THIN LAYER DRYING MODELS FOR CASSAVA PARTICULATE DRYING

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ABSTRACT

Cassava particulates from the cultivars CAS 001, CAS 002 and CAS 003 were subjected to thin-layer drying at $100^{O}C$ (in an oven dryer) after being fermented for 48 hours. The experimental data obtained from the drying was fitted with ten selected non-linear thin-layer drying models using MATLAB curve fitting tool box.

Three of these models, which coincidentally contain the drying parameter, n gave the best fit based on regression coefficient (R^2), root mean square of errors (RMSE)and sum of square of errors (SSE).

These are the two-parameter Page equation, three-parameter Osoka and Oruh equation and four-parameter Midilli et al equations

Models that contained the drying parameter, n, gave the best overall fit. Three thin-layer drying models were recommended, in decreasing order of accuracy, for modeling kinetics of cassava particulate drying: Midilli et al equation ,Osoka and Oruh equation, and Page equation.

Keywords: cassava, drying, kinetics, model, thin-layer, moisture content.

INTRODUCTION

Cassava is one of the major root tubers produced in the forest zones of Nigeria, with yields as high as 38 million metric tonnes per annum (Nwosu, 2006). In Nigeria over 70% of the cassava yield is processed into gari, a convenient storage cupboard staple food (Sanni and Olubamiwa, 2003).

The process involves roasting – alternate cooking and drying – of fermented cassava mash, causing the starch in it to gelatinize. During this process, the fermented cassava mash is dried at a temperature above $70^{O}C$ and from a moisture content of 45 – 53% to a moisture content of about 12% or less, for white gari and 10% or less, for yellow gari, to make it suitable for storage (Ajibola, 1987; Sefa-Dedeh and Plange, 2001).

The development of accurate kinetic models to describe drying is important to the establishment of good theoretical basis for the design of drying systems. The use of kinetic models has become one of the more rigorous approaches to the design and simulation of drying systems. Kinetic models can be analytical (solved with a variety of simplifying assumptions) or purely empirical (built by regression on experimental data). Though empirical models are only valid for a specified set of experimental conditions and extrapolation to other materials and drying condition may lead to significant errors, they are significant in the design of drying systems (Kudra and Efremov, 2002).

The thin-layer drying models describe the drying kinetics of a layer of sufficiently small product thickness (particulate or slices) for which the air characteristics of temperature, velocity and humidity everywhere in the layer are considered uniform (Colson and Young, 1996; Akpinar, 2006) Thin-layer drying models are independent of drying technology, nevertheless they are specific to the properties of the dried products. Due to this specificity, many food products have been studied using these models (Sun and Woods, 1994; Mwithiga and Olwal, 2005). Among these are linear as well as non-linear models.

Oyerinde et al (2006) evaluated five thin-layer drying models for the drying of cassava particulate and recommended the Henderson equation with a regression coefficient of 0.975. In their work, linear regression was used for fitting the experimental data to the models.

This is a poor choice because most of the models are inherently non-linear exponential functions. Linear regression introduces the natural logarithm which not only has a discontinuity at zero, but is unreliable for values less than unity, for which its values are negative.

Thus most of the thin-layer drying models used in their work gave very poor fit results. Non-linear regression will be used in this study.

REVIEW OF NON LINEAR THIN LAYER DRYING MODELS

1. One Parameter Models

One parameter exponential model (Model 1): This is a simple model that assumes negligible internal resistance to moisture movement from within the material to the surface of the material, and it is given as:

$$MR = \exp(-k\,t) \quad (1)$$

where; k is the drying constant (Lewis, 1921).

2. Two Parameter Models

The Page equation (Model 2): This is a modified form of Equation 1 used to describe thin layer drying of shelled corn.

$$MR = \exp(-k\,t^{n}) \quad (2)$$

where; k is the drying constant and n is the drying parameter (Page, 1949).

Henderson and Pabis equation (Model 3): This is the simplest approximation of the diffusion equation.

$$MR = a \exp(-k\,t) \quad (3)$$

where; a is an empirical constant and k is the drying parameter (Henderson and Pabis, 1961).

Wang and Singh equation (Model 4): MR

$$=1+at+bt^2 \quad (4)$$

where; a and b are empirical constants (Wang and Singh, 1978).

Thompson equation (Model 5): Thompson et al (1968) determined the solution of the exponential model in the second order and obtained a polynomial expression of the form;

$$t = a \ln(MR) + b \ln(MR)^2 \quad (5)$$

where; a and b are empirical constants.

3. Three Parameter Models

Logarithmic equation (Model 6):

$$MR = a \exp(-k\,t) + c \quad (6)$$

where; a and c are empirical constants and k is the drying parameter (Yagcioglu et al, 1999).

Approximation of Diffusion equation (Model 7):

$$MR=a \exp(-k\,t)+(1-a)\exp(-k\,b\,t) \quad (7)$$

where; a and b are empirical constants and k is the drying parameter (Yaldiz and Ertekin, 2001).

Osoka and Oruh equation (Model 8): Osoka and Oruh (2007) solved the equation of Fick's second law numerically in three dimensions and obtained a fitting analytical model of the form;

$$MR = a \exp(-k\,t^{n}) \quad (8)$$

where; a is an empirical constant, k is the drying constant and n the drying parameter.

4. **Four Parameter Models**

Two term equation (Model 9):

$$MR = a \exp(-g\, t) + b \exp(-k\, t) \quad (9)$$

where; a, b and g are empirical constants and k is the drying parameter (Sharaf-Eldeen et al, 1980)

Midilli et al equation (Model 10):

$$MR = a \exp(-k\, t^{n}) + b\, t \quad (10)$$

where; a and b are empirical constants, k is the drying constant and n the drying parameter (Midilli et al, 2002).

MATERIALS AND METHODS

Raw Materials: Cassava cultivars (CAS 001, CAS 002 and CAS 003), water, basin.

Equipment and Apparatus: A laboratory Gallenhamp Graffin Oven, Knife, Hessian (sack) bag, grating machine, weighing balance, weight.

Samples of each cassava cultivar were harvested, peeled, washed and mashed, using a grating machine. Each sample was tied in a Hessian (sack) bag and subjected to a heavy weight for forty eight hours to squeeze out water and ferment. About 70g of each sample was taken out and sieved with a mesh of size 1.4mm. 50g of the sieved sample was weighed out into a flat aluminum plate of diameter 13.2cm and placed in a laboratory Gallemhamp Graffin oven that is electrically operated from a 240V mains supply and maintained at a temperature of $100^{O}C$.

After 45seconds the oven was switched off and the mash removed and weighed. The mash was returned to the oven for the next phase of the drying cycle. Subsequently the mashes were dried in the oven for additional 5, 10, 15, 20, 25, 30 and 60minutes. Each time the mashes were weighed and returned to the oven for the next phase of drying.

The moisture content was determined by the oven method upon drying to constant weight, thus:

Mass of water in sample = mass of sample – mass of dry cassava (11)

% Moisture content (wet basis) = (mass of water in sample)/(Initial mass of sample) x 100 (12)

% Dry cassava = 100% - % moisture content (wet basis) (13)

Moisture content (dry basis) = % Moisture content (wet basis) / % Dry cassava (14)

Moisture ratio was calculated using:

Moisture ratio (MR) = Moisture content at any time / Initial moisture content (15)

That is:

$$MR = MC_t / MR_O \quad (16)$$

Equation (16) was used due to the continuous fluctuation of relative humidity of the drying air in the type of oven used, as recommended by several researchers for open sun drying process (Yaldiz and Ertekin, 2001; Midilli and Kucuk, 2003; Togul and Pehlivan, 2003).

RESULTS AND DISCUSSION

Table 1: Table of drying kinetic data for CAS 001

t (hours)	0	0.0125	0.0958	0.2625	0.5125	0.8458	1.2625	1.7625	2.7625
MR (Dimensionless)	1	0.9608	0.8762	0.6837	0.4063	0.2221	0.1320	0.0549	0.0001

Table 2: Parameter values and Numerical fit results for models using CAS 001 Drying Data

Model no	a	b	c	g	k	n	R^2	RMSE	SSE
1	-	-	-	-	1.662	-	0.9974	0.02068	0.00342
2	-	-	-	-	1.724	1.068	0.9980	0.01908	0.00255
3	1.005	-	-	-	1.672	-	0.9974	0.02191	0.003361
4	-1.052	0.2559	-	-	-	-	0.9674	0.07791	0.04249
5	-0.7026	-0.04365	-	-	-	-	0.9959	0.06415	0.0288
6	1.012	-	-0.00864	-	1.638	-	0.9975	0.02331	0.00326
7	0.2422	0.9979	-	-	1.664	-	0.9974	0.02388	0.00342
8	0.9934	-	-	-	1.721	1.082	0.9981	0.02028	0.002467
9	0.5024	0.5024	-	1.672	1.672	-	0.9974	0.02593	0.003361
10	0.9926	0.002615	-	-	1.743	1.094	0.9981	0.02198	0.002415

Table 3: Table of drying kinetic data for CAS 002

t (hours)	0	0.0125	0.0958	0.2625	0.5125	0.8458	1.2625	1.7625	2.7625
MR (Dimensionless)	1	0.9669	0.8882	0.6956	0.4441	0.2373	0.1210	0.0329	0.0000

Table 4: Parameter values and Numerical fit results for models using CAS 002 Drying Data

Model no	a	b	c	g	k	n	R^2	RMSE	SSE
1	-	-	-	-	1.6	-	0.9970	0.02246	0.004034
2	-	-	-	-	1.707	1.134	0.9994	0.01074	0.0008075
3	1.012	-	-	-	1.624	-	0.9973	0.02288	0.003665
4	-1.044	0.2516	-	-	-	-	0.9813	0.05987	0.02509
5	-0.6829	-0.04825	-	-	-	-	0.9988	0.02428	0.03536
6	1.039	-	-0.03075	-	1.513	-	0.9981	0.02033	0.002479
7	13.68	0.9774	-	-	1.203	-	0.9982	0.02011	0.002427
8	0.991	-	-	-	1.703	1.155	0.9995	0.01039	0.0006474
9	2.546	-1.451	-	1.156	0.9206	-	0.9986	0.01952	0.001904
10	0.9913	-0.001	-	-	1.695	1.15	0.9995	0.01131	0.0006394

Table 5: Table of drying kinetic data for CAS 003

t (hours)	0	0.0125	0.0958	0.2625	0.5125	0.8458	1.2625	1.7625	2.7625
MR (Dimensionless)	1	0.9668	0.9078	0.7086	0.5746	0.3737	0.2248	0.1103	0.0124

Table 6: Parameter values and Numerical fit results for models using CAS 003 Drying Data

Model no	a	b	c	g	k	n	R^2	RMSE	SSE
1	-	-	-	-	1.181	-	0.9975	0.01907	0.002909
2	-	-	-	-	1.188	1.031	0.9976	0.01965	0.002702
3	0.997	-	-	-	1.176	-	0.9975	0.0203	0.002884
4	-0.8655	0.1868	-	-	-	-	0.9893	0.04184	0.01226
5	-0.9508	-0.073	-	-	-	-	0.9994	0.02542	0.004524
6	1.035	-	-0.04274	-	1.071	-	0.9985	0.01717	0.001768
7	1.101	1.18	-	-	1.2	-	0.9975	0.02189	0.002875
8	0.9886	-	-	-	1.175	1.055	0.9979	0.02019	0.002446
9	1.132	-0.136	-	1.218	1.61	-	0.9976	0.02344	0.002748
10	0.9929	-0.01316	-	-	1.116	0.998	0.9984	0.01891	0.001787

Most of the thin-layer models gave relatively good fit to the experimental data except Wang and Singh equation (Model 4).

The one parameter exponential model gave fit results with regression coefficients of 0.9970 - 0.9975. The two parameter model that gave the best fit for all cassava cultivars was the Page equation with a regression coefficient of 0.9976 – 0.9994, which is an improvement on the one parameter model, though another two parameter equation (Thompson equation) gave the best overall fit for drying data from CAS 003. Osoka and Oruh equation was the only three parameter model that also offered a better fit than the one parameter exponential model and Page equation with a regression coefficient of 0.9979 – 0.9995, except for drying data from CAS 003 where the logarithmic equation also gave a fit that was an improvement over the one and two parameter models.

The equation of Midilli et al was the four parameter model that gave a better fit than that of Osoka and Oruh, with regression coefficients of 0.9981 – 0.9995.

The top three thin-layer drying models have the drying parameter, n, as a common parameter aside the drying constant, k. This parameter (the drying parameter, n) therefore has a major role to play in the drying kinetics of cassava particulate.

CONCLUSION

Cassava particulate can be modeled adequately using the thin-layer drying model. The model to be chosen must have the drying parameter, n, as a parameter in its equation aside the drying constant, k.

The suitable thin-layer drying models for the kinetic study of drying of fermented cassava particulate, in order of decreasing efficiency are: Osoka and Oruh equation, Midilli et al equation and Page equation.

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