CHARACTERISTICS ABSORPTION AND MODELING OF UNRIPE PLANTAIN CHIPS

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Abstract

In this study, water absorption characteristics of dried unripe plantain chips were investigated by soaking in distill water at 20°C, 30°C and 40°C. The data generated were fitted into three models namely Peleg, Weibull and exponential. The statistical criteria used in evaluation of the models were coefficient of determination (R^2), reduced chi-square (χ^2), mean bias error (*MBE*) and root mean square error (*RMSE*). The result shows that temperature did not affect water absorption properties initially, but it did affect it as re-hydration progressed. The result of R^2 shows that Weibull model has the highest value of 0.979 and exponential model has lowest value of 0.653. Therefore, Weibull model was adjudged to have successfully fitted water absorption of unripe plantain chips.

Keywords: modeling, exponential, temperature, water absorption

1 Introduction

Plantains are rich source of carbohydrate and calories to many people worldwide. About 12 million metric tons are produced in Africa annually (Fakayode *et al.* 2011). Plantain production in Africa is estimated at more than 50% of worldwide production (FAO 1990). The major producing countries with an annual output exceeding a million tonnes include Nigeria, Ghana, Cote d'Ivoire and Cameroon (Baruwa *et al.* 2011). Nigeria is one of the largest plantain producing countries in the world (Demir *et al.* 2004). Despite its prominence, Nigeria does not feature among plantain exporting nations because it produces more for local consumption than for export (Akinyemi *et al.* 2010). Frison and Sharrock (1990) observed that banana and plantain represent more than 25% of the food energy requirement of Africa. It has a very high nutritional value in source of dietary carbohydrates, vitamins and minerals. Plantains are extremely rich in vitamin A (Kainga and Seiyabo 2012).

Plantain flour is derived from mature but unripe plantain fruits by carefully peeling off its greenish skin. The fruit is then sliced into flat shapes (chips) and spread under the sun to dry. It may also be dried in the ovens or mechanical dryers. After the chips have been dried to safe moisture content of about 13%, it will be pulverized into flour. The flour can be reconstituted in boiling water to form a gelatised paste called 'amala' (in Yoruba and foufou in Cameroon) which can be eaten with different soups or sauces. The flour is also used for several other traditional dishes ranging from 'akara', ukpo ogede' and soups (Onuoha *et al.* 2014). Because of the health benefits of plantain flour, the popularity of the food has increased tremendously in Nigeria recently. The diabetic patients are encouraged to eat "amala" from plantain flour due to its low sugar content. It is also gradually finding applications in weaning food formulation and composite flour preparations (Olaoye *et al.* 2006; Otegbayo *et al.* 2002; Mepba *et al.* 2007; Ogazi *et al.* 1996).

The shelf life of unripe plantain chips is grossly affected by many factors and is a major problem limiting the production of plantain flour in Nigeria due to unavailability of established storage conditions that can guarantee longer shelf life (Olorunda and Adelusola 1997; Wills *et al.* 1989). Conventionally, this unripe plantain chips is sold in the market in baskets and loose sacks so that buyers can see the product. As a result of this, the product is exposed to insect infestation and becomes moldy over time due to its hygroscopic nature. However, as this product is becoming popular due to its health benefit, there is a need to design effective storage system that would elongate its shelf life. To do this there is need to be informed about the water absorption properties of this product so as to guarantee an effect storage system. Hence modeling of the water absorption pattern of the chips is necessary. This serves as the objective of the study.

There have been literature on modeling of food product; for instant (Ali *et al.* 2006) studied modeling of water absorption of chickpeas (*Cicer arietinum L.*) using Peleg's equation. Afolabi *et al.* (2014) studied modeling the water absorption characteristics of different maize types during soaking using Peleg equation. Sibian *et al.* (2013) studied absorption behaviour of pearl millet soaking using Peleg model but literature on modeling of plantain chips is scarce hence there is need to examine this.

2 Material and Methods

2.1 Water Absorption Kinetics of Dehydrated Plantain Chips Experiments

Dried plantain chips with initial moisture content of 13.1% (db) and average size of 3cm × 0.4cm × 0.15cm. The samples were soaked in distill water at temperature of 20°C, 30°C and 40°C in a thermostatically controlled water bath. For every 1 g of plantain chip, 200ml of distill water in the beaker was used, that is (1:20) as recommended by (Ali *et al.* 2010). Plantain samples were periodically taken from the water and placed on absorbent paper to remove surface moisture from the chips and weighed to determine weight gain. This was repeated until samples reached saturation moisture content. Values of triplicates for each experiment were measure and the average results were used in modeling process. The moisture ratio (*MR*) is computed in Equation 1.

$$MR = \frac{W_r}{W_d} \tag{1}$$

2.2 Mathematical Model

Three well known models namely Peleg, Weibull and exponential were used for re-hydration process. The experimental data were fitted into these three different models as presented in Table 1. These mathematical models shows the correlation between moisture ratio and soaking time with various coefficients attached to each model.

2.3 Statistical Analysis

Statistical analyses were performed on the experimental and simulated data to determine the discrepancies between the observed and simulated values. The constant of each model was determined using a non-linear regression analysis performed using programming protocol of Statistical Package for Social Scientist (SPSS 15.0 versions) software. The statistical criteria used to evaluate the efficacy of the models were coefficient of determination (R^2), reduced chi-square (χ^2), mean bias error (*MBE*) and root mean square error (*RMSE*). Goodness of fit is said to have occurred in a model if R^2 value is high and other criteria such as χ^2, *RMSE* and *MBE* values are low (Demir *et al.* 2004; Maydeu-Olivares and Garcıa-Forero 2010). The equation for each statistical criterion is as shown in Equations 2-4.

$$\chi^2 = \frac{\sum_{i-1}^{n}\left(MR_{(\exp,i)} - MR_{(pred,i)}\right)^2}{N - z} \quad (2)$$

$$MBE = \frac{1}{N}\sum_{i=1}^{n}\left(MR_{(\exp,i)} - MR_{(pred,i)}\right) \quad (3)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{n}\left(MR_{(\exp,i)} - MR_{(pred,i)}\right)^2} \quad (4)$$

Table 1 Mathematical drying models

Model	Equation	References
Peleg	$M_t - M_0 = \frac{t}{k_1 + k_2 t}$	Ali *et al.* (2010)
Weibull	$MR = \exp\left[-\left(\frac{t}{\beta}\right)\right]^{\alpha}$	Khazaei (2008)
Exponensial	$MR = \exp(-kt)$	Khazaei (2008)

3 Results and Discussion

3.1 Water Absorption Pattern of the Chips

Figure 1 shows the water absorption properties of the plantain chips over time. The graph shows gradual inclination with a less steep gradient over a period of 36 minutes. Within this period, although at different rehydrating temperatures of 20°C, 30°C, 40°C, the graph had close patterns of rehydration but after 36th minute, the rehydrating patterns were greatly affected by temperature. At first, temperature did not played a significant role in water absorption into molecular cell of the samples; so, water absorption took place through the capillary cells freely without the influence of temperature but when the samples has taken relatively sufficient moisture, the rate of water absorption was not as fast as initially. Therefore, moisture at elevated temperature had higher energy to penetrate the granular cells of the samples than at lower temperature. This phenomenon has been earlier reported by (Ali *et al.* 2010; Ajala *et al.* 2012; Ajala 2014).

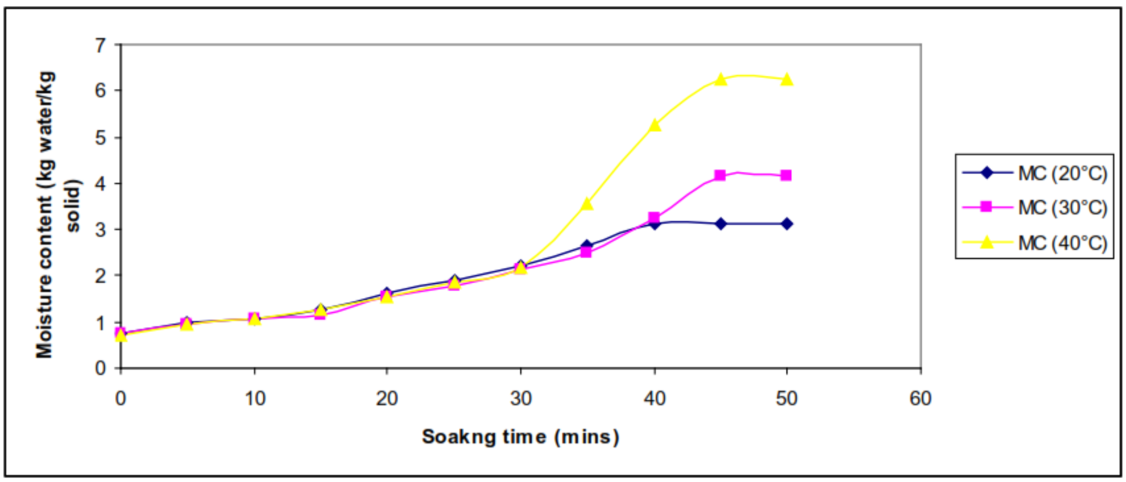

Figure 1 Moisture content against time

Figure 2 shows the rate of change of moisture in the samples. The gradient of change in moisture varies at different temperatures with different gradients; the highest gradient found in samples rehydrated at 40°C followed by 30°C and the least is 20°C. This implies that water absorption per hour was faster at 40°C than 30°C and 20°C due to the reason earlier gave above. After the 15 minute, the slope of the curves were less steep and the graphs gradually flattened off which means faster moisture change in the samples only took about one-third of re-hydrating time. Water absorption after this time was gradual until it reached the saturation point. Ali *et al.* (2010) gave similar report that the phenomenon of water absorption curves are characterized by an initial phase of rapid water pickup followed by an equilibrium phase, during which the re-hydrating samples approaches its full soaking capacity. The same observation was reported by other researchers such as (Afolabi *et al.* 2014, Addo *et al.* 2006; Hung *et al.* 1993; Maharaj and Sankat 2000; Shittu *et al.* 2004; Sopade *et. al* 1992)

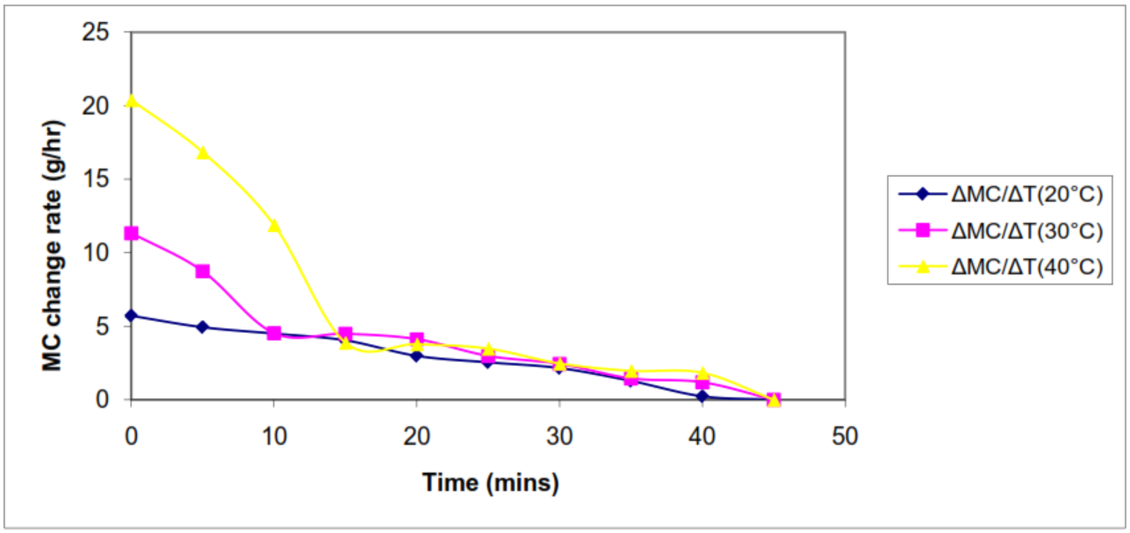

Figure 2 Re-hydration change rate against time

3.2 Statistical analysis of the models.

The values of statistical criteria used to evaluate the models are as presented in Table 2. The acceptability of these models is based on the high values of R^2 and low values of the other statistical criteria as shown. The lowest value of R^2 is 0.653 (exponential model) while the highest R^2 value is 0.979 (Weibull model). The lowest value of χ^2 is 0.001984 (Weibull model) while the highest value is 0.038375 (exponential model). The lowest value of MBE is -0.04619 (exponential model) while the highest value is 0.004715 (Weibull model). The lowest value of *RMSE* is 0.040289 (Weibull model) and the highest value is 0.186778 (exponential model). Close examination of these statistical criteria show that Weibull model has the highest value of R^2 and lowest values of χ^2 and *RMSE*. Therefore Wiebull model is adjudged to have the best fit in modeling this re-hydration process.

Table 2 Models Evaluation using statistical criteria

Model	Temperatur (°C)	R^2	χ^2	*MBE*	*RMSE*
Peleg	20	0.882	0.010926	-0.02983	0.094551
	30	0.913	0.008835	-0.03280	0.085021
	40	0.935	0.008592	-0.01582	0.083844
Weibull	20	0.941	0.005678	0.00471	0.068157
	30	0.979	0.001984	0.00174	0.040289
	40	0.950	0.006656	0.00326	0.073795
Exponential	20	0.748	0.023397	-0.04619	0.145841
	30	0.701	0.025798	-0.03916	0.153141
	40	0.653	0.038375	-0.03491	0.186778

Figure 3 further proves the reliability of the Weibull model to adequately predict the re-hydration behaviour of the plantain samples. It shows the closeness of the experimental and predicted values of the moisture ratio at each temperature of the observation. The experimental and predicted values are closely related even sometime the graph overlaps each other.

The constant in each model is as presented in Table 3. The value of k_1 in Peleg model is as follows; 91.78, 60.192 and 27.643 (minutes) which correspond to 20°C, 30°C and 40°C, respectively. This shows that the value of k_1 is indirectly related the temperature of rehydration. k_1 is called Peleg rate constant and connotes mass transfer rate into/from a food sample. It relates with water absorption rate in that at lower value of k_1, there is high initial water absorption rate within the sample as reported by Sibian *et al.* (2013). The lower the value of k_1, the higher the water absorption rate. This k_1 is also temperature sensitive as its value decreased at higher temperature, the rate of water absorption is increased as shown in the curve (Figure 1). This observation has been reported earlier by other researchers such as Afolabi *et al.* (2014); Maharaj and Sankat (2000); Quicazán *et al.* (2012); Sopade *et al.* (1992); Tunde-Akintunde (2010).

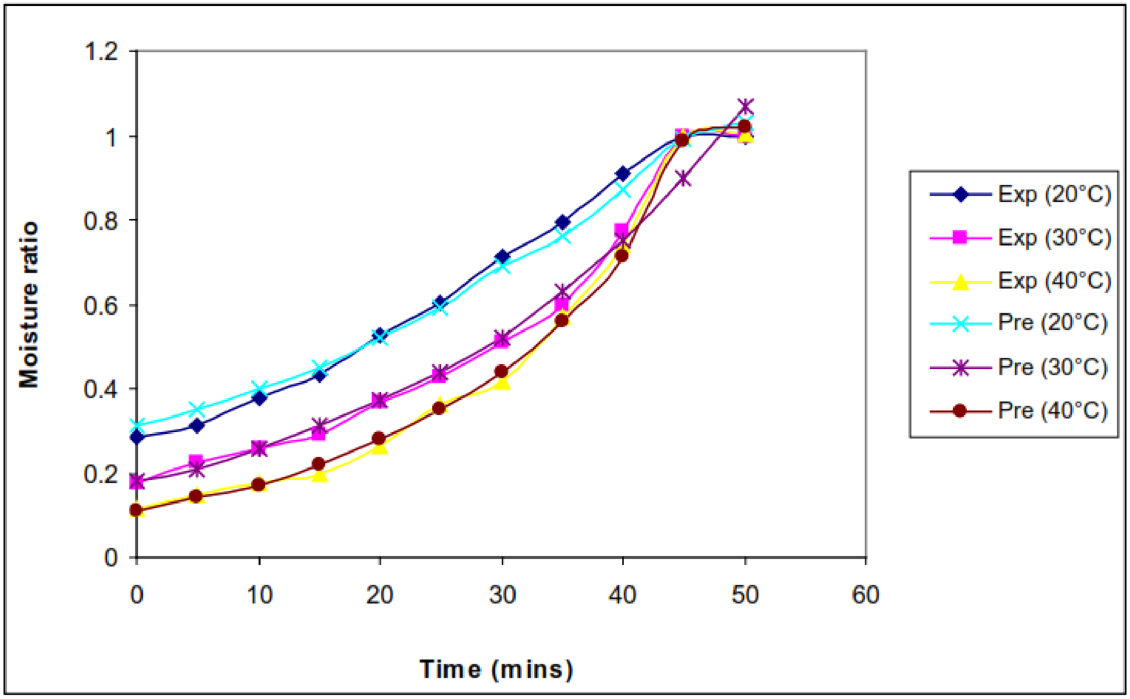

Figure 3 Experimental and predicted moisture ratio against time using Weibull model

The parameter k_2 is known as Peleg capacity constant and relates to the extent of water absorption. The lower the value of k_2, the higher the water absorption. This assertion has been reported by Turhan *et al.* (2002); Sibian *et al.* (2013); Resio *et al.* (2006). The value of β in Weibull is as follows; -38.191, -27.908 and -21.48 for 20°C, 30°C and 40°C, respectively. The values of β increase as the rehydrating temperature increases showing the same trend as in Peleg model. Also, the value of α increase with increase in temperature from 0.305, 0.179 and 0.109 for re-hydrating temperature of 20°C, 30°C and 40°C. The increase in α value is an indication of initial higher water absorption rate as reported by Shafaei and Masoumi (2014); Elçin and Belma (2015). The values of k in exponential model increase as the temperature increases as shown in Table 3. The values are as follows: 8.744 min^{-1}, 14.422 min^{-1} and 17.977 min^{-1} for 20°C, 30°C and 40°C, respectively. This effect of temperature on model constants has been earlier reported by other researchers such as Sabrina *et al.* (2012); Sedat *et al.* (2001).

Table 3 Values for model constants

Model	Temperatur	k	k_1	k_2	α
Peleg	20		91.780	0.410	
	30		60.192	-0.228	
	40		27.643	-0.918	
Weibull	20				0.305
	30				0.179
	40				0.109
Exponential	20	8.744			
	30	14.422			
	40	17.977			

4 Conclusion

Temperature and soaking time affected water absorption behaviour of the unripe plantain chips samples in such a way that as temperature increased, water absorption was also increased. Weibull model had best fit and represent well the re-hydration characteristics of the dehydrated plantain chips.

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Nomenclature

α	: Drying constant in the model
β	: Drying constant in the model
k	: Drying constant in the model
k_1	: Drying constant in the model
k_2	: Drying constant in the model
M_0	: Initial moisture content of the sample (g water/g solid)
M_t	: Instantaneous moisture content of the sample (g water/g solid)
M_s	: Saturation moisture content of the sample (g water/g solid)
MBE	: Mean bias error
MR	: Moisture ratio
MR_{exp}	: Experimental moisture ratio
MR_{pre}	: Predicted moisture ratio
N	: Number of observation
RMSE	: Root mean square error
R^2	: Coefficient of determination
t	: Re-hydration time (mins)
W_d	: Weight of dehydrated plantain chips (g)
W_r	: Weight of re-hydrated plantain chips (g)
χ^2	: Reduced chi square
z	: Number of constant in the models