

Reconstitution potentials and moisture sorption isotherms of selected freeze dried Nigerian soups

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Abstract

Selected Nigerian soups were freeze dried with the aim of establishing their storage stabilities and reconstitution potentials. Freshly prepared soups were freeze-dried under vacuum for 12–14 hr. Sorption isotherms were determined at 27°C using gravimetric method at water activities (a_w) of 0.1 – 0.8. Reconstitution potentials were determined at 30 and 100°C using gravimetric methods. Data were analyzed using SPSS for the best fit model equations (Peleg, GAB, Oswin, and Langmuir). The rehydration ratios of the freeze dried soups ranged from 1.00 to 9.11 g absorbed water/g dry matter. Soups were optimally reconstituted at 30°C for 30 min and at 100°C for 5 min. The equilibrium moisture contents of freeze dried soups ranged from 8.84 to 27.50%. The GAB model was the best estimator for predicting the monolayer moisture contents of the soups, which ranged from 7.87 to 9.82% (dry basis), and were within the acceptable limit of 10% dry basis for good storage stability.

Practical applications

Traditionally, soups are generally reheated several times in the day to prevent spoilage, while in modern homes, most soups are kept under frozen condition to preserve them and to avoid nutritional losses which can arise as a result of periodical heating once used, but these methods of soup preservation had been shown to lead to losses of nutrients. Development of shelf stable soups that requires little energy to preserve them for considerable length of time is desirable. Freeze drying (FD) is a gentle technique, which retains the nutritional and sensory properties of food products and their final products can be reconstituted easily by simple addition of liquid. The moisture sorption isotherms, which describe water activity food products are of special interest in the design of Nigerian soups FD process and are also required for the prediction of soups storage stability, shelf life, and calculation of drying time.

1 | INTRODUCTION

Traditional foods are foods recognized by customs and traditions of rural communities (Okeke *et al.*, 2009). They are derived from indigenous plants that are cultivated by the rural dwellers. Traditional foods are of two categories, those that are consumed in the areas where they are grown as traditional dietary staples, for example, cassava, potatoes, plantains, cocoyam, yam, and maize, and those that are consumed as accompanying relishes and sauces, which include oilseeds, fruits and vegetables (Okeke *et al.*, 2009). The items that fell into second category are usually used for preparation of traditional soups.

Ethnic groups and tribes in Nigeria have indigenous soups that are associated with their traditions. These soups are consumed with staple

foods made from cassava, yam, cocoyam, sweet potatoes, plantain, and maize. However, soups are reheated several times in the day to prevent spoilage. This method of vegetable preservation leads to loss of vitamins (Hart *et al.*, 2005). Therefore, proper preservation and utilization of vegetables for maximum nutritional benefits is of utmost importance.

Soup preservation with limited amount of energy can be carried out by drying methods. Dehydration is one of the widely used techniques for fruits and vegetables preservation, which reduces their moisture contents to a level at which microbial spoilage and deterioration reactions are minimized. Many dehydration methods have been used for fruits and vegetable preservation, but each method has its implication on the final product qualities which include degradation of the

TABLE 1 Selected Nigerian soups recipes

Ogbono	Ewedu	Ila	Kuka
Bitter Leaf (20 g)	Leaves (120 g)	Okro (fruit-640 g)	Meat (1000 g)
Ogbono (ground-240 g)	Egusi (ground-40 g)	Pepper (14 g)	Onion (75 g)
Palm oil (80 mL)	Water (500 mL)	Ugwu (200 g)	Dry fish (50 g)
Water (2000 mL)	Crayfish (40 g)	Meat (1000 g)	Stockfish (500 g)
Maggi (8 g)	Potash (1 g)	Crayfish (40 g)	Kuka (Powder 150 g)
Onion (3400 g)	Iru (5 g)	Onion (300 g)	Maggi (10 g)
Iru (locust beans-10 g)	Salt (5 g)	Salt (14 g)	Salt (8 g)
Fish (Smoked-310 g)		Palm oil (40 mL)	Curry(3 g)
Meat (1000 g)		Water (2000 mL)	Thyme(1.4 g)
Crayfish (ground-40 g)		Maggie cube (8 g)	Crayfish (30 g)
Periwinkle (deshelled-94 g)		Iru (locust beans-10 g)	Water (2000mL)
Salt (10 g)			Palm Oil (100 mL)
Pepper (ground-14 g)			

Adapted from FIRO (2006).

physiologically active compounds, color, and texture (Krokida *et al.*, 2001). Freeze drying (FD) is one of the dehydration methods that is reported to be a gentle technique, which retains the biological features of raw materials, flavor, aroma, and color, and their final products can be reconstituted easily by adding water (Jayathilakan *et al.*, 2012). FD is a dehydration method where the removal of water results in end product of good quality attributes (Li *et al.*, 2004), and a process whereby solvent (usually water) is removed from a frozen mass by sublimation (Ratti, 2001). It is a low-temperature process which minimizes chemical alteration or food degradation that occurs during dehydration of food products (Castro *et al.*, 1997). FD has been rated as the best preservation method over other dehydration methods such as air or drum drying (Hsueh *et al.*, 2003) and has received utmost attention by many researchers. Li *et al.* (2004) and Yun *et al.* (2006) reported that FD could be used to dry sea cucumbers with good quality attribute upon rehydration. Paakkonen and Mattila (1991) discovered that sensory quality of dried fruits could be improved if dried at very low temperature. Strawberry freeze dried at 20°C retained better quality than when oven dried at 60°C. Better quality products can be obtained when food are dried at lower temperature to guide against structural losses, reduction in pore size, and shrinkage that occur at higher temperature (Hammami and Rene, 1997).

Water activity (a_w) is an important concept in food processing and storage technology and it is described as the ratio of the equilibrium water vapor pressure of a food sample to its saturated vapor pressure at the same temperature. It is directly related to microbiological stability and deteriorative changes that occur in stored foods (Khalloufi *et al.*, 2000). The water activity of food stuff at given temperature and at different moisture contents can be described by sorption isotherms. Sorption isotherms are of special interest in the design of food preservation processes and are required for food stability and shelf life prediction, and for the estimation of drying time (Khalloufi *et al.*, 2000).

Reconstitution potential of dehydrated food products is a measure of the induced damage in the materials during drying, such as integrity loss and reduction of hydrophilic properties, which reduces their ability to rehydrate (Marques *et al.*, 2009). Theoretically, dehydrated food product is expected to absorb water to the same moisture content as the initial product before drying, if there are no adverse effects on the integrity of the tissue structure (Senadeera *et al.*, 2000). Rapid and complete rehydration is very important for dried products (Vega-Gálvez *et al.*, 2009) and it is maximized when structural disruption at the cellular level is minimized (Crapiste, 2000).

This study aimed at determining the reconstitution potentials and moisture sorption isotherms of selected freeze dried Nigerian soups prepared from “ewedu” (*Corchorus olitorus*), “ila” (*Hibiscus esculentus*), “ogbono” (*Irvingia gabonensis*), and “kuka” (*Adansonia digitata*), as well as analyzing the adsorption data for the best fit model.

2 | MATERIALS AND METHODS

2.1 | Preparation of soups

Ewedu, ila, ogbono, and kuka soups were prepared according to recipes described by FIRO (2006). The soups recipes were presented in Table 1 and the procedures for the preparation of the soups were described below:

2.1.1 | Ewedu soup preparation

Already detached fresh Ewedu leaves from the parent stalks were thoroughly washed with water to remove dirt. A considerable amount of water was added to the leaves before blending in a blender. A piece of potash was added to the blend, which was already placed in a clean pot. After 5 min of boiling, Egusi powder was sprinkled into it, while the pot was kept open. The mixture was stirred gently and was allowed

TABLE 2 Desiccants preparation at 27°C

Water activity(a_w)	Quantity of Conc H_2SO_4 /250 mL water
0.80	71.29
0.70	86.28
0.60	99.36
0.50	111.65
0.40	123.3
0.30	135.92
0.20	149.08
0.10	167.61

Source: Perry and Green (1984).

to simmer on low heat for 5 min. Before heat was removed, ground crayfish, locust bean, and salt were added to the mixture.

2.1.2 | Ogbono soup preparation

The thoroughly washed pieces of fish, meat, and onions placed in a clean pot contain considerable amount of water were boiled until they were softened. The boiled meat and fish were minced using a mincer to aid drying and the mixture was placed in a clean pot. Ground pepper, ground crayfish, periwinkles, oil, and ground Ogbono were added to the mixture. Gentle stirring and medium heat boiling of the mixture were allowed for 5 min before chopped vegetable and seasoning were added. The mixture was also allowed to simmer for 5 min before heat was removed.

2.1.3 | Okro soup preparation

The thoroughly washed pieces of fish, meat and onions placed in a clean pot contain considerable amount of water were boiled until they were softened. The boiled meat and fish were minced using a mincer to aid drying and the mixture was placed in a clean pot. Ground pepper, ground crayfish, and oil were added to the mixture. Gentle stirring and medium heat boiling of the mixture were allowed for 10 min. In addition, chopped okro fruits and seasoning were added to the boiling mixture and was allowed to simmer until the okro tendered and the required consistency was reached.

2.1.4 | Miyan kuka soup preparation

The thoroughly washed pieces of fish, meat and onions placed in a clean pot contain considerable amount of water were boiled for 25 min. The boiled meat and fish washed stock fish and dried fish were minced using a mincer to aid drying and the mixture was placed in a clean pot. Also, curry, ground pepper, and water to the mixture and was further cooked for 20 min. Kuka leaves powder was further added to mixture and the mixture and gently stirred. Before heat was removed, the soup was allowed to steam for 15 min. All the soups were allowed to cool and then packaged in stainless steel trays prior to FD.

2.2 | FD of soups

Freshly prepared soups (350 g) were spread in the drying trays and placed in FD chamber of CRC FD-10N-50 model freeze dryer for about 12–14 hr. The shelf temperature was at 25°C, while the pressure of the drying chamber was maintained at 80 Pa during drying and the cold trap temperature was maintained at −40°C. The samples were dehydrated until final moisture contents of 6.0–7.0% were reached. The dried soups were subsequently packaged in 0.1 mm poly-vinyl chloride bags and stored at room temperature for further analyses.

2.3 | Storage studies

The equilibrium moisture contents and moisture adsorption isotherms of the soups were determined gravimetrically according to the methods of Oyelade et al. (2001) and Famurewa et al. (2012); 0.50 ± 0.001 g of each freeze dried soup was weighed into sample bottles of similar shapes and sizes. The bottles were placed in desiccators containing varied concentration of sulfuric acid. The desiccants were prepared by adding varied concentrations of sulfuric acid to 250 mL of deionized water at 27°C, following the water activity and temperature described in Table 2. The desiccators were maintained at water activities values of 0.1 to 0.8 at an interval of 0.1, and kept at room temperature (27°C) on the shelf. Each sample was weighed daily using a digital balance until a constant weight was observed in three consecutive readings, then the samples was assumed to be at equilibrium (± 0.001 g). The equilibrium moisture content for each soup was obtained from the moisture adsorption isotherm plot.

2.4 | Modeling of adsorption data

The adsorption data obtained were analyzed using four best fit model equations (Peleg, Guggenheim, Anderson and de Boer-GAB, Oswin and Langmuir) by employing the linear regression analytical procedure. These models were chosen because of their simplicity and ease of evaluation (Ajisegiri et al., 2007). However, the linear forms of the models were shown in Table 3. The fitness of the models were established through the coefficient of determination (R^2), root mean square error (RMSE) and mean percentage deviation (%E). The RMSE and %E are defined as shown in Equations 1 and 2, respectively.

TABLE 3 Linear forms of the sorption models used to fit experimental values

Models	Equations
GAB	$M = \frac{M_0 b c a_w}{(1 - c a_w)(1 - c a_w + b c a_w)}$
Oswin	$M = C \left(\frac{a_w}{1 - a_w} \right)^n$
Peleg	$M = C_1 a_w^3 + C_2 a_w^4$
Langmuir	$M = \frac{C M_0^2 a_w}{M_0 (1 + a_w)}$

GAB, Guggenheim, Anderson and de Boer; M , equilibrium moisture content (% dry basis); C : temperature (°C), a_w : water activity; M_0 : monolayer moisture content.

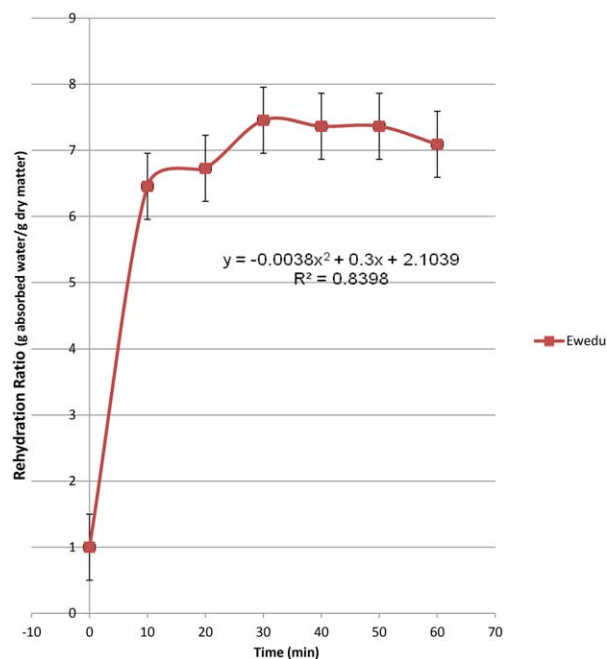


FIGURE 1 Rehydration curves of freeze dried Ewedu soups at ambient temperature.

$$RMSE = \sqrt{\frac{\sum (M_{exp} - M_{pred})^2}{n}} \quad (1)$$

$$\%E = \frac{100}{n} \sum \left| \frac{M_{exp} - M_{pred}}{M_{exp}} \right| \quad (2)$$

where M_{exp} is the experimental equilibrium moisture content, M_{pred} is the predicted moisture contentment, and n is the number of observations.

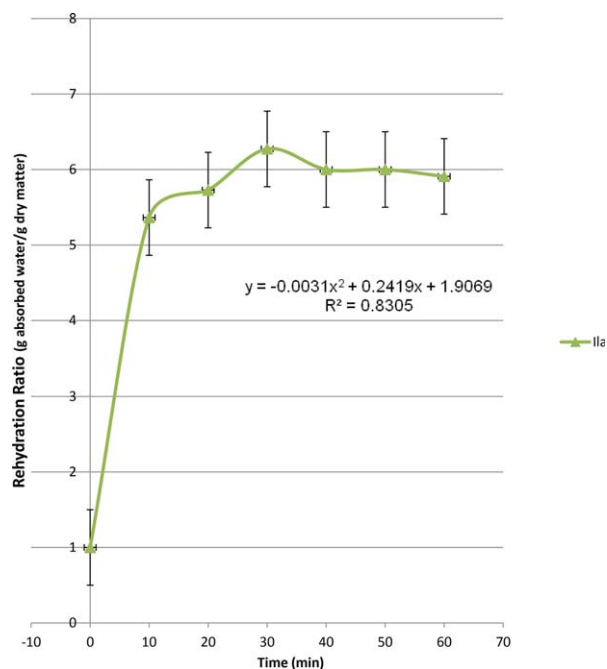


FIGURE 2 Rehydration curves of freeze dried Ila soups at ambient temperature

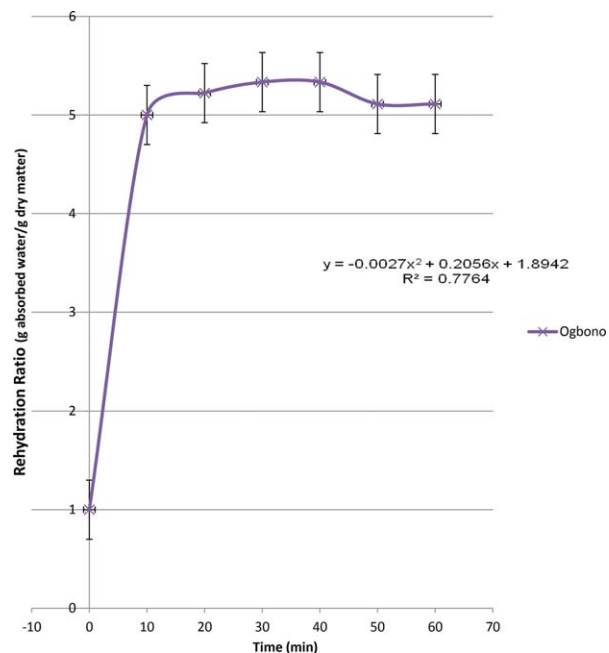


FIGURE 3 Rehydration curves of freeze dried Ogbono soups at ambient temperature

2.5 | Rehydration of freeze dried soups

The rehydration potentials were analyzed using the method of You-sif *et al.* (2000). The rehydration potentials of freeze dried soups were evaluated by immersing preweighed samples, held by fine muslin cloth in pyrex glass containers, containing water at 30 and 100°C. The samples (in replicate for each time interval and

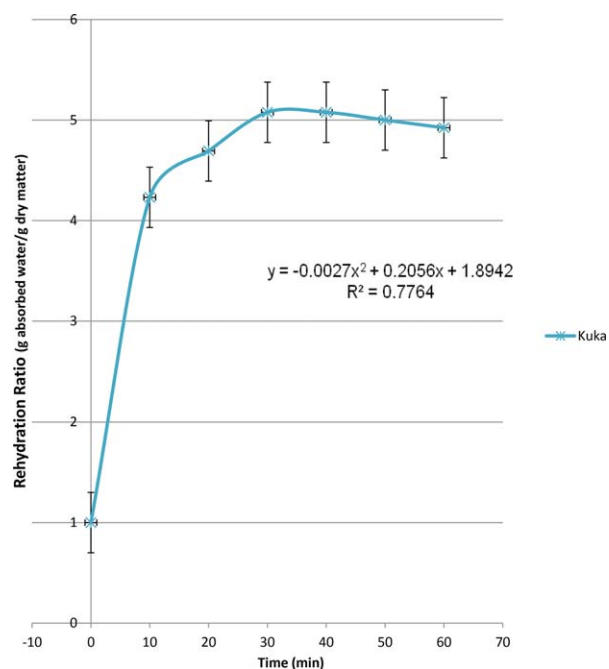


FIGURE 4 Rehydration curves of freeze dried Kuka soups at ambient temperature

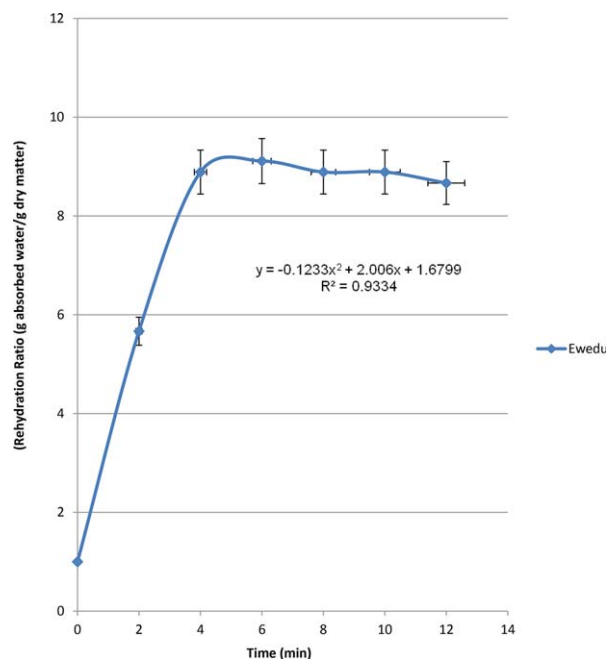


FIGURE 5 Rehydration curves of freeze dried Ewedu soups at 100°C

treatment temperature) were drained with filter paper (placed on a buchner funnel, for 30 s) and reweighed at 0, 10, 20, 30, 60, 90, and 120 min for samples rehydrated at 30°C; and at 0, 2.0, 4.0, 6.0, 8.0, 10.0, and 12.0 min for samples rehydrated at 100°C. The dehydration ratio was expressed as the ratio of the weight of water absorbed (g) to the weight of the dry sample (g). The rehydration rate was determined from the slope of the rehydration ratio against rehydration time.

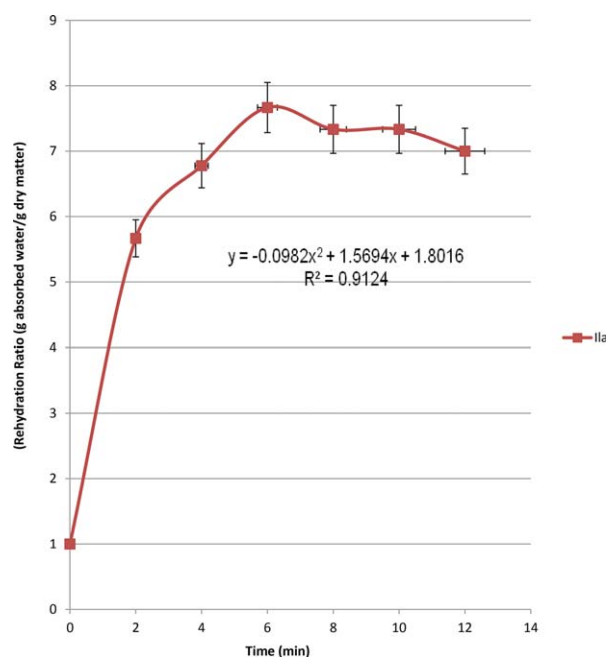


FIGURE 6 Rehydration curves of freeze dried Ila soups at 100°C

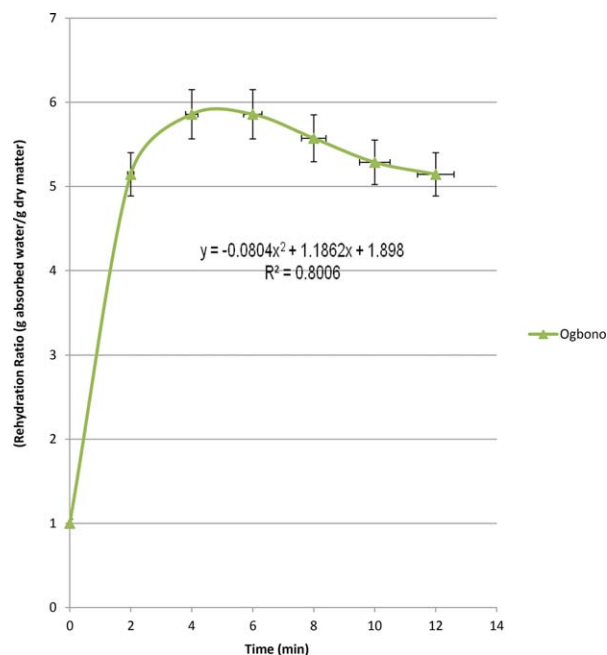


FIGURE 7 Rehydration curves of freeze dried Ogbono soups at 100°C

2.6 | Determination of quantity of water needed for reconstitution

The quantities of water to be added to reconstitute the soups were determined by adopting the method of Davies and El-Okene (2009a) for moisture content adjustment. The quantity of distilled water was calculated using Equation 3:

$$M = W_s \left\{ \frac{M_1 - M_2}{1 - M_1} \right\} \quad (3)$$

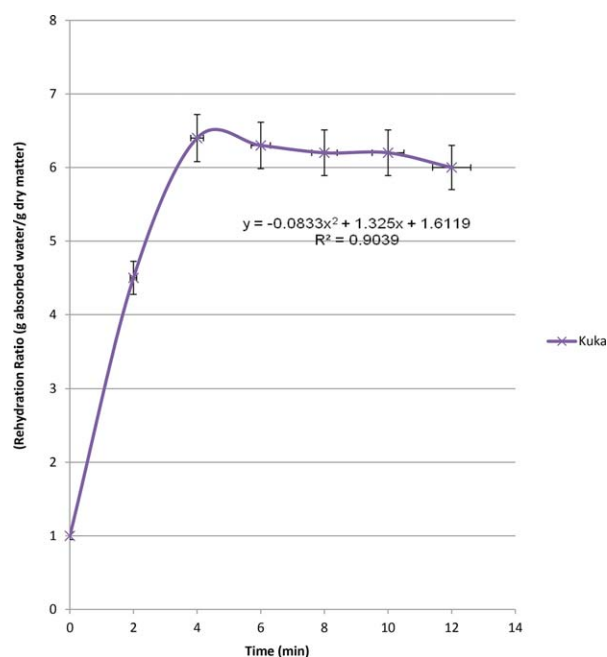


FIGURE 8 Rehydration curves of freeze dried Kuka soups at 100°C

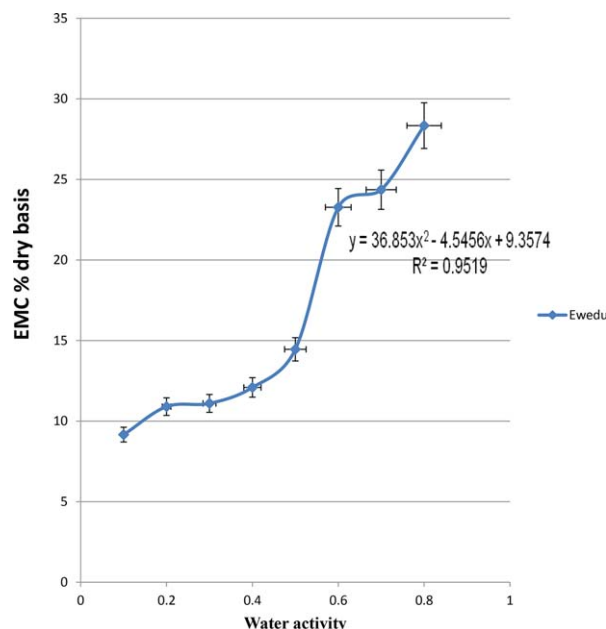


FIGURE 9 Moisture adsorption isotherm curves of freeze dried Ewedu soups at ambient temperature

where M , weight of distilled water added (g), W_s , weight of sample (g), M_1 , initial moisture content of the sample (%), and M_2 , final moisture content of the sample (%).

2.7 | Reconstitution of freeze dried soups

The quantities of water obtained from moisture content adjustment method were used to reconstitute the dried soups at 30 and 100 °C; 100 g of freeze dried soups were soaked with predetermined quanti-

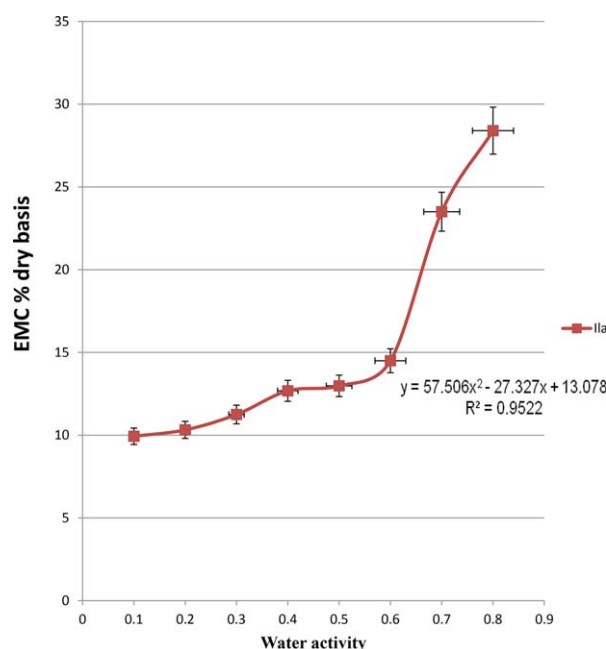


FIGURE 10 Moisture adsorption isotherm curves of freeze dried Ila soups at ambient temperature

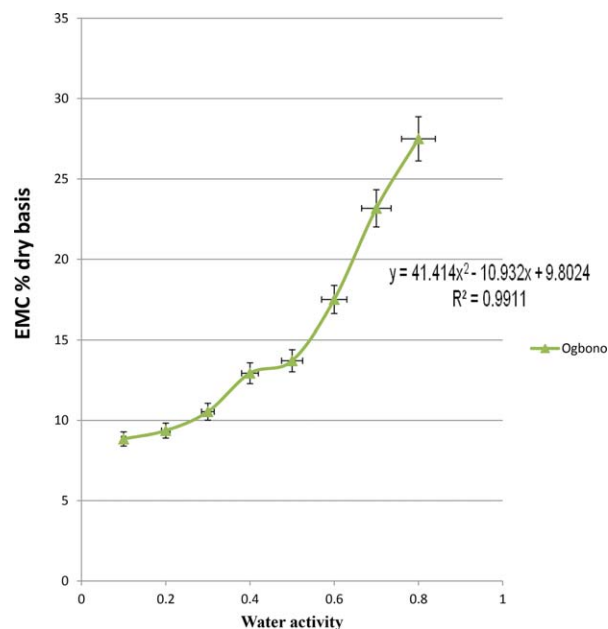


FIGURE 11 Moisture adsorption isotherm curves of freeze dried Ogbono soups at ambient temperature

ties of water for 5 and 30 min (optimum rehydration time), as already established in their rehydration potentials.

2.8 | Statistical analysis

Data obtained were analyzed using SPSS version 14.0, Chicago.

3 | RESULTS AND DISCUSSION

3.1 | Rehydration potential of freeze dried soups

The rehydration curves of dried freeze dried soups at $30 \pm 2^\circ\text{C}$ and 100°C are shown in Figures 1–8. The rehydration ratios of the freeze dried soups at room temperature ranged from 1.00 to 7.46 g absorbed water/g dry matter (ewedu), 1.00 – 6.27 g absorbed water/g dry matter (ila), from 1.00 to 5.33 g absorbed water/g dry matter (ogbono) and from 1.00 to 5.08 g absorbed water/g dry matter (kuka), while the rehydration ratios of the freeze dried soups at 100°C ranged from 1.00 to 9.11 g absorbed water/g dry matter (ewedu), 1.00 – 7.67 g absorbed water/g dry matter (ila), from 1.00 to 5.86 g absorbed water/g dry matter (ogbono) and from 1.00 to 6.40 g absorbed water/g dry matter (kuka). Variation in rehydration might be due the influence of temperature on water absorption and the nature of the ingredients of the soups. Decrease in the rehydration curves of the soups after 30 min of soaking at room temperature and 5 min of soaking at 100°C correlated with the loss of solute during rehydration. Highest rehydration ratios were observed for all the soups soaked in hot water at 100°C for 5.0 min, but at room temperature, samples soaked in distilled water for 30 min had the highest rehydration ratios. Therefore, 100 g of freeze dried soups was soaked for 30 min at room temperature or 5 min at 100°C with a pre determined quantity of water (721.67 ml for ewedu, 198.63 mL for ogbono, 309.14 mL for ila, and 336.39 mL for kuka) for optimum reconstitution.

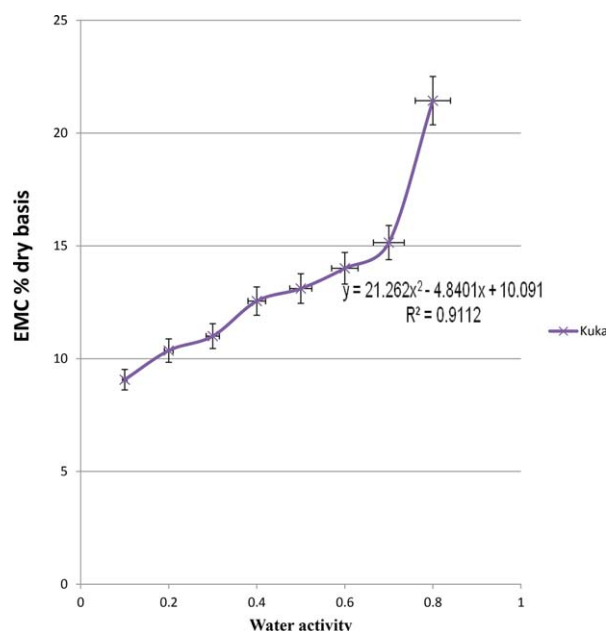


FIGURE 12 Moisture adsorption isotherm curves of freeze dried Kuka soups at ambient temperature

Plant materials rehydration is influenced by their polarity, hydrophobicity, and presence or absence of internal open space (Yousif *et al.*, 2000). It also depends on structural changes in cell matrix and vegetable tissues, which occur during drying and might lead to shrinkage and collapse (Kaymak-Ertekin, 2002). At both lower and higher temperatures (30 and 100 °C), freeze dried ewedu soup exhibited

significantly higher rehydration ratios than other soup samples (Figures 1 and 2), but at 100 °C, less time was required for reconstitution of all the samples. Similarly, Yousif *et al.* (2000) observed lesser rehydration time of freeze dried oregano leaves at higher temperature. Higher rehydration rates were observed at the beginning of rehydration in the soups reconstituted at 100 °C. High coefficient of determination R^2 suggested that all the models had good fits (Figures 1–8).

3.2 | Water adsorption isotherms of freeze dried soups at ambient temperature

The relationships between the equilibrium moisture contents of freeze dried soups stored at ambient temperature and the water activity were presented in the sorption isotherms in Figures 9–12. The equilibrium moisture contents of freeze dried ewedu ranged from 9.16 to 28.34%, freeze dried ila ranged from 9.93 to 28.40%, freeze dried ogbono ranged from 8.84 to 27.50% and freeze dried kuka ranged from 9.07 to 21.44%. It was observed that as the water activity increased, the equilibrium moisture contents of the freeze dried soups increased. A Type II sigmoidal isotherm that showed asymptotic trend as water activity was closed to 0.8 was observed for the soups. Similar trend was reported by Kane *et al.* (2008) for sorption isotherms of *Mentha pulegium* and *Mentha rotundifolia* leaves. Calculated model constants, coefficient of determination (R^2) and % RMS for each model of the freeze dried soups are represented in Table 4. High coefficient of determination R^2 implied that all the models had good fits. Out of all

TABLE 4 Models for the adsorption isotherm of freeze dried Nigerian soups

Sample	Models	A	B	C	D	R^2	RMSE	%E	F-CAL	F-Tab (0.05)
Ewedu	GAB	9.82	42.45	0.84		0.93	0.13	−0.03	93.9	9.01
	Peleg	34.82	5.29	1.76	−0.22	0.96	0.07	0.02	147.74	6.26
	Oswin	16.97	0.39			0.92	0.42	0.04	83.98	19.33
	Langmuir	5.19	4.12			0.73	4.67	1.23	24.07	19.33
Ila	GAB	7.87	1.47E+08	0.91		0.95	0.21	0.06	138.79	9.01
	Peleg	11.45	45	0.06	4.18	0.97	0.02	0.01	235.54	6.26
	Oswin	15.55	0.39			0.88	0.45	0.13	55.02	19.33
	Langmuir	4.23	4.62			0.60	4.76	1.36	16.21	19.33
Ogbono	GAB	8.24	164.88	0.89		0.99	0.07	−0.02	496.78	9.01
	Peleg	33.16	9.85	2.72	0.05	0.99	0.00	−0.00	951.65	6.26
	Oswin	15.61	0.40			0.96	0.24	0.07	181.45	19.33
	Langmuir	4.26	4.64			0.75	4.30	1.23	26.29	19.33
Kuka	GAB	8.36	1.22E+08	0.73		0.93	0.09	0.03	207.22	9.01
	Peleg	15.39	152.06	0.24	13.90	1.00	0.18	−0.06	3299.30	6.26
	Oswin	13.73	0.25			0.89	0.09	0.03	138.61	19.33
	Langmuir	16.02	0.99			1.00	6.24	2.07	9.032	19.33

GAB, Guggenheim, Anderson and de Boer equation; A, B, C, D, Constant parameters; R^2 = Coefficient of determination; RMSE, root mean square error; %E, mean percentage deviation.

TABLE 5 GAB monolayer moisture content (M_o) of freeze dried Nigerian soups at 27°C

Sample	M_o (%)	F-CAL	F-Tab (0.05)
Ewedu	9.82	93.9	9.01
Ila	7.87	138.79	9.01
Ogbono	8.24	496.78	9.01
Kuka	8.36	207.22	9.01

the models used in this study, the GAB model was the best for predicting the monolayer moisture content of the products, followed by the Peleg model. This is in agreement with Rohvein *et al.* (2004) and Siripatrawan and Jantawat (2006) who reported that GAB model was the foremost versatile sorption model accessible within the literature to fit the experimental sorption data for almost all the food products and over a wide range of water activity. The freeze dried soups monolayer moisture contents were presented in Table 5. The monolayer moisture contents of the soups ranged from 7.87 to 9.82% (dry basis). The monolayer moisture content is a measure of the amount of water that can be adsorbed in a single layer of the dry product (Kulchan *et al.*, 2010). It also defines the physical and chemical stability of foods with respect to lipid oxidation, enzyme activity, non-enzymatic browning, flavor preservation, and product structure (Menkov, 2000). However, the monolayer moisture content values obtained in this study were within the acceptable limit of 10% dry basis for food products (Bell and Labuza, 2000).

4 | CONCLUSION

The equilibrium moisture contents of the freeze dried soups increased as the water activity increased. The GAB model was found to be the best estimator for predicting the monolayer moisture content of the product, followed by the Peleg model. However, the monolayer moisture content values obtained in this study is within the acceptable limit of 10% dry basis for food products. Highest rehydration ratios were observed for all the soups soaked in hot water at 100°C for 5.0 min, but at room temperature, samples soaked in distilled water for 30 min had the highest rehydration ratios. It was established that 100 g of freeze dried soups could be reconstituted with 721.67 mL (ewedu), 198.63 mL (ogbono), 309.14 mL (ila), and 336.39 mL (kuka) of water for 30 min at room temperature or 5.0 min at 100°C for optimum reconstitution.

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