American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-4, Issue-5, pp-45-49
www.ajer.org
Research Paper Open Access

Rehydration characteristics and modeling of cassava chips

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ABTRACT: *Cassava chips with dimension 4x2x0.2cm were re-hydrated in distilled water at 20^{0}C, 30^{0}C and 40^{0}C in a laboratory water bath. Kinetics of re-hydration was investigated using three different re-hydration models namely Peleg, exponential and Weibull. The pattern of water absorption was observed to be faster at the initial period of soaking. Higher temperature induces faster moisture absorption in the chips. Non linear regression analysis was used to fit in the experimental data and the coefficient of determination was found to be greater than 0.72 for all the models. The values of R^2, RMSE, MBE and reduced chi square showed that Weibull model best described the re-hydrating behaviour of the cassava chips.*

KEY WORD: *rehydration, modeling, temperature, cassava chips*

I. INTRODUCTION

Cassava chips are the most common form in which dried cassava root are marketed. It is a rich source of cassava pellet, alcohol, industrial starches and cassava beer (Wheatly *et al*, 1995, CBN, 2012). Processing cassava chips involves peeling and slicing into flat shapes before drying either in sun or mechanical dryers (Tewe 1994). The methods of preservation include storing in baskets, silos, bags and cribs. The major challenge facing the shelf life of cassava chips is moisture gain during storage due to hygroscopic nature and tends to absorb moisture which promotes the formation of moulds and thus early deterioration of the chips. Having this information makes it therefore utmost important to consider effective storage system for cassava chips. The shelf life of cassava chips is expected to be between 6-12 months if properly stored. The duration of storage is influence by other factors such as insect infestation but since dried cassava chips are hard for insect to penetrates, moisture absorption by the chips make it soft and helps insects to penetrate into these chips and cause deterioration. Therefore, the key factor to monitor is how to prevent moisture from gaining entrance into the storage system where the chips are kept. Consequently, to design effective storage for the chips, knowledge of water absorption properties is required which necessitated modeling of water transfer in chips slab. This is the objective of the study.

Empirical models have been applied to study absorbing characteristics of foods; for instant Peleg model (Gowen et al., 2007), Weibull distribution model (Garcia-Pascual *et al.*, 2006; Machado, *et al.*, 1999; Marabi, et al., 2003) and exponential model (Gowen *et al.*, 2007; Kashaninejad, *et al.*, 2007). So, these three models would be used to study the re-hydrating behaviour of the chips.

II. MATERIALS AND METHODS

(a) Re-hydration kinetics of dehydrated cassava chips experiment

The re-hydration behaviour of the chips was studied using three temperatures namely 20, 30 and 40^{o}C. The chips were placed inside a beaker containing water. The ratio of the dried chips to water was 1: 30 as recommended by Johnson, et al., 1998; Bhuvaneswari et al., 1999**.** The beaker was then placed in a water bath at a pre-set temperature. The chips were removed at interval of time from the water and placed on absorbent cloth to remove the free water on the surface the chips and the change in weight of the chips was recorded. The samples were subsequently returned to water via wire mesh, and the process was repeated until the chips moisture content attained saturation moisture content. Experiments were triplicated and the average results were used for modeling process. The moisture ratio (MR) is computed in equation 1 as follows:

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

(b) Mathematical model

Three equations were used for re-hydration modelling process. The experimental data were fitted into these three different models as presented in Table 1. These models described the relationship between moisture gain and soaking time with various coefficients attached to each model

Table I: Mathematical drying models

Models	Equation	References
Peleg	$M_t - M_0 = \frac{t}{k_1 + k_2 t}$	Bahadur *et al.*, 2007
Weibull	$MR = \exp(-(\frac{t}{\beta})^{\alpha}$	Khazaei, 2008
Exponential	$MR = \exp(-kt)$	Khazaei, 2008

(c) Statistical Analysis

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 to determine the goodness of fit of experimental data into mathematical equation. According to Maydeu-Olivares and CGarcı´a-Forero (2010), the goodness of fit (GOF) of a statistical model describes how well it fits into a set of observations. GOF indices summarize the discrepancy between the observed values and the values expected under a statistical model. GOF statistics are GOF indices with known sampling distributions, usually obtained using asymptotic methods that are used in statistical hypothesis testing. In this study, statistical criteria such as coefficient of determination (R^2), reduced chi-square (χ^2), root mean square error (RMSE) and mean bias error (MBE) were used to test the reliability of the models. The equation for each statistical criterion is as shown in equations 2-4

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

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

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

III. RESULTS AND DISCUSSION

(a) Water absorption pattern of the Chips

Figure 1 shows the water absorption characteristics of the chips at 20, 30 and 40^{o}C. The chips exhibited almost the same pattern in the first 15 minutes but the graph shows wide gap among each other thereafter. The graph shows an increase rate of water absorption followed by slower absorption as soaking time increased. Previous works by other researchers show identical curves (Abu-Ghannam and McKenna, 1997; Bello et al., 2004; Sopade et al., 1992, Mahir *et al.*, 2002, Maharaj and Sankat, 2000).

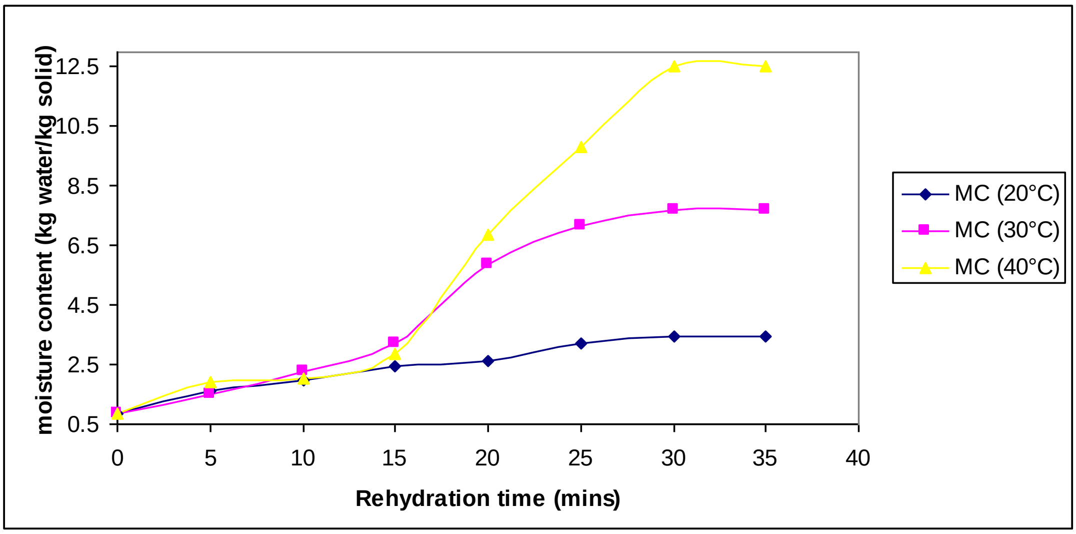

Figure 1: Moisture content against time

Temperature shows a significant influence on the re-hydrating profile of the chips. At the end of 30 minutes, the chips had gained moisture of 3.35 kg water/kg solid, 7.12 kg water/kg solid and 12.35kg water/kg solid at 20, 30 and 40^{o}C respectively. From these values, higher temperature aids the absorption because water molecules are exited to penetrate into the granular cell of the chips. The same observation has been reported by Smiles (2005) and Ajala *et al* 2012.

Figure 2 shows the change in rate of re-hydration of the samples at 20, 30 and 40^{o}C. The change in rate of re-hydration implies the amount of change in moisture the sample absorbed within an interval of time. From the graph, sample re-hydrated at 40^{o}C has an initial value of 48.5g/hr followed by 32.0g/hr at 30^{o}C and 9.02g/hr at20^{o}C. As soaking time increased, the graph declined down the slope and flattened off showing that the change in water absorption continue to decline as the sample tends to saturation point when moisture are no longer absorbed. This saturation stage was branded relaxation stage by Khazaei 2008.Similar curve has been reported by Bahadur *et al.*, (2007).

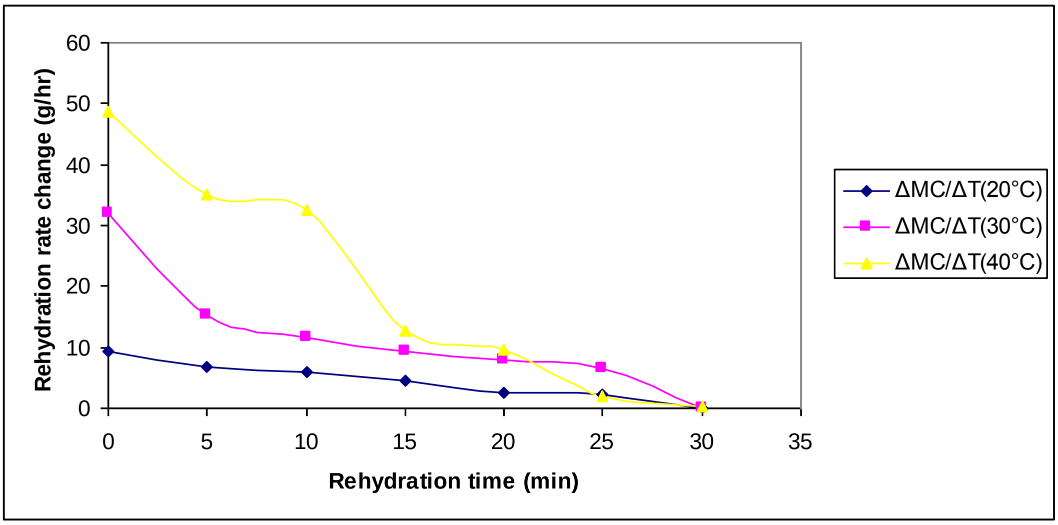

Figure 2: Re-hydration change rate against time

Table 2 shows the values of statistical criteria used in evaluating the three models used. The lowest value of chi square is found to be 0.019396 (exponential model) while the highest is 0.79384 (Weibull model). The lowest value of MBE is -0.0296 (exponential model) while the highest is 0.714286 (Weibull model). Furthermore, t he lowest value of RMSE is found to be 0.128939 (exponential model) while the highest is 0.890977 (Weibull model).The values of R^2 of Peleg model is as follows: 0.955, 0.966 and 0.827; Weibull:

0.926, 0.967 and 0.920; exponential: 0.733, 0.677 and 0.775 for 20, 30 and 40^{o}C respectively. On the average, the value of R^2 for Peleg, Weibull and exponential are 0.916, 0.937 and 0.728. From these values, the highest value of R^2 is found to be 0.937 which correspond to Weibull model while the lowest value of R^2 is 0.728 correspond to exponential model. Therefore, in this study, Weibull model is considered the best model to represent re-hydrating characteristics of cassava chips because it has best fit with experimental data. A good fit occurred when R^2 is high and other statistical criteria such as reduced chi square, MBE and RMSE are low (Ahmet *et al.*, 2007).

Table 3 shows the value of re-hydrating constant of the samples. In Peleg model, the lowest value for k_1 is 8.429 minutes while the highest value is 60.563 minutes. Lowest value for k_2 is -1.046 while highest is 0.708. The re-hydrating constant in Weibull model is stated thus: α lowest value is 0.095 while α highest value is 0.405. β lowest value is 29.445 minutes while the highest is 12.465 minutes . The lowest value of k in exponential model is 3.525 min^{-1} while the highest value is 11.566 min^{-1}. The value of K_1 in Peleg model and k in exponential model are inversely related to moisture absorption. This implies that as k_1 and k increase, water absorption decreases. This is the same observation reported by Mahir *et al* (2002). Contrariwise, β values increases as water absorption increases

Table II: Models Evaluation using statistical criteria

Model	Temp (^{o}C)	R^2	χ^2	MBE	RMSE
Peleg	20	0.956	0.54802	0.518571	0.740284
	30	0.966	0.40016	0.411429	0.632582
	40	0.827	0.78878	0.672857	0.888133
Weibull	20	0.926	0.54048	0.54	0.735173
	30	0.967	0.39752	0.425714	0.630492
	40	0.920	0.79384	0.714286	0.890977
Exponential	20	0.733	0.027985	-0.03879	0.154879
	30	0.677	0.034653	-0.0296	0.172345
	40	0.775	0.019396	-0.05695	0.128939

Table III: Values for model constants

Model	Temp (^{o}C)	k (min^{-1})	k_1(min)	k_2 (-)	α **(-)**	β (min)
Peleg	20		60.563	0.708		
	30		30.495	-0.066		
	40		8.429	-1.046		
Weibull	20				0.188	-29.445
	30				0.095	-16.911
	40				0.405	-12.465
Exponential	20	11.566				
	30	7.851				
	40	3.525				

CONCLUSION

Temperature affects water absorption behaviour of the samples in such a way that as temperature increase, water absorption is faster. Weibull model had best fit and represent well the re-hydration characteristics of the dehydrated cassava chips.

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