment for the selected cowpea.

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