SUITABLE MODEL FOR THIN LAYER DRYING KINETICS OF WHITE AND PINK-FLESHED TANNIA (*XANTHOSOMA SAGITTIFOLIUM*) CORMELS

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ABSTRACT

Drying is an essential unit operation in the conversion of fresh tannia (Xanthosoma sagittifolium) cormels into flour with the attendant benefits of improved shelf life and better storability. Information on the drying kinetics of the cormels will foster a good understanding of its behaviour during drying. Rate of moisture loss during the process can also be described by appropriate models. This study therefore, investigated the thin layer drying kinetics of two cultivars of tannia cormels at different temperature levels and determined the most suitable model for its prediction. White and pink-fleshed cormel slices of 3mm thickness were dried at 60, 70 and 80°C temperature levels. Data obtained from the drying experiments were fitted into ten selected models namely Newton, Page, modified Page, Logarithmic, Henderson and Pabis, Midilli, Verma, Two term, Thompson, and Wang and Singh models. The highest and the lowest drying rates were obtained at 80 and 60°C respectively. Page and modified Page models were the most suitable models for describing the drying behaviour of both tannia cultivars with highest R^2 in excess of 0.9941 and lowest error estimates ($RMSE \leq 0.0251$; $\chi^2 \leq 0.0008$; $MBE \leq 0.0060$). The drying took place predominantly in the falling rate period which indicated that moisture removal from tannia cormels occurred mainly by diffusion mechanism.

***Keywords*:** Tannia cormels, Drying characteristics, Drying rates, Falling rate period, Diffusion mechanism, Modelling.

INTRODUCTION

Tannia (*Xanthosoma sagittifolium*) is cultivated primarily for its corms and cormels although its leaves are also used as vegetables in some places all over the world. The corm is the vertical swollen underground stem of tannia which is used in its propagation while the cormels are developed at the base of the mature corm. The corms and cormels serve as main food items in many parts of the tropics including Nigeria (Ogunlakin *et al.*, 2012; Adeyanju *et al*., 2019). Although tannia is not considered as prestigious as cassava and yam in Nigeria, it is superior to them in terms of nutritional value. It also has some promising potentials such as suitability as a binding agent in tablets manufacturing, formulation of weaning food, production of pasta from its flour blends, production of lager beer etc (Odeku *et al.*, 2005; Aderolu, 2009; Owusu-Darko *et al*., 2014).

Tannia cormel is highly susceptible to post-harvest loss which reduces its quality attributes and stability in storage (Owusu-Darko *et al*., 2014). However, its post-harvest losses can be prevented by immediate processing of the harvested cormels into products of better storability such as flour, chips and flakes (Iwuoha and Kalu, 1995). Drying is an important operation in the conversion of fresh tannia cormels into these products with the attendant benefit of improved shelf life and storage stability.

Drying involves the reduction of the amount of moisture in agricultural materials to a pre-determined level by the application of heat, thereby reducing their weights and protecting them against attack of insects, molds and other micro-organisms (Sahay and Singy, 1994; Doymaz and Kipcak, 2019). It can be done in either thin layer or deep bed (which consists of series of thin layers). Thin layer drying involves moisture removal by passing heated air over a single kernel or layer of the material until the equilibrium moisture content (EMC) is attained (Ronoh *et al.*, 2010).

The interactions of various operating conditions such as drying air (temperature, pressure, relative humidity and air velocity), the nature and geometry of the material, pre-drying treatments and methods of drying as well as their effects on the thin layer drying characteristics of agricultural materials have been investigated with the purpose of improving the energy efficiency and optimising the process (Erbay and Icier, 2010; Jaiyeoba and Raji, 2012). Drying kinetics under various conditions has been investigated for pre-treated cassava chips (Tunde-Akintunde and Afon, 2009), Amaranth grains (Ronoh *et al.*, 2010), pumpkin slices (Limpaiboon, 2011), Ibadan-local tomato varieties (Jaiyeoba and Raji, 2012), mango (Aremu *et al*, 2013), cocoyam corms (Nwajinka *et al*., 2014), unripe Cardaba banana (Olawoye *et al*., 2017), pineapple (Tunçkal *et al*., 2018), black mulberry (Doymaz and Kipcak, 2019) and yam tuber (Ojediran *et al*., 2020).

Several models have been developed to describe thin layer drying of agricultural and food products (Ronoh *et al*., 2010; Afolabi *et al*., 2015). Many of these models have been used to predict the drying characteristics of several agricultural and food materials with different degrees of performance. This study therefore, aimed at determining the most suitable model for predicting the thin layer drying kinetics of white and pink-fleshed cultivars of tannia (*X. sagittifolium*) cormels.

MATERIALS AND METHODS

Materials

White (NXs. 001) and pink-fleshed (NXs. 002) cultivars of tannia (*X. sagittifolium*) cormels used in this study were obtained from Ogunmakin market, Ogunmakin town, Ogun State, Nigeria. The cormels were cleaned, peeled manually using a sharp, thin stainless steel knife and cut into 3mm thick slices for the drying

Drying kinetics of tannia cormels

The cormel slices were dried at 60, 70 and 80°C temperature levels using a laboratory oven dryer (Uniscope, SM 9053, England). The drying characteristics such as moisture content, moisture ratio and drying rate during drying of the tannia cormels were obtained. The masses of the samples before, during and after drying were measured using an electronic weighing balance (Kerro digital scale, Taiwan, 0.1 g). Moisture losses of samples were recorded at 30 minutes' intervals for the first three hours and 60 minutes' intervals afterwards. The drying process continued until a constant weight was reached (Afolabi *et al*., 2014). Moisture ratio (MR) was evaluated based on equation 1 (Fawohunre *et al*., 2019; Ojediran *et al*., 2020).

$$MR = \frac{M_t - M_e}{M_i - M_e} \quad (1)$$

where:

M_t = moisture content of the cormel at any given time, t (%, dry basis)

M_i = initial moisture content of the cormel (%, dry basis)

M_e = moisture content of the cormel at equilibrium (%, dry basis)

Drying curves such as variations in moisture ratios, moisture content and drying rate against drying time were obtained from the analysis to describe the drying characteristics of the cormels. Cormel drying rate was determined using equation 2 (Kadam *et al*., 2011; Raviteja *et al*., 2019).

$$DR = \frac{M_w}{M_d\, t} \quad (2)$$

where:

DR = drying rate of the cormel (kg water /kg DM − h)

M_w = mass of moisture removed from the cormel (kg)

M_d = mass of the dry matter in the cormel (kg)

t = drying time (h)

Modelling of tannia cormels drying characteristics

The data obtained from the drying experiments were fitted into ten selected thin layer drying models namely Newton, Page, modified Page, Logarithmic, Henderson and Pabis, Two term, Midilli, Verma, Thompson, and Wang and Singh models. The tested models and their mathematical representations are presented in Table 1. Non-linear regression analysis was carried out on the experimental data with the aid of statistical software, Statistix 9.0, to obtain the drying constants and model empirical constants.

The moisture ratios (MR_{pre}) were predicted using the selected models and these predictions were then correlated with the experimental data (MR_{obs}). Goodness of fit for each model was determined on the basis of highest coefficient of determination (R^2) and lowest error estimates in terms of Root Mean Square Error (*RMSE*), Mean Bias Error (*MBE*) and reduced Chi square (χ^2). The mathematical expressions for the determination of R^2, *RMSE*, *MBE* and χ^2 are as presented in equations 3, 4, 5 and 6 respectively (Afolabi *et al*., 2015; Olawoye *et al*., 2017; Doymaz and Kipcak, 2019; Ojediran *et al*., 2020).

$$R^2 = \frac{(\sum_{i=1}^{N}(MR_{exp,i} \cdot MR_{pre,i}))^2}{(\sum_{i=1}^{N}(MR_{exp,i})^2) \cdot (\sum_{i=1}^{N}(MR_{pre,i})^2)} \quad (3)$$

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

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(MR_{(pre,i)} - MR_{(exp,i)}) \quad (5)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{(pre,i)} - MR_{(exp,i)})^2}{N - z} \quad (6)$$

Where:

$MR_{exp,i}$ = ith experimental moisture ratio (dimensionless)

$MR_{pre,i}$ = ith predicted moisture ratio (dimensionless)

N = number of observations

z = number of constants in the model

Table 1. Selected thin layer drying models.

S/No	Model Name	Model	References
1	Newton	MR = exp(-kt)	Afolabi *et al*. (2015)
2	Page	MR = exp(-kt^n)	Tunçkal *et al*. (2018)
3	Modified Page	MR = exp(-(kt)^n)	Aremu *et al.* (2013)
4	Henderson & Pabis	MR = a exp(-kt)	Olawoye *et al*. (2017)
5	Logarithmic	MR = a exp (-kt) + c	Nwajinka *et al*. (2014)
6	Two Term	MR = a exp (-kt) + c exp (-gt)	Olawoye *et al*. (2017)
7	Midilli	MR = a exp (-kt) + bt	Fawohunre *et al*. (2019)
8	Verma	MR = a exp (-kt) + (1-a) exp (-gt)	Olawoye *et al*. (2017)
9	Wang & Singh	MR = 1 + at + bt^2	Doymaz and Kipcak, (2019)
10	Thompson	MR = 1 + a ln (MR) + b (ln(MR))^2	Thompson *et al*. (1968)

RESULTS AND DISCUSSION

Drying characteristics of white and pink-fleshed cultivars of tannia cormels were studied at 60, 70 and 80°C temperature levels. Suitability of ten selected thin layer models in describing the rate of moisture removal was also investigated in this study.

Drying kinetics of tannia cormel slices

The drying curves of white and pink-fleshed tannia slices at different temperature levels are presented in Figures 1a and 1b respectively. It was observed that moisture content decreased continuously throughout the period of the experiment until EMC was reached at each of the temperature levels considered. The drying rates were higher as the drying temperature increased for both varieties. The cormels dried at 80^{o}C had predominantly highest drying rates and shorter drying periods while drying at 60^{o}C had the lowest drying rates with attendant longer duration of drying. The higher drying rates at higher drying temperature levels could be attributed to the increase in the gained kinetic energy of the water molecules in the cormels as the temperature increased which resulted in larger water vapour pressure deficit that helped to enhance the drying process. This could be observed from the steeper nature of the slope of the drying curves at higher temperature levels.

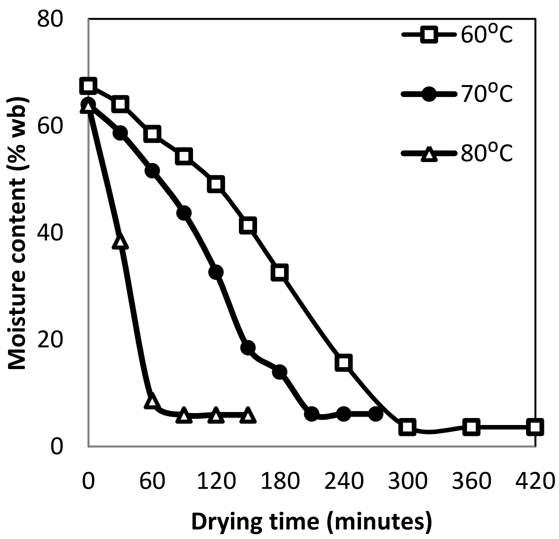

Fig. 1a. Drying curve for fresh white-fleshed tannia slices

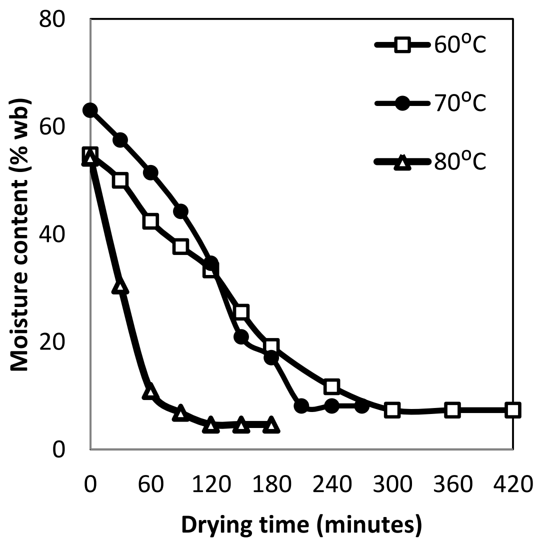

Fig. 1b. Drying curve for fresh pink-fleshed tannia slices

removing the bound moisture present in the cormels, having depleted the free water and capillary water. This could be observed from the steeper nature of the slope of the drying curves at the earlier stages of the drying for all temperature levels. Similar results have been reported for basil leaves (Kadam *et al*., 2011), castor seeds (Ojediran and Raji, 2011), roselle (Suherman *et al*., 2012), cocoyam corms (Nwajinka *et al*., 2014), taro cormels (Afolabi *et al*., 2015) and mint leaves (Raviteja *et al*., 2019).

No marked constant rate was observed for both cultivars as the drying processes took place predominantly in the falling rate regime for all temperature levels considered. This showed that the drying process can be described principally by the diffusion mechanism. Similar findings have been reported by Ojediran and Raji (2011), Aremu *et al.* (2013), Afolabi *et al*. (2015) and Doymaz and Kipcak (2019)

Modelling of the drying kinetics of tannia cormels

Data obtained from the drying experiments were fitted into ten relevant thin layer drying models to determine the most suitable models for describing the drying characteristics of the cormels under the given conditions. The empirical constants, model coefficients and statistical parameters (R^2, *RMSE*, χ^2 and *MBE*) which were calculated for all the tested drying models are as presented in Tables 2a and 2b.

Table 2a. Drying constants and statistical parameters for tannia cormels

Air temperature		**60°C**		**70°C**		**80°C**	
Model		**White**	**Pink**	**White**	**Pink**	**White**	**Pink**
Newton	k	0.0075	0.0081	0.0108	0.0101	0.0374	0.0337
	R^2	0.9820	0.9947	0.9811	0.9825	0.9947	0.9976
	RMSE	0.0543	0.0270	0.0552	0.0500	0.0300	0.0135
	χ^2	0.0033	0.0008	0.0035	0.0029	0.0012	0.0002
	MBE	-0.0034	0.0017	-0.0062	-0.0077	0.0059	-0.0028
Page	n	1.3439	1.0931	1.3960	1.3356	1.3855	0.9326
	k	0.0014	0.0052	0.0017	0.0020	0.0094	0.0433
	R^2	0.9941	0.9965	0.9970	0.9956	0.9988	0.9971
	RMSE	0.0251	0.0190	0.0183	0.0215	0.0149	0.0175
	χ^2	0.0008	0.0005	0.0004	0.0006	0.0004	0.0005
	MBE	0.0060	0.0028	0.0015	0.0015	-0.0043	-0.0003
Modified Page	n	1.3439	1.0931	1.3960	1.3356	1.3855	0.9326
	k	0.0074	0.0081	0.0103	0.0097	0.0344	0.0345
	R^2	0.9941	0.9965	0.9970	0.9956	0.9988	0.9971
	RMSE	0.0251	0.0190	0.0183	0.0215	0.0149	0.0175
	χ^2	0.0008	0.0005	0.0004	0.0006	0.0004	0.0005
	MBE	0.0059	0.0028	0.0012	0.0015	-0.0043	-0.0002
Henderson & Pabis	a	1.0568	1.0225	1.0591	1.0512	1.0042	1.0000
	k	0.0079	0.0083	0.0113	0.0105	0.0376	0.0337
	R^2	0.9776	0.9941	0.9780	0.9801	0.9947	0.9976
	RMSE	0.0496	0.0249	0.0503	0.0458	0.0299	0.0135
	χ^2	0.0032	0.0008	0.0034	0.0028	0.0018	0.0003
	MBE	0.0068	0.0051	0.0059	0.0036	0.0065	-0.0028
Logarithmic	a	1.1499	1.0209	1.1596	1.1562	0.9924	0.9733
	k	0.0062	0.0084	0.0087	0.0080	0.0390	0.0372
	c	-0.1176	0.0022	-0.1252	-0.1297	0.0127	0.0302
	R^2	0.9918	0.9939	0.9894	0.9906	0.9939	0.9979
	RMSE	0.0318	0.0252	0.0346	0.0313	0.0325	0.0172
	χ^2	0.0015	0.0010	0.0019	0.0016	0.0042	0.0007
	MBE	0.0069	0.0051	0.0030	0.0020	0.0085	0.0034
Two term	a	1.1566	1.0683	1.2377	1.1876	1.8800	0.9987
	k	0.0087	0.0087	0.0131	0.0118	0.0558	0.0337
	c	-0.1566	-0.0683	-0.2377	-0.1876	-0.8800	0.0013
	g	1.0000	1.0000	1.0000	1.0000	1.0316	1.0000
	R^2	0.9852	0.9961	0.9899	0.9887	0.9990	0.9983
	RMSE	0.0401	0.0201	0.0336	0.0343	0.0132	0.0145
	χ^2	0.0029	0.0007	0.0023	0.0024	0.0007	0.0011
	MBE	0.0054	0.0038	0.0022	0.0018	-0.0029	0.0007

Table 2b. Drying constants and statistical parameters for tannia cormels (cont'd)

Air temperature		60°C		70°C		80°C	
Model		**White**	**Pink**	**White**	**Pink**	**White**	**Pink**
Midilli	A	1.0354	1.0245	1.0368	1.0287	1.0054	1.0031
	K	0.0069	0.0084	0.0097	0.0089	0.0386	0.0355
	B	-0.0002	0.0000	-0.0003	-0.0003	0.0001	0.0002
	R^2	0.9903	0.9936	0.9881	0.9896	0.9940	0.9982
	RMSE	0.0346	0.0258	0.0367	0.0330	0.0324	0.0154
	χ^2	0.0018	0.0010	0.0022	0.0017	0.0042	0.0006
	MBE	0.0076	0.0050	0.0034	0.0023	0.0084	0.0023
Verma	A	1.1566	1.0683	1.2377	1.1876	1.8800	1.0973
	K	0.0087	0.0087	0.0131	0.0118	0.0558	0.0337
	G	1.0000	1.0000	1.0000	1.0000	0.9082	0.0337
	R^2	0.9852	0.9961	0.9899	0.9887	0.9990	0.9983
	RMSE	0.0401	0.0201	0.0336	0.0343	0.0132	0.0146
	χ^2	0.0024	0.0006	0.0018	0.0019	0.0007	0.0005
	MBE	0.0054	0.0038	0.0022	0.0018	-0.0029	0.0003
Wang & Singh	A	-0.3351	-0.3651	-0.4792	-0.4555	-1.2232	-1.0355
	B	0.0280	0.0340	0.0587	0.0540	0.3471	0.2494
	R^2	0.9984	0.9932	0.9966	0.9963	0.9614	0.9296
	RMSE	0.0139	0.0285	0.0210	0.0204	0.0832	0.0924
	χ^2	0.0002	0.0010	0.0006	0.0006	0.0138	0.0142
	MBE	0.0001	0.0053	-0.0047	-0.0037	0.0257	0.0234
Thompson	A	-2.4074	-1.7574	-1.6392	-1.8080	-0.1039	0.0785
	B	-0.2307	0.1425	-0.1353	-0.1599	0.1375	0.2609
	R^2	0.9832	0.9868	0.9860	0.9871	0.9329	0.9718
	RMSE	0.3828	0.3882	0.1739	0.1604	0.3337	0.1625
	χ^2	0.1884	0.1937	0.0403	0.0343	0.2227	0.0440
	MBE	0.0588	0.0952	-0.0335	-0.0255	0.1571	0.1121

All the selected drying models performed relatively well in predicting the thin layer drying of both white and pink-fleshed tannia slices under the drying conditions considered with R^2 ranging from 0.9296-0.9990. The predicted MRs for Page and Modified Page models were the same for all the conditions considered and the only variations were observed in the drying constant (k) and empirical constant (n) at different temperature levels. Wang and Singh, Modified Page, Verma and Midilli models gave consistently good estimations with R^2 and *RMSE* in all cases being within the ranges of 0.9296–0.9984 and 0.0139–0.0924, 0.9941–0.9988 and 0.0149–0.0251, 0.9852–0.9990 and 0.0132–0.0401, 0.9881–0.9982 and 0.0154–0.0367, respectively. Verma model had the highest R^2 (0.9990, for white-fleshed cormel at 80°C) while Wang and Singh model gave the lowest R^2 (0.9296, for pink-fleshed cormel at 80°C). The curves showing the variations in the experimental MRs and those predicted by the best drying models (with highest R^2) are as presented in Figures 2 and 3.

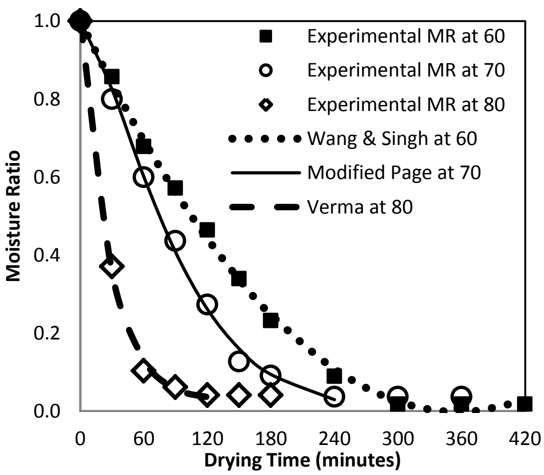

Fig. 2. Experimental and predicted MRs for white-fleshed tannia slices

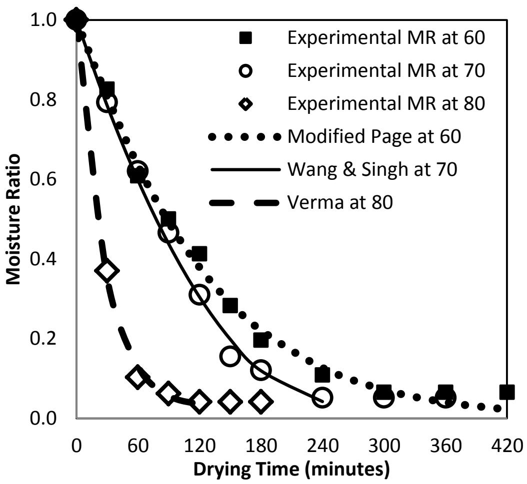

Fig. 3: Experimental and predicted MRs for pink-fleshed tannia slices

Page and Modified Page models performed best in describing the drying characteristics of tannia slices under the temperature levels considered with consistently high R^2 ($\geq$ 0.9941) and low error estimates ($RMSE \leq 0.0149$, $MBE \leq 0.0059$ and $\chi^2 \leq 0.0035$). The paths followed by the predictive curves of Page and Modified Page models were the same for both tannia cultivars and all temperature levels considered. This indicated that drying rates of both cultivars of tannia cormels were solely dependent on temperature levels and higher temperature differentials between the cormel slices and the drying air resulted in faster moisture removal. Similar results have been published for pumpkin slices (Limpaiboon, 2011), leek slices (Doymaz, 2008) and pre-treated cassava chips (Tunde-Akintunde and Afon, 2009).

CONCLUSIONS

The drying characteristics of white and pink-fleshed cultivars of tannia cormels have been investigated in this study. Drying at higher temperature levels is recommended to obtain higher temperature differentials and subsequently, ensure faster drying and shorter drying period to attain the equilibrium moisture content under the given conditions. The drying process was found to be predominantly in the falling rate period for all temperature levels considered. Page and modified Page models were the most suitable models for describing the drying characteristics of both cultivars of tannia cormels.

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