Study on Drying Kinetics of Fermented Corn Grains

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Abstract

Corn grains were fermented for three days and later drained and dried at 60^0C, 65^0C and 70^0C in a convective hot air dryer. Kinetics of drying was investigated using Fick's second law. Drying pattern was observed to be in the falling rate period. Non linear regression analysis software (SPSS), was used to fit in the experimental data and the coefficient of determination was found to be greater than 0.90 for all the models except Midilli. The values of R^2, RMSE, MBE and reduced chi square showed that Logarithm model best described the drying behaviour of the samples.

Keyword: fermented corn, hot air drying, mathematical modeling, laboratory tunnel dryer

1. Introduction

Corn or maize constitutes a staple food in many regions of the world. Corn flour is also used as a replacement for wheat flour to make cornbread and other baked products (Onuk *et al.,* 2010). It can also be consumed in the unripe state when the kernels are fully grown but still soft simply by boiling or roasting the whole ears and eating the kernels right off the cob (Doebly, 1994). It is a major source of starch and cooking oil (corn oil) and of corn gluten. According to Wikipedia (2006) maize starch can be hydrolyzed and enzymatically treated to form syrups, particularly high fructose corn syrup which can also be fermented and distilled to produce grain alcohol. Fermented corn grains are widely used as weaning food for infant and as dietary staples for adults (Akobundu and Hoskins, 1982). Some of African foods derived from fermented maize are ogi, agidi, kenkey, bogobe, injera, kisira and grain alcohol.

Generally, treatments such as steeping, milling, sieving and drying are involved in preparation of these fermented foods (Osugbaro, 1990). Mostly in Africa, after harvesting, drying of corn is done by spreading the product under sun for moisture removal though cheaper but the products are of low quality due to environmental contamination such as dust and insects. In view of this fact, drying of corn using mechanical dryer is a better option over sun drying considering the economic importance of the product to Africans. Therefore, the general objective of the study is to investigate optimal drying temperature for fermented corn grains by using mathematical modeling of thin layer drying. This is to analyze the moisture diffusion coefficients which play important role in moisture transport during drying since mathematical modeling using thin layer drying models has been applied in drying of fruits, vegetables, seafood and other agricultural products (Jain and Pathare, 2007; Midilli et al., 2002; Thuwapanichayanan et al., 2008).

2. Material and Methods

(a) Drying Experiment

Dried corn grains procured from a local market was used for the experiment. They were sorted and winnowed so as to eliminate all form of dirt and physical contaminants that were likely to be present in the samples. After that, the sorted corn grains were soaked in potable water for three days to effect fermentation. After fermentation, they were drained and dried. The drying experiment was performed in a tunnel dryer built in the Department of Food Science and Engineering, Ladoke Akintola University of Technology, Ogbomoso Nigeria. The dryer was operated at air temperature of 60^0C, 65^0C and 70^0C at constant air velocity of 1.7 m/s. The dryer was installed in an environmental condition of 51% relative humidity and 29^0C ambient temperature. The temperature and the air velocity in the dryer were at steady state before samples were introduced into the dryer. Corn grains with rectangular slab-like structure were selected for the experiments. The grain had average dimensions of 8x5x3 mm measured with vernier caliper. The samples were placed in the dryer and removed manually every 1 hour to determine weight loss of the sample. The drying experiment was stopped when three consecutive sample weights remained constant.

(b) Mathematical model

To understand the suitable model for the drying characteristics of the samples, the experimental data were fitted in four models described in Table 1

Table 1: **Mathematical drying models**

Models	Equation	References
Henderson and Pabis	MR=aexp(-kt)	Westernman, *et al.,* (1973), Chinnman (1984)
Newton	MR=exp(-kt)	Kingly et al., (2007)
Midilli et al.,	MR=aexp(-kt^n) +bt	Midilli et al.,(2002)
Logarithms	MR=aexp(-kt) +c	Togrul and Pehlivan (2003)

These models show relationship between moisture ratio and drying time. Moisture ratio (MR) during the thin layer drying was obtained using equation 1

$$MR=\frac{M_i - M_e}{M_O - M_e} \qquad (1)$$

Where MR= dimensionless moisture ratio, Mi = instantaneous moisture content (g water/g solid), Me =equilibrium moisture content (g water/ g solid), Mo = initial moisture content (g water/ g solid). However, due to continuous fluctuation of relative humidity of the drying air in the dryer, equation 1 is simplified in equation 2 according to Dimente and Munro, (1993) and Goyal *et al.,* (2007)

$$MR=\frac{M_i}{M_O} \qquad (2)$$

(c) Statistical Analysis

The drying model constants were estimated using a non-linear regression analysis. The analysis was performed using Statistical Package for Social Scientist (SPSS 15.0 versions) software. The reliability of the models was verified using statistical criteria such as coefficient if determination (R^2), reduced chi-square (χ^2), root mean square error (RMSE) and mean bias error (MBE). A good fit is said to occur between experimental and predicted values of a model when R^2 is high and χ^2, RMSE and MBE are lower (Demir et al., 2004). The comparison criteria method can be determined as follows:

$$\chi^2 = \frac{\sum_{i-1}^{n}(MR_{(\exp,i)} - MR_{(pred,i)})^2}{N - z} \qquad (3)$$

$$\text{MBE} = \frac{1}{N}\sum_{i=1}^{n}(MR_{(pred,i)} - MR_{(\exp,i)}) \qquad (4)$$

$$\text{RMSE} = \left[\frac{1}{N}\sum_{i=1}^{n}(MR_{(pred,i)} - MR_{(\exp,i)})^2\right]^{1/2} \qquad (5)$$

(d) Determination of Moisture Diffusivity

Fick's equation can be simplified to describe the drying characteristics of fermented corn grains. The simplified equation was used to determine the effective moisture diffusion from the samples during drying. The equation according to Srikiatden and Roberts, (2005) is represented thus:

$$\text{MR} = \frac{M - M_0}{M_0 - M_e} = \frac{8}{\pi^2}\sum_{n=0}^{n=1}\frac{1}{(2n-1)^2}\exp\frac{-(2n-1)^2\pi^2 D_{eff}t}{4l^2} \qquad (6)$$

Where D_{eff} is the moisture diffusivity (m^2/s), t is the drying time (s), *l* is the half of the slab thickness (m)
The effective moisture diffusivity (D_{eff}) was calculated from the slope of plot of ln MR against drying time (t) according to Doymas, (2004) and is represented in equation 7

$$k = \frac{D_{eff}t}{4l^2} \qquad (7)$$

Where *k* is the slope.
The model that best described the drying behaviour of the samples was used to evaluate the moisture diffusivity of the product.

3. Results and Discussion

(a) Effect of temperature on moisture content and moisture ratio

The pattern of moisture loss in the sample is shown in Figure 1. From the graph, it is shown the sample exhibited a falling rate pattern. This is true because most agricultural products often exhibit falling rate period as reported by Velic et al. (2007), Karel and Lund, (2003); Ramaswamy and Marcotte, (2006). During the falling rate period, drying occurred which mainly controlled by internal factor of diffusion mechanism in the grain as reported by Ramaswamy and Marcotte, (2006) unlike constant rate period which could be controlled by external condition such as temperature, air humidity and air velocity. At this stage, there was no resistance to mass transfer as reported by Gupta *et al*., (2002). The effect of temperatures on the drying characteristics of the sample is shown in Figure 1. From this Figure, it took 4 hours for moisture loss from 0.69 (g water/g solid) to 0.17 (g water/g solid) at drying temperature of 70^0C. Also, it took 4 hours to bring moisture content from 0.73 to 0.28 g water/ g solid at 65^0C while it took the same hour to bring the moisture content of the sample from 0.73 to 0.38 g water/ g solid. It was deduced from this data that higher temperature induced higher moisture removal from the grains. The greater the temperature difference between the drying air and the food, the greater the heat transfer to the food and faster the moisture removal from the grains.

This observation was earlier reported by Bellagha et al., (2002). Also, Figure 2 shows the pattern of dimensionless moisture ratio against drying time. It was discovered that drying rate was faster at 70^0C than 65^0C and 60^0C; this is because moisture removal was faster at 70^0C than other two temperatures. This same observation was well reported in literature (Guine et al 2009, and Belghit *et al.*, 1999)**.** Also, the moisture ratio gradient caused by temperature difference between the solid and drying medium at 60^0C was lower than 65^0C and the moisture gradient at 70^0C was steepest. This could explain further the reason for moisture removal at 70^0C was faster than other temperatures.

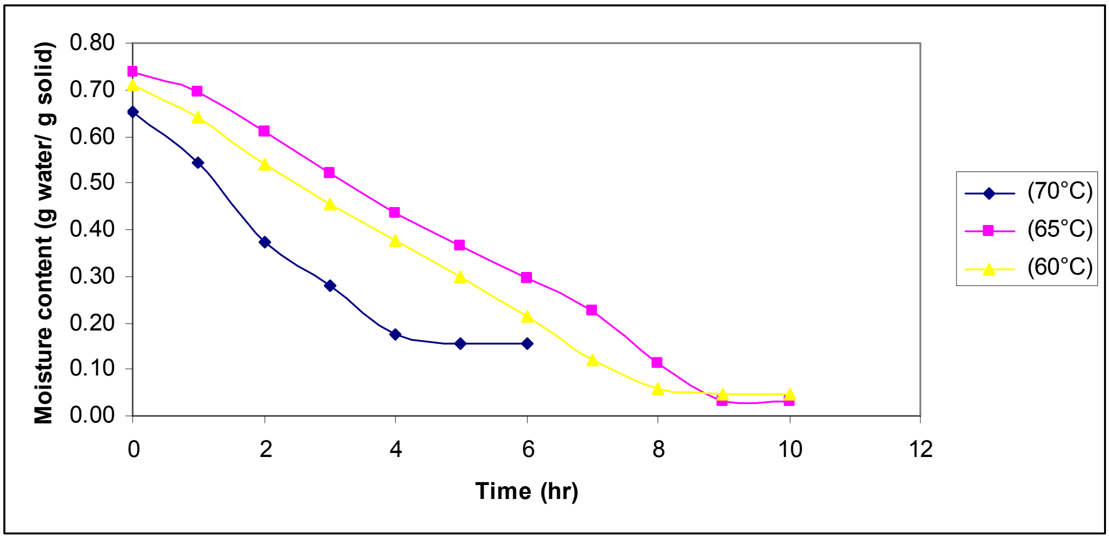

Figure 1 Graph showing moisture content against time

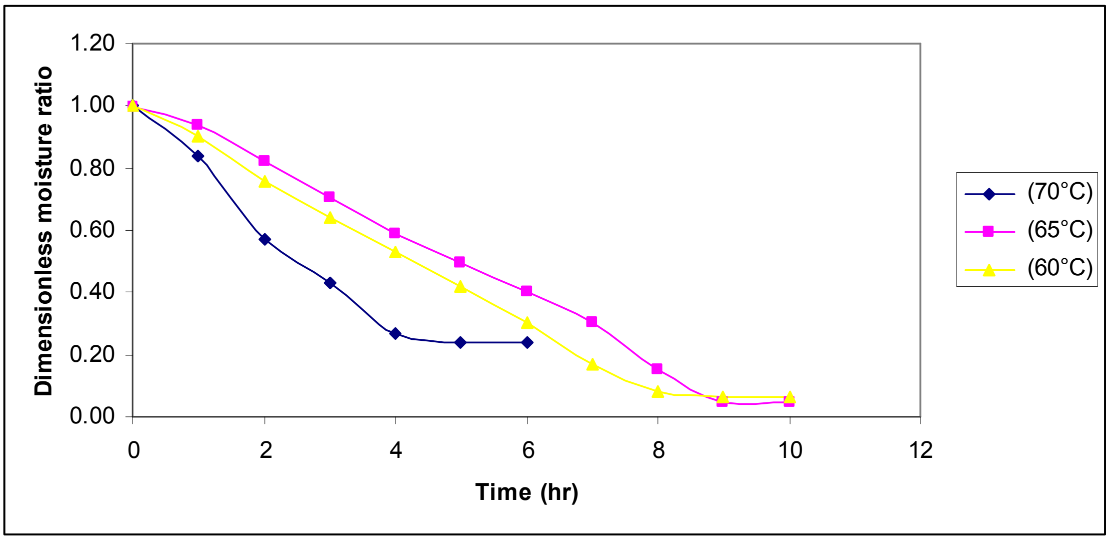

Figure 2: Graph showing moisture ratio against time

(b) Statistical results

The result of statistical criteria for the model is shown in Table 2 which was determined form fitting the experimental moisture ratio against drying time using four models to evaluate the goodness of fit. Coefficient of determination (R^2) was greater than 0.90 except Midilli. The values of chi square ranged from 0.002317 to 0.05815 for Henderson and Pabis model, from 0.002181 to 0.009818 for Newton, from 0.000815 to 0.018972 for Midilli and from 0.001826 to 0.003961 for Logarithms. The lowest values for MBE was 0.000296 in Henderson and Pabis Model while the highest value was 0.01285 in Newton model. The lowest RMSE value was 0.022771 found in Midilli model while 0.094473 in Newton model was the highest value. The goodness of fit for a model is when R^2 is high and chi square, RMSE, MBE values are low. The results from the model shows that Logarithms model has the highest value of R^2 and lowest value of chi square which suggested that Logarithms model best described the experimental thin layer drying of the samples. The values of constant of Logarithms equation were 0.998, 5.298 and 1.949 for *n*. The values were -0.308, -0.021 and -0.077 for *k* while the values were 0.039, -4.269 and -0.920 for *c*. Details for other constants is available in Table 2. Because Logarithms model best described the drying behaviour of the samples, it was used for subsequent calculation for

Table 2: Values of statistical parameters

Model	Temp	R^2	X2	MBE	RMSE
Henderson and	70	0.969	0.002317	0.000296	0.039301
Pabis	65	0.948	0.05815	0.00194	0.068208
	60	0.955	0.005288	0.0008736	0.065042
Newton	70	0.976	0.002181	0.007854	0.043238
	65	0.917	0.009818	0.01285	0.094473
	60	0.936	0.007875	0.00846	0.084613
Midilli	70	0.861	0.018972	0.00126	0.079523
	65	0.992	0.001157	0.005335	0.026348
	60	0.996	0.000815	0.00451	0.022771
Logarithms	70	0.979	0.003961	0.01182	0.0445
	65	0.993	0.002178	0.00727	0.039802
	60	0.997	0.001826	0.00791	0.03644

Table 3: Values for model constants

Model	Temp	n	a	k	b	c
Henderson	70		1.115	-0.313		
and Pabis	65		1.214	-0.266		
	60		1.213	-0.252		
Newton	70			0.275		
	65			0.168		
	60			0.203		
Midilli	70	-6.1E-7	0.852	0.009	-0.118	
	65	-0.089	-0.049	-3.060	-0.021	
	60	1.464	0.988	0.075	-0.011	
Logarithms	70		0.998	-0.308		0.039
	65		5.298	-0.021		-4.269
	60		1.949	-0.077		-0.920

(c) Effective Diffusivity

Table 4 presents the values for effective moisture diffusivity of the fermented corn grains. It is shown that the effective diffusivity is temperature dependent. The lowest value was 2.78 x 10^{-11} m^2/s at 60^0C while the highest value was 3.06 x 10^{-11} m^2/s at 70^0C. In summary, effective moisture diffusivity was directly influenced by temperature. This observation is in line with other authors such as Velic et al., (2007), **(**Abraham et al., 2004; Hawlander et al., 1991; Welti *et al.,* 1995; Jaya and Das 2003). The values of effective moisture diffusivity obtained are within the range of food product (10^{-11} to 10^{-6} m^2/s) as reported by Doymaz 2007. However, the value of moisture diffusivity was less than that of vegetables. For instance, tomato dried at 75^0C has D_{eff} of 12.27x10^{-9} m^2/s as reported by Akanbi *et al.,* 2006. The lower values in corn grain when compared to vegetables were due to the lower moisture content of the grain, internal structure and thick outer coat of the corn.

Table 4: Effective moisture diffusivities for fermented corn grains

Drying air velocity (m/s)	Drying air temperature (^{0}C)	Effective moisture diffusivity (m^2/s) (D_{eff}x 10^{-11})
1.37	60	2.78
1.37	65	2.95
1.37	70	3.06

4. Conclusion

From the study, the following were made: Fick's law of diffusion for thin layer drying can be used to model drying characteristics of fermented corn; effective moisture diffusion during the experiment increased with increase in temperature, moisture diffusivity fall with the range of food products and logarithmic model best described the drying behavior of the corn compared to other models

Nomenclature

a	Drying constant in the model
b	Drying constant in the model
c	Drying constant in the model
k	Drying constant in the model
l	half of the thickness of the sample (m^2)
M_0	initial moisture content of the sample (g water/g solid)
M_i	instantaneous moisture content of the sample (g water/g solid)
M_e	equilibrium 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	Drying constant in the model
N	number of observation
RMSE	root mean square error
R^2	coefficient of determination
t	drying time (hr)
χ^2	reduced chi square
z	number of constant in the models

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