INFLUENCE OF OSMOTIC DEHYDRATION ON MASS TRANSFER KINETICS OF COCOYAM SLICES (*Colocasia esculenta* and *Xanthosomaspp)*IN SUGAR SOLUTION

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Abstract
Osmotic dehydration is a preservation method that provides high quality products by means of water removal without phase change for the production of intermediate moisture foods. Hence, the current study evaluate the mass transfer kinetics of osmotic dehydration of two cocoyam cultivars of (Colocasia esculenta and Xanthosomaspp) in sucrose solutions in order to extend the shelf life of the tubers. Cocoyam tubers were cut into 20mmx50mmx5mm; 20mm x 50mm x 10mm; 20mm x 50mm x 15mm and 20mm x 50mm x 20mm and then osmotically dehydrated in sucrose solution of 44ºB, 52ºB, 60ºB and 68ºB for 14h, maintained in water bath at 20 ºC, 30ºC and 40ºC. Samples were evaluated gravimetrically at 30min interval for the first 2h and subsequently at 2h interval for the remaining 12 h. Cocoyam slices were then air dried at 100^{0}C in a cross flow force drought oven (Gallenkamp, model OV–160) for 24 h and, then weighed. From the data obtained, moisture and solid content, water loss and solid gain were calculated. Furthermore, mass transfer during osmotic dehydration was analyzed using Fick's model, and moisture and solid diffusivities were estimated. Activation energies for moisture and solids transfer were calculated using Arrhenius equation. The results indicated that water-loss, solid gain increased in sucrose concentration and temperature. However, these parameters decreased with increase in thickness of cocoyam slices. water loss values of 0.4230, 0.4710, 0.4926 and 0.6701 and solids 0.2163, 0.3298, 0.3712 and 0.4316 were obtained for 20 x 50×10mm slices osmosed in 44ºB, 52ºB and 68ºB sucrose solution respectively at 30ºC. The solution concentration of 44ºB resulted in moisture diffusivity of 31.61×10^{-9} m^2/s for Colocasia cultivar and 24.63 x 10^{-9} m^2/s for Xanthosoma spp. with slice thickness of 20mm and temperature of 40ºC. Moisture and solid diffusivities occurred at a temperature of 40ºB for the two cocoyam cultivars. Activation energy for moisture diffusivities was lower than those required for solid diffusion.

Keywords: Cocoyam, osmotic dehydration, mass transfer kinetics, drying rate, moisture loss

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1. INTRODUCTION

Osmosis is the movement of water molecules through a selectively-permeable membrane through awater potential gradient from an area of high water potential (low solute concentration) to an area of low water potential (high solute concentration).Osmotic dehydration (OD) is a water removal technique which is applied to horticultural products such as fruits and vegetables to reduce the water content while increasing soluble solid content (Moreira *et al.*, 2011; Falade and Ogunwolu, 2012; Haj Najafi *et al.*, 2014). Osmotic dehydration (OD) of foods has been reported to involve diffusion of water from food to solution and diffusion of solute from solution to the food as a result of chemical potential gradient between the osmotic solution (OS) and the intracellular fluid of the cellular food (Rastogi and Raghavarao,2004). Osmotic dehydration technique has received considerable attention recently due to its low energy and temperature requirement as compared to other conventional dehydration method, coupled with these, it produces a good quality final product in terms of the colour, texture and flavour (Falade and Ogunwolu, 2012; HajNajafi *et al.*, 2014). Osmotic treatment is actually a combination of dehydration and impregnation processes, which can minimize the negative modifications of fresh food components. Itis the partial removal of water by direct contact of a product with a hypertonic medium such as a high concentration of sugar or salt solution for fruit and vegetable.

The process is also known to improve the nutritional quality and sensory qualities of food because the process is effective at ambient temperature which may bring about minimal change in texture, colour and flavour of food (Rastogi*et al.,*2000; Haj Najafi *et al.,* 2014). It is a mild treatment at 20°C that does not cause cell death(Jalaee *et al.*, 2010). Also, the process is not energy intensive with no phase change during moisture removal from the food material hence; it improves the colour, flavour and texture of food materials(Karthanos *et al.,* 1995; Ertekin *et al.*, 1996; Pokharkar, 2001). Several factors have been reported to affect osmotic dehydration process which is mass transfer dependent. Some of these factors include processingtemperature and concentration of osmotic solution, immersion time, size and raw material characteristics, rate of agitation and brine to tissue ratio (Panades *et al.*, 2008).Several studies have been carried out both as a single process or in combination with drying techniques by several authors on osmotic dehydration (Alvarez *et al.,* 1995; Lenart, 1996; Sankat *et al.,* 1996; Simal *et al.,* 1997; Mavroudis *et al.,* 1998b; Nieto *et al.,* 1998; Ramaswamy and Nsonzi, 1998; Venkatachala *et al.,* 1998; Rappa *et al.,* 1999).

Osmotic pre-treated with subsequent dehydration has attracted a strong commercial interest and has been successfully applied to tropical fruits, notably mangoes and plantain (Hope and Vitele, 1972),apple, pear, banana, strawberry, peach and apricot(Falade and Aworh, 2005; Falade *et al.,* 2007;Falade and Shogaolu, 2010; Falade and Oyedele, 2010; Raji *et al.,* 2010; Jalaee *et al.,* 2010). Several osmotic agent have been reportedly use either alone or in combination such as salt sugar and/or high fructose corn syrup(Biswal and LeMaguer, 1990; Biswal and Bozorgmehr, 1992; Quintero-Ramos *et al.,* 1995);mixture of salt, sugar and corn starch syrup Collignan and Raoult-wack (1994) and sorbitol in combination sorbitol with whey(Torregiani *et al.,*1995).

However, Cocoyam has special attributes in supplying vitamin C, riboflavin and niacin and mineral element to the diet (Onwueme,1994). It has a higher starch and low sugar content. It can be cooked by steaming, roasting and frying and consumed as an energy yielding food. Cocoyam tuber mature rapidly, and can only be stored for a few days, limiting their availability all year round. Processing of cocoyamtuber into shelf stable intermediate moisture fruit products through less capital intensive technologies such as osmotic dehydration with subsequent air-drying will reduce their postharvest losses, add value to the tuber and extended shelf life by makingthe commodities available all year round. Modeling of the air-drying behavior of fresh and osmotically pretreated cocoyam slices will provide data needed for the process and equipment design.However, the amount of sugar added to the fruit by the osmotic bath would result in a sweeter product, which could be incorporated in cereal flakes or pie (Onwueme,1994).

However, in order to meet consumers expectations on processed food products;. It is, therefore, important to reduce the damage done to the cocoyam during the drying process which occur at high temperatures over long times in the presence of oxygen by size reduction of cocoyam tuber. The powder produced from cocoyam can find use in preparation of beverages where they are mixed with chocolate or cocoa and dried milk. Processing of cocoyam varieties into shelf stable intermediate moisture fruit products through less capital intensive technologies such as osmotic dehydration with air-drying will reduce their postharvest losses, add more value and extended shelf life of the finalproduct. Moreover, modeling of the air-drying behavior of fresh and osmotically pretreated cocoyam slices will provide data needed for the process and equipment design.However, no work can be found in the literature on osmotic dehydration of cocoyam varieties grown in Nigeria.

Also, little or no information exists on the modeling of the air-dryingbehavior of fresh and osmotically pretreated cocoyam slices.Several research studies have been documented on osmotic dehydration; however, there is no established rule about the factors affecting osmotic dehydration process.

Therefore, this study was dedicated to evaluate the influence of osmotic dehydration on mass transfer kinetics of varietal differences of cocoyam slices (*Colocasia esculenta* and *Xanthosomaspp)* in sugar solution

2. MATERIALS AND METHODS

Materials

Two varieties of matured Cocoyam (*Colocasia esculenta*) and (*Xanthosoma spp*) varieties were procured from a local market (Bodija) in Ibadan, Nigeria. Dry sucrose was used to prepare osmotic solution of 44, 52, 60 and 68 degree brix concentration using distilled water was also purchased from a local market in Ibadan. The osmotic solutions were prepared with clean containers.

Raw material preparation

Cocoyam tubers were carefully peeled and cut into (50x20x10)mm, (50x20x15)mm and (50x20x20)mm manually using a sharp stainless steel knife. Temperatures of the solution were maintained at 20°, 30° and 40°C. A total of 36 experimental runs were produced. Five numbers each of different geometry were weighed and immersed in the osmotic solution at varied concentration and temperature. The weight loss was monitored at interval of 30 min for 2 h and interval of 2 h for 12 h. cocoyam syrup ratio of 1:20 was used and the osmotic solution was maintained in water bath at 20^{o}C, 30^{o}C and 40 ^{o}C.The soluble solid (brix content) of the osmotic medium was monitored with an Abbe refractometer. Samples were withdrawn from the osmotic medium, cleaned of the surface moisture of the tuber and the weight taken. At the end of 14 h, the samples were taken out of the osmotic solution and the osmotically dehydrated samples were air-dried using a cross flow oven or using a temperature of 60^{o}C. Drying was terminated after 24h and the weight determine for various slices thickness (5mm, 10mm, 15mm and 20mm) according to the method of Sankat *et al*.(1996). Fresh batches of previously osmosed Cocoyam slices were air dried at 60^{o}C for 24h. Moisture content and moisture diffusivity is determined by Fick's equation.

Determination of process parameters

The osmotic dehydration process was evaluated using the following parameters: water loss, solid gain, moisture content (dry basis), moisture diffusivity, solute diffusivity and activation energy according to the method described by Panagiotou *et al.*, 1999 andBrooker*et al*., 1973 using equations 1, 2, and 3; while moisture diffusivity was calculated using Fick's model for moisture movement in infinite slab (Equation 4). This can be expressed in logarithmic form (Equation 6). The slope (B) was calculated by plotting In MR versus time. The effective moisture diffusivity was derived from the slope as reported by Senadeera *et al.,* 2003

Water loss (WL)= $$WL = \frac{(M_o - m_o) - (M - m)}{M_o} \quad \text{----------------} \quad 1$$

Solid Gain= $$SG = \frac{m - m_o}{M_o} \quad \text{--}2$$

Moisture Content = $$MC_{db} = \frac{M - m}{m} \quad \text{---------------------------} \ 3$$

To calculate moisture and solid diffusivity through the Cocoyam slice during dehydration, Infinite slab, moisture ratio

$$MR = \frac{m_i - m_e}{m_{oi} - m_e} = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n-1)^2} \exp\left[-(2n-1)^2 \frac{\pi^2 D_{eff} t}{L^2} \right] \quad \ldots 4$$

$$\frac{m_i - m_e}{m_{oi} - m_e} = \frac{8}{\pi^2}\exp\left[\frac{-\pi^2 D_{eff}\, t}{L^2}\right] \quad \ldots 5$$

But $MR = \dfrac{m_i - m_e}{m_{oi} - m_e}$

This can be expressed in logarithmic form,

$$\ln MR = A - Bt \text{ -------------- } 6$$

where constant B is $\left[\dfrac{-\pi^2 D_{eff}\, t}{L^2}\right]$ and M is the slope. The slope (B) is calculated by plotting Ln MR versus time. The effective moisture diffusivity is derived from the slope by the method described by Senadeera *et al.*, 2003.

M_o= Initial mass of fresh fruit prior to osmotic dehydration
M= Mass of fruits after time (t) of osmotic dehydration
m= Dry mass of fruit after time (t) of osmotic dehydration
m_o= Dry mass of fresh fruit
M_i= Moisture content of fruit after time (t)
M_e= Moisture content of fruit at equilibrium
M_o= Moisture content of fresh fruit prior to osmotic dehydration.
B= Roots of Bessel function ≈ 1
D_{eff}= Diffusion coefficient (m^2/s)
t= Time (s)

Calculated D_{eff} values were fitted to the Arrhenius type of equation,

$$D_{eff} = D_o + \left(\frac{-E_a}{R} \cdot \frac{1}{(T + 273.15)}\right)$$

where,
D_0= reference diffusion coefficient at infinitely high temperature and R is the ideal gas constant and E_a is the activation energy.A general form of the equation can be written in logarithmic form.

$$\ln D_{eff} = \ln D_o + \frac{-E_a}{R(T + 273.15)}$$

slope of $\dfrac{-E_a}{R}$ is calculated by plotting $\ln D_{eff}$ versus $\dfrac{1}{T + 273.15}$. Hence, the activation energy, E_a was derived.

3. RESULTS AND DISCUSSION

Effect of slices thickness on waterloss and solid gain by cocoyam

The effect of slices thickness on water-loss and solid gain by cocoyam slices (*Collocasia spp* and *Xanthosoma spp*) immersed in sucrose solution of 68°B at 30°C solution temperature is shown in Figure 1 and 2.

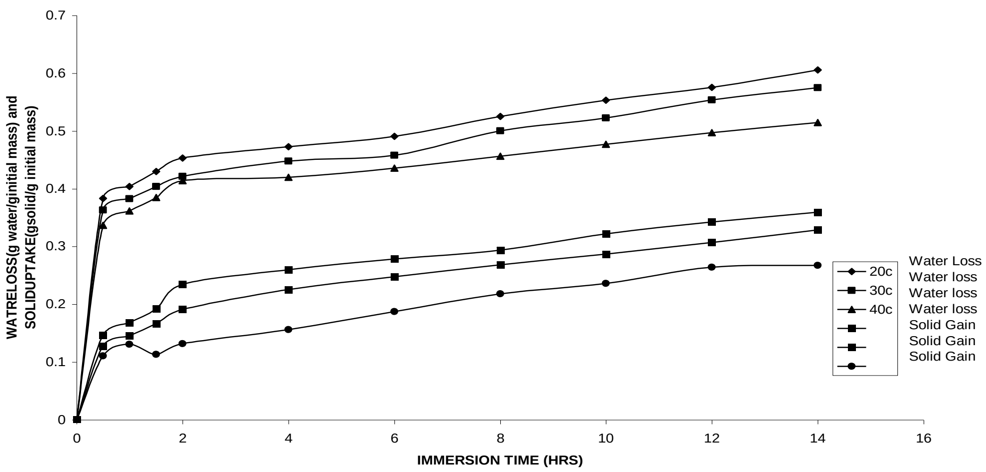

Fig 4.1: EFFECT OF SOLUTION TEMPERATURE ON WATERLOSS AND SOLID UPTAKE OF 20MM COCOYAM SLICES(XANTHOSOMA SPP) IMMERSED IN 60 DEG. BRIX SUCROSE SOLUTION

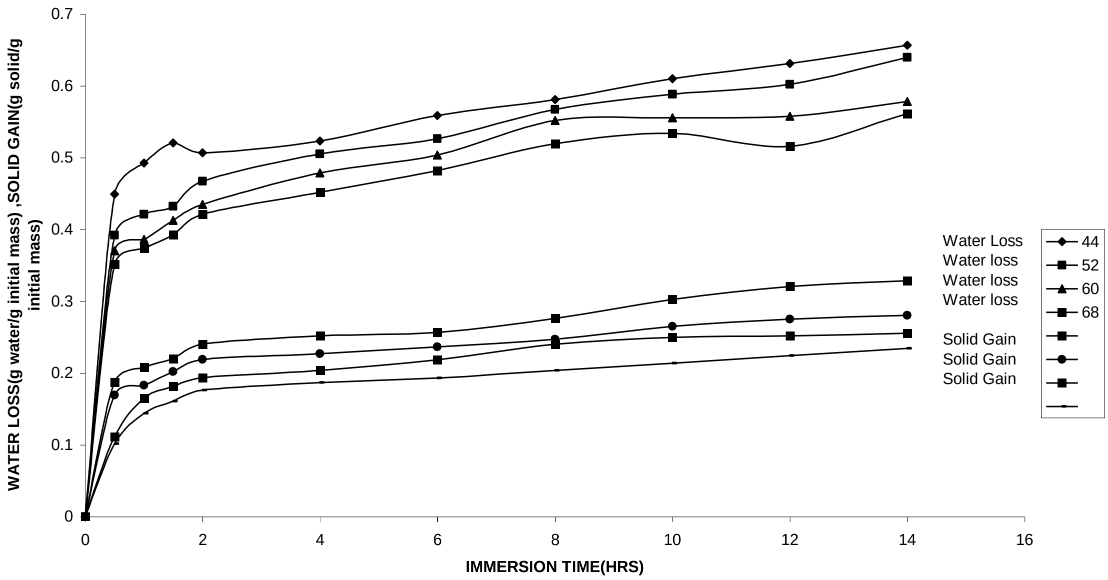

Fig 4.2: EFFECT OF SUCROSE CONCENTRATION ON WATERLOSS AND SOLID GAIN OF 20MM COCOYAM SLICES(XANTHOSOMA SPP) IMMERSED IN SUCROSE SOLUTION AT 40 DEG .C

Water loss from the cocoyam slices increased as the thickness of the cocoyam slices decreased. The highest value of water loss was observed for the 10mm slices thickness after 14 hr of osmotic treatment. This is an agreement with an earlier work on banana by Nabawanuka (1993) and Rastogi and Raghavarao (1997a, b) on carrot. Solid gain decreased with increased thickness of the two cocoyam varieties. Higher solid gain was recorded in 10mm slices compared to 15mm and 20mm thick slices for the two cocoyam varieties. The higher water loss and solid gain recorded in thinner slices were due to increased specific area of contact with osmotic solution. This is in agreement with the report of Leria *et al.* (1985) increase in water loss and solid gain.Water loss and solids gain increased with increased sucrose solution concentration which may be due to the increased osmotic potential as the strength of the sucrose solution increased. Several authors have also reported that the extent of water loss is dependent on the strength of the osmotic solution (Sankat *et al.,* 1996;Falade *et al.,* 2007; Raji *et al.* 2010; Falade and Shogaolu, 2010; Falade and Ogunwolu, 2014). Water loss is the amount of water which diffuses from the fruit to the solution as a result of differences in the osmotic pressure of the solution and fruit solids (Panagiotu *et al.,* 1999). Several authors opined that critical osmotic pressure always occur where the rate of water removal increases cellular disintegration and diffusion increases rapidly with an increase in the concentration of osmotic solution (Rastogi *et al.,* 2000; Falade and Ogunwolu, 2014). The studies have shown that water loss and solids gain increased with decreased cocoyam thickness but increased with sucrose solution concentration and immersion time. Because the extent of water loss from the cocoyam tuber was greater than solids gain which brings about consequent reduction in the weight of the cocoyam slices during osmotic treatment. Osmotic treatment time is one of the most influential variables during osmotic dehydration of fruits which is due to the fact that the waterloss, weight reduction and solid gain was based on the time. Increase in solution concentration up to 45 ºBrix resulted in an increase in the osmotic pressure gradients and hence, higher water loss (and solid uptake) values throughout the osmosis period were obtained. When the osmotic solution concentration was increased, water loss and solid gain took place in parallel mode; the rate of water loss is always higher than the solid gain. In osmotic dehydration process, the concentration gradient between the intracellular fluid and osmotic solution create a difference of osmotic pressure, which lead to diffusion of water and solid molecules through semi-permeable membrane of this fruit to achieve osmotic equilibrium. So, the increase in solute concentration led to increase in solid gain and waterloss. Further increase of sugar concentration reduced the water loss that might have led to the sugar gain by the fruits which was not desirable. This is attributed to the diffusion of water from dilute medium to concentrated solution (hypertonic solution) through a semi-permeable membrane until the concentration equilibrium was reached. The driving force in this process is the water activity gradient caused due to the osmotic pressure. From the results, it was observed that, the increasing time enhances the waterloss(WL), and solid gain (SG) and then decreased. This can be explained by the ionization characteristics and low molecular weight of sugar which made it easily diffuse into the product and increased the driving force for dehydration. On the other hand, solid gain increased in the early stages, remained almost constant for a short period of time. The reduced value of solid gain could be attributed to movement of soluble between the cocoyam slices and osmotic agent (sugar solution) used due to increase in concentration temperature. Chavan (2012) opined that a maximum sample size of 10mm irrespective of the shape may be ideal for osmotic dehydration process.

Effect of solution concentration by cocoyam slices during osmotic dehydration

Several authors have reported that increase in osmotic solutionconcentration resulted in corresponding increases in water loss as a result ofincreased osmotic solution concentrations henceincreased weight reductions. The result from the Table shows that the increase in solute concentrations leads increase in water loss and solid gain in cocoyam slices. The choice of solute to use during osmotic dehydration is a function of organoleptic quality properties, solute solubility, permeability of cell membrane and cost of the process (Qi,LeMaguer, & Sharma,1998). Rahman and Lamb (1990) have also reported in their studies that increase in water loss and sugar gain may bring about a corresponding increase of sugar concentration and temperature because the rate at sugar will diffuse into cocoyam slices depends on sugar concentration and temperature as solution concentration is a principal factor to be considered in osmotic dehydration process. Figures 4 and 4 shows the effect of sucrose concentration on water loss and solid gain by 15mm cocoyam varieties immersed in sucrose solution at 30ºC showing that higher the concentration of sucrose gives rise to higher water loss.

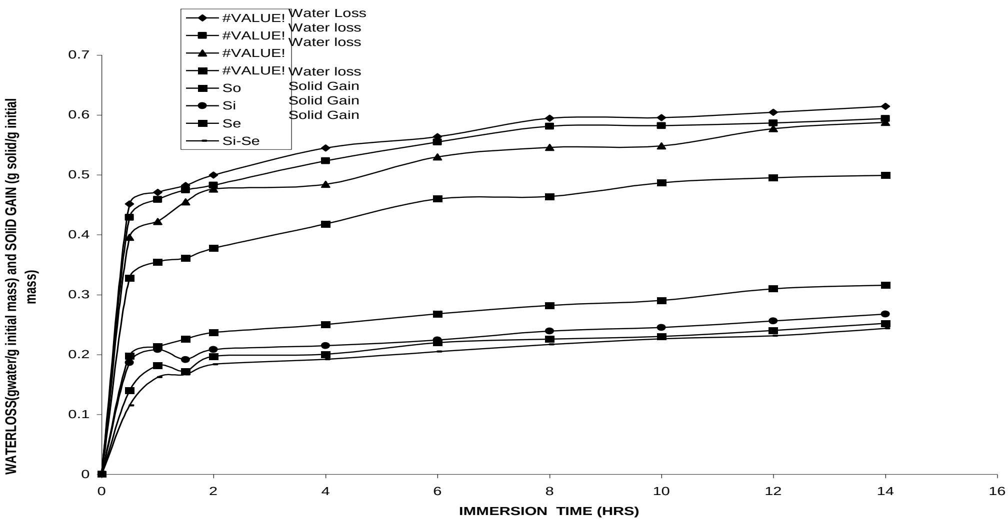

Fig 4.3: EFFECT OF SLICE THICKNESS ON WATER LOSS AND SOLID GAIN OF COCOYAM (xanthosoma spp)IMMERSED IN SUCROSE SOLUTION OF 68 DEG BRIX

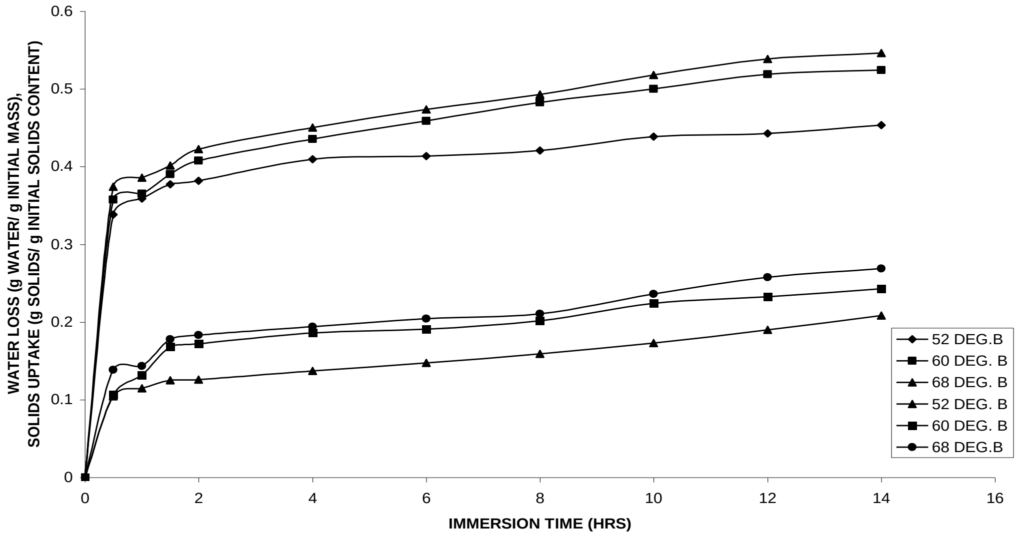

Fig. 4.4: EFFECT OF SOLUTION CONCENTRATION ON WATER LOSS AND SOLIDS UPTAKE WHEN 15mm SLICES OF COCOYAM(COLOCACIA SPP) IS IMMERSED IN 30°C SOLUTION TEMPERATURE.

Waterloss and solid gain increased with increases concentration of sucrose solution. Cocoyam varieties (*Collocasiaspp* and *Xanthosomaspp*) immersed 68^{0}C osmotic solution gave the maximum water loss and solid gain compared to 60^{0}B, 52^{0}B, and 44^{0}B. Increased water loss and solid gain with increasing solution concentration is due to higher concentration difference between the cocoyam solids and osmotic solution.This result agrees with result on previous studies by Conway *et al*. (1983), Lerici *et al.* (1985), Lenart and Lewicki (1990) that water loss from fruit pieces increased with increase osmotic.

Solution concentration will facilitate higher solute uptake and water loss. There was an increase in the rate of dehydration with an increase in solution concentration due to difference in osmotic pressure build up during osmotic dehydrationbetween the cocoyam slices and the surrounding solute concentration used (Azoubel and Murr, 2004; Falade *et al.*, 2007). The results of this study is in close agreement with other results reported by several authors for osmotic dehydration such as the work done on cantaloupe, mango slices, apricot and guava cubes (Fermin and Corzo, 2005; Mastrantonio *et al.*, 2005; Ito *et al.*, 2007; Ispir and Togrul, 2009; Ganjloo *et al.*, 2011). The results from this study have shown that faster weight reduction and water loss may bring some advantages by using hypertonic solution.The use of sugar as osmotic agent in osmotic dehydration process have been reported to increase the drying process due to the ability of sugar to lower water activity(Taiwo *et al.*, 2003). The high capacity of sucrose to lower water activity has been reported to increase the driving force of the drying process, when sugar is added to the osmotic solution (Lerci *et al.*, 1985). These osmotic dehydration processes have been reported to be an effective dehydration technique or sweetening food product due to the high efficiency of this process (Mayor *et al.*, 2006).It has also been reported from severalstudies that thick solid barrier formed at the surface of the food material when hypertonicsolution is used enhances the water removal process with a reduction in loss of nutrients; a similar effect also occur when high molecular solutes with low solute concentration is used.

It should be noted that solids gain is largely a differential process, while water removal is due to osmotic mechanism resulting from differences in water chemical potential between the cells of the cocoyam slices and osmotic solutions (Fito *et al.*, 2001). From this study, it was observed that the type of osmotic solution has an influence on the osmotic dehydration. Increasing in percentage of sucrose has a positive effect on the rate of water loss. The rate of solid gains in cocoyam slices treated by different sucrose concentrations gives a higher solid gain (Chiralt and Talens, 2005), which could be related to product characteristics, and to tissue microstructure such as cell packaging, permeability, and porosity. Another factor that can be considered also in this process of mass transfer is the epidermis resistance layer that found in tomato (Kross *et al.*, 2004). Loss of water and solids uptake near the surface at the beginning of osmotic dehydration might have been resulted in structural changes leading to compaction of these surface layers and increased mass transfer resistance for water and solids; (Singh *et al.*, 2007). The rate of water loss could be correlated with the rate of solid gains.Lazarides *et al*. (1997) also reported the increased in the mass transfer of sugar molecules with the increasing concentration to possible membrane swelling effect, which might increase the permeability of the cell membrane. Jeferson *et al*. (2010) explained that the concentrated solutions might have promoted the formation of a dense layer of solutes at the surface of the osmotic dehydrated fruit. This layer acts as a barrier against the penetration of the solution into the fruit tissue. According to Mujica-Paz *et al*. (2003), diluted solutions penetrated better into the fruit tissues than concentrated ones. With increased sugar concentration, the osmotic solution becomes more viscous, making the solution penetration even more difficult. The same result has been reported by Ito *et al*. (2007).

Effect of solution temperature on water loss and solid gain by cocoyam varieties

Temperature has been reported as the most important variable affecting the kinetics of masstransfer during osmotic dehydration. Beristain *et al.* (1990) also reported that increase in temperatureof osmotic solution may lead to water loss increase while temperature does not have a significant effect on solid gain.The effect of solution temperature on water loss and solid gain of osmosed cocoyam slices is shown in Figures 5 and 6.

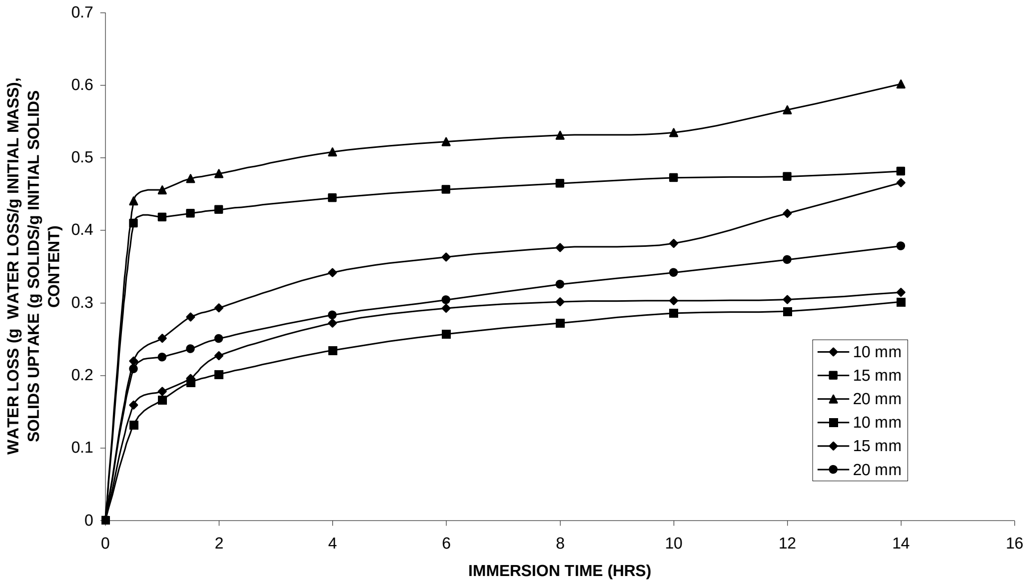

Fig 4.5: EFFECT OF SLICE THICKNESS ON WATER LOSS AND SOLIDS UPTAKE OF COCOYAM SLICES (COLOCACIA SPP) IMMERSED IN 68 DEG. BRIX SUCROSE SOLUTION AT 30°C SOLUTION TEMPERATURE

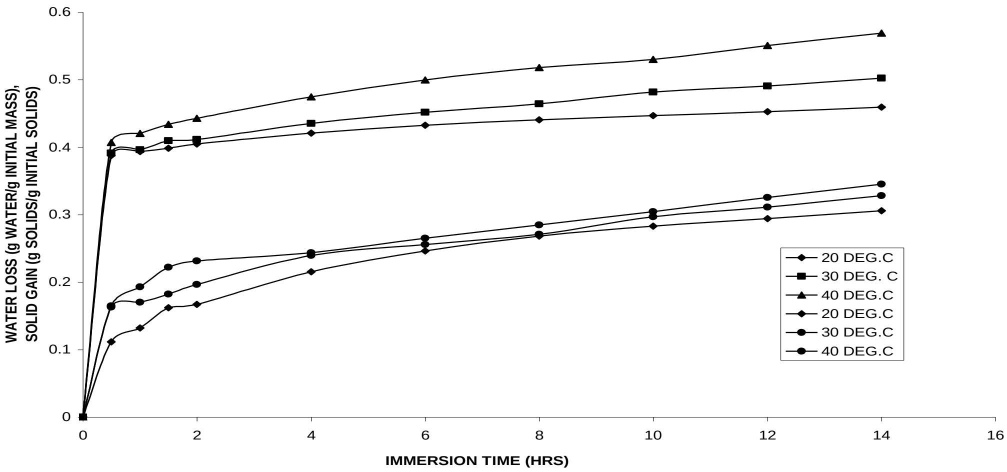

Fig 4.6: EFFECT OF SOLUTION TEMPERATURE ON WATER LOSS AND SOLIDS UPTAKE WHEN 20MM SLICES OF COCOYAM(COLOCASIA SPP) IS IMMERSED IN 68 DEG. BRIX SUCROSE SOLUTION

The result shows that higher osmotic solution temperature gave higher water loss while solid gain increased with increased solution temperature as shown by the 20mm cocoyam slices immersed in 68°B sucrose solution. However, it has been reported that diffusion is a temperature dependent phenomenon which does not have a significant effect on osmotic dehydration rate.

Cocoyam slices immersed in 40°C solution temperature showed higher water loss while20°C sucrose solution temperature exhibited increased in solid gain. The high water loss recorded at higher solution temperature is due to increased in rate of diffusion at higher temperature which enhances the removal of water and solid uptake. Wang *et al.*, (1989) reported that thermal denaturation occur at temperature above 45°C which may bring about increased in rate biochemical reactions and favour enzymatic browning and flavour deterioration. Consequently, higher solution temperature should be used to facilitate faster solute diffusion into the cocoyam slices which will generate water removal from the cocoyam slices.In addition, Falade *et al.* (2007) also reported in his study on watermelon slabs immersed into sucrose solution that water loss and solid gain increased with the solution temperature. The increase in solid gain and water loss is a result of the increase in the rate of diffusion due to the presence of porous structure in the cocoyam slices which have the ability to release the air trapped in the tissue resulting in more effective to the removal of water by osmotic pressure at high temperature. Meanwhile, solution temperature has been reported by several authors to decrease solid gain while the interaction between temperature and agitation decreases value of solid gain. This may be due to reduction in viscosity of hypertonic solution and increase in diffusion coefficient of water increased at high temperature (Falade *et al.*, 2007; Singh *et al.*, 2007). The higher uptakevalues of treatments above 20°C were probably due to the membrane swelling and plasticizing effect, which improved the cell membrane permeability to sugar molecules.

Effect of varietals differences on the osmotic dehydration of Cocoyam

Different plant species or different cultivars of the same plant species with different maturity age of the same cultivar have been reported to give real or actual responses to osmotic dehydration process (Charles Tortoe, 2010). Varietals difference on the osmotic dehydration of cocoyam has little or no significant effect on osmotic dehydration. The two varieties (*Collocasiaspp* and *Xanthosomaspp*) showed similar behaviour during osmotic dehydration's two varieties showed similar effect on waterless and solid gain during osmotic dehydration but *Xanthosomaspp* showed higher water loss and solid gain than *Collocasiaspp.* Also, *Xanthosomaspp* showed a marginal increase in moist and solid diffusivity as shown in Tables 1 and 2. Activation energy required for moisture and solid diffusion was higher in *Xanthosoma* than *Collocasia.* Species, variety and maturity level all have a significant effect on the natural tissue structure in terms of cell membrane structure, protopectin to soluble pectin ratio, amount of insoluble solids, intercellular spaces, tissue compactness and entrapped air. These structural differences substantially affect diffusional mass exchange between the product and osmotic medium. Hartel (1967) showed that under identical process conditions different potato varieties give substantially different (by ca 25%) weight reduction(water loss). Chavan, 2012 also reported that variety and maturity of fruits and vegetables mainly control water loss and solid gain during osmotic dehydration process. It was also reported that different fruits variability is a function of how tissues are closely packed together, solid content solubility and behaviour of the fruit towards enzymatic activity.

***Moisture and solid diffusivity of cocoyam immersed in sucrose solution*.**

Moisture and solid contents of cocoyam (*Collocasiaspp*) immersed in 44, 52, 60 and 68ºB of sucrose solution at 20ºC, 30ºC and 40ºC were determined during immersion. Moisture ratio (MR) and solid ratio (SR) were plotted against immersion time to determine moisture and solid diffusivities. Moisture and solid diffusivity obtained from the plots are shown in Tables 1 and 2 for the cocoyam variety. Moisture and solid diffusivity increased with increased slices thickness in sucrose solution. Moisture and solid diffusivity was high in 20mm in 68^0B sucrose solution. Samples pretreated at lower concentrations showed steeper curve. Table 1 shows the effects of thickness and drying temperature on average D_{eff} (10^9 m^2/s)of fresh and osmotically pretreated air-dried cocoyam cultivar slices. Generally, effective diffusivity increased with increased drying air temperature and thickness of samples (Table 1). Nieto *et al.* (2001), worked on mango reported that changes in moisture diffusivity property of mango to the increased resistance to water flux caused by shrinkage, solid uptake and/or starch gelatinization and protein–carbohydrate mucilage degradation. Several researcher have reported different experimental diffusion coefficient results (Demirel and Turhan (2003) and Queiroz and Nebra (2001). The solution concentration of 44ºB resulted in moisture diffusivity of 31.61×10^{-9} m^2/s for *Colocasia* cultivar and 24.63 x 10^{-9} m^2/s for *Xanthosoma spp*. with slice thickness of 20mm and temperature of 40ºC (Table 1).

Table1: Moisture diffusivity (m^2/s) of cocoyam slices (*Collocasia spp*) immersed in sucrose solution at different temperatures

		Diffusivity x 10^{-6} (m^2/s)		
Concentration	Slice thickness	20ºC	30ºC	40ºC
44ºB	10 mm	06.77	07.46	8.21
	15 mm	14.22	14.85	17.44
	20 mm	20.43	24.12	25.22
52ºB	10 mm	07.33	07.69	08.22
	15 mm	15.70	15.79	18.40
	20 mm	21.16	27.25	28.12
60ºB	10 mm	07.45	08.22	09.92
	15 mm	15.75	16.94	20.00
	20 mm	24.41	27.54	30.15
68ºB	10 mm	08.22	08.87	09.93
	15 mm	16.43	18.38	21.52
	20 mm	26.39	27.99	31.61

Table 2: Solid diffusivity (m^2/s) of Cocoyam slices (*Collocasiaspp*) immersed in sucrose solution at different temperatures

		Diffusivity x 10^{-6} (m^2/s)		
Concentration	Slice thickness	20ºC	30ºC	40ºC
44ºB	10 mm	06.46	06.52	06.75
	15 mm	12.13	13.52	14.80
	20 mm	18.36	18.52	20.88
52ºB	10 mm	06.52	06.62	07.37
	15 mm	13.99	14.21	14.93
	20 mm	18.89	21.99	24.48
60ºB	10 mm	06.65	06.65	08.21
	15 mm	13.50	14.29	17.92
	20 mm	22.05	23.86	24.56
68ºB	10 mm	06.67	09.12	12.03
	15 mm	14.53	15.50	19.62
	20 mm	23.25	24.54	26.89

Generally moisture diffusivities decreased as moisture content decreased by drying. This is because moisture migration becomes increasingly difficult as the physical structure becomes denser and harder during drying(Olatidoye *et al.,* 2016).As the osmotic concentration increases during osmotic dehydration,moisture diffusivity reduced. Hence the 44ºB had the highest moisture diffusivity. Mavroudis *et al.(*1998) stated that the incorporation of sugar into starchy materials would in general decrease moisture diffusivity because of reduction in the porosity of the material. This is in agreement with work reported by Saurel,(1994). It has been reported that the diffusion coefficient of any sample depends on factors such as sample preparation (Karim and Hawlader 2005), pretreatment and drying conditions. Dandamrongrak *et al.* (2002) reported moisture diffusivities of bananas in the range of 4.3–13.2×$10^{-10}$$m^2/s$ for different types of sample preparation at 50ºC.

Activation energy for moisture and solids diffusion during osmotic dehydration of cocoyam slices

Activation energy for moisture and solids diffusion for cocoyam slices immersed in 44, 52, 60 and 68ºB of osmotic solution at 20º, 30º and 40ºC were determined using an Arrhenius type relationship (Equation 3.5) value of moisture and solid diffusivity in Tables 5 and 6 were slotted into the Arrhenius type equation and linearized.

The values were then plotted against inverses of absolute temperature. The plots were found to be straight line in the range of temperature investigated. Activation energy (kJ/Mol) was deduced from the slopes of the graph plotted, which represented the energy required for the process to take place. The values are reported in Tables 3 and 4. Activation energy for moisture and solid diffusivity increased with increase in solution temperature and concentration of solution, but decrease with increase in slice thickness. Highest energy of activation was consistently recorded in the 20mm. Generally, energy require for moisture diffusion was lower than those required for solids diffusion when cocoyam were immersed in high concentration solution and at high solution temperature. Temperature shows greater influence in moisture and solid diffusivity. This may be attributed to the surface area of the sizes. Established value of energy required at different processing condition will help to optimize the process using the least energy to achieve maximum output.This could be due to the different conditions under which the experiments were carried out.

Table 3:Moisture diffusivity (m^2/s) of cocoyam slices (*Xanthosomaspp*) immersed in sucrosesolution at different temperatures

Diffusivity x 10^{-6} (m^2/s)				
Concentration	Slice thickness	20ºC	30ºC	40ºC
44ºB	10 mm	06.42	06.75	06.96
	15 mm	14.42	14.92	14.99
	20 mm	18.26	18.91	20.04
52ºB	10 mm	06.49	07.24	07.39
	15 mm	13.64	14.21	14.83
	20 mm	18.89	21.84	24.22
60ºB	10 mm	06.65	06.79	08.32
	15 mm	13.72	14.54	17.65
	20 mm	22.15	23.77	24.87
68ºB	10 mm	06.69	09.32	12.23
	15 mm	14.75	15.74	19.33
	20 mm	23.45	24.63	24.68

Table 4:Solid diffusivity (m^2/s) of cocoyam slices (*Xanthosomaspp*) immersed in sucrose solution at different temperatures

	Diffusivity x 10^{-6} (m^2/s)			
Concentration	Slice thickness	20ºC	30ºC	40ºC
44ºB	10 mm	06.32	06.67	06.93
	15 mm	13.31	13.40	14.89
	20 mm	18.24	18.55	20.48
52ºB	10 mm	06.44	07.02	07.44
	15 mm	13.68	14.11	14.52
	20 mm	19.77	21.80	24.51
60ºB	10 mm	06.48	08.32	08.44
	15 mm	13.65	17.34	14.29
	20 mm	20.89	23.33	24.52
68ºB	10 mm	06.72	09.17	13.20
	15 mm	14.47	15.40	18.91
	20 mm	23.20	24.72	26.55

Table5:Energy required to effect moisture uptake during osmotic dehydration of cocoyam varieties.

E_a (kJ/mol.)			
Concentration	Slice thickness	*Collocasia spp*	*Xanthosomaspp*
44ºB	10 mm	3.92	5.59
	15 mm	3.19	4.15
	20 mm	0.19	0.45
52ºB	10 mm	5.86	6.17
	15 mm	3.94	4.80
	20 mm	3.83	3.50
60ºB	10 mm	7.67	6.19
	15 mm	3.20	5.44
	20 mm	3.18	3.92
68ºB	10 mm	8.62	8.29
	15 mm	5.53	7.23
	20 mm	4.72	3.55

Table 6:Energy required to effect solid uptake during osmotic dehydration of cocoyam varieties

E_a (kJ/mol.)			
Concentration	Slice thickness	*Collocasia spp*	*Xanthosomaspp*
44ºB	10 mm	2.51	6.52
	15 mm	2.43	6.47
	20 mm	1.85	4.32
52ºB	10 mm	2.79	6.71
	15 mm	2.66	5.51
	20 mm	2.56	4.43
60ºB	10 mm	3.58	6.79
	15 mm	3.28	5.99
	20 mm	2.59	5.82
68ºB	10 mm	3.67	7.57
	15 mm	3.79	6.76
	20 mm	3.77	5.99

4. CONCLUSIONS

Immersion of cocoyam in sucrose solution with subsequent drying at a various temperatures produces a suitable and acceptable intermediate moisture product. Infusion of solute and water loss by cocoyam slices were enhanced by the osmotic conditions and the subsequent drying lowered the moisture content and the water activity of the product which invariably increase the shelf life of the product, it enables the product to be transported easily and even stored for a longer period and also gave raw cocoyam a future market potential. Moisture and solid diffusivities increased with increase in solution temperature and solution concentration. However, moisture and solid diffusivity increased with increased slice thickness in sucrose solution. Hence, it is better to carry out osmotic dehydration at thinner slices, higher sucrose concentration and higher temperature in order to save cost, time and energy.Osmotic dehydration might be proposed as an effective pretreatment in combined preservation techniques. It may also act as a treatment for producing fresh like, minimally processed food or manufacturing food pieces as additional components in many products.

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