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*RESEARCH ARTICLE*

# COMPARATIVE MOISTURE ADSORPTION BEHAVIOUR AND ISOTHERM MODELLING OF SEED POWDERS FROM FOUR BAMBARA GROUNDNUT (*VIGNA SUBTERRANEA* L. VERDC.) CULTIVARS FROM CÔTE D'IVOIRE

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## *Abstract*

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Bambara groundnut (*Vigna subterranea* L. Verdc.) is a african legume widely cultivated in sub-Saharan Africa and constitutes a nutritionally complete food for many West African populations. Since its seed powder is hygroscopic, mastery of its moisture sorption behavior is essential for optimizing drying and storage conditions and ensuring product quality. Moisture sorption isotherms are fundamental tools for predicting the stability and shelf life of dehydrated food products. The present study therefore sought to characterize and model the hygroscopi c behavior of seed powders of four cultivars of bambara groundnut from Côte d'Ivoire: Red Mottled Beige (RMB), Uniform Red (UR), Uniform Black (UB) and Beige with Black Hilum (BBH). The experim ental adsorption isotherms were determined by the static gravimetric microclimate method at room temperature (29 ± 1°C). Three widely used sorption isotherm models GAB, Oswin and Chung-Pfost were fitted to the experimental data by direct nonlinear least squares regressi on. The monolayer moisture contents (Mo) of the four powders were estimated from the GAB model parameters. The results showed that the adsorption isotherms of all four bambara groundnut powders are of Type II, according to the BET classification. The GAB model provided the best fit to the experimental data, with the highest $R^2$ values (0.996) and the lowest SEM (0.902) and RMSE (0.625) values, outperforming both the Oswin and Chung-Pfost models. The monolayer moisture contents determined were 5.9% (RMB), 5.6% (UR), 5.4% (UB) and 5.7% (BBH) on a dry basis. These low Mo values, markedly below those reported for dried fruits,indicate that bambara groundnut powders require relatively little bound water to achieve monolayer stability. Storing the powders at or below their respective Mo values is recomme nded to minimize chemical deterioration reactions including lipid oxidation, Maillard browning and enzymatic degradation and to ensure their microbiological and physicochemical stability throughout the post-drying storage period.



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## Introduction:-

Bambara groundnut (*Vigna subterranea* L. Verdc.) is a leguminous plant originating from West Africa, widely cultivated throughout sub-Saharan Africa under various vernacular names, including voandzou (Madagascar), njugo bean (southern Africa) or earth pea (West Africa). It is considered the third most important legume in Africa after groundnut and cowpea (Bamshaiyeet al., 2011). As a nitrogen-fixing crop, bambara groundnut contributes to soil fertility and is particularly well adapted to poor and semi-arid soils, making it a crop of great agronomic importance in regions prone to food insecurity (Mkandawire, 2007). The seeds are recognized as a nutritionally complete and balanced food, being rich in proteins (15-25%), carbohydrates (50-60%), lipids (5-8%) and dietary fiber, as well as essential micronutrients including iron, zinc and calcium (Gbaguidiet al., 2015).

In many West African countries, these dried seeds are transformed into flour or powder, which serves as a raw material for the preparation of a variety of traditional foods, including bread, thick porridges and fermented products. The conversion of bambara groundnut seeds into powder form offers several practical advantages, notably improved handling, extended shelf life and greater versatility in food formulation. However, since powder is a hygroscopic material, it is highly sensitive to moisture uptake during storage, which can trigger deteriorative reactions including microbial growth, caking, lipid oxidation and loss of nutritional quality (Goli, 1997). It is therefore imperative to stabilize the quality of bambara groundnut powder by rigorously controlling its drying and storage conditions.

Moisture sorption isotherms describe the equilibrium relationship between the water activity of a food product and its equilibrium moisture content (EMC) at a given temperature. They are fundamental tools in food science and technology, providing essential information for the optimization of drying, packaging and storage operations (Van den Berg and Bruin, 1981). In the food industry, knowledge of sorption isotherms is indispensable for predicting the qualitative and microbiological stability of dehydrated products, as well as for selecting appropriate packaging materials that limit moisture transfer between the product and its environment (Arslan and Tog'rul, 2005). The shape of the sorption isotherm reflects the physicochemical interactions between water molecules and the food matrix constituents proteins, starch, sugars, dietary fibers and thus directly informs on the hygroscopic nature of the product. Furthermore, a thorough understanding of hygroscopic behavior is essential for accurately assessing the drying kinetics and determining the critical moisture content below which the product is considered stable for storage. Sorption isotherms also allow the prediction of the optimal packaging choice for dehydrated food products (Ouafiet al., 2015).

Since sorption isotherms are determined experimentally at a limited number of water activity values, the use of mathematical models is essential to interpolate and extrapolate the moisture sorption behavior of food products across a wider range of conditions. Mathematical modeling facilitates the prediction of hygroscopic behavior, the optimization of drying processes and the rational design of storage systems (Arslan and Tog'rul, 2005). Numerous empirical, semi-empirical and theoretical models have been proposed in the literature to describe the moisture sorption behavior of food products, including the GAB (Guggenheim-Anderson-de Boer), BET (Brunauer-Emmett-Teller), Oswin, Henderson, Halsey and Chung-Pfost models, among others. It is imperative to select an appropriate model when analyzing experimental sorption data, as no single model provides a universally accurate fit for all food products. The selection of the most suitable model depends on several criteria: the quality of fit to experimental sorption data, the range of water activity covered, the theoretical basis and physical interpretability of the model parameters, the simplicity of the equation, and the specific objectives of the study (Arslan and Tog'rul, 2005). Among the models most widely used in the food science literature, the GAB model is particularly valued for its theoretical soundness and its ability to accurately describe sorption data across a broad range of water activity values (0.05-0.95), as well as for providing a direct estimate of the monolayer moisture content (Mo), a key parameter for assessing food stability (Timmermann, 2003).

Since bambara groundnut (voandzou) seed powder is a hygroscopic material, ambient storage conditions particularly relative humidity and temperature can have a significant impact on its physicochemical and microbiological quality. Fluctuations in moisture content during storage may promote caking, microbial proliferation, lipid oxidation and non-enzymatic browning, all of which contribute to a reduction in shelf life and nutritional value. Therefore, a thorough characterization of its sorption behavior is imperative to establish reliable storage guidelines. The determination of sorption isotherms for bambara groundnut powder will enable the prediction of its shelf life under different storage conditions, the identification of its critical moisture content for microbiological acceptability, and the establishment of safe water activity thresholds below which chemical and enzymatic deterioration reactions are minimized (Ouafiet al., 2015). Such information is essential for the development of appropriate drying protocols and packaging strategies aimed at extending the shelf life of this nutritionally valuable food product. The present study sought to model the adsorption isotherms of seed powders of four bambara groundnut cultivars Red Mottled Beige, Uniform Red, Uniform Black and Beige with Black Hilum at room temperature (29 ± 1°C), using the GAB, Oswin and Chung-Pfost models, and to determine the monolayer moisture content of each cultivar as a key indicator of powder stability during storage.

## Materials and Methods:-

### Biological Material:-

The plant material consists of fresh seeds from four cultivars of Bambara groundnut [Red Mottled Beige (RMB), Uniform Red (UR), Uniform Black (UB), Beige with Black Hilum (BBH)]. The cultivation of these four varieties of Bambara groundnut took place in the village of Diasson (Adzopé, Côte d'Ivoire). The seeds were harvested at physiological maturity. The freshly harvested seeds (20 kg) were processed in the laboratory according to the method used by Diallo (2015) for the various analyses.

### Production of bambara groundnut powder:-

The production of bambara groundnut seed powders was carried out in accordance with the diagram utilised by Diallo (2015). The seeds of each bambara groundnut cultivar were washed with water and then dried at room temperature in the laboratory for 24 hours. The subsequent grinding of the grains was conducted using an electric grain mill (DY368 DIF, Leipzig, Germany). The powders were then sieved (AS 200 sieve shaker; Retsch GmbH, Germany) in order to obtain a powder with a particle size of 0.5 mm. The resulting powder was then bagged and stored at room temperature (29 ± 1°C).

### Determination of moisture adsorption isotherms:-

The adsorption isotherms of seed powders from four cultivars of Bambara groundnut were determined by the gravimetric method. The process begins with the preparation of saturated salt solutions. Each prepared saturated salt solution is then placed in a desiccator to establish the equilibrium relative humidity, 24 hours before the start of mass measurements. The temperature and internal relative humidity of the desiccators are then constantly monitored using a thermo-hygrometer (Haar-47 synthhygro, Göttingen, Germany). Table 1 provides data on the water activities of the various saturated salt solutions used in this study. In cases of high water activities ($a_w > 0.7$), thymol crystals are placed in the desiccators to inhibit mold growth (Ngabea, 2022).

The microclimate method involves the placement of five grams of each bambara groundnut powder, which has been dried in an oven at 105°C for 24 hours, into desiccators containing a saturated salt solution. The variation in mass of each bambara groundnut powder is monitored using a digital display electronic balance (Scientech SA 210, Beijing, China) with a precision of 0.001 g. The bambara groundnut powder is weighed regularly twice a day (at regular time intervals of 8 hours) until a constant mass is obtained, indicating the end of the exchange between the powder and the ambient air. This is indicative of hygroscopic or thermodynamic equilibrium, which is characterised by the absence of exchange of matter (water) between the powder and the ambient air, resulting in a stabilisation of mass (variation less than or equal to 0.001 g).

Each experiment is performed in triplicate. The results are expressed as a percentage of water absorbed per 100 g of dry matter. Following the attainment of equilibrium, the moisture or water content of each bambara groundnut powder is to be determined by the following equation:

$$Xeq = \frac{\mathrm{Wm} - \mathrm{Dm}}{\mathrm{Dm}} \times 100$$

Wm = wet mass (g);
Dm = dry mass (g);
Xeq = Equilibrium moisture content (g/100g of d.m.)
The pairs (aw, Xeq) constitute the points of the adsorption isotherm.

**Table 1: Selected salts used for preparing saturated salt solutions and their corresponding water activities (29 ± 1°C)**

| Salt Solutions | Water Activity |
|---|---|
| Potassium hydroxide (KOH) | 0.07 |
| Lithium chloride (LiCl) | 0.11 |
| Potassium acetate ($CH_3COOK$) | 0.23 |
| Magnesiumchloride ($MgCl_2$, $6H_2O$) | 0.34 |
| Potassium carbonate ($K_2CO_3$) | 0.43 |
| Calcium nitrate ($Ca(NO_3)_2$) | 0.56 |
| Sodium nitrite ($NaNO_2$) | 0.65 |
| Sodium nitrate ($NaNO_3$) | 0.72 |
| Sodium chloride (NaCl) | 0.75 |
| Potassium chloride (KCl) | 0.83 |
| Bariumchloride ($BaCl_2$) | 0.90 |
| Potassium sulfate ($K_2SO_4$) | 0.95 |

**Mathematical modelling of adsorption data:-**

Numerous mathematical equations have been proposed for modeling food sorption isotherms. The implementation of these models is a methodological approach that facilitates the evaluation of their quality and precision. This evaluation is carried out through a comparative analysis of the model with experimental adsorption data (Feradjiet al., 2008). As illustrated in Table 2, three models (GAB, Oswin, and Chung-Pfost) were used to fit the experimental adsorption isotherms of seed powders from four bambara groundnut cultivars. These models are adopted as standard models to describe the sorption isotherms of food products by the American Society of Agricultural Engineers (Ngabea, 2022).

**Table 2 : Mathematical models used to describe adsorption isotherms of bambara groundnut powders**

| Model name | Equation | Parameters | Range |
|---|---|---|---|
| GAB (1966) | $M = \frac{MoCKaw}{(1-Kaw)(1+(C-1)Kaw)}$ | K, C, $M_0$ | Full curve |
| Oswin (1946) | $M = A\left(\frac{aw}{1-aw}\right)^B$ | A et B | Full curve |
| Chung-Pfost (1967) | $M = \frac{1}{B}(\ln A - \ln(-\ln aw))$ | A et B | Full curve |

M is the moisture content of the product on a dry basis (g of water/100 g of dry matter).
Mo is the monolayer moisture content in the B.E.T theory (g/100 g d.m.).
K is the constant related to the properties of the multilayer molecules or correction factor.
C is the Guggenheim constant related to the heat of sorption.
A and B are constants.
aw is the water activity.

The determination of the constants of the models employed was achieved through the utilisation of nonlinear regression. The applicability of the models was evaluated using statistical parameters such as the coefficient of determination ($R^2$), which is one of the primary criteria for predicting the best fitting of experimental adsorption isotherms by a model. In addition to $R^2$, the standard error of moisture (SEM) and the root mean square error (RMSE) were utilised (Kakouet al., 2015). The calculation of these two statistical parameters is outlined below:

$$SEM = \sqrt{\frac{\sum_{i=1}^{N}(X_{eqi.exp} - X_{eqi.pre})^2}{d_f}}$$

$$RMSE = \frac{1}{N}\sum_{i=1}^{N}(X_{eqi.exp} - X_{eqi.pre})^2$$

**Where:**
Xeqi,exp : I th experimental equilibrium moisture content (% d.m.);
Xeqi,pre : i-th predicted equilibrium moisture content (% d.m.);
N : number of experimental data points,
df : degrees of freedom of the model regression, {df = N - n},
n : number of variables in each model.

**Statistical Analysis:-**
The modelling of experimental adsorption isotherms necessitates the employment of statistical methods of regression and correlation analysis. The quality of fit of the mathematical models was assessed by examining the distribution of experimental data points relative to the theoretical curves of the mathematical models and by the sum of squared deviations (Tsamiet al., 1990). The solving method employed in this study was Minitab software, version 18.4. The software provides the coefficient of determination ($R^2$), the standard error of moisture (SEM), and the root mean square error (RMSE) as criteria for model fitting and selecting the most appropriate model.

## Results and Discussion:-

**Adsorption characteristics of powders from four different bambara groundnut cultivars**
As illustrated in Figure 2, a comparison is made of the experimental adsorption isotherms of the powders of the four bambara groundnut cultivars (Red Mottled Beige, Uniform Red, Uniform Black, and Beige with Black Hilum). It is important to note that each point on the experimental adsorption isotherm represents the average of three replicate equilibrium moisture content (EMC) measurements, ensuring the statistical reliability of the data. The adsorption isotherms demonstrate that the absorption of water by the four bambara groundnut powders is minimal at low water activities ($a_w < 0.25$), which corresponds to conditions where water molecules are tightly bound to the most energetically active sites of the food matrix and are therefore unavailable for chemical or microbial reactions (Labuza, 1980). Conversely, at high water activities ($a_w > 0.75$), a sharp and rapid increase in moisture uptake is observed, reflecting the predominance of capillary condensation and the dissolution of soluble constituents such as sugars and salts. This behavior in the high water activity range is particularly critical from a food stability perspective, as it corresponds to conditions favorable to microbial growth, enzymatic activity and accelerated Maillard browning reactions (Labuza and Altunakar, 2007).

The experimental adsorption isotherms of the four bambara groundnut seed powders are of type II (sigmoid shape), according to the BET classification of Brunauer, Emmett and Teller (1938), as is the case for the majority of protein and starch-rich agri-food products. This sigmoidal shape is characteristic of multilayer water adsorption: at low water activities, water is bound as a monolayer to polar active sites (proteins, starch, fiber); at intermediate activities, additional layers form progressively; and at high activities, capillary condensation dominates (Al-Muhtaseb et al., 2002). The following ranking was established for the four bambara groundnut powders according to their decreasing hygroscopicity at the highest water activity measured: the Uniform Black cultivar (43.8 ± 0.009 g/100g d.m.), the Beige with Black Hilum (42.0 ± 0.007 g/100g d.m.), the Uniform Red (41.6 ± 0.005 g/100g d.m.) and the Red Mottled Beige (41.3 ± 0.009 g/100g d.m.). These inter-cultivar differences in hygroscopicity may be attributed to variations in their biochemical composition, particularly the proportion of hydrophilic constituents such as proteins, dietary fibers and soluble carbohydrates, which are known to strongly influence water-binding capacity in legume flours (Rao et al., 2016). The relatively narrow range of EMC values across cultivars (41.3-43.8 g/100g d.m.) suggests, however, an overall similar moisture-binding behavior, consistent with their shared botanical origin. These results are analogous to those reported by Alakali and Satimehin (2007), who determined the sorption isotherms of bambara groundnut flours, both dehulled and non-dehulled, and likewise observed sigmoid-shaped Type II isotherms, confirming the typical hygroscopic behavior of this legume species regardless of processing.

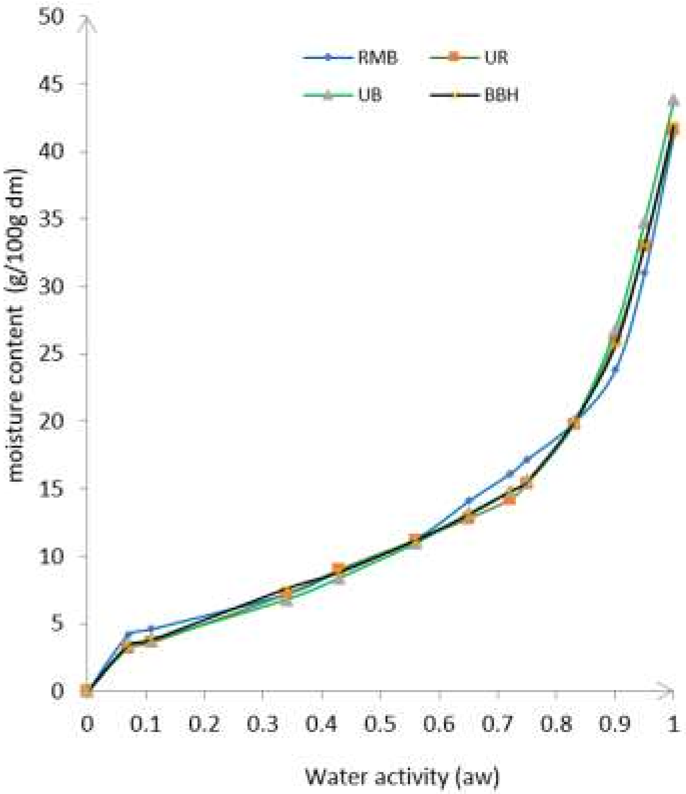


**Figure 2: Experimental adsorption isotherms of the powders from the four bambara groundnut cultivars (29°C± 1°C)**

RMB: Red Mottled Beige
UR: Uniform Red
UB: Uniform Black
BBH: Beige with Black Hilum

**Fitting of adsorption models to experimental data of seed powders from four bambara groundnut cultivars:-**
The mathematical modeling of moisture sorption isotherms is a fundamental step in understanding the hygroscopic behavior of food powders and in establishing appropriate storage and packaging conditions (Van den Berg and Bruin, 1981). In this study, the experimental adsorption isotherms of the four bambara groundnut cultivars (RMB, UR, UB and BBH) were fitted using three well-established models, namely the GAB (Guggenheim–Anderson–de Boer), Oswin and Chung-Pfost models. These models were selected for their wide application in the literature for describing the sorption behavior of food materials over a broad range of water activity values. The models, their equation constants, coefficients of determination ($R^2$), standard errors of moisture (SEM) and root mean square errors (RMSE) are presented in Table 3. The goodness of fit of each model was assessed using these three statistical criteria, which are among the most commonly employed in food sorption studies (Lomauroet al., 1985). Specifically, the $R^2$ value quantifies the proportion of variance in the experimental data explained by the model, while SEM and RMSE measure the average deviation between experimental and predicted values, with lower values indicating better predictive accuracy. The most applicable model is therefore the one that simultaneously presents the highest $R^2$ value ($R^2 > 0.85$) and the lowest SEM and RMSE values (<10%) (Benhamou et al., 2010). The use of combined criteria rather than a single indicator ensures a more robust and reliable model selection, minimizing the risk of overfitting or misrepresentation of the experimental data.

The fitting of experimental adsorption isotherm data to mathematical models is essential for predicting the moisture sorption behavior of food powders and for optimizing their packaging and storage conditions (Van den Berg and

Bruin, 1981). Among the models evaluated in this study, the GAB (Guggenheim-Anderson-de Boer) model presents the lowest values of SEM (0.902) and RMSE (0.625), as well as the highest $R^2$ value (0.996) (Table 3), indicating an excellent goodness of fit between the model predictions and the experimental data. These statistical criteria low SEM and RMSE combined with high $R^2$ are widely accepted criteria for model selection in food moisture sorption studies (Lomauro et al., 1985). In contrast, the Chung-Pfost model presents the lowest $R^2$ value and the least favorable SEM and RMSE values, suggesting that it is poorly suited to describe the sigmoid-shaped (Type II) sorption behavior typically observed in food products rich in proteins and starch such as bambara groundnut powders. The GAB model is therefore considered the most appropriate for fitting the experimental adsorption isotherms of the four bambara groundnut powders. This superiority of the GAB model can be attributed to its three-parameter structure, which accounts for both monolayer and multilayer water adsorption phenomena, unlike simpler two-parameter models (Timmermann, 2003). Consequently, it provides the optimal fit to the experimental adsorption isotherms of bambara groundnut powders. This result is in agreement with those reported by Arevaldo-Pinedoet al., (2004) and Moradet al., (2024), who also found the GAB model to best describe the sorption isotherms of Inga edulis pulp and Moroccan dates, respectively, confirming its versatility and robustness for a wide range of plant-based food products.

Regarding the monolayer moisture content (Mo), derived from the GAB model, it represents the quantity of water tightly and specifically bound to the active sites of the food matrix in a monomolecular layer. This parameter is widely recognized as a key indicator of food stability, since it corresponds to the water activity level at which chemical and biochemical deterioration reactions are at their minimum (Labuza, 1980). Consequently, Mo can be used as an effective criterion to regulate the stability of bambara groundnut powders during storage. The Mo values of the four bambara groundnut cultivar powders ranged narrowly from 5.4% to 5.9% (d.b.), specifically 5.9% (RMB), 5.6% (UR), 5.4% (UB) and 5.7% (BBH). This narrow inter-cultivar range suggests a relatively homogeneous hygroscopic behavior of the powders, likely attributable to similarities in their macromolecular composition, particularly their protein and starch contents, which constitute the primary water-binding sites in legume flours (Al-Muhtasebet al., 2002). These values are markedly lower than those reported by Ferradji and Malek (2005) for dried fruits, namely apricots (11.7%), raisins (14%) and figs (9.7%). This difference can be explained by the considerably higher soluble sugar content of dried fruits, which increases their hygroscopicity and thus their capacity to bind water at the monolayer level (Saravacos and Maroulis, 2001). In contrast, bambara groundnut powders, being rich in proteins and complex carbohydrates, exhibit a lower affinity for water at low water activity levels. At the various Mo values determined, chemical deterioration reactions including lipid oxidation, non-enzymatic browning (Maillard reactions) and enzymatic degradation are minimal, and the stability of bambara groundnut powders is satisfactory during storage (Chung et al., 1967). Therefore, storing bambara groundnut powders at moisture contents at or below their respective Mo values would be recommended to ensure optimal preservation of their nutritional and organoleptic quality.

**Table 3 : Estimated parameters of models for the 4 cultivars of bambara groundnut powder.**

| Models | Parameters and Statistical Criteria | RMB | UR | UB | BBH |
|---|---|---|---|---|---|
| GAB | Mo | 0.059 | 0.056 | 0.054 | 0.057 |
| | C | 40.661 | 27.461 | 31.405 | 30.537 |
| | K | 0.857 | 0.870 | 0.886 | 0.868 |
| | EQM | 0.625 | 0.453 | 1.271 | 0.287 |
| | ESH | 0.902 | 0.768 | 1.285 | 0.610 |
| | $R^2$ | 0.996 | 0.997 | 0.997 | 0.998 |

| | | | | | |
|---|---|---|---|---|---|
| OSWIN | A | 10.5 | 09.67 | 9.80 | 9.91 |
| | B | 0.384 | 0.437 | 0.438 | 0.425 |
| | EQM | 0.672 | 0.500 | 0.246 | 0.280 |
| | ESH | 0.906 | 0.782 | 0.548 | 0.585 |
| | $R^2$ | 0.990 | 0.997 | 0.997 | 0.998 |
| Chung-Pfost | A | 3.675 | 2.95 | 2.811 | 3.067 |
| | B | 14.706 | 13.459 | 12.821 | 13.569 |
| | EQM | 1.243 | 2.685 | 3.789 | 2.438 |
| | ESH | 1.233 | 1.812 | 2.152 | 1.726 |
| | $R^2$ | 0.960 | 0.965 | 0.956 | 0.958 |

With regard to the applicability of each model to the individual cultivars, the results reveal contrasting fitting performances across models and genotypes, reflecting differences in the shape of their respective adsorption isotherms. The GAB (Guggenheim–Anderson–de Boer) model provided the best overall fit to the experimental data of the BBH (Beige with Black Hilum) cultivar (Figure 3), yielding the most favorable statistical parameters among all model–cultivar combinations, with $R^2 = 0.998$, SEM = 0.610 and RMSE = 0.287. These values confirm an excellent agreement between the GAB model predictions and the experimental adsorption data for this cultivar, well above the acceptability threshold of $R^2 > 0.85$ and SEM/RMSE < 10% defined by Benhamou et al. (2010). The three-parameter structure of the GAB model, which accounts simultaneously for monolayer and multilayer water adsorption, appears particularly well adapted to describing the sigmoidal isotherm shape of the BBH cultivar over the full range of water activity studied.

The Oswin model, a two-parameter empirical model derived from a mathematical transformation of the Type II sigmoid curve, demonstrated enhanced applicability to the experimental data of two cultivars (Figure 4). For the UB (Uniform Black) cultivar, the Oswin model achieved $R^2 = 0.997$, SEM = 0.548 and RMSE = 0.248, while for the BBH cultivar it yielded $R^2 = 0.998$, SEM = 0.585 and RMSE = 0.280. These results indicate that the Oswin model offers a competitive fit for these two cultivars, comparable in quality to the GAB model for BBH, and even slightly superior for UB in terms of SEM and RMSE. However, unlike the GAB model, the Oswin model does not provide a direct estimate of the monolayer moisture content (Mo), which limits its practical use for assessing the storage stability of these powders.

The Chung-Pfost model (Figure 5) provided a satisfactory but comparatively weaker fit to the experimental data of the RMB (Red Mottled Beige) cultivar ($R^2 = 0.960$; SEM = 1.233 and RMSE = 1.243). While the $R^2$ value remains above the 0.85 acceptability threshold, the SEM and RMSE values are markedly higher than those obtained with the GAB and Oswin models for the other cultivars, suggesting that the Chung-Pfost model captures the overall trend of the isotherm but with lower precision in predicting individual moisture content values. This is consistent with the known limitations of the Chung-Pfost model, which was originally developed for cereal grains and may be less appropriate for protein- and lipid-rich legume powders such as bambara groundnut (Chen and Morey, 1989).

Finally, Figure 6 reveals that none of the three models evaluated provided a satisfactory fit to the experimental adsorption data of the UR (Uniform Red) cultivar, as all three failed to meet the statistical acceptability criteria simultaneously. This cultivar-specific fitting failure may be attributable to a distinctive isotherm shape resulting from particular physicochemical properties of the UR powder, such as differences in protein structure, sugar profile or lipid composition relative to the other cultivars. These findings suggest that the moisture sorption behavior of the UR cultivar may require the evaluation of additional or more flexible models such as the Peleg, Smith or modified GAB models to achieve an adequate description of its experimental adsorption data.

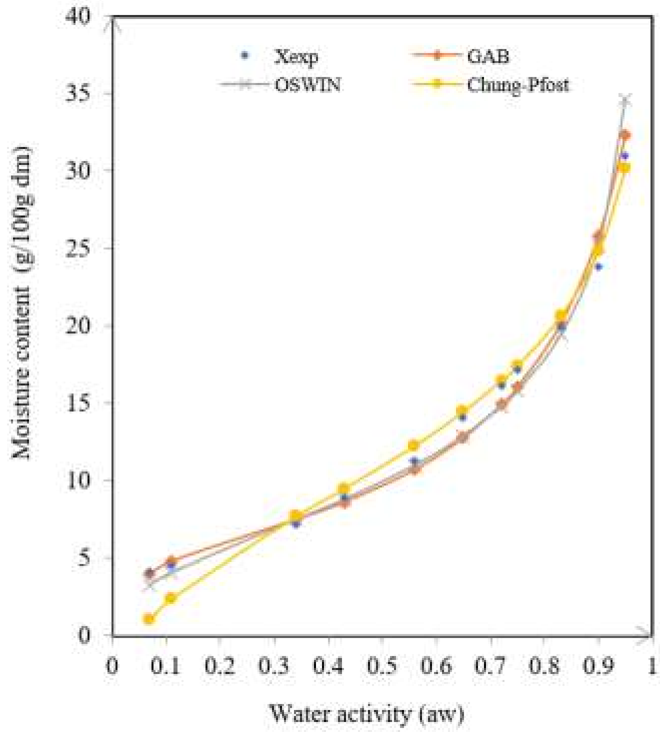


**Figure 3 : Comparaison of experimental and predicted adsorption isotherms of the BBH cultivar's.**

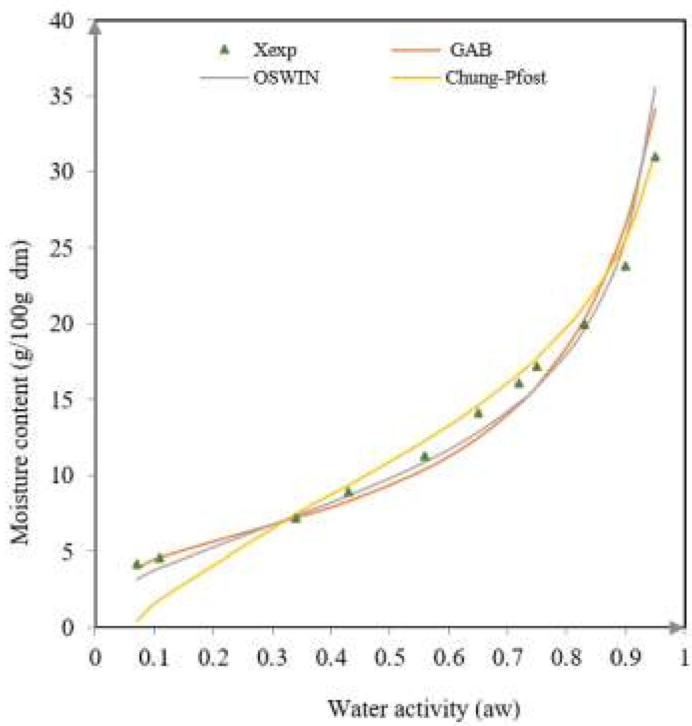


**Figure 4 : Comparaison of experimental and predicted adsorption isotherms of the UB cultivar’s**

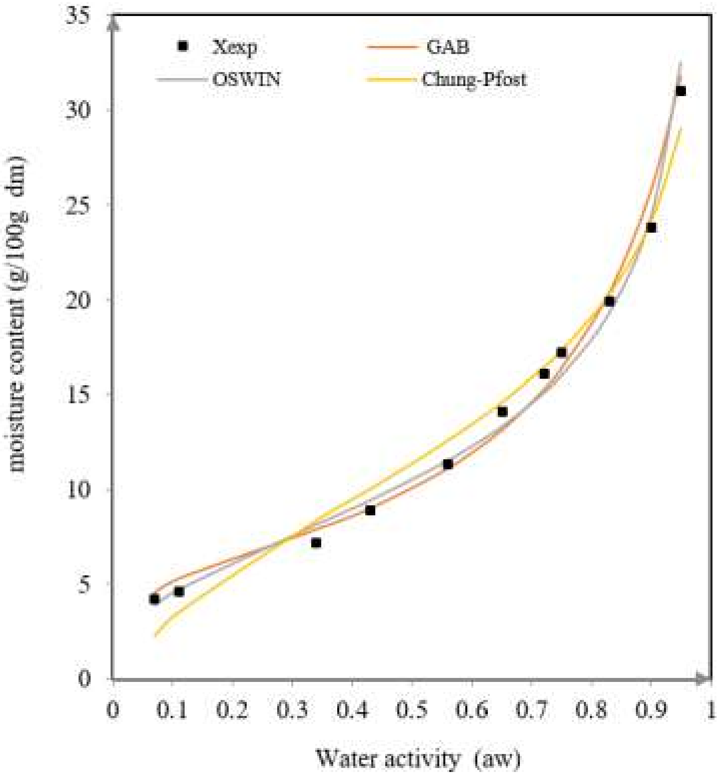


**Figure 5 : Comparaison of experimental and predicted adsorption isotherms of the RMB cultivar's**

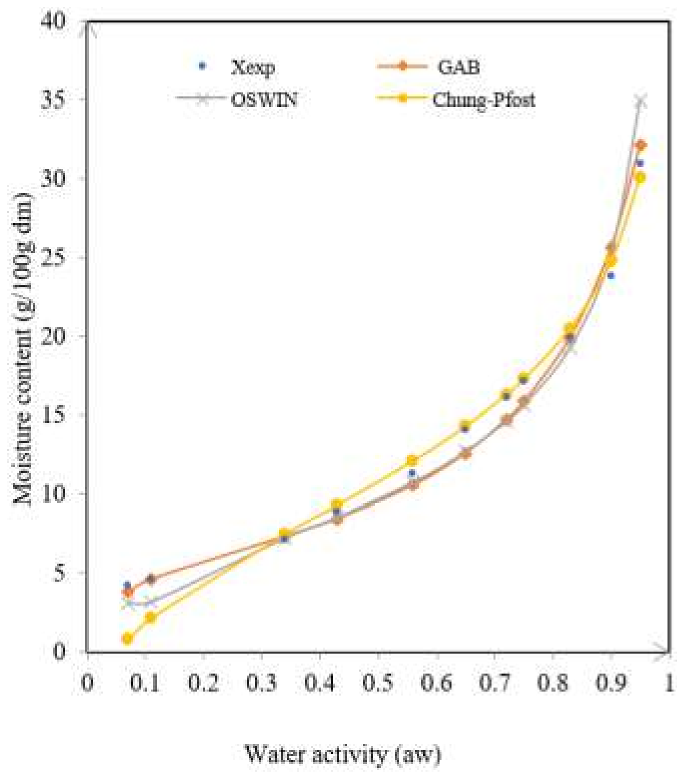


**Figure 6 : Comparaison of experimental and predicted adsorption isotherms of the UR cultivar's**

## Conclusion:-

The objective of this study was to determine the experimental adsorption isotherms of seed powders from four cultivars of bambara groundnut. These experimental adsorption isotherms are of type II. The powder of cultivar UB showed the lowest degree of hygroscopicity, while that of cultivar RMB showed the highest degree of hygroscopicity. Of the three models used, the G.A.B. model provided the best fit for the experimental adsorption isotherm curves of the powders of the four bambara groundnut cultivars. The monolayer moisture contents of the powders of the four bambara groundnut cultivars, RMB, UR, UB and BBH, are respectively 0.059%; 0.056%; 0.054% and 0.057%, at 29°C. It is essential to determine the monolayer moisture contents of the powders of these four bambara groundnut cultivars in order to facilitate the stabilization of their organoleptic and microbiological qualities during storage, which will in turn facilitate their subsequent use.These findings constitute a significant contribution to the knowledge of the hygroscopic properties of bambara groundnut powders from Côte d'Ivoire and provide a scientific basis for the rational design of drying and storage protocols for this nutritionally valuable legume. Future studies should consider the determination of desorption isotherms to characterize the hysteresis phenomenon, as well as the evaluation of the effect of temperature on sorption behavior, in order to develop more comprehensive moisture sorption models applicable to a wider range of storage conditions.

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