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MODELLING THE DRYING BEHAVIOUR OF GARLIC (Allium sativum)

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ABSTRACT

Garlic (Allium Sativum) is a medicinal food and is also used as food ingredient and natural preservative. Freshly harvested garlic begins to loss its nutritional characteristics after harvest. Drying increases its shelf life and retains its proximate composition, aids in better packaging, which will serve as a marketing tool and also as a process whereby the activities of most decay-causing microbes are either deactivated or reduced to safe levels. Modelling the drying behaviour of garlic was investigated on thin layers within the drying temperature range of 60°C through to 100°C using a laboratory convective drying method (oven) and the emanating experimental data are fitted to the three thin- layer drying models such as page, Henderson-pabis, and Lewis model to determine the model that would suitably describe the drying kinetics of the garlic. The various related thin layer drying model constants and coefficients were obtained using regression methods. The result shows that drying took place almost entirely within the falling rate period. The temperature -dependent effective diffusivity was shown to be in values that ranged from 1.49x10-6 to 6.30x10-7m2/sec in the temperature range applied in this work. And the related activation energy was found to be 12.83kJ/mol. The fitting results also showed the Page model as suitable for predicting the thin layer drying kinetics of garlic.

Keywords: Garlic, drying behaviour, activation energy, effective moisture diffusivity

1. INTRODUCTION

Garlic (Allium sativum) is primarily produced in a few locations, but it is transported globally, there is a growing demand for functional or medicinal foods like garlic because of its nutritional value, which has a positive impact on an individual's well-being and health, and may have preventative or therapeutic effects on a variety of diseases. Garlic is one of the most important functional foods or food components for human consumption. (Koch and Lauson,1996), Furthermore, in-vivo studies in animal and human clinical trials show that garlic has enormous benefits in a variety of pathological conditions, including hyperlipidemia (Jabbari et al., 2005), cardiovascular disorders, and arteriosclerosis (Rahman et al., 2006). Furthermore, epidemiological studies have revealed that people who consume a lot of garlic have a lower risk of developing stomach cancer (Galeone et al., 2006). Fresh garlic is relatively high in moisture content (around 70% w.b.), indicating that it is unsuitable for long-term storage. As a result, the majority of garlic supplements sold today are dried garlic powder tablets standardized on allicin (Sovova, 2000; Lawson et al., 1995).

In general, garlic is sold as a fresh product in the local market, but producers have been looking for new commercial uses in recent years. There are verities of methods used for processing freshly harvested garlic such as drying, distillation, maceration in oil, hydroalcoholic short extraction, and hydroalcoholic long maceration. (Rahman et al., 2006). The potential health benefits of garlic consumption are largely determined by the manufacturing process (Staba et al., 2001).

The vegetable mass of garlic contains more than two-thirds water in its harvested form, transportation, storage, and other handling costs would rise as a result. Furthermore, when the dormancy period (60–80 days) ends, the garlic sprouts emerge quickly. As a result, the nutritional value of garlic is reduced, and the quality of garlic is reduced due to withering of the stem and trunk (Amiri Chayjan et al., 2012).

Drying is one of the most common methods for producing garlic products for use as food ingredients, natural preservatives, and functional or medicinal foods. Rahman et al. (2006) demonstrated that drying temperature and time have significant effects on the retention of the active components responsible for microbial growth inhibition Song and Milner, (2001) looked into the effect of microwave or oven heating on anticarcinogenic properties.

Drying may be the most cost-effective method of reducing the weight to less than one-third of the initial weight. Furthermore, low moisture content reduces microbial and enzymatic changes during storage, thereby extending the product's shelf life (Sacilik and Unal, 2005; Barrozo et al., 2001). However, because drying involves phase change, it is a much more energy-intensive process. It is a complex process that includes transient mass and heat transfer with specific rate processes, which may result in changes in product quality (Al-Neama and Farkas, 2016).

Review of literature shows Pezzutti and Crapiste (1997) investigated temperature-dependent changes in garlic flavor during dehydration. They noticed a loss of flavor strength at high temperatures. Sharma and Prasad (2004) dried garlic cloves using a continuous microwave of 10–40 W in conjunction with hot air at temperatures ranging from 40–70 °C and velocities ranging from 1.0 to 2.0 ms-1. They observed diffusivity dependences on initial moisture content, air temperature, and microwave power at various velocities. Several studies (Bozkir et al., 2019; Figiel, 2009; lter et al., 2018; Younis et al., 2018; Thuwapanichayanan et al., 2014; Ruhanian and Movagharnejad, 2016; Ondro et al., 2017) investigated various drying techniques, which involve, microwave drying, combined microwave convective drying, convective hot air, vacuum microwave drying similarlhy, Amiri Chayjan et al. (2012) investigated the thin- layer drying properties of garlic sheets in semi fluidized and fluidized bed conditions. The bed was exposed to convective air at various temperatures and speeds. They tested various empirical correlations to determine the diffusivity coefficient in the product. However, none of these studies investigated the drying mechanism of garlic.

Knowledge of the drying mechanisms is required to optimize the process. Vegetable drying is a complex phenomenon that involves the product's simultaneous actions of heat and mass transfer. Understanding such a phenomenon requires a thorough understanding of the air-product balances as well as control over the kinetics of product drying and processing.

The present study was undertaken to model the drying behaviour of garlic and the emanating experimental data was fitted to the four thin layer drying models to determine the model that would suitably describe the drying kinetics of the garlic. This would also create a robust data base for the required process design.

2. MATERIALS AND METHODS

2.1. Sample Collection and Preparation Procedure.

Freshly harvested garlic were purchased from Ondewari community market, Southern Ijaw Local Government Area Bayelsa State on the 3rd of February 2022, and then taken to the Food Processing and Storage Laboratory of the department of Agricultural and Environmental Engineering in the Niger Delta University, Wilberforce Island, Baylesa State. The Niger Delta University is located arround Latitude 4°51'N to 5°02'N, and from longitude 6°.04'E to 6°17'E. They were thoroughly washed to remove all debris and the samples were unpeeled and cut into slices of thickness 2mm (uniformity in all the specimens). The initial moisture content of the garlic slices was measured according to the standard procedure of the Association of Official Analytical Chemists (AOAC, 2005)

2.2. Data Collection

Drying is a progressive moisture reduction phenomenon until a constant weight is reached. Therefore, the specimens were taken and the initial weight was recorded using Top digital balance with 0.01 g precision and thicknesses were also recorded using a Vanier Caliper and then the initial moisture content of the samples was obtained. The specimens were oven dried using WTC Binder oven Model (1718) at different temperature levels such as 60, 70, 80, 90, and 100oC, the moisture reduction process (i.e. weight loss) for each sample was monitored at specific time intervals (of about 5-mins) to point of equilibrium and in a manner as described in the works of Zibokere and Egbe (2019) on red head palm weevil larvae, and on catfish (Sankat and Mujaffar, 2006). Each sets of the specimen were dried to a constant final weight and was repeated 3-times for each of the temperature levels and average values are recorded. The oven drying was according to the standard procedure of the Association of Official Analytical Chemists (AOAC, 2005). The weight differences were used to determine the final moisture content for each replicate, all measured on dry-basis as

$$\mathrm{MR} = \frac{\mathrm{M} - \mathrm{M_e}}{\mathrm{M_o} - \mathrm{M_e}} \qquad 1$$

where

M_e = equilibrium moisture content (emc), $\mathrm{kg_{H_2O}/kg_{solid}}$

M_o = initial moisture content, $\mathrm{kg_{H_2O}/kg_{solid}}$.

However, for a rather cylindrical geometry of the bio-product samples, it was desired to obtain the equivalent moisture ratios by transformation using the Fick's second law diffusion equation as (Guine *et al.*, 2011; Motevali *et al.*, 2012; Chen *et al.*, 2013)

$$\mathrm{MR} = \frac{\mathrm{M} - \mathrm{M_e}}{\mathrm{M_o} - \mathrm{M_e}} = \frac{8}{\pi^2}\int_{n=1}^{\infty}\frac{1}{n^2}\, e^{-(n)^2\frac{\pi^2 D_e t}{L^2}} = \qquad 2$$

where MR is moisture ratio

n denotes the number of terms in the series (0, 1, 2, 3,),

t is drying time,

D_e is effective moisture diffusivity ($m^2\, s^{-1}$)

L relates to the geometric diameter, d_c of the samples (Mohsenin, 1986)

$d_c = (L \times W \times T)^{\frac{1}{3}}$

The factor, d_c is the dimensional estimator for L (length), W (width) and T (thickness) being the major, intermediate and minor diameters of the biomaterials. Then Equation 2 will now give (Guine et al, 2011)

$$\mathrm{MR} = 0.8106 = \int_{n=1}^{\infty} \varepsilon_n^{-2}\, e^{-9.87\varepsilon_n\left(\frac{D_e t}{r_c^2}\right)} \qquad 3$$

where $\varepsilon_n = n^2$ seen as the root of a related Bessel function in terms of n

r_c = geometric radius of the biomaterials, and

$\left(\frac{D_e t}{r_c^2}\right)$ can be recognized as a Fourier factor.

$$\mathrm{MR} = 0.8106 = e^{-9.87\left(\frac{D_e t}{r_c^2}\right)} \qquad 4$$

Taking natural log on both sides, equation 4 will linearize to equation 5

$$\ln(\mathrm{MR}) = -\left(47\mathrm{De}\left(\frac{1}{R_c}\right)^2 \mathrm{t} + 1\right) \qquad 5$$

2.2.1. Effective Moisture Diffusivity, D_e

The effective moisture diffusivity, follows (Guine *et al.*, 2011)

$$\mathrm{De} = -slope\,\frac{[r_c^2]}{47} \qquad 6$$

2.2.2. Fitting to Thin-layer Drying Models

Data obtained from the drying experiments were fitted to seven thin-layer drying models as detailed below –

Lewis model

$$\mathrm{MR} = \mathrm{e}^{-\mathrm{kt}} \quad \text{[Bruce, 1985]} \qquad 7$$

Henderson-Parbis model

$$\mathrm{MR} = a\mathrm{e}^{-\mathrm{kt}} \quad \text{[Henderson and Pabis, 1961]} \qquad 8$$

Page model

$$\mathrm{MR} = \mathrm{e}^{-\mathrm{k}t^{n}} \quad \text{[Vega-Gálvez, 2010]} \qquad 9$$

a, b, and n are model constants, while k is the kinetic (drying) rate constant.

The nonlinear least squares regression approach was used to regress each of the fitted models (Haydar *et al.*, 2014). The experimental data utilized in the fitting were processed to statistical indicators such as coefficient of determination, r^2, reduced chi-square, X^2, and root mean square error, RMSE, using SPSS 17.0 Microsoft Excel software. These were used as indicators in selecting the best drying model. Following the procedure in Ndukwu *et al.*, (2010) and Burubai (2015) the statistical indicators were evaluated as follows

$$r^2 = 1 - \left[\sum_{i=1}^{n}(\mathrm{MR}_{\mathrm{pre,i}} - \mathrm{MR}_{\mathrm{exp,i}})^2\right] \qquad 17$$

10

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\mathrm{MR}_{\mathrm{pre,i}} - \mathrm{MR}_{\mathrm{exp,i}})^2}{n}} \qquad 11$$

$$\chi^2 = \frac{\sum_{i=1}^{n}(\mathrm{MR}_{\mathrm{pre,i}} - \mathrm{MR}_{\mathrm{exp,i}})^2}{n - k} \qquad 12$$

Where,

$\mathrm{MR}_{\mathrm{pre.}}$ = predicted moisture ratio, $\mathrm{MR}_{\mathrm{exp.}}$ = experimental moisture ratio, n = number of observations and k = Number of constants

The set decision rule was that the model with the highest R^2 value, and the least χ^2 and RMSE values was selected as the best fit in describing the drying characteristics of the garlic samples. (Wang *et al.*, 2006; Maydeu-Olivares and Garca-Forero, 2010; Darvishi *et al.*, 2012).

2.2.3. Activation Energy, E_a

Arrhenius type function was used to estimate the activation energy as (Saxena and Dash, 2015; Da Silva *et al.*, 2015)

$$D_e = D_o(\mathrm{e}^{-E_a/Rt}) \qquad 13$$

where

E_a = activation energy, kJ/mol, D_e = effective diffusivity at m^2/s, D_o = pre-exponential factor of the Arrhenius equation at °K, m^2/s, R = universal gas constant (8.314×10^{-3}, kJ/mol.K) and t = air temperature expressed in °K

Simplification of Equation 13 gives

$$\ln D_e = \ln D_o - \frac{E_a}{Rt} \qquad 14$$

or

$$-\frac{E_a}{R} t^{-1} = \ln D_e - \ln D_o \qquad 15$$

$$\frac{E_a}{Rt} = \ln\left(\frac{D_o}{D_e}\right) \qquad 16$$

$$\frac{E_a}{R} t^{-1} = \ln\left(\frac{D_o}{D_e}\right) \qquad 17$$

Plotting of $\ln D_e$ as a function of t^{-1} with regression line of slope, z can be given as;

$$z = -\frac{E_a}{R} \qquad 18$$

The activation energy can be estimated as (Taheri-Garavanda *et al.*, 2011; Navneet *et al.*, 2012). Shown in equation 19

$$E_a = -zR \qquad 19$$

3. RESULTS AND DISCUSSION

3.1 Drying Kinetics of garlic (*Allium sativum*)

The moisture ratio of garlic (*Allium sativum*) fluctuates with drying time, as shown in figure 1. As expected, the drying environment had a considerable effect on moisture migration from the interior to the exterior in the drying of the garlic samples, as reported in the literature on drying of visco-elastic materials (The figure depicts how drying time increased dramatically with drying temperature for the same state of drying as shown by the moisture ratio. This means that the rate of moisture loss during drying is a function of drying time.

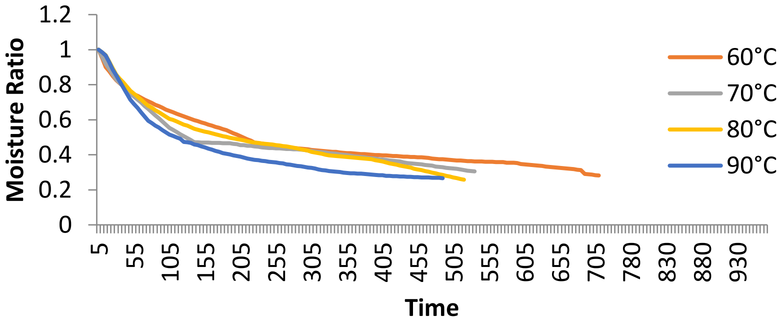

Figure. 1: Moisture ratio versus drying time of garlic (*Allium sativum*) at different drying temperatures.

Figure 2 the curves have a greater beginning slope and become asymptotic to the axis of drying time. This form adequately describes a faster initial moisture loss, and as moisture available for evaporation at the surface of the samples becomes less in drying Santa and Mujaffar (2006), Jain and Pathare (2007), Burubai (2015), Zibokere and Egbe (2015).

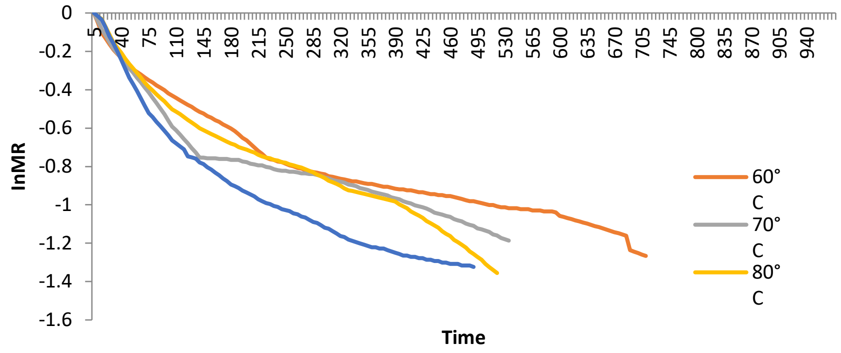

Fig. 2: Drying curves of garlic (*Allium sativum*)
(Logarithmic moisture ratio vs drying time)

3.2. Fitting Experimental Data into Thin-Layer Drying Models

The statistical results from the thin-layer drying models for the different drying temperatures employed in this study are summarized in Tables 1. The criteria used to pick the best model representing the thin-layer drying characteristics of garlic were the model with the highest r^2 value and the lowest RMSE values. The fitting statistical results in the Table1 showed that for Page model r^2 ranges from 0.976-0.994, χ^2 ranges from 0.00137-0.00223 and RMSE 0.00015-0.00007, and Henderson-Pabis model r^2 Ranges from 0.9204-0.9227, χ^2 ranges from 0.02534-0.04898 and RMSE has 0.01003-0.01775, while for Lewis model r^2 ranges from 0.8307-0.83868, χ^2 ranges from 0.0110999-0.3713 and RMSE ranges from 0.00521-0.00734. The simply implies that these empirical models are capable of capturing the drying behavior of garlic.

Table 1: Statistical Measures garlic (*Allium sativum*) on Thin-layer Drying Models

Model	**Temp. (^{0}C)**	**Fitting Constants & Coefficient**	**χ^2**	**RMSE**	**R^2**
Page	60	k = 0.343, n = 2.224	0.00223	0.00013	0.9978
	70	k = 0.201, n = 1.977	0.00168	0.00015	0.9976
	80	k = 0.159, n = 1.342	0.00155	0.00010	0.9979
	90	k = 0.033, n = 1.644	0.00187	0.00009	0.9994
	100	k = 0.031, n = 1.743	0.00137	0.00007	0.9995
Henderson-Parbis	60	a = 2.876, k = 1.6555	0.04898	0.01775	0.9214
	70	a = 2.067, k = 1.9184	0.03761	0.01424	0.9213
	80	a = 2.006, k = 0.6994	0.03644	0.01453	0.9204
	90	a = 1.998, k = 0.1896	0.02534	0.01003	0.9227
	100	a = 1.899, k = 0.2488	0.02708	0.01054	0.9209
Lewis	60	k = 0.343,	0.03713	0.00737	0.8307
	70	k = 0.201	0.02876	0.00639	0.8523
	80	k = 0.159	0.02998	0.00772	0.8374
	90	k = 0.033	0.01699	0.00517	0.8816
	100	k = 0.031	0.01819	0.00519	0.8868

3.3. Estimation of Effective Moisture Diffusivity and Activation Energy

In order to estimate effective moisture diffusivity, logarithmic moisture ratio values, ln(MR), were plotted as a function of drying time, 't' in minutes at various drying temperatures in figure 2 using equation 6. The nearly flattened regression line indicated that at higher drying temperatures, less energy was required to remove moisture because water molecules within the body matrix tend to become free moisture at the surface of the samples. As a result, the effective moisture diffusivity, De, increased as drying time and temperature increased. The De values in this study ranged from 4.7317 x $10^{-10}m^2/s$ at lower temperatures to 6.675 x $10^{-10}m^2/s$ at higher temperatures, with a related activation energy, Ea, of 12.83 kJ/mol using slope method figure 3, similar to the trend observed by Xiong et al. (1992) for porous foods and in the work of (Daniel et al., 2016).

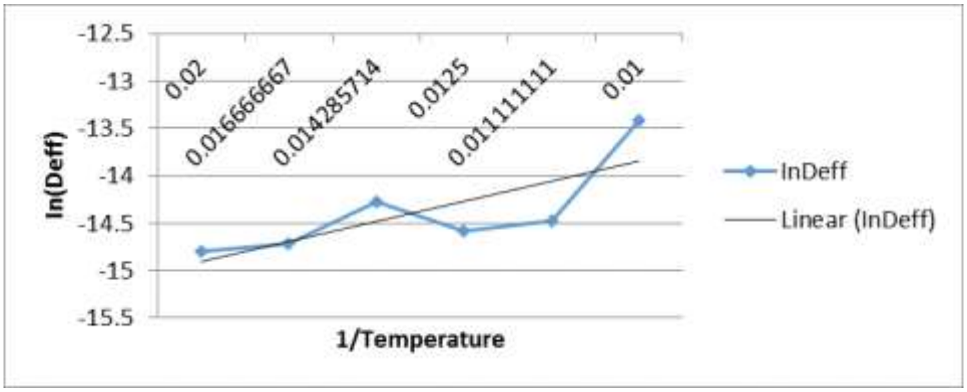

Figure 3: Estimation of Activation Energy in garlic (*Allium sativum*).

4. CONCLUSIONS AND RECOMMENDATIONS

Modelling the drying behaviour of garlic was investigated. From the results it shows the specimen fall under the falling rate period like other biomaterials. Amongst the three models investigated page model was the best predicting the drying behaviour of Garlic having undergo statistical analysis of the drying parameters and the temperature dependent effective moisture diffusivity ranging from 4.7317 x $10^{-10}m^2/s$ to 6.675 x $10^{-10}m^2/s$ as the temperature increases from 60°Cto100°C.The related activation energy obtained was 12.83 kJ/mol. The research could be applied to the design and development of drying equipment for the preservation of garlic. However, the work limited the selection of thin-layer drying models to only three. An attempt could be made to extend the selection base beyond the limit used in this work in order to achieve a higher degree of freedom on the statistical exactness of the drying data for improved drying system design.

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