

FREEZING AND THAWING CHARACTERISTICS OF SOME SELECTED NIGERIAN SOUPS

AKEEM OLAYEMI RAJI^{1,4}, RAHMAN AKINOSO^{2,4}, UCHE IBANGA³ and MONSURAT OYEWALE RAJI²

¹Department of Food Agric and Biological Engineering, College of Engineering and Technology, Kwara State University, Malete, Ilorin, Nigeria

²Department of Food Technology, University of Ibadan, Oyo State, Nigeria

³Federal College of Freshwater Fisheries Technology, New Bussa, Niger State, Nigeria

⁴Corresponding authors.

TEL: +2348060867687

EMAIL: akeem.raji@kwasu.edu.ng;

EMAIL: akinoso2002@yahoo.com

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ABSTRACT

Freezing and thawing characteristics of some Nigerian soups (*Ila, Ewedu, Ogbono and Kuka*) were investigated. The soups were prepared using standard recipe and packaged in plastic and aluminum containers, frozen at -20°C and thawed with microwave oven water (2.45 GHz), hot water (100°C) and at ambient condition ($30 \pm 2^{\circ}\text{C}$). Freezing and thawing durations, rates, losses and points of the soups were determined using standard methods. Data were analysed using SPSS at $P = 0.05$. Freezing duration, rate, loss and points were 70.0–145.0 min, 0.4–0.7°C/min, 1.75–3.79%, and -1.8 to -2.4°C respectively. Thawing duration, rate, loss and points were, 1.8–53.0 min, 0.4–10.9°C/min, 0.1–2.4% and -1.7 to -2.3°C respectively. Soups packaged in aluminium containers frozen faster than in plastic containers. Microwave-thawed soups in plastics showed the best thawing characteristics which include high thawing rate, short thawing time and low thawing loss.

PRACTICAL APPLICATIONS

Evidence of richness of Nigerian soups has been reported by many researchers. In order to maintain the quality of frozen selected Nigerian soups and to reduce the cost of their preservation, the freezing and thawing characteristics of the selected soups should be established. Freezing is an effective preservation technique that maintains the keeping quality of both processed and freshly harvested products. This method of preservation is considerably complex and quality of frozen food depends not only on the temperature, the freezing rate, freezing time and maintenance of the cooling chain, but also on the thawing conditions. Freezing and thawing characteristics of the selected Nigerian soups established are essential in the calculation of refrigeration requirements and the design of equipments for Nigerian soups preservation. Also, the data obtained can be applied to cold chain marketing of the soups to guide against sensory and nutritional losses during cold storage.

INTRODUCTION

Freezing is an effective method of preservation that maintains the keeping quality of both processed and freshly harvested product (Martinez-Romero *et al.* 2004). The effort of freezing and the formation of either small or large crystals are critical to minimize nutritional losses (Bin and Da-wen 2002). Frozen food will inevitably lose some special attributes of freshly prepared products (Sjofn *et al.* 2000).

Knowledge of Freezing and thawing properties of food are important in order to estimate the refrigeration requirements for freezing systems and to design the necessary equipment for effective processing, to conserve energy required for freezing, to establish a reliable process and prevent product quality deterioration (Delgado and Sun 2001).

Vegetables are important items of diet in many Nigerian homes. Asides that they add varieties to the menu, they are

TABLE 1. RECIPES USED FOR PREPARATION OF SOUPS

<i>Ogbono</i>	<i>Ewedu</i>	<i>Ila</i>	<i>Kuka</i>
Bitter Leaf (20 g)	Leaves (120 g)	Okro (fruit–640 g)	Meat (1,000g)
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 (2,000 mL)	Crayfish (40 g)	Meat (1,000 g)	Stockfish (500 g)
Maggi (8 g)	Potash (1 g)	Crayfish (40 g)	Kuka (Powder150 g)
Onion (3,400 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 (1,000 g)		Water (2,000 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 (2,000 mL)
Salt (10 g)			Palm Oil (100 mL)
Pepper (ground–14 g)			

Adapted from FIIRO (2006) Methods

valuable sources of nutrients especially in rural areas where they contribute substantially to minerals, vitamins, fiber and other nutrients which are usually in short supply in daily diets (Mepba *et al.* 2007). Besides, they add flavour, variety, taste, colour and aesthetic appeal to what would otherwise be a monotonous diet (Shiundu 2002; Hart *et al.* 2005). They are in abundance shortly after the rainy season but become scarce during the dry season during which cultivated types along the river beds are used. Vegetables have gained a widespread acceptance as a dietary constituent in Nigeria, generally forming a substantial portion of the diet in the preparation of soups and stews (Hart *et al.* 2005).

Nigeria is a multi-cultural society with different traditional soups which are indigenous to different ethnic groups and tribes. The soups are consumed along with traditional dietary staples, obtained from cassava, yam, cocoyam, sweet potatoes, plantain and maize. Though, there is no universally accepted short list of such plants mentioned above, different tribes in Nigeria have evolved their preferences and feeding habits. FIIRO (2006) established the recipe and nutritional contents of stews and soups commonly consumed in Nigeria so as to serve as a reference to interested individuals, corporate organizations, researchers, medical practitioners, nutritionists and dieticians, public health workers and food technology programmes.

Evidence of the richness of traditional African dishes in nutrients had been reported by FIIRO (2006) and OGUCHE (2012), but fundamental information about their freezing and thawing characteristics have not been established, despite their nutritional significance and attachment to African culture. Therefore, studies on the freezing rate, freezing time, freezing point, freezing loss, thawing time, thawing point and thawing loss of some selected Nigerian soups stored under conventional freezing conditions should be investigated. Soups considered were chosen because they are popularly consumed along with staple foods from the three

major tribes in Nigeria and these were prepared from ‘ewedu’ (*Corchorus olitorus*), ‘ila’ (*Hibiscus esculentus*), ‘ogbono’ (*Irvingia gabonensis*) and ‘kuka’ (*Adansonia digitata*).

MATERIALS AND METHODS

Materials

The ingredients used for the preparation of the above soups were purchased from local markets at Ipata and Ago in Ilorin, Kwara State, Nigeria.

Preparation of Soups

Selected Nigerian soups (*Ewedu*, *Ila*, *Ogbono* and *Kuka*) were prepared using facilities of the department of Food Agric and Biological Engineering, Kwara State University Nigeria. The preparation methods used for the selected soups were those earlier established by recipe book of the Federal Institute of Industrial Research, Oshodi (FIIRO 2006). The recipes used for the soups were presented in Table 1 and the methods of preparation were described below:

Preparation of Ewedu Soup. Fresh *Ewedu* leaves were detached from the parent stalks and they were washed thoroughly to remove dirt. The leaves were blended in a blender containing considerable amount of water. The blend was later poured into a clean pot, small piece of potash was added into the pot and it was boiled for 5 min. *Egusi* powder was sprinkled into it, while the pot was kept open. The low heat was simmered for 5 min and it was gently stirred. Ground crayfish, locust bean and salt were added to it before heating was stopped. The soup was allowed to cool and then packaged into different containers prior to freezing

Preparation of Ogbono Soup. Fish and meat were cut into pieces and they were washed thoroughly. The meat, fish and sliced onion were placed in clean pot containing considerable amount of water and the mixture were boiled until the meat softened. Pepper, crayfish, periwinkle, oil and 'ogbono' (ground) were added to the mixture. The mixture was stirred gently and it was allowed to boil over a medium heat for 5 min. Chopped vegetable and season were added and the mixtures were allowed to simmer for 5 min. The soup was allowed to cool and then packaged into different containers (100 g per container) prior to freezing.

Preparation of Okro Soup. Fish and meat were cut into pieces and they were washed thoroughly. The meat, fish and sliced onion were placed in clean pot contain considerable amount of water and the mixture were boiled until the meat softened. Pepper, milled crayfish and oil were added to the mixture. The mixture was stirred gently and it was allowed to boil over a medium heat for 10 min. Chopped okro fruits and seasoning were added and the mixtures were allowed to simmer until meat, vegetable and okro tendered and the required consistency was reached. The soup was allowed to cool and then packaged into different containers (100 g per container) prior to freezing.

Preparation of Miyan Kuka Soup. The pieces of fresh meat were washed and placed in a clean pot. Clean water and sliced onions were added to it. The mixture was heated for 25 min. Washed stockfish, curry, dried fish, ground pepper and water were added to the boiling mixture. It was further cooked for 20 min. Ground 'kuka' leaves was added and it was gently stirred. The soup was allowed to steam for 15 min, cooled and packaged into different containers (100 g per container) prior to freezing.

Determination of Latent Heat of Fusion of the Soups. The latent heat of fusion of each soup was determined using the method of Singh and Heldman (2000) as described in Eq. (1):

$$L_f = m_m L \quad (1)$$

where L_f is the latent heat of fusion of the soup, L is the latent heat of fusion of water (333.20 kJ/kg), m_m is the moisture content of the soup

Measurement of Density

Density of each soup was determined using the method of SINGH and HELDMAN (2000). 100 g of each soup was poured into measuring cylinder to determine the volume it has occupied. The volume occupied was recorded and the density was obtained using Eq. (2):

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \quad (2)$$

Important Parameters for Predicted Freezing Time Calculation

Thickness of the aluminium container = 0.003 m

Thickness of the plastic container = 0.003 m

Length of the aluminium container = 0.055 m

Length of the plastic container = 0.055 m

Thermal conductivity of the aluminium container = $161 \text{ Wm}^{-1}\text{K}^{-1}$ (Singh and Heldsman 2000)

Thermal conductivity of the plastic container = $0.55 \text{ Wm}^{-1}\text{K}^{-1}$ (Fellows 2000)

Surface heat transfer coefficient of the chest freezer = $9.00 \text{ Wm}^{-2}\text{K}^{-1}$ (Fellows 2000)

Temperature of the freezing medium = -20C

The Measurement of Freezing Point and the Experimental Freezing Time

The method of Jie *et al.* (2003) was adopted to establish the freezing points and the freezing time of soup samples. The freezing point and the freezing time for each soup packaged in plastics and aluminium containers were determined from their cooling curves. The sensors were the probes of the digital thermometers and they were calibrated in the mixture of water and ice before readings were taken. The probes were positioned at the centre of the frozen mass, while the samples with the probes were placed in freezer (-20C) and the temperature values were recorded at 5 min interval. The temperature value at which the rate of change of temperature on the freezing curve is at the minimum indicated the beginning of the formation of ice crystals (freezing point). The freezing point of each soup was taking at the above temperature. The experimental freezing time of each soup was taken when the sensor reading was at -20C , which is the temperature of the freezing medium.

Freezing Rate. The freezing rate as defined by the International Institute of Refrigeration (IIF) is the difference between the initial and final temperature of the product divided by the freezing time (Martinez-Romero *et al.* 2004). The freezing rate of food was calculated using Eq. (3).

$$\text{Freezing rate (C/min)} = \frac{T_1 - T_2}{t} \quad (3)$$

where T_1 is the initial temperature of the product before freezing (C); T_2 is the temperature at which the product freezes (C); t is the freezing time

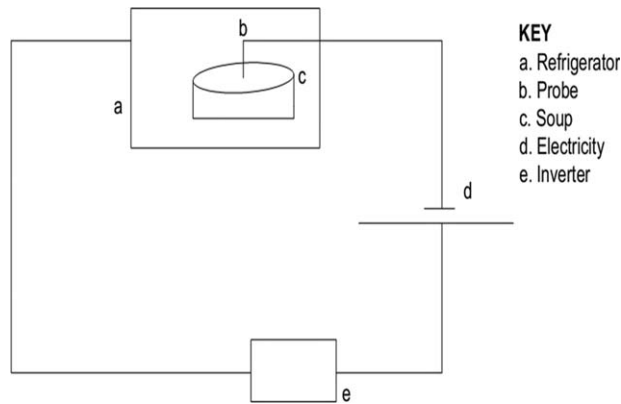


FIG. 1. DESIGN SYSTEM FOR DERIVING THE FREEZING AND THAWING CHARACTERISTICS OF SOUPS

Determination of the Predicted Freezing Time. The freezing time of food was calculated using Eq. (4).

$$t_f = \frac{\lambda \rho}{Q_f - Q_a} \left[\frac{L}{4} \left[\frac{1}{h} + \frac{x}{K_1} \right] + \frac{L^2}{16k_2} \right] \quad (4)$$

where

t_f (s) is the freezing time; $L_{(M)}$ is the length of the packaging materials; h ($\text{Wm}^{-2}\text{K}^{-1}$) is the surface heat transfer coefficient; Q_f (C) is the freezing point of the food; Q_a (C) is the temperature of the freezing medium; λ (Jkg^{-1}) is the latent heat of crystallization; ρ (kgm^{-3}) is the density of the food; x (m) is the thickness of the packaging; k_1 ($\text{Wm}^{-1}\text{K}^{-1}$) is the thermal conductivity of the packaging; k_2 ($\text{Wm}^{-1}\text{K}^{-1}$) is the thermal conductivity of the frozen zone,

4 and 16 are factors which represent the shortest distance between the centre and the surface of the food (Fellows 2000).

Percentage Difference Between the Predicted and Experimental Freezing Time. The assessment of the prediction accuracy was made by comparison of the numerically calculated times for the centre temperature of the food to reach -20°C for freezing with the experimentally measured times. The percentage differences were calculated according to the procedure of Delgado and Sun (2007) as stated in Eq. (5).

$$\% \text{ Difference} = \frac{\text{Experimental} - \text{Predicted}}{\text{Experimental}} \times \frac{100}{1} \quad (5)$$

Freezing Loss Determination. The freezing loss of the frozen soups were determined from known weights of the

TABLE 2. MOISTURE CONTENT AND THERMAL CONDUCTIVITY OF SELECTED NIGERIAN SOUPS

Sample	Moisture contents (%)	Thermal conductivity (W/mK)
<i>Ewedu</i>	88.60 ± 0.14	0.53 ± 0.00
<i>Ila</i>	77.25 ± 0.35	0.48 ± 0.00
<i>Ogbono</i>	68.70 ± 0.14	0.45 ± 0.00
<i>Kuka</i>	78.54 ± 0.06	0.49 ± 0.00

Source: Raji and Akinoso (2013)

soups before and after freezing and expressed as % freezing loss (AOAC 2005) using Eq. (6).

$$\% \text{Freezing loss} = \frac{W_1 - W_2}{W_2} \times \frac{100}{1} \quad (6)$$

where W_1 is the weight of the soup before freezing; W_2 is the weight of the soup after freezing

Thawing Methods

The soups frozen in aluminum and plastic containers were thawed using the three different thawing methods stated below.

Thawing in Microwave Oven. The frozen soups were thawed in a microwave oven operated at frequency of 2.45 GHz (LG, MS2024W, 450 W max. power) using defrost setting, until the temperature at the centre of the soups reached 0°C . The changes in temperature was monitored with the aid of digital thermometer with a probe inserted at the centre of the frozen mass. The time taken to thaw the soup from -20°C to 0°C was designated as the thawing time of the soups in a microwave oven.

Thawing in Hot Water. The frozen soups were thawed in a water bath containing boiling water (100°C) until the temperature at the centre of the soups reached 0°C . The change in temperature was monitored with the aid of digital thermometer with a probe inserted at the centre of the frozen mass. The time taken to thaw the soup from -20°C to 0°C was designated as the thawing time of the soups in hot water.

Thawing at Ambient Temperature. The frozen soups were thawed at ambient temperature ($28\text{--}32^\circ\text{C}$) on a plastic

TABLE 3. SOME PHYSICAL PROPERTIES OF SELECTED NIGERIAN SOUPS

Sample	Volume (cm^3)	Density (kg/m^3)	Latent heat (kJ/kg)
<i>Ewedu</i>	98.67 ± 0.03	$1,013.47 \pm 0.31$	295.22 ± 0.47
<i>Ila</i>	94.26 ± 0.05	$1,060.90 \pm 0.57$	257.40 ± 1.17
<i>Ogbono</i>	90.94 ± 0.04	$1,099.62 \pm 0.49$	228.91 ± 0.47
<i>Kuka</i>	94.08 ± 0.06	$1,062.93 \pm 0.68$	261.70 ± 0.20

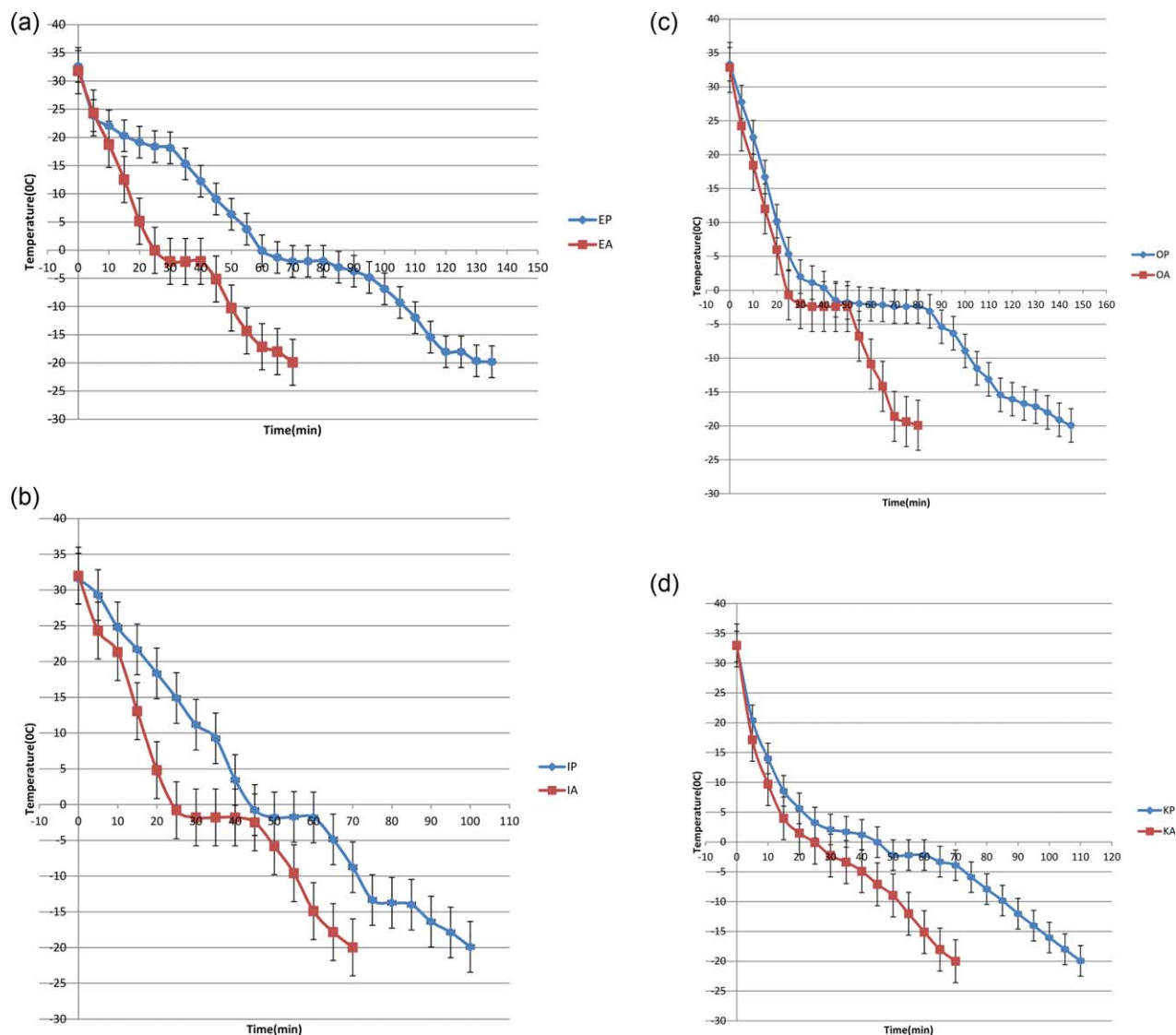


FIG. 2. COOLING CURVES IN PLASTIC AND ALUMINIUM CONTAINERS

(A) *Ewedu*; EP = *Ewedu* in Plastic Container and EA = *Ewedu* in Aluminium Container

(B) *Ila*; IP = *Ila* in Plastic Container and IA = *Ila* in Aluminium Container

(C) *Ogbono*; OP = *Ogbono* in Plastic Container and OA = *Ogbono* in Aluminium Container

(D) *Kuka*; KP = *Kuka* in Plastic Container and KA = *Kuka* in Aluminium Container.

table until the temperature at the centre of the soups reached 0°C. The change in temperature was monitored with the aid of digital thermometer with a probe that was already inserted at the centre of the frozen mass. The time taken to thaw the soup from -20°C to 0°C was designated as the thawing time of the soups at ambient temperature.

Measurement of Thawing Point of Soup Samples. The method of Rahman (1995) was adopted to establish the thawing points of some selected Nigerian soups. The thawing point for each soup was determined from their

cooling curves (Fig. 1). The frozen soup samples containing probes already positioned at their centres were removed from the chest freezer operating at -20°C. They were then thawed at room temperature (28–32°C) until the final temperature reached the room temperature, while the change in temperature was monitored and recorded at 5 min interval. The temperature values obtained were plotted against time to establish the thawing curves. The thawing points were obtained directly from the thawing curves by determining the temperature at which the rate of change of temperature was at a minimum during thawing.

TABLE 4. PREDICTIVE MODEL EQUATIONS AND COEFFICIENT OF DETERMINATIONS FOR THE COOLING CURVES OF SELECTED NIGERIAN SOUPS

Sample	Equation	Model	Coefficient of Determination (R^2)
EP	$T = -0.3560t + 26.289$	Linear	0.97
EA	$T = -0.6853t + 24.104$	Linear	0.94
IP	$T = -0.5157t + 28.146$	Linear	0.97
IA	$T = -0.6599t + 24.344$	Linear	0.92
OP	$T = 0.00017t^2 - 0.532t + 24.128$	Polynomial	0.90
OA	$T = -0.5721t + 22.39$	Linear	0.90
KP	$T = 0.0019t^2 - 0.5514t + 21.18$	Polynomial	0.90
KA	$T = 0.0071t^2 - 1.0812t + 24.056$	Polynomial	0.93

Where T = temperature, t = time, EP=Ewedu in Plastic Container, EA=Ewedu in Aluminium Container, IP= Ila in Plastic Container, IA=Ila in Aluminium Container, OP=Ogbono in Plastic Container, OA=Ogbono in Aluminium Container, KP=Kuka in Plastic Container and KA=Kuka in Aluminium Container

Thawing Rate Determination. Thawing rate is the difference between the initial and final temperature of the product divided by the thawing time (Martinez-Romero *et al.* 2004). The thawing rate was determined using Eq. (7).

$$\text{Thawing rate (C/h)} = \frac{T_1 - T_2}{t} \quad (7)$$

where T_1 is the temperature of the frozen soup; T_2 is the temperature of the thawed soup; t is the thawing time

Thawing Loss Determination. The thawing losses of the soup samples were determined from known weights of the soups before and after thawing and expressed as % freezing loss (AOAC 2005) using Eq. (8).

$$\% \text{Thawing loss} = \frac{W_1 - W_2}{W_2} \times \frac{100}{1} \quad (8)$$

where W_1 is the weight of the soup before thawing; W_2 is the weight of the soup after thawing

Statistical Analysis. Statistical analyses such as means, percentage errors and standard deviations were carried out using SPSS version 14.0, Chicago.

RESULTS AND DISCUSSION

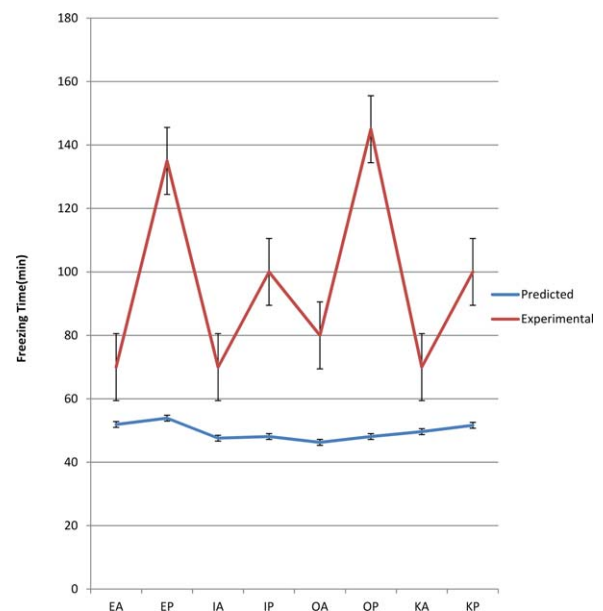
Selected Physical Properties of Nigerian Soups

The density of the selected soups ranged from $1,013.47 \pm 0.31$ to $1,099.62 \pm 0.49$ (kg/m^3) as shown (Table 3). The highest and lowest densities were recorded in *Ogbono* and *Ewedu* soups respectively. High density in *Ogbono* soup might be due to presence of *Ogbono* seed powder with more compact molecular arrangement. The latent heat reported ranged between 228.91 ± 0.47 – 295.22 ± 0.47 (kJ/kg). It has been established that there is direct correlation between the latent heat and moisture content (Table 2) of food product (Singh and Heldsman 2000). This implies that as the mois-

ture content increases, the latent heat increases. This was noticed in the soup samples, with *Ewedu* having the highest moisture content and latent heat. It is evident that increase in density value will decrease the latent heat of food. This was observed in the soup samples, with *Ogbono* soups having the highest density and the lowest latent heat (Table 3).

Frozen Properties of Some Selected Nigerian Soups

The frozen properties (freezing points, cooling curves, freezing time, freezing rate and freezing loss) of freshly prepared selected Nigerian soups are described below:

**FIG. 3.** FREEZING TIME OF SELECTED NIGERIAN SOUPS

EP = *Ewedu* in Plastic Container, EA= *Ewedu* in Aluminium Container, IP= *Ila* in Plastic Container, IA= *Ila* in Aluminium Container, OP = *Ogbono* in Plastic Container, OA= *Ogbono* in Aluminium Container KP= *Kuka* in Plastic Container and KA= *Kuka* in Aluminium Container.

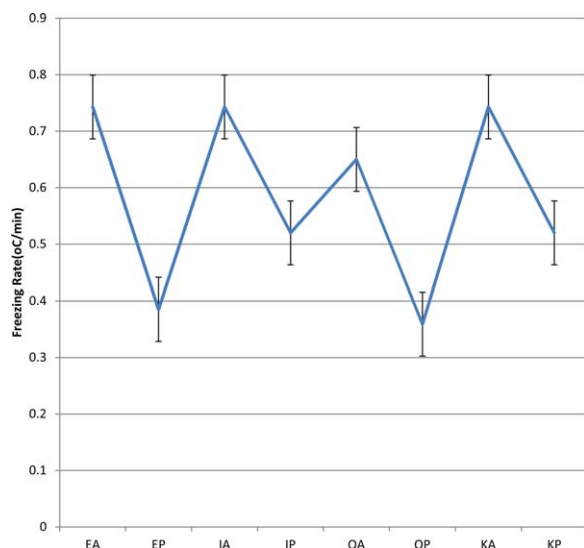


FIG. 4. FREEZING RATE OF SELECTED NIGERIAN SOUPS

EP = *Ewedu* in Plastic Container, EA = *Ewedu* in Aluminium Container, IP = *Ila* in Plastic Container, IA = *Ila* in Aluminium Container, OP = *Ogbono* in Plastic Container, OA = *Ogbono* in Aluminium Container KP = *Kuka* in Plastic Container and KA = *Kuka* in Aluminium Container.

Freezing Point and Cooling Curves. The freezing points and duration were determined practically from the cooling curves (Fig. 2) and the results obtained were summarized below: *Ewedu* in plastic (-2.0°C , 70 min), *Ewedu* in aluminium (-2.0°C , 30 min), *Ila* in plastic (-1.8°C , 50 min), *Ila* in aluminium (-1.8°C , 35 min), *Ogbono* in plastic (-2.4°C , 70 min) and *Ogbono* aluminium (-2.4°C , 35 min) and *Kuka* in plastic (-2.3°C , 50 min) and *Kuka* in aluminium (-2.3°C , 30 min). All the predictive cooling curve models had high coefficient of determination R^2 (0.90–0.97) and satisfied lack of fit test at $P < 0.05$ (Table 4).

The freezing point of a food is the highest temperature at which ice may exist in that food in thermal equilibrium (Ribero *et al.* 2007). The freezing point is sometimes also defined as the equilibrium freezing or equilibrium thawing point, which is the temperature where the slowest rate of change of temperature is observed (Rahman 1995; Rahman *et al.* 2002). This is one of the most important thermodynamic properties required for the prediction of thermal and physical properties in a frozen food. The knowledge of the freezing point is very important to analyze freezing and thawing of foods (Rahman *et al.* 2002; Ribero *et al.* 2007) and it is a key reference for determining a suitable temperature for food storage (Jie *et al.* 2003). The results obtained showed that the nature of the packaging materials and the constituents of the soups significantly influenced their cooling curves. The freezing points obtained ranged between -1.8°C and -2.4°C , with a reference value of -2.12°C

(Fig. 2). the freezing points reported is within the range of -1.05°C to -6.60°C reported by Auleda *et al.* (2011) for pear juice with a sucrose value of 10–40 °Brix.

Freezing Time. The freezing time obtained for the selected soup samples are presented in Fig. 3. The experimental freezing time value ranged from 70.00 ± 2.00 to 145.00 ± 1.50 min, while the predicted values ranged between 46.26 and 53.9 min. However, the nature of the packaging materials and the constituents of each soup significantly influenced their freezing time.

It was observed that the nature of the packaging materials had a significant influence on the frozen properties of soups and it is an important factor for calculating the freezing time. Freezing time prediction method should be tested and compared with the experimental data, in order to have compatible estimates with the real process as applicable in engineering calculations (Resende *et al.* 2012). For freezing time calculation for soups packaged in plastics and aluminum containers, a great difference between the predicted and experimental values was observed. The predicted values ranged between 46.26 – 53.9 min (Fig. 3), with *Ewedu* packaged in Plastic container having the highest and *Ogbono* packaged in aluminium having the lowest. The experimental values ranged between 70.00 and 145.00 min (Fig. 3), with *Ogbono* in plastic containers having the highest and *Ewedu* in aluminium containers having the lowest, while the percentage errors between the experimental freezing time and the predicted freezing time ranged between 25.89 and

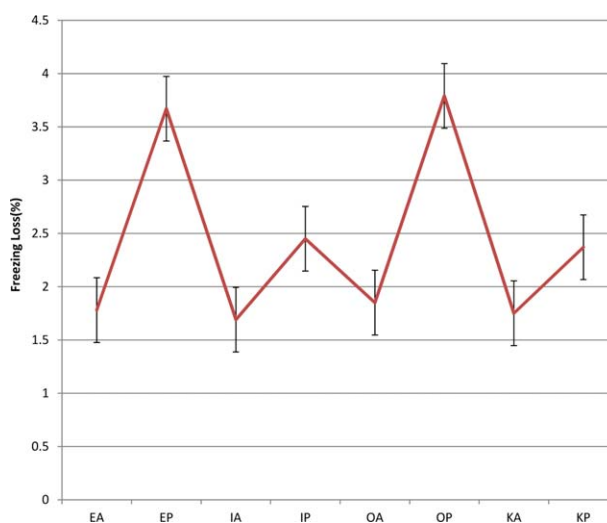


FIG. 5. FREEZING LOSS OF SELECTED NIGERIAN SOUPS

EP = *Ewedu* in Plastic Container, EA = *Ewedu* in Aluminium Container, IP = *Ila* in Plastic Container, IA = *Ila* in Aluminium Container, OP = *Ogbono* in Plastic Container, OA = *Ogbono* in Aluminium Container KP = *Kuka* in Plastic Container and KA = *Kuka* in Aluminium Container.

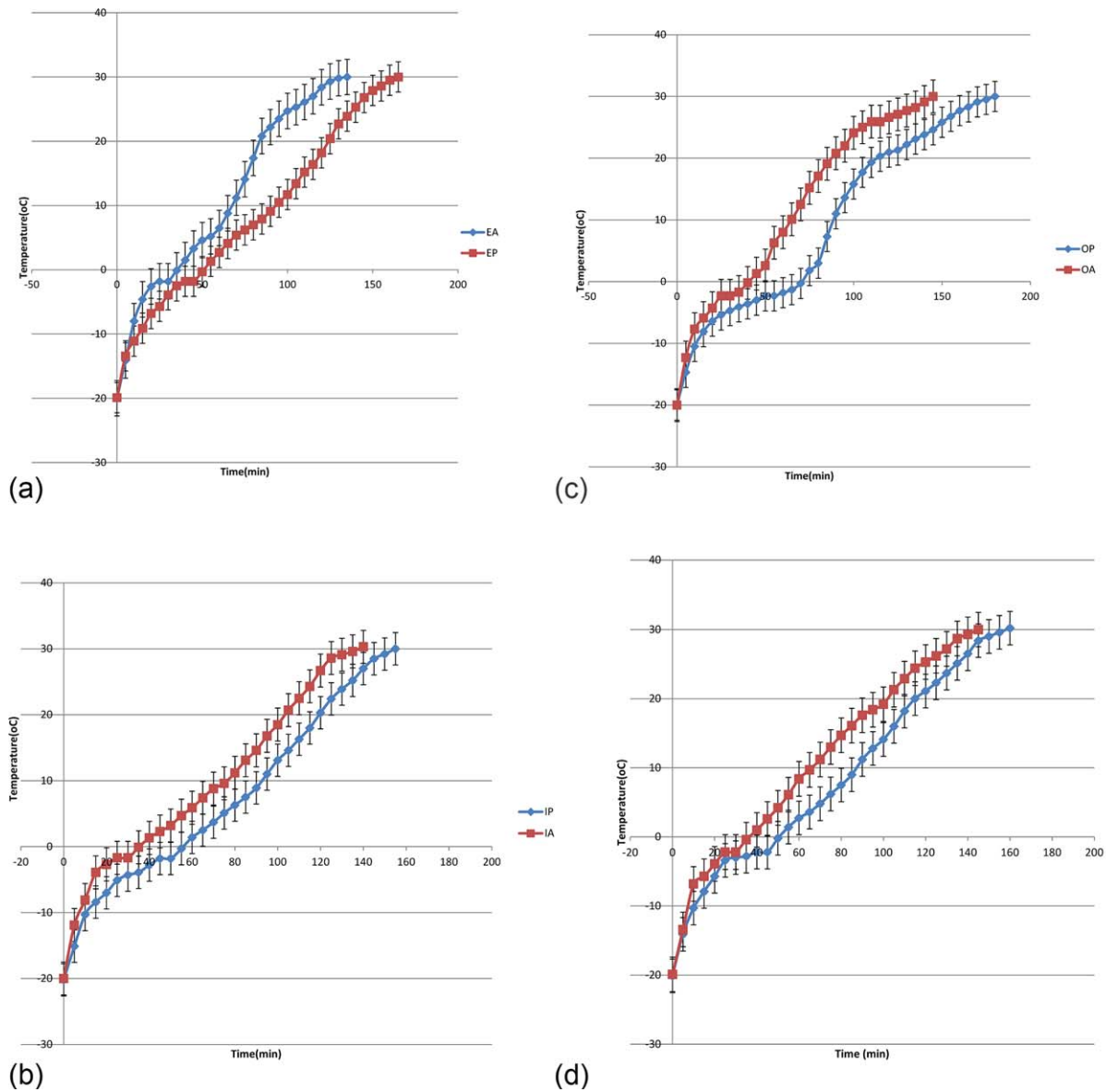


FIG. 6. THAWING CURVE IN PLASTIC AND ALUMINIUM CONTAINERS

(A) Ewedu; EP = Ewedu in Plastic Container and EA=Ewedu in Aluminium Container

(B) Ila; IP= Ila in Plastic Container and IA=Ila in Aluminium Container

(C) Ogbono; OP = Ogbono in Plastic Container and OA= Ogbono in Aluminium Container

(D) Kuka; KP= Kuka in Plastic Container and KA=Kuka in Aluminium Container

66.84% (Fig. 3), with *Ogbono* in plastic container having the highest percentage errors and *Ewedu* in aluminium containers having the lowest percentage errors. The difference between the predicted and the experimental freezing time might be as a result of assumptions in Eq. (4), which are the thermal conductivities of the packaging materials and the surface heat transfer coefficient of the chest freezer. Variation in the freezing time might be related to the, moisture content of the soups, the thermal properties of the soups and the

nature of the packaging materials. The nature of the packaging materials influenced the rate of heat transfer during the freezing process (Fellows 2000). Soups packaged in aluminium experienced shorter freezing time compared to the soups packaged in plastic containers. This was because aluminium conduct heat more readily than plastic (Fellows 2000). The result obtained was similar to the report of Resende *et al.* (2012) on air blast freezing of fruit pulp model in commercial boxes and found that differences in the

TABLE 5. PREDICTIVE MODEL EQUATIONS AND COEFFICIENT OF DETERMINATIONS FOR THE THAWING CURVES OF SELECTED NIGERIAN SOUPS

Sample	Equation	Model	Coefficient of Determination (R^2)
EP	$T=0.2742t - 14.157$	Linear	0.99
EA	$T= -0.0009t^2 + 0.474t - 15.312$	Polynomial	0.98
IP	$T=0.0003t^2 + 0.251t - 14.366$	Polynomial	0.99
IA	$T=0.3127t - 12.264$	Linear	0.98
OP	$T=-0.0003t^2 + 0.3197t - 16.132$	Polynomial	0.97
OA	$T=-0.0012t^2 + 0.5032t - 16.057$	Polynomial	0.98
KP	$T=-0.0009t^2 + 0.4343t - 14.484$	Polynomial	0.99
KA	$T=-0.0009t^2 + 0.4343t - 14.484$	Polynomial	0.99

where T = temperature, t = time, EP = *Ewedu* in Plastic Container, EA = *Ewedu* in Aluminium Container, IP = *Ila* in Plastic Container, IA = *Ila* in Aluminium Container, OP = *Ogbono* in Plastic Container, OA = *Ogbono* in Aluminium Container, KP = *Kuka* in Plastic Container and KA = *Kuka* in Aluminium Container

behaviour of the cooling rate exist between different boxes placed in different positions of the pile, he concluded that heat transfer occurred in all direction and was not uniform in all the surfaces.

Freezing Rate. Figure 4 shows the freezing rate values obtained for the selected soups samples subjected to freezing. The values obtained ranged from 0.359 ± 0.00 to 0.743 ± 0.03 C/min as significantly influenced by the nature of the packaging materials and the constituents of each soup.

Soups packaged in aluminium containers had higher freezing rates with *Ewedu*, *Ila* and *Kuka* soups packaged in aluminium containers having the highest (0.743 C/min), While the soups packaged in plastics containers experienced lower freezing rates with *Ogbono* packaged in plastics having the lowest freezing rate (0.359 C/min). This might be due to high thermal conductivity of the aluminium containers used. The rate of freezing and the formation of small ice crystals in freezing are critical to minimize tissue damage and drip loss in thawing. Farouk *et al.* (2003) reported that higher rate of freezing improved the quality of frozen products. Soups frozen in aluminium containers might experi-

ence little quality loss during freezing. The freezing rate and the freezing time are two of the most important variables that affect the magnitude of cellular and tissue damage (Lilia *et al.* 2013). The size of ice crystals forming as a material freezes is dependent on the freezing rate. Soups packaged in Plastic containers might experience cellular damage because of their poor freezing rates, which was as a result of poor thermal conductivity of the plastic containers. In general, the slower the freezing rate, the larger the ice crystals formed and the more damage to the materials (Lilia *et al.* 2013).

Freezing Loss. The results of the freezing loss values obtained for the selected soups samples subjected to freezing are revealed in Fig. 5. The freezing loss values ranged from 1.69 ± 0.01 to $3.79 \pm 0.2\%$ as significantly affected by the nature of the packaging materials and the constituents of each soup.

Temperature reduction during freezing is accompanied by water transition from liquid to ice, which results in the product solidification and essential change in numerous physical features of food (Błński 2006). The freezing loss of soups under investigation was expressed in percentage, with

TABLE 6. THAWING PROPERTIES OF EWEDU SOUPS SUBJECTED TO FROZEN STORAGE

Sample	Thawing time (min)	Thawing rate (C/min)	Thawing loss (%)
PH	7.00 ± 1.00^d	2.86 ± 0.42^b	1.03 ± 0.32^{ab}
AH	10.33 ± 0.58^c	1.94 ± 0.11^b	0.63 ± 0.25^{ab}
PM	1.83 ± 0.29^e	10.91 ± 1.79^a	0.13 ± 0.06^b
AM	9.50 ± 0.50^c	2.11 ± 0.11^b	1.53 ± 0.38^{ab}
AR	39.00 ± 1.00^b	0.51 ± 0.01^c	1.27 ± 0.35^a
PR	52.67 ± 0.58^a	0.38 ± 0.00^c	0.83 ± 0.15^{ab}

Mean values having different superscripts within a column are significantly different ($P < 0.05$). PH= Packaged in plastics but thawed with hot water, AH= Packaged in aluminium but thawed with hot water, PM= Packaged in plastics but thawed with microwave AM= Packaged in aluminium but thawed with microwave, AR= Packaged in aluminium but thawed at room temperature and PR= Packaged in plastics but thawed at room temperature.

TABLE 7. THAWING PROPERTIES OF ILA SOUPS SUBJECTED TO FROZEN STORAGE

Sample	Thawing time (min)	Thawing rate (C/min)	Thawing loss (%)
PH	8.00 ± 0.50^c	2.50 ± 0.16^b	0.50 ± 0.10^c
AH	10.33 ± 0.15^c	1.94 ± 0.03^c	0.53 ± 0.21^c
PM	2.77 ± 0.25^d	7.23 ± 0.66^a	0.20 ± 0.10^d
AM	9.77 ± 0.25^c	2.05 ± 0.05^{bc}	0.80 ± 0.10^b
AR	35.00 ± 3.00^b	0.57 ± 0.05^d	2.13 ± 0.12^a
PR	53.00 ± 1.00^a	0.38 ± 0.01^d	0.90 ± 0.10^b

Mean values having different superscripts within a column are significantly different ($p < 0.05$). PH= Packaged in plastics but thawed with hot water, AH= Packaged in aluminium but thawed with hot water, PM= Packaged in plastics but thawed with microwave AM= Packaged in aluminium but thawed with microwave, AR= Packaged in aluminium but thawed at room temperature and PR= Packaged in plastics but thawed at room temperature.

TABLE 8. THAWING PROPERTIES OF OGBONO SOUPS SUBJECTED TO FROZEN STORAGE

Sample	Thawing time (min)	Thawing rate (C/min)	Thawing loss (%)
PH	9.67 ± 0.29 ^d	2.07 ± 0.06 ^b	0.27 ± 0.15 ^c
AH	11.17 ± 0.76 ^d	1.79 ± 0.12 ^{bc}	0.40 ± 0.20 ^c
PM	1.93 ± 0.12 ^e	10.35 ± 0.65 ^a	0.17 ± 0.06 ^c
AM	14.67 ± 0.58 ^c	1.36 ± 0.05 ^c	0.80 ± 0.10 ^b
AR	34.67 ± 1.53 ^b	0.58 ± 0.03 ^d	1.87 ± 0.15 ^a
PR	47.67 ± 2.52 ^a	0.42 ± 0.02 ^d	0.83 ± 0.12 ^b

Mean values having different superscripts within a column are significantly different ($P < 0.05$). PH= Packaged in plastics but thawed with hot water, AH= Packaged in aluminium but thawed with hot water, PM= Packaged in plastics but thawed with microwave AM= Packaged in aluminium but thawed with microwave, AR= Packaged in aluminium but thawed at room temperature and PR= Packaged in plastics but thawed at room temperature.

Ogbono in plastic having the highest freezing loss and and *Kuka* in aluminium having the lowest freezing loss. There is an inverse relationship between the freezing rate and the freezing loss, the higher the freezing rate the lower the percentage freezing loss (Farouk *et al.* 2003). This was observed in soups subjected to different frozen conditions, where *Ogbono* in plastic container had the lowest freezing rate and the highest freezing loss. Relatively, there was little mass loss from sublimation, which might increase along with storage duration.

Thawing Properties of Some Selected Nigerian Soups

The thawing properties of the soups investigated under the influence of packaging materials and thawing conditions were melting point, thawing curves, thawing time, thawing rate and thawing loss.

Melting Points and Thawing Curves. The melting points and duration values of the frozen soups were obtained from the thawing curves (time-temperature curve) presented in Fig. 6. *Ewedu* in plastic (−1.80C, 40 min), *Ewedu* in aluminium (−1.80C, 25min), *Ila* in plastic (−1.80C, 45min), *Ila* in aluminium (−1.70C, 25 min), *Ogbono* in plastic (−2.3C, 50min) and *Ogbono* aluminium (−2.3C, 25 min) and *Kuka* in plastic (−2.2C, 40 min) and *Kuka* in aluminium (−2.2C, 25 min) (Fig. 6). All the predictive cooling curve models had high coefficient of determination R^2 (0.97–0.99) and satisfied lack of fit test at 95% confidence level (Table 5).

The melting point is sometimes defined as the equilibrium thawing point, which is the temperature where the slowest rate of change of temperature was observed during thawing (Rahman 1995; Rahman *et al.* 2002). It was noticed that the nature of the packaging materials and the constituents of the soups significantly influenced their thawing

curves. The observed melting points were in the range of −1.7C to −2.3C, with a reference value of −2.12C (Fig. 6). The melting point and freezing point are interwoven and interrelated. Rahman *et al.* (2002) reported that the melting point could be directly interpreted as the freezing point. It was observed that the melting points were 0.1C lower than the freezing points, the exception was *Ewedu* soups which had the same values for melting and freezing points. Similar findings were reported by James *et al.* (2005) who established the freezing and melting points of cured meats.

Thawing Time. The thawing time obtained for the selected soup samples are presented in Tables (6–9). The thawing time value ranged from 1.83 ± 0.29 to 53.00 ± 1.00 min. However, the nature of the packaging materials and the constituents of each soup significantly influenced their thawing time at 95% confidence level.

Soups packed in plastics and thawed at room temperature experienced the longest thawing time, with *Ila* soup packed in plastic and thawed at room temperature having the longest thawing time (53.00 ± 1.00 min), followed by *Ogbono* in the same condition (47.67 ± 0.52 min). The lowest thawing time was recorded for soups packed in plastics and thawed in microwave oven. Under microwave thawing, *Ewedu* soups in plastic containers had the shortest thawing time (1.83 ± 0.29 min), followed by *ogbono* packed in plastic container (1.93 ± 0.12 min). The nature of the packaging materials and thawing conditions had a significant influence on the thawing time. Soups packed in aluminum containers had poor thawing characteristics because the container used had poor retention of heat (Fellows 2000). Absorption and retention of the heat accelerate thawing and thereby lowering the thawing time. Plastic containers used had low thermal conductivity and had good absorption and retention of heat (Fellows 2000). These attributes made soups packed in plastic containers to thaw more readily when placed in hot water

TABLE 9. THAWING PROPERTIES OF KUKA SOUPS SUBJECTED TO FROZEN STORAGE

Sample	Thawing time (min)	Thawing rate (C/min)	Thawing loss (%)
PH	7.83 ± 0.76 ^e	2.55 ± 0.25 ^b	0.47 ± 0.25 ^c
AH	9.500 ± 0.50 ^d	2.11 ± 0.11 ^c	0.90 ± 0.10 ^c
PM	2.22 ± 0.08 ^f	9.02 ± 0.33 ^a	0.77 ± 0.59 ^{bc}
AM	11.50 ± 0.50 ^c	1.74 ± 0.08 ^d	1.27 ± 0.59 ^c
AR	33.00 ± 1.00 ^b	0.61 ± 0.02 ^e	2.40 ± 0.66 ^a
PR	49.00 ± 1.00 ^a	0.41 ± 0.01 ^e	1.80 ± 0.36 ^{ab}

Mean values having different superscripts within a column are significantly different ($P < 0.05$). PH= Packaged in plastics but thawed with hot water, AH= Packaged in aluminium but thawed with hot water, PM= Packaged in plastics but thawed with microwave AM= Packaged in aluminium but thawed with microwave, AR= Packaged in aluminium but thawed at room temperature and PR= Packaged in plastics but thawed at room temperature.

and microwave oven than soups packed in aluminum containers. Longer thawing time was recorded in soups packed in plastic containers and thawed under atmospheric condition than those packed in aluminum container and thawed under the same condition. The unique property of microwaves is that it penetrates and produces heat deep within food materials which eventually accelerates thawing (Li and Sun 2002). Microwave thawing requires shorter thawing time and smaller space for processing, and reduces drip loss, microbial problems and chemical deterioration (Li and Sun 2002). Using this apparatus, thawing time was drastically reduced, compared to convective thawing at atmospheric temperature and in hot water.

Thawing Rate. Tables (6–9) shows the thawing rate values obtained for the selected soups samples subjected to thawing. The values obtained ranged from 0.38 ± 0.00 to 10.91 ± 1.79 C/min as significantly influenced by the nature of the packaging materials and the constituents of each soup.

Different thawing methods resulted in different thawing rates (Tables (6–9)). The studies found out that *Ewedu* packed in plastic and thawed in microwave oven had highest thawing rate (10.91 ± 1.79 C/min), followed by *Ogbono* with a thawing rate of 10.35 ± 0.65 C/min. Thawing in this way increased the thawing rate in many folds when compared to other conditions. The thawing rates of frozen samples in microwave thawing depend on material properties, dimensions and the magnitude and frequency of the electromagnetic radiation (Li and Sun 2002). Factors such as thermal properties varying with temperature, irregular shapes and heterogeneity of the food make the thawing process more complicated (Li and Sun 2002). *Ewedu* and *Ila* soups in plastic containers, thawed at room temperature had the lowest thawing rate (0.38 C/min). The nature of the packaging materials and thawing conditions had a significant influence on the thawing time, thawing rate and thawing loss, this is similar to what Goral (2008) reported on the effect of different techniques of freezing and defrosting on the quality of spice vegetables after a long-term frozen storage. Plastic containers absorbed heat and retained it to thaw the soups packed in them at a considerable rate in hot water and microwave thawing conditions, while aluminum containers conducted heat away from the soups they contained, creating less effective thawing rate in hot water and microwave thawing conditions. The slowest rate of defrosting of the examined soups was obtained under atmospheric thawing condition, regardless of the packaging materials used. Similar result was obtained by Goral (2008) during freezing and defrosting of packed vegetable spices.

Thawing Loss. The results of the thawing loss values obtained for the selected soups samples subjected to thawing are revealed in Tables (6–9). The thawing loss values ranged

from 0.13 ± 0.06 to 2.40 ± 0.66 % as significantly affected by the nature of the packaging materials and the constituents of each soup at $P < 0.05$.

Considering the weight of soups recorded during defrosting, it is possible to point out that the manner of defrosting has an effect on the percentage thawing loss (Tables (6–9)). It was discovered that defrosting by microwave caused a limited weight loss. Conventionally, frozen soup with longer thawing time had minimal amount of thawing loss which might be as a result of minimal structural damage associated with intracellular ice crystals produced during freezing (Farouk *et al.* 2003). Also, thawing and refreezing contributed to increase in ice crystal sizes and structural damage during storage and hence added to minimal thawing loss. Additionally, loss of water binding capacity might have occurred due to increasing levels of low-temperature denaturation of protein, which will have the effect of reducing the influence of freezing rate on thawing loss (Ngapo *et al.* 1999; Farouk *et al.* 2003).

CONCLUSIONS

Freezing characteristics of *Ila*, *Ewedu*, *Ogbono* and *Kuka* soups depend on container-type and their constituents. All the soups packaged in aluminium containers had higher freezing rates than soups packaged in plastic containers, with *Ogbono* soup having the lowest freezing rates in both packaging materials. The nature of packaging materials and the thawing methods significantly influenced the thawing characteristics of the selected soups. Microwave-thawed plastic soups had limited thawing loss and time, but had highest thawing rate. Freezing and thawing properties established are essential in the calculation of refrigeration requirements and the design of equipments for effective processing and preservation of Nigerian soups.

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