# Moisture Adsorption Isotherms of African Arrowroot Lily (*Tacca involucrata*) Tuber Mash as Influenced by Blanching and Natural Fermentation

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## Abstract

The adsorption isotherms of African arrowroot lily (*Tacca involucrata*) as influenced by blanching and natural fermentation were investigated at 10, 20, 30, and 40°C using gravimetric method. The BET, GAB, Oswin, Halsey, Henderson equations were fitted to the experimental sorption data and Clausius-Clapeyron equation was used to determine the isosteric heat of sorption. The equilibrium moisture content of the products at a given water activity is decreased by blanching and fermentation. The developed models, GAB, Oswin, Halsey and Henderson equations in that order provided good fit to experimental data. The BET monolayer moisture contents ( $M_o$ ) values were lower than the values predicted by the GAB model. The surface areas for monolayer moisture sorption decreased with increasing temperature and blanching and fermentation reduced these values. Isosteric heat of sorption decrease at the average temperatures investigated with increase in moisture content. Blanching and fermentation offer perspectives to improve the shelf life of the product.

Keywords: blanching, fermentation, moisture adsorption, monolayer moisture content

# 1. Introduction

The African arrowroot lily (*Tacca involucrata*) is a perennial plant that belongs to the family *Araceae* of the order Arales. The plant is native to tropical Africa and is widely distributed in most parts of the forest and savannah regions of Nigeria. The African arrowroot lily produces underground swollen stems or tubers, which are the main food reserve. The tubers are spherical in shape and measures up to 5 cm in diameter. The tuber known as "gbache" and "onu-umwah" respectively by the Tiv and Etulo people is one of the unconventional and less exploited sources of food for human and animal nutrition. In Benue, Nassarawa and Plateau States of Nigeria, the tubers are processed into thick gels, which are eaten with soups, stews and beniseeds. The starch is used as a thickening agent for soups and in local textile industries for improving the strength and shine of clothing. There is increasing attention to the cultivation and utilization of the plant since it acts as a "bridge tuber crop" between the planting and harvesting periods of the conventional roots and tubers such as cassava, potato and vam. Unfortunately, the African arrowroot lily tubers are highly perishable and therefore require adequate and prompt preservation or processing for shelf life extension. Several preservation processes have been developed in order to extend the shelf life of foodstuffs by lowering the availability of water to microorganism and inhibiting some chemical reactions. Water activity  $(a_w)$  describes water availability and mobility in foods while moisture content is an important criterion to judge food quality (Arslan & Togrul, 2006). To understand the stability of foodstuffs, the relationship between moisture content and water activity known as moisture sorption isotherm has to be established. This stability is mainly a consequence of the relationship between the equilibrium moisture content of the food material and its corresponding water activity at a given temperature (Myhara et al., 1998). An addition or removal of water changes the composition and dimensions of products and may induce phase changes (Irzyniec & Klimezak, 2003).

Sorption isotherms of foodstuffs are essential for design, modeling and optimization of many processes such as aeration, drying and storage (Labuza, 1968; Bala, 1991; Ariahu et al., 2006). Knowledge of sorption isotherms is also important for predicting stability and quality changes during packaging and storage of dried

foods and for ingredient mixing prediction (Jamali et al., 2006). The knowledge of sorption isotherms at different temperatures allows the isosteric heat of sorption to be defined. The heat of sorption determines the interaction between an adsorbent and adsorbate. Water availability in the reactions of food degradation depends both on water content and on the properties of the diffusion surface, which is the thermodynamic function of sorbed water. The thermodynamic functions of several foods have been evaluated using experimental sorption data (Al-Muhtaseb et al., 2004; Mcminn & Magee, 2003). However, information is unavailable on the equilibrium moisture content (EMC) of African Arrowroot lily tubers at various relative humidity and temperatures. The world's energy demand for human nutrition and industrial purposes is growing very rapidly. The present cassava initiative and emphasis by the Federal Government of Nigeria is a response to the search for cheaper sources of starch for domestic and international industrial markets. Starch is used for production of ethanol, glucose, sugar syrup, artificial honey and various pharmaceuticals. Their demands have resulted to increase in the price of the conventional staples. There is therefore the urgent need to shift emphasis to the less exploited and unconventional tuber crops such as *Tacca involucrata* for domestic and industrial uses. Such a shift will reduce the current competition demand and pressure on the common staples like yam, potatoes and cassava.

There is the need to study the equilibrium moisture content of African arrowroot lily tubers in order to understand its drying characteristics and storage behavior. The present study was carried out with the objective of determining moisture adsorption isotherms of the African arrowroot lily lily in order to investigate whether pretreatments like blanching and fermentation could have an effect on the storage stability. The net isosteric heat of sorption was calculated from the experimental data. Moisture sorption models in literature were used to analyse the isotherms. Efforts were also made to find out the most suitable model describing the isotherms of African arrowroot lily.

### 2. Materials and Methods

## 2.1 Sources of Materials and Preliminary Handling

Mature (4-5 months) tubers (5-6 cm, diameter); 76% (wet basis) moisture content were harvested from farm lands in the University of Agriculture, Makurdi; and transported to the laboratory in jute bags. The tubers were promptly sorted and washed with tap water to remove adhering soil and other foreign matter. Air tight 500 ml capacity plastic containers (12.5 cm diameter x 11.8 cm height each) and wire gauze were purchased from a local market.

The flow chart for the production the various *Tacca involucrata* tuber products are shown in Figure 1. Essentially, the tubers were peeled and sliced to 0.5 cm thickness using stainless steel knives. The slices were divided into four sub-lots/ sub-lot I was blanched, wet milled and the mash subjected to accelerated natural fermentation 'involves back-sloping' as described below. Sub-lot II was blanched but non-fermented. Sub-lot III was non-blanched, mashed and subjected to accelerated natural. Sub-lot IV, which served as control in this research, was non-blanched and non-fermented.

Adequacy of blanching was verified using peroxidase test strips (Sigma Company, California, USA). Accelerated natural fermentation was achieved using the methods described by Ariahu et al. (1999). In this process, 120 g of mash of each of sub-lots I and III was placed in a covered 500 ml glass beaker at room temperature ( $30 \pm$ 2°C) for 24 hours. At the end of this period, 50% of the fermenting mash was used as starter for a new fermentation cycle. During this process, the pH and titratable acidity (an index of lactic bacteria activities) were monitored (Results not shown). The fermentation process was continued until pH of the concentrates stabilized by remaining constant with further increase in fermentation cycles. The pH of the concentrates was 4.00, 4.30, 6.20 and 6.50 for BF, NBF, BNF and NBNF respectively (Igbabul et al., 2012). As starch gelatinizes at temperatures above 60°C (Gevauden et al., 1989), the various sub-lots were dried at 55°C in a vacuum oven to minimize the influence of heating especially on the non-blanched samples. The dried samples were milled using a bench-top hammer mill (Brook Compton series 200, Christy Hunt England) to pass through a sieve size of 500 µm. Each powder was packed in 10 g sachets in polyethene bags and sealed with an electric impulse sealing machine (model 210-8E, Clamco Corporation, Cleveland, Ohio). Sub-lots I, II, III and IV were designated as blanched - fermented (BF), blanched - non fermented (BNF), non blanched fermented (NBF) and non blanched - non fermented (NBNF) flours respectively. The packaged products were stored on a dry shelf in air- tight metal containers until used and moisture adsorption studies.

## 2.2 Sorption Isotherm Studies

Sorption studies were as described by Ariahu et al. (2006) with some modifications. Sulphuric acid solutions were used to provide water activities ranging from 0.08-0.93 as described by Ruegg (1980). About 100 ml of each acid solution were introduced into 500 ml airtight plastic containers. In each plastic container, wire gauze was

forced into place over the sulphuric acid solution to form support for the samples. Triplicate samples, each of 0.5 g of the dried products were weighed in crown corks and placed on the wire gauze above the sulphuric acid solutions for adsorption isotherm studies. The containers were covered tightly with lids and allowed to equilibrate in a thermostatically controlled cooled incubator (Gallenkamp model no GB 4043 U.K) at the selected temperature of 10, 20, 30 and 40°C respectively. The samples were removed and weighed every 2 days until difference between consecutive reading were < 0.5% of each sample weight. The total time for removal and putting back in the air tight containers was about 2-5 min as recommended by the Cooperative Project, COST 90 (Gal, 1988). This minimized atmospheric moisture sorption or desorption during weighing (The adsorption results are presented in this paper). The EMCs were determined by material balance from the initial moisture contents (Toledo, 1980).

### 2.3 Modeling of Sorption Isotherms

The equilibrium moisture data were fitted using the BET, GAB, Oswin, Halsey Henderson models (Iglesias & Chirife, 1978; Rizvi, 1995; Lomauro et al., 1985a, 1985b; Iglesias & Chirife, 1982). These models (Equations (1)-(5)) in Table 1 were chosen for their versatility, relatively simple mathematical computations and their reported fits for starchy foods. Monolayer moisture contents were evaluated using the BET ( $a_w$  up to 0.48) and GAB ( $a_w$  up to 0.83) models. The sorption data were analyzed using analysis of variance (ANOVA), least square linear regression and non-linear regression equations. ANOVA was by multiple range F-test (Gupta, 1978). The derivatives and constants of Oswin, BET, Henderson and Halsey models were obtained by least square linear regression from their respective equations. The non-linear regression (NLR) using window release 6.0 of SPSS software (SPSS Inc., 1993).

The goodness of fit of the different models were evaluated with the percentage root mean square of error (% RMS) between the experimental ( $M_{obs}$ ) and predicted ( $M_{est}$ ) moisture contents as described by Iglesias and Chirife (1976a), Mok and Hettiarachchy (1990), and Wang and Brennan (1991):

$$\% RMS = \sqrt{\frac{\sum \left(\frac{M_{obs} - M_{est}}{M_{obs}}\right)^2}{n} \times 100}$$

Where  $M_{obs}$  and  $M_{est}$  are experimental and predicted moisture values respectively and n is number of experimental data.

#### 2.4 Isosteric Heat of Sorption

The net isosteric heat of sorption gives a measure of the water-solid binding strength. The determination of the sorption of the differential molar quantities derived from the temperature dependence of the sorption isotherm was calculated by applying Clausius-Clapeyron equation:

$$\ln a_{w} = C_{st} \frac{1}{RT}$$

Where  $\Delta H_{st}$  = net isosteric heat,  $C_{st}$  = constant related to entropy of sorption, T = temperature at absolute condition (°C) and R= molar gas constant (0.008314 kJ/mol °C)

To the isosteres obtained at constant moisture contents up to 30 g H<sub>2</sub>O/100 g solids following the procedure reported by Iglesias and Chirife (1976b), MCMinn and Magee (2003) and Ariahu et al. (2006). Re-plotting the experimental sorption isotherm in the form In ( $a_w$ ) versus I/T, for a specific moisture content,  $\Delta H_{st}$  was determined from the slope ( $-\Delta H_{st}$  /R). This procedure is based on the assumption that  $\Delta H_{st}$  is invariant with temperature and requires measurement of the sorption isotherms at more than two temperatures (Tsami et al., 1990a).

The predictive models for the relationship between moisture content and net isosteric heats was proposed by Tsami et al. (1990b) using an empirical equation to describe the relationship between  $\Delta$ Hst and the equilibrium moisture content:

$$\Delta$$
Hst =  $\Delta$ Ho exp. (M/Mc)

where M is the equilibrium moisture content,  $\Delta$ Ho is the isosteric heat of sorption of first molecule of water; Mc is a characteristic moisture content of the food material. For the adsorption isotherms of NBNF, BF, NBF and BNF *Tacca involucrata* products, the following models are proposed:

$$\Delta H_{st} = 66.1797 \text{ exp. } 0.0660 \text{ M} \text{ (r}^2 = 0.988)$$

$$\Delta H_{st} = 42.3724 \text{ exp. } 0.0838 \text{M} \text{ (r}^2 = 0.967)$$
  
 $\Delta H_{st} = 38.4425 \text{ exp. } 0.7920 \text{M} \text{ (r}^2 = 0.983)$   
 $\Delta H_{st} = 43.7348 \text{ exp. } 0.0693 \text{M} \text{ (r}^2 = 0.986)$ 

## 3. Results and Discussion

#### 3.1 Sorption Isotherms

The adsorption isotherms of Tacca involucrata at 10, 20, 30 and 40°C are shown in Figures 2-5. These temperatures were selected as possible storage conditions. The isotherms have a sigmoidal shape depicting an increase in the equilibrium moisture content with  $a_w$ . This is typical of type II isotherms (Brunauer et al., 1940), and has been reported for starchy products such as potato and wheat starch (Van den Berg, 1981), potato starch gel (McMinn, 1996), cookies and corn snacks (Palou et al., 1997).

It can be seen from the curves, that the equilibrium moisture contents (EMCs) increased with increase in water activity and were lower as the temperature increased. The effect of temperature on food isotherms is extremely important in food technology. During storage, a dry food product stored in sealed package may be exposed for long periods of time to temperatures higher than the temperature at which it was package. Consequently, the activity of the water vapour at constant moisture content increases thereby altering the food's quality (Dural & Hines, 1993). The water activity shift of food isotherms at constant moisture content with respect to temperature variation has been shown to be directly related to the rates of food deteriorative reactions (Van den Berg & Bruin, 1981; Iglesias & Chirife, 1982; Labuza, 1984). Hill and Rizvi (1982) noted that generally, increasing the temperature results in an increase in water activity. For most dry foods, an increase in water activity of 0.1 may decrease the shelf life by a factor of two to three. Therefore, the greater influence of temperature on the water sorption isotherms of the native NBNF indicates that pretreatments such as blanching and fermentation would enhance storage stability of the products.

As temperature is increased at constant  $a_w$ , the equilibrium moisture content decreases. The amount of adsorbed water by the Tacca involucrata tuber products therefore decreased with increase in temperature at constant relative humidity. Thus, the products became less hygroscopic at higher temperatures.

The results obtained from the present study therefore implied that the equilibrium moisture content of the products at a given water activity is decreased by blanching and fermentation, and these treatments offer perspectives to improve shelf life. Comparison of Figures 2-5 and especially Figures 3 and 4 suggests that these treatments have a stronger effect on moisture adsorption than blanching. Further examination of the isotherms indicated that the pretreatments (blanching and fermentation) had significant (p < 0.05) effects on the moisture sorption isotherms. Generally, the native (NBNF) samples had higher positioned isotherms and hence higher moisture sorptive capacity followed by BNF, then NBF and lowest for the BF at the temperatures investigated. This observation indicates that blanching and fermentation treatments could have affected the sorption sites of the flour. The heat may have damaged some active binding sites while fermentation may have modified the tissue structures thereby reducing the number of active binding sites that are available for water molecules. The higher sorptive capacity of the NBNF samples could be due to availability of relatively more undamaged and unoccupied binding sites. Studies by Johnson and Brennan (2000) indicated that the sorptive capacity of a product can be influenced by treatment or denaturation processes like heating, desalting and pH changes. As reported by Kapsalis (1984) and Johnson and Brennan (2000), heat treatment may change the polar and other groups that bind water along with changes in capillary and other configurations of the food structure thereby affecting the moisture sorption of the food product.



Figure 1. Flow chart for production of various Tacca involucrata tuber products

BF = Blanched fermented, BNF = Blanched non-fermented, NBF = non-blanched fermented and NBNF = Non-blanched non-fermented.



Figure 2. Moisture isotherms of non-blanched non-fermented *Tacca involucrata* tuber product at 10°C ( $\bullet$ ), 20°C ( $\blacktriangle$ ), 30°C (O), and 40°C (**X**)



Figure 3. Moisture adsorption isotherms of blanched non-fermented *Tacca involucrata* tuber product at 10°C ( $\bullet$ ), 20°C ( $\blacktriangle$ ), 30°C ( $\bigcirc$ ) and 40°C (X)



Figure 4. Moisture adsorption isotherms of blanched non-fermented *Tacca involucrata* tuber product at 10°C ( $\bullet$ ), 20°C ( $\blacktriangle$ ), 30°C (O) and 40°C (**X**)



#### Water activity

Figure 5. Moisture adsorption isotherms of blanched and fermented *Tacca involucrata* tuber product at 10°C ( $\bullet$ ), 20°C ( $\blacktriangle$ ), 30°C ( $\bigcirc$ ) and 40°C (**X**)

#### 3.2 Comparisons of Sorption Models

The percent root mean square of error (% RMS) of the various models tested in this study is presented in Table 2. According to Wang & Brennan (1991), percent root mean square of error (% RMS) values of  $\leq$  10% indicate a reasonably good fit for practical purposes. The BET isotherm is usually valid for a<sub>w</sub> between 0.1 and 0.5 (Chirife and Iglesias, 1978). This is considered a disadvantage when compared with the GAB model which predicts EMCs up to a<sub>w</sub> of 0.90 (Rizvi, 1995). Generally, the GAB model and the predictive equations generated in this study (Table 3) gave the best fit to the overall data analysed. The Halsey and Oswin models also described the sorption data adequately. These results are in conformity with the observations of Bizot (1983), Lomauro et al. (1985a, 1985b) and Palou et al. (1997) that the GAB model fits best in various foods of plant and animal origin. The Henderson model gave an r<sup>2</sup>  $\geq$  0.869 for the sorption of the water by *Tacca involucrata* products. In comparison with the other models investigated, the Henderson equation gave the lowest r<sup>2</sup> values.

#### 3.3 Monolayer Moisture Contents and Derivative

The monolayer moisture content ( $M_o$ ) is a measure of the moisture content for maximum stability of a food material (Rockland & Nishi, 1980). The  $M_o$  values calculated using the BET and GAB models (Tables 4 and 5) indicated that the blanched and fermented samples gave the least monolayer values in both the adsorption and desorption models. This could be an indication that pretreatments (blanching and fermentation) might have destroyed some active sites and/or affected the tissues leading to a decrease in its sorptive ability and subsequently the monolayer moisture contents. The GAB equation gave higher monolayer values than BET model. Studies by other workers showed similar variations in  $M_o$  values between the GAB and BET equations. The results obtained in this present study are consistent with those of Labuza et al. (1985) who reported that the  $M_o$  values for corn and fish flour calculated by the GAB and BET models were different. Similar trends were reported by Van den Berg (1985) for starch, Mok and Hettiarachcy (1990) for sunflower products and Palou et al. (1997) for cookies and corn snacks. Dural and Hines (1993a, 1993b) and also Timmermann et al. (2001) reported that the  $M_o$  values determined from the GAB equation were 3 to 18% higher than values predicted by the BET equation.

The results for the surface areas of sorption ( $S_o$ ) obtained from this study were higher than the values of 100-250 m<sup>2</sup>/g solid exhibited by most foods as reported by Labuza (1968). The higher magnitude of surface area exhibited by the Tacca involucrata tuber products could be attributed to the fact that water molecules are able to plasticize the various long chain polymers that make up the structural matrix, thus exposing more sites for sorption. In addition, since the water molecule is smaller, it is able to enter smaller pores and crevices thus increasing the surface area more than surface area predicted using nitrogen in the BET theory (Labuza, 1968).

## 3.4 Isosterics Heat of Sorption

The net isosteric heats of sorption (Figure 6) increased until a maximum and then decreased with increase in moisture content until it finally leveled off. The increase in isosteric heats at low moisture contents can be explained considering that the sorption of water by the dry matrix lead to swelling of the food polymers resulting in the exposure of sorption sites of higher binding energies not previously available. After the maximum, the decrease in isosteric heat with the amount of water sorbed, can be qualitatively explained considering that initially, sorption occurred on the most active available sites giving rise to greatest energy interaction. As these sites became occupied, sorption occurred on the less active site giving lower heats of sorption. (Palou et al., 1997; Dural and Hines (1993) explained that such curves are indication of surface heterogeneity. The trend observed in this study conformed to the report of Wang and Brennan (1991) and Loong et al. (1995).

The maximum bet isosteric heat were higher than those reported by Iglesias and Chirige (1976b) for tapioca (12.6 kJ/mol), Benado and Rizvi (1985) for sorghum (17.0 kJ/mol); Labuza et al. (1985) for cornflour (18.6 kJ/mol), and Palou et al. (1997) for cookies (between 6.7-10.1 kJ/mol) and cornsnacks (7.5 kJ/mol). The differences in the isosteric heats could be due to differences in the chemical and structural compositions of the food materials. Palou et al. (1997) advanced some reason for the variation in the net isosteric heats of sorption between their work and that of others. These workers attributed their low net isosteric heats of sorption to the extensive heat treatment that the studied products received. In this present study, the heat treatment may have damaged some sorptive sites resulting in lower net isosteric heats. This is possibly the reason for the highest net isosteric heats observed for othe NBNF (native) samples that did not receive any pre-treatment. If this reasoning holds, it then implies that the pre-treatment that affected the sorption sites most was fermentation followed by blanching.

## 4. Conclusions

The moisture sorption isotherms of Tacca involucrata tuber flour follow the type II isotherm pattern for the temperature range of 10 to 40°C. Temperature has effect on the sorption behavior at higher  $a_w$  values being observed at the same moisture content when temperature is increased. Among the models evaluated, the Henderson model proved the least adequate function to describe the experimental data. The other models fit the data reasonably well, with the best fit being the GAB model. The GAB monolayer values are higher than the BET values for the African arrowroot lily powder. Blanching and fermentation reduce the hygroscopic and other thermodynamic properties of the dehydrated products, with the BF sample having the least EMCs, monolayer moisture values, surface area of sorbent and net isosteric heats of sorption.



Figure 6. Isosteric heats  $(\Delta H_{ST})$  of moisture adsorption in blanched and fermented  $(\Delta)$ , blanched non-fermented  $(\bullet)$ , non-blanched fermented (O) and native (A) *Tacca involucrata* tuber products

Model	Mathematical expression
Brunauer-Emmett-Teller (BET) (Brunauer et al, 1938)	$\frac{a_{w}}{(1-a_{w})M} = \frac{1}{M_{0}C} + \frac{C-1}{M_{0}C}a_{w}$
Guggenheim-Anderson-de Boer (Bizot 1983)	$\frac{M}{M_0} = \frac{GKa_w}{(1 - Ka_w)(1 - Ka_w + GKa_w)}$
Halsey (1948)	$a_w = \exp\left[\frac{A}{RT\theta^r}\right]$
Oswin(1946)	$M = A \left[ \frac{a_w}{1 - a_w} \right]^B$
Henderson (1952)	$\ln(1-a_w) = -ATM^B$

M = moisture content (g H<sub>2</sub>O/100g solids), Mo = monolayer moisture content (g H<sub>2</sub>O/ 100g solids),  $a_w$  = water activity, C = BET constant, G and K = GAB constants, A, B and r are constants,  $\theta = \frac{M}{M_0}$ , T= Temperature (°K).

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Product	Temperature (°C)	Equation	$r^2$
BNF	10	$M = 173.05_{a}^{3} - 203.92a_{w}^{2} + 99.63a_{w}$	0.984
	20	$M = 161.12 a_{w}^{3} - 188.13 a_{w}^{2} + 87.79 a_{w}$	0.9915
	30	$M = 145.8a_w^3 - 172.65a_w^2 + 79.90a_w$	0.9969
	40	$M = 115.17a_{w}^{3} - 138.03a_{w}^{2} + 68.45a_{w}$	0.9972
NBF	10	$M = 242.30a_{w}^{3} - 284.40a_{w}^{2} + 111.06a_{w}$	0.9932
	20	$M = 204.15 a_w^3 - 244.37 a_w^2 + 98.577 a_w$	0.9893
	30	$M = 165.95 a_w^{-3} - 205.10 a_w^{-2} + 86.979 a_w$	0.9864
	40	$M = 122.44a_{w}^{3} - 151.73a_{w}^{2} + 68.365a_{w}$	0.9878
BF	10	$M = 225.86a_w^3 - 258.18a_w^2 + 98.041a_w$	0.9899
	20	$M = 188.37a_{w}^{3} - 219.09a_{w}^{2} + 85.88a_{w}$	0.9909
	30	$M = 137.87a_{w}^{3} - 164.00a_{w}^{2} + 69.405a_{w}$	0.9929
	40	$M = 104.94a_w^3 - 126.75a_w^2 + 56.321a_w$	0.9814
	10	$M = 204.95a_w^3 - 266.85a_w^2 + 134.49a_w$	0.9902
NBNF	20	$M = 152.07 a_w^3 - 197.96 a_w^2 + 10855 a_w$	0.9956
	30	$M = 122.02a_{w}^{3} - 148.24a_{w}^{2} + 81.998a_{w}$	0.9899
	40	$M = 106.71a_{w}^{3} - 134.30a_{w}^{2} + 74.439a_{w}$	0.9966

 $^{1}M$  = moisture content (gH2O/100g solids),  $a_{w}$  = water activity,  $r^{2}$  = coefficient of determination. BNF = blanched non fermented, NBF = non blanched fermented, BF= blanched fermented and NBNF = non blanched non fermented (control) *Tacca involucrata* tuber products.

Table 3. Goodness of fit of various sorption models to moisture adsorption data of *Tacca involucrata* tuber product

Product	Sorption	%RMS				
	Model	Temperature (°C)				
		10	20	30	40	Mean
	$GAB^1$	8.07	6.47	9.41	6.78	7.68
	Oswin <sup>2</sup>	10.44	11.45	5.24	4.81	7.99
BNF	Henderson <sup>3</sup>	16.60	15.25	12.93	10.52	13.54
	Halsey <sup>4</sup>	7.04	5.69	5.64	6.32	6.17
	Experimental <sup>5</sup>	6.84	9.15	6.21	3.21	6.35
	GAB	3.03	8.49	8.83	5.79	6.54
	Oswin	14.89	11.29	7.14	4.31	9.41
NBF	Henderson	22.40	18.93	13.66	10.52	16.38
	Halsey	8.55	8.12	4.16	15.29	9.03
	Experimental	7.21	8.39	5.54	5.89	6.75
	GAB	6.81	6.62	9.95	6.50	7.82
	Oswin	15.71	13.31	8.04	5.23	10.59
BF	Henderson	24.44	21.23	15.49	9.77	17.73
	Experimental	9.53	7.44	2.89	5.05	6.22
	GAB	6.82	5.81	5.36	7.60	6.40
	Oswin	5.40	4.22	6.32	3.70	4.91
NBNF	Henderson	9.30	12.60	10.78	14.41	12.29
	Nelsey	7.05	5.81	8.77	4.52	6.54
	Experimental	6.11	5.16	4.14	4.11	4.63

I. GAB equation (Bizot 1983), 2. Owsin (1946). 3. Henderson (1952); 4. Halsey (1948), 5. This work, %RMS = percentage root mean square of error. BNF= blanched non fermented, NBF = non blanched fermented, BF= blanched fermented and NBNF = non blanched non fermented (control) Tacca involucrata tuber products.

Product	Temp (°C)	А	В	С	Mo (gH <sub>2</sub> O/100 g)	$S_o (m^2/g \text{ solid})$
	10	-2.1874 E-3	0.1097	-49.14	9.3032	326.89
DNE	20	-1.989 E-3	0.1250	-64.13	8.1263	285.51
DINF	30	-2.4344 E-4	0.1267	521.29	7.8800	276.86
	40	1.6772 E-3	0.1326	80.06	7.4473	261.65
	10	-2.8242 E-3	0.1256	-43.46	8.1462	386.20
NDE	20	-3.4801 E-3	0.1391	-38.96	7.3758	259.14
INDF	30	-1.2330 E-4	0.335	1083.92	7.4821	252.88
	40	-1.8967 E-3	0.1448	77.31	6.8120	239.57
	10	-4.3328 E-3	0.1533	-34.38	6.7126	235.84
DE	20	-4.0398 E-3	0.1624	-39.20	6.3155	221.89
БΓ	30	-2.1043 E-3	0.1732	-81.29	5.8460	205.39
	40	-14033 E-4	0.1926	1373.11	5.1897	182.34
	10	-13891 E-3	0.1677	49.30	14.6014	513.34
NDNE	20	-2.8214 E-3	0.720	26.53	13.3591	469.36
INDINF	30	-3.5100 E-3	0.1054	301.34	9.6086	332.18
	40	-1.6193 E-4	0.1145	71.73	5.1897	302.45

Table 4. BET parameters and derivatives for moisture adsorption by Tacca involucrata tuber products

A and B = intercept and slope coefficients respectively where A = //MoC and B= (C-1)/MoC; C = BET constant,  $M_o$  = monolayer moisture contents,  $S_o$  = apparent, surface area of sorbent. BNF = blanched non fermented, NBF = non blanched fermented, BF = Blanched fermented and NBNF = non blanched non fermented Tacca involurata tuber products.

Table 5. GA	AB parameters and	derivatives f	or moisture	adsorption by	Tacca involucrata	tuber products
	1			1 2		1

Product	Temp (°C)	G	K	Mo
				(g H2O/100g solids)
BNF	10	3.5680	0.8112	11.4994
	20	3.4984	0.8336	9.7224
	30	2.5793	0.8408	8.8278
	40	1.9898	0.8665	8.5914
NBF	10	6.1371	0.8213	8.1940
	20	4.9047	0.8294	7.6983
	30	4.8570	0.8414	7.8494
	40	4.2934	0.8658	7.4860
BF	10	5.9524	0.8123	7.3938
	20	5.3942	0.8455	6.5798
	30	5.0725	0.8652	6.3742
	40	4.2545	0.8754	5.9236
NBNF	10	3.3698	0.7513	16.4201
	20	2.2331	0.7662	15.8653
	30	1.8074	0.7671	11.5263
	40	1.7523	0.7707	9.7245

G and K = GAB constants,  $M_o$  monolayer moisture content, BNF = blanched non fermented, NBF = non blanched fermented and NBNF = non blanched non fermented Tacca involucrate tuber products.

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