Characterization and sorption isotherm of dehydrated beef made in Nigeria

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Issoufou Amadou1*, Halima O. Diadie2, Olasunkanmi S. Gbadamosi3 and Charles T. Akanbi3

Abstract: Sorption isotherms of dehydrated beef were determined at room temperature and Brunauer, Emmett and Teller (BET) isotherm model and Guggenhein, Aderson and Boer isotherm model were used to calculate the monolayer values. It was found that the isotherms were similar and they all exhibited BET type shape (sigmoid). At both desorption and adsorption, samples adsorbed moisture at the 0.9 water activity which resulted in mould growth. The monolayer values were quite useful in assessing the storage stabilities of dehydrated meat.

1. Introduction
It is important to note that quite a few of the meat products consumed today have their roots in ancient times. Fresh cuts such as leg of lamb and wild boar chops have been consumed for thousands of years. Processed products such as Kilishi (dehydrated meat developed in the hot climate area of the Saharan Africa) have been made for hundreds of years and are examples of how meat was preserved before the introduction of modern technology (Abera, 2019; Barbut, 2014). It is natural that the production of meat derived foods that one consumes is related to the general influence of the society in which he lives; the red meat consumed is derived from sheep, cattle, goat and pigs (Adeyeye, 2016; Ratsimba et al., 2017).

Almost all biological materials naturally possess high moisture content (80% Wet basis and above). This significantly increases the bulk volume as well as mass of the biomaterial, leading to difficulties in handling and transport. Moreover, foods containing high concentrations of water are generally more susceptible to deterioration by microbial contamination and enzymatic activity. The excess moisture increases the water activity in the food, enabling microbiological spoilage and

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PUBLIC INTEREST STATEMENT
Food of animal origin can easily be perishable due to temperature fluctuation, poor management, poor technology or infrastructure and lack of awareness. Meat either dry or fresh present an easy medium for microbial growth that can be harmful to the health. Techniques for evaluating beef drying conditions can be of help to address the appropriate packaging solution. Thus, this research work is of interest to food processors, food vendors, regulatory agents and the public, it would help in quality improvement and in reducing sharp practices by processors and retailers of this dehydrated beef.
destruction of the material. The water content of foods can be controlled by removing water through dehydration or by adding solutes to the food. In both cases, the concentration of solutes in the food increases and the concentration of water decreases (Olaoye, 2011; Satyanarayan, Dev, Vijaya, & Raghavan, 2012). The water content of a food may bear little relationship to its water activity. Fresh meat has a water content of 75% but a water activity of 0.98. In the anhydrous state, proteins are fairly stable. Five to ten percent water is sufficient to permit denaturation and thereafter the rate of denaturation is more or less related to the amount of water present—dilute solutions are more susceptible to denaturation than concentrated ones (Ihekoronye & Ngoddy, 1985). In general, the biological material like meat always tends to come together when facing a tough condition to prevent their interior from losing the moisture.

The stability of meat, like many other foods, depends on its water activity, which measures the water available to support physicochemical changes and the growth of microorganisms (Labuza, 1984, 1975). The relationship between water activity and moisture content is usually presented in the form of a sorption isotherm. One of the most important properties of the meat used in comminuted products is its binding characteristics. Without adequate protein-to-protein interaction, the pieces will not hold together to produce the desired texture, nor will they stabilize the fat and bind moisture. Consequently, most of the meat used also should be lean skeletal muscle, since this has a higher quantity of the necessary proteins (Amadou, Le, Shi, & Jin, 2011; Toldrá, 2006; Zhou, Liu, Chen, Chen, & Labuza, 2014).

Water activity ($a_w$) has its most useful application in predicting the growth of bacteria, yeasts and moulds. For a food to have a useful shelf life without relying on refrigerated storage, it is necessary to control either its acidity level or the level of $a_w$ or a suitable combination of the two. This can effectively increase the product’s stability and make it possible to predict its shelf life under known ambient storage conditions. Food can be made safe to store by lowering the water activity to a point that does not allow dangerous pathogens such as Clostridium botulinum and Staphylococcus aureus to grow in it (Adyeyee, 2016; Lukwago, Mukisa, Atukwase, Kaaya, & Tumwebaze, 2019; Scott, 1975). Given the complexity of the phenomena involved in water sorption, there are four mathematical models based on more or less physical bases. These are three three-parameter models (modified BET, modified Halsey and GAB: Guggenheim, Anderson, & Boer) and one model with four parameters (Peleg) (Benhamou, Kouhila, Zeghmati, & Benyoucef, 2010). Among the thermal models proposed in the literature, the model most often applied to fruit and food is that of Brunauer, Emmett and Teller (BET) (Ferradji, Matallah, & Malek, 2008).

Meat is a very complex product that can be affected by antemortem and postmortem factors. Components of the muscle itself, like contractile proteins and connective tissue affect the characteristics of the final product (Olaoye, Obajemihi, & Metiboba, 2016). Water removal depends on the partial pressure of water over the food and the energy of binding of the water in food; to reach a suitable level of stability of the end food product and during its storage, water activity must be maintained within an acceptable range. Thus, sorption isotherm is the equilibrium moisture content (EMC) of a material at any specified relative humidity (RH) at a constant temperature (Igene, Farouk, & Akanbi, 1990; Iheogwara & Okonkwo, 2016; Labuza, 1975; Zhang, Sun, & Zhang, 2017). It is therefore important to understand the moisture sorption characteristics and evaluate monolayer values of dehydrated meat. However, little information exists on dehydrated meat produced for use in the sub-Saharan area. In addition, knowledge of the sorption characteristics and monolayer values of dehydrated meat in the tropics is required in regard to its keeping quality and acceptability. The objective of this work was to determine the sorption isotherm and evaluate monolayer values of dehydrated beef over the range of water activities commonly experienced in the tropics.

2. Materials and methods

2.1. Materials

Fresh and low-fat content meat (beef meat “muscles of chuck or round”) were purchased from a local market in Ile-Ife, Nigeria. Preparation of samples was carried out using oven drying method.
at Food Science and Technology Processing Laboratory of Obafemi Awolowo University, Ile-Ife. All the chemicals and reagents used were of analytical grade.

2.2. Methods

2.2.1. Sample preparation
Samples were taken from the dried sliced beef muscle from cow hams, which were selected from an experienced local butcher. Zero-point 3-cm-thick slices were obtained from the muscle which was previously cut aseptically fresh to obtain enough meat consistency for cutting. The slices were placed inside the oven set at 70°C for 6 h.

2.2.2. Proximate analysis
The proximate composition was determined as described by the methods of Association of Official Analytical Chemists (AOAC) (1990). For moisture content, dried sliced beef meat samples were weighed into pre-weighed dry dishes. The uncovered dishes were placed in a hot air oven and were dried till constant weight at 103 ± 2°C. The dishes were removed and cooled, they were weighed and loss in weight was recorded as moisture content using the following formula:

\[ MC = \frac{\text{mass of water}}{\text{mass of water + solidein}} \times 100 \]  

(1)

For ash determination, known weight of the sample was weighed into porcelain crucible previously ignited and weighed. The sample was ignited on a hot plate until charred. The crucible was then placed in a muffle furnace maintained at 600°C for 6 h. The crucible was cooled and reweighed.

The protein content of the samples was determined using the Association of Official Analytical Chemists (AOAC) (1990) method. Meat sample (0.50 g) was weighed into a Kjeldahl flask. Ten millilitres of concentrated sulphuric acid were added followed by one Kjeltec tablet. The mixture was digested on a heating racket to obtain a clear solution. The digestate was cooled and made up to 75 ml with distilled water and transferred onto Kjeldahl distillation unit followed by the addition of 50 mL of 40% sodium hydroxide solution. The mixture was distilled and the ammonia formed in the mixture was subsequently distilled into 25 ml, 2% boric acid solution containing 0.5 ml of the mixture of 100 ml of bromocresol green solution (prepared by dissolving 100 mg of bromocresol green in 100 ml of methanol) and 70 ml of methyl red solution (prepared by dissolving 100 mg of methyl red in 100 ml methanol) as indicators. The distillate collected was titrated with 0.05 M HCl. Blank determination was also carried out by excluding the sample from the above procedure.

\[ \text{Crude protein(%) = } \frac{1.401 \times M \times (F \times \text{mL tirrant - mL blank})}{\text{sample weight}} \times 100 \]  

(2)

\( M = \) Molarity of acid used = 0.05

\( F = \) Kjeldahl factor = 6.25

The Soxhlet method of fat determination was used. Five grams of the sample were weighed unto a fat-free extraction thimble, which was then placed in a Soxhlet extractor. The reflux condenser and the round-bottom flask containing the extraction solvent (hexane) are fixed to the Soxhlet extractor; then heat is applied and the extraction, the oil was dried by evaporating the extracting solvent and allowing it to stand in an oven at 100°C for about 30 min. The flask together with oil was weighed and the fat content was calculated as described in Association of Official Analytical Chemists (AOAC, 1990).

2.2.3. Sorption isotherm determination
The moisture desorption isotherms of dehydrated meat content were obtained in duplicate at room temperature. The moisture desorption isotherms were evaluated by static gravimetric method using
the EMC at different water activity levels. Sulphuric acid solutions were used as the humidity source. The water activities of the solution covered the activity range of 0.1–0.9. The sulphuric acid solutions were prepared with reagent grade concentrated sulphuric acid and distilled water. Duplicate samples between 1 and 2.5 g each were weighed in plastic recipient and put in the upper section of the 9 desiccators with the lower section containing a saturated solution of sulphuric acid of known RH and then placed in ambient temperature levels that ranged from 25°C to 40°C. The saturated solutions of sulphuric acid are given in Table 1 (Matz, 1991).

After insertion of samples and sulphuric acid solution, desiccators were covered up and placed at room temperature. The room temperature was recorded twice daily and a mean value of which was calculated. The samples were weighed periodically until no significant variation in weight was detected using a precision balance. Data were collected until equilibrium was reached according to Labuza (1984) method where EMC was determined considering the initial moisture contents of samples, using the following formula:

\[
EMC = \frac{w_f - w_i + \frac{\%H_2O}{100} \cdot w_i}{w_i + \left[ \frac{\%H_2O}{100} \right]} 
\]  

(3)

where:

\( w_f \) = final weight of sample

\( w_i \) = initial weight of sample

\( \%H_2O \) = initial moisture content on wet basis

2.2.4. Sorption equations

Both BET and GAB are formulas used to determine the monolayer of a food. The BET value is found by plotting \( a_w/(1- a_w)M \) versus \( a_w \) and using the intercept to find the monolayer. The GAB monolayer value may be determined by utilizing linear or non-linear methods. The percentage difference in EMC between the duplicate samples was on the average less than 5\% when the average of the two values was considered as the values. BET and GAB sorption equations were used to analyze the sorption isotherm data.

BET (Ayeranci, Ayرانci, & Dogantan, 1990)
\[
\frac{a_w}{M(1-a_w)} = \frac{1}{M_0C} + \frac{C-1}{M_0C} a_w
\]

where

\[M_0 = \text{BET monolayer value}\]
\[C = \text{constant for a given water sorbent system}\]
\[a_w = \text{water activity}\]
\[M = \text{equilibrium moisture content}\]

GAB (Maroulis, Tsami, Marinos-Kouris, & Saravacos, 1988)

\[
\frac{M}{M_m} = \frac{ABa_w}{(1-Ba_w)(1-Ba_w+ABa_w)}
\]

Equation (Equation 5) has been arranged into second-degree polynomial in the following form:

\[
\frac{a_w}{M} = A_1 a_w^2 + A_2 a_w + A_3
\]

where

\[A_1 = \frac{B}{M_m} \left[ \frac{1}{A} - 1 \right]\]
\[A_2 = \frac{1}{M_m} \left[ 1 - \frac{2}{A} \right]\]
\[A_3 = \frac{1}{M_mAB}\]
\[a_w = \text{water activity}\]
\[A, A_1, A_2, A_3, B, C = \text{constants}\]
\[M = \text{equilibrium moisture content}\]
\[M_m = \text{GAB monolayer}\]

3. Results and discussion

3.1. Proximate analysis

The results of the proximate composition of the dehydrated meat samples on a wet basis were presented in Figure 1. Chemically, meat is composed of four major components including water, protein, lipid, carbohydrate and many other minor components such as vitamins, enzymes, pigments and flavour compounds (Idowu, Omobuwajo, & Falade, 2010; Ihekoronye & Ngoddy, 1985). The moisture content of dehydrated meat on a wet basis found to be 15.44%, and as predicted, the high protein value was 24.03%. However, the meat sample used in this case showed a fat content of 18.00%, followed by a 2.33% ash value. The fibre content was however low (0.4%). The value of carbohydrate as obtained by difference was significantly high (39.80%). It is a fact that the protein content of the particular meat used is high due to the fact that the sample has low-fat content as the meat is trimmed to remove almost completely the fat (Igene et al., 1990; Iheagwara & Okonkwo, 2016). The relative proportions of all these constituents give meat its particular structure, texture, flavour, colour and nutritive value. However, because of its unique biological and chemical nature, meat undergoes progressive deterioration from the time of slaughter until consumption (Barbut, 2014; Idowu et al., 2010).
3.2. Isotherm and characteristics of dehydrated meat

A static gravimetric method was used to bring dehydrated meat samples into equilibrium with the solution of the desired RH, using concentrated sulfuric acid (H$_2$SO$_4$). Then, the moisture content of the samples was determined as described previously. The experimental data for sorption equilibrium moisture of samples for water activities studied at room temperature are given in (Table 2). The EMC increased with increasing water activity in the case of adsorption isotherms; whereas, in the case of dehydrated meat.

| EMC % | Water activity $a_w$ | Days required to reach equilibrium | Remarks |
|-------|---------------------|-----------------------------------|---------|
| Ads   | Des                 | Ads Des Ads Des Ads Des Des Des |
| 18.87 | 19.75               | 0.1 25 21 | Slightly dried, change of reddish brown colour to light brown and bad smell |
| 22.40 | 17.29               | 0.3 25 24 | Slightly dried, and there was colour retention |
| 25.74 | 17.00               | 0.5 23 24 | Slightly dried, and there was colour retention |
| 23.02 | 20.46               | 0.7 25 14 | Good shape, dried and there was colour retention |
| 25.62 | 19.20               | 0.8 14 14 | Moist, dark coloured and mould growth |
| 62.64 | 32.81               | 0.9 17 12 | Moist, dark coloured and mould growth |

**Table 2. Sorption isotherm of dehydrated meat at room temperature**

**Ads**: adsorption characteristic **Des**: desorption characteristics.
desorption, the EMC exhibited slight changes with an increasing water activity (Figure 2). In the drying process, the ultimate water activity ($a_{w}$) of semi-dehydrated meat approaches 0.60–0.90, which is equivalent to a RH of 60–90% at ambient temperature (Chang, Huang, & Pearson, 1996). At the 0.9 $a_{w}$ in both cases of desorption and adsorption, the samples adsorbed moisture to the extent that the mould grew on them which implied that at 0.9 water activity, dehydrated meat could allow the growth of microorganisms as it is shown in Figure 3. The bacterial charges of dehydrated meat in the tropics in general are high, with a wide range of microorganisms (Inusa & Said, 2017); this will not be unconnected with the type of meat used and the processing of the meat that is usually carried out unhygienically. Indeed, the study of sorption isotherm of dehydrated beef is expected to have a wide range of how the bacteria could be reduced despite the possible post-production contamination (Adeyeye, 2016; Lukwago et al., 2019). The moisture sorption isotherms obtained were sigmoid in

Figure 2. Moisture sorption isotherm curves of dehydrated meat.

![Moisture sorption isotherm curves of dehydrated meat.](image-url)

Figure 3. Dehydrated meat samples with mould growth at 90% $a_{w}$ of sorption isotherms.
shape while the EMC agrees with the generally observed fact that the quality of the adsorbed and desorbed moisture increases with an increase in water activity. The steepness of the curves at $\alpha_w \geq 0.75$ is primarily because at higher $\alpha_w$ more water is readily available for bonding at the active sites of the hydrophilic product (Zhang et al., 2017). The experiment results were compared with the work of Iheagwara and Okonkwo (2016) and Kalilou, Collignan, and Zakhia (1998). The increase in the moisture content at the near 75% RH shows that the product, if exposed to a relatively humid environment, can absorb moisture from the atmosphere. Moreover, this corroborated our previous work on dried tomato in the tropics area (Akanbi, Remi Sikiru, & Ademola, 2006). In addition, Chang et al. (1996) reported that muscle with a high-water holding capacity will have good water adsorption properties at a moderate-to-low-moisture range.

### 3.3. BET and GAB monolayer values

The moisture sorption isotherm determination was used to observe the monolayer moisture content using the BET equation with the line of best fit as shown in Figure 4. However, Table 3 was gotten by analysis of sorption data according to GAB equation and the values of GAB constants ($M_m$, B and A). The monolayer values were observed to have a direct bearing on the EMC of the product at different water activities. The BET and GAB monolayer values were always below 10 g/100 g which were the maximum values reported for food materials (Kaymak-Ertekin & Sultanoğlu, 2001; Labuza, 1984; Maroulis et al., 1988). This indicates that the product has been sufficiently dried to moisture at which a product is stable and not subjected to deterioration. The higher values of the GAB monolayer (3.47–8.109 g/100 g) compared with BET monolayer (4.36–5.37 g/100 g) are in line with literature.

| Sample | GAB $M_m$(g/100g) db | GAB constants B | A |
|--------|----------------------|----------------|---|
| Meat   | 3.47                 | 0.93           | 4.91 |
|        | 8.109                | 0.82           | 7.08 |

**Table 3. Analysis of sorption data according to GAB equation**

![Figure 4. BET Equation and monolayer plots for sorption isotherm curves of dehydrated meat at room temperature.](image-url)
(Kaymak-Ertekin & Sultanoğlu, 2001; Van den Berg, 1985). Elsewhere, Kaymak-Ertekin and Sultanoğlu (2001) reported the moisture adsorption and desorption isotherms of green and red peppers at different temperatures and water activities that the BET equation gave the best fit for the αw range of 0.1–0.5. Since the GAB model covers the entire activity range, its monolayer value has been suggested by Van den Berg (1985) to give a better representation of the safe moisture content of the product. The monolayer values are useful in assessing the storage stabilities of food materials such as dehydrated meat. Indeed, the sorption isothermal technique is used to lower the water content of food while decreasing its perishability. However, different food materials respond differently when it comes to the prediction of its stability. Undoubtedly, these results would make it possible to deduce the shelf life of this product which once perished in the few days after processing if the water content is not appropriate. This work corroborates with the results by Yaptenco (2017) on moisture sorption isotherms of dried sandfish.

4. Conclusion

Dehydrated meat in the tropics can be prepared using different methods of drying, and safe moisture (monolayer value) was obtained at room temperature. Important information on the characteristics and isotherms were obtained and can be useful in predicting the dehydrated meat shelf-life, packaging requirements and drying conditions. Further studies on the adsorption and desorption isotherm of dehydrated meat in tropics in order to obtain hysteresis at a wider range of temperatures are needed.

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Competing Interests

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References

Abera, W. G. (2019). Review on high-pressure processing of foods, Geziel Abera. Cogent Food & Agriculture, 5, 1568725. doi:10.1080/23311932.2019.1568725
Adeyeye, S. A. O. (2018). Quality and safety assessment of sun dried meat product (kundi) from Ibadan, Oyo state, Nigeria. Cogent Food & Agriculture, 2, 1209074. doi:10.1080/23311932.2016.1209074
Akanbi, C. T., Remi Sikiru, A., & Ademola, O. (2006). Drying characteristics and sorption isotherm of tomato slices. Journal of Food Engineering, 73(2), 157–163. doi:10.1016/j.jfoodeng.2005.01.015
Amadou, I., Le, G. W., Shi, Y. H., & Jin, S. (2011). Reducing, radical scavenging, and chelation properties of fermented soy protein meal hydrolysate by Lactobacillus plantarum LP6. International Journal of Food Properties, 14(3), 654–665. doi:10.1080/1094291090312502
Association of Official Analytical Chemists (AOAC). (1990). Methods 932.06, 925.09, 985.29, 923.03: Official methods of analysis of the AOAC, 1990. In Association of official analytical chemists (15th). Arlington, VA: AOAC.
Ayeranci, E., Ayranci, G., & Dogantan, Z. (1990). Moisture sorption isotherms of dried apricots, fig and raisin at 20°C and 30°C. Journal of Food Science, 55, 1591–1593. doi:10.1111/j.1365-2621.1990.tb03577.x
Barbut, S. (2016). Review: Automation and meat quality-global challenges. Meat Science, 96(1), 335–345. doi:10.1016/j.meatsci.2013.07.002
Benhamou, A., Kouhila, A., Zeghmati, B., & Benyousef, B. (2010). Modélisation des isothermes de sorption des feuilles de marjolaine. Revue Des Energies Renouvelables, 13(2), 233–247. https://www.researchgate.net/profile/Amina_Benhamou/publication/325335439
Chang, S. F., Huang, T. C., & Pearson, A. M. (1999). Control of the dehydration process in production of intermediate-moisture meat products: A review. In S. L. Taylor, Ed., Advances in food and nutrition research, pp. 71–161. Academic Press. https://www.taylorfrancis.com/books/9780415850579/chapters/10.1080/00652119008808017
Ferradji, A., Mataliah, M. A. A., & Malek, A. (2008). Conservation des dattes ‘deglet nour’: isothermes d’adsorption à 25, 30 et 40 C. Revue Des Energies Renouvelables, 8, 207–219. https://pdfs.sem
Amadou et al., Cogent Food & Agriculture (2019), 5: 1710440
https://doi.org/10.1080/23311932.2019.1710440

Olooye, J. O., Obajemini, O. I., & Metiboba, T. C. (2016). Effects of processing methods and packaging materials on the quality attributes of Suya meat. Ukrainian Journal of Food Science, 248. doi:10.24263/2310-1008-2016-4-2-7

Olooye, O. A. (2011). Meat: An overview of its composition, biochemical changes and associated microbial agents. International Food Research Journal, 18(3), 877–885. http://www.ifrj.upm.edu.my/18%20(03)%202011/(4)/IFRJ-2010-227.pdf

Ratsimbiasa, A., Leroy, S., Chacornac, J. P., Rakoto, D., Arnaud, E., Jeannoda, V., & Tolon, R. (2017). Staphylococcal ecosystem of kitoza, a traditional malagasy meat product. International Journal of Food Microbiology, 246, 20–24. doi:10.1016/j.ijfoodmicro.2017.02.001

Satiyanarayana, R., Dev, S., Vijaya, G., & Raghavan, S. (2012). Advancements in drying techniques for food, fiber, and fuel. Drying Technology, 30(11–12), 1147–1159. doi:10.1080/07373937.2012.692747

Scott, W. J. (1975). Water relation of food spoilage microorganisms. In E. M. Mrak & G. F. Stewart (Eds.), Advanced in food research (Vol. 7, pp. 83–127). New York, NY: Academic Press. doi:10.1016/S0065-2628(08)60247-5

Toldra, F. (2006). The role of muscle enzymes in dry-cured meat products with different drying conditions. Trends in Food Science and Technology, 17(4), 164–168. doi:10.1016/j.tifs.2005.08.007

Van den Berg, C. (1985). Development of B.E.T. like models for sorption of water foods; theory and relevance. In D. Simatos & J. L. Multon (Eds.), Properties of water in foods (pp. 119–131). Dordrecht: Martinus Nijhoff. https://link.springer.com/chapter/10.1007/978-94-009-5103-7_8

Yaptenco, K. F. (2017). Moisture sorption isotherms and mathematical model selection for dried sandfish (Holothuria scabra). Agricultural Engineering International: CIGR Journal, 19(2), 176–186. https://cigrjournal.org/index.php/ejournal/article/viewFile/3807/2559

Zhang, L., Sun, D. W., & Zhang, Z. (2017). Methods for measuring water activity (aw) of foods and its applications to moisture sorption isotherm studies. Critical Reviews in Food Science and Nutrition, 57(5), 1052–1058. doi:10.1080/10408398.2015.1108282

Zhou, P., Liu, D., Chen, X., Chen, Y., & Labuza, T. P. (2014). Stability of whey protein hydrolysate powders: Effects of relative humidity and temperature. Food Chemistry, 150, 457–462. doi:10.1016/j.foodchem.2013.11.027
