Drying of bambara beans was studied at 40°C at every 30 minutes in a Laboratory oven. Effective moisture diffusivity ranges between 5.886 x 10^{-10} m²/s – 4.354 x 10^{-10} m²/s respectively. The statistical criteria used in evaluation of the model were maximum coefficient of determination R² and minimum root mean square error [RMSE]. Determination for goodness of fit statistics for drying of the beans was carried out. Midilli model was used to predict the drying curve. The Midilli model was found to produce accurate predictions for all the four varieties of bambara beans and the model was shown to be an excellent model for predicting drying behavior of TVSU-47 and the R² value was 0.9971 and the value of root mean square error was 0.0149 respectively.

**Keyword:** Bambara beans, Midilli model, Diffusivity, Drying

**1. INTRODUCTION**

Thin layer drying is the process of drying in one layer of sample particles or slices. Many mathematical models are used in order to describe the thin layer drying process. Mathematical modeling of thin layer drying is important for performance improvements of drying. Thin layer drying models fall in three categories as theoretical, semi-empirical and empirical [1]. Dehydration is an important preservation process which reduces water activity through the decrease of water content, avoiding potential deterioration and contamination during long storage periods. Other important objectives of food dehydration are weight and volume reduction, intended to decrease transportation and storage costs [2, 3].

Bambara bean represents the third most important grain legume in semi-arid Africa. It is resistant to high temperature and is suitable for marginal soils where other leguminous crops cannot be grow [4] bambara bean (*Vigna subterranea* L.) Verdc.is an annual, creeping legume with glabrous, trifoliate leaves. It has a deep taproot surrounded by lateral profuse roots bearing N-fixing nodules. Flowers are presented as papilionaceous racemes. Once fertilized, the flower is drawn below the soil through a tunnel. Fruits are 2 or 3-seeded pods, 1.5 to 3 cm long, wrinkled and at first indehiscent. Seeds are round, smooth and very hard when dry [5]. Average yields are 300-800 kg/ha, but can range from 100 kg/ha up to 4 t/ha. Bambara beans contained 63 % of carbohydrate and 18% of protein [6]. Bambara bean is a less utilized legumes[7]. It is harvested by hand when the plant turns yellow or when the pods are matured [6].Bambara bean is rich in protein, carbohydrate, iron and essential amino acids [8] .Bambara beans are used for milk making [9]. The plant is used for medicinal purpose, the leaves are eating as anti – vomiting [10]. The plant is also used to treat venereal diseases [10].The aim of this study is to investigate the kinetics of the thin layer drying of bambara beans

**2. MATERIALS AND METHODS**

**2.1 Material**

The varieties of bambara beans [TVSU-47], [TVSU-513], [TVSU-1597] and [TVSU-1834] used in this study were collected from International Institute of Tropical Agriculture [IITA] Ibadan Oyo State Nigeria. The seeds had been cleaned manually to remove all foreign matter such as dust, dirt, stones, chaff as well as immature or broken seeds. The seeds were kept in a clean nylon and labeled.
2.2 Method
Drying of bambara beans were carried out according to the method of Kaptos et al., (2013) [11] in a laboratory oven using temperature of 40°C. To determine the moisture loss of drying sample during experiments. Bambara beans were taken out of the oven and weighed at every 30 minutes. The moisture losses of the samples were determined with the help of a digital electronic balance having an accuracy of 0.01g. The changes in the mass of the seeds with time were used to plot the kinetics curve of water loss.

2.3 Mathematical Modelling
The moisture ratio [MR] and drying rate during experiments were calculated using the following equations

\[ MR = \frac{M_t - M_{t+\Delta t}}{M_0 - M_0} \]  

\[ RD = \frac{M_t}{t} - M_{t+\Delta t} \]  

Where \( MR, M_0, M_t, \) and \( M_{t+\Delta t} \) are the moisture ratio initial moisture content at \( t \) and moisture content at \( t+\Delta t \) kg moisture/kg dry matter respectively, \( t \) is the drying time [min]. The air drying curves were fitted with midilli model. The regression analysis was performed using the Matlab software. Non-linear regression used to evaluate the goodness of fit of Midilli model to the experimental data are the coefficient of determination \( [R^2] \) and the root mean square error was used for data analysis. The higher the value of \( R^2 \) and the lower the values of the root mean square error analysis [RMSE] indicate the better fitness of Model. These parameters were calculated as follows;

\[ R^2 = \frac{1 - \text{Residual sum of squares}}{\text{Corrected total squares}} \]  

\[ RMSE = \sqrt{\frac{1}{N} \sum (MR_{\text{exp,i}} - MR_{\text{pre,i}})^2} \]  

Where \( MR_{\text{exp,i}} \) is the experimentally observed moisture ratio, \( MR_{\text{pre,i}} \) is the \( i \)th predicted moisture ratio and \( N \) is the number constants.

3. RESULT, AND DISCUSSION

3.1 Drying Characteristics of Bambara beans
Fig 1, showed the drying rate curve of Bambara beans. The moisture content reduces as the drying time increased. The moisture ratio reduced as the drying time increased [12]. Continuous decrease in moisture ratio indicates that diffusion has governed the internal mass transfer. Experimental results showed that the drying time is an effective parameter for the drying of bambara beans. The drying process took place in a falling rate period except a very short accelerating period in the beginning. It was further observed that the drying rate was faster at the beginning than at the end. The reduction rate at the end of the drying may be due to reduction in moisture content as drying advances[13].Midilli model was applied to describe the drying kinetics of Bambara beans through the fit to the experimental data. Result of \( R^2 \) [values above 0.950] showed a good assessment of the thin layer drying to represent the drying curves but when the performance of the modeling was evaluated with the RMSE and \( R^2 \) the Midilli model showed good fitting result for both statistical terms with highest \( R^2 \) value of 0.9971 and lowest RMSE value of 0.0149 for TVSU-47.

Table 1: Statistical analysis of the mathematical model of Drying for four varieties of Bambara beans

<table>
<thead>
<tr>
<th>Models</th>
<th>TVSU-47</th>
<th>TVSU-513</th>
<th>TVSU-1597</th>
<th>TVSU-1834</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( R^2 )</td>
<td>( RMSE )</td>
<td>( R^2 )</td>
<td>( RMSE )</td>
</tr>
<tr>
<td>Midilli</td>
<td>0.9971</td>
<td>0.0149</td>
<td>0.9906</td>
<td>0.0274</td>
</tr>
</tbody>
</table>

For better physical understanding of the mass transfer occurring in the drying process of bambara beans, the diffusion coefficients were calculated from the drying rate constants. Effective moisture diffusivity \( [D_{\text{eff}}] \) versus inverse absolute temperature was plotted. The effective diffusivity increased with increasing drying time. The highest and the lowest diffusivity values were \( 5.886 \times 10^{-10} \text{ m}^2/\text{s} \) and \( 4.358 \times 10^{-10} \text{ m}^2/\text{s} \) which agreed to the findings of other researchers [Robert et al., 2008]. \( D_{\text{eff}} \) values of varieties of Bambara bean were in the range of \( 4.354 \times 10^{-10}, 5.177 \times 10^{-10}, 5.353 \times 10^{-10} \) and \( 5.886 \times 10^{-10} \).
Fig 1: Drying Rate curve of Bambara beans

![Drying Rate curve of Bambara beans](image)

Table 2. Values of effective moisture diffusivity for dried varieties of Bambara beans

<table>
<thead>
<tr>
<th>Samples</th>
<th>$D_{\text{eff}} (10^{-10})$ (m$^2$/s)</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVSU-47</td>
<td>4.354</td>
<td>0.949</td>
</tr>
<tr>
<td>TVSU-513</td>
<td>5.886</td>
<td>0.956</td>
</tr>
<tr>
<td>TVSU-1597</td>
<td>5.177</td>
<td>0.948</td>
</tr>
<tr>
<td>TVSU-1834</td>
<td>5.353</td>
<td>0.942</td>
</tr>
</tbody>
</table>

For better physical understanding of the mass transfer occurring in the drying process of bambara beans, the diffusion coefficients were calculated from the drying rate constants. Effective moisture diffusivity [$D_{\text{eff}}$] versus...
inverse absolute temperature was plotted. The effective diffusivity increased with increasing drying time. The highest and the lowest diffusivity values were 5.886 x 10^{-10} m²/s and 4.358 x 10^{-10} m²/s which agreed to the findings of other researchers [Robert et al., 2008]. D̅ eff values of varieties of Bambara bean were in the range of 4.354 x 10^{-10}, 5.177 x 10^{-10}, 5.353 x 10^{-10} and 5.886 x 10^{-10}.

4. CONCLUSION

In order to explain the drying behavior of four selected varieties of bambara beans, midilli model was applied. The study showed that the drying of bambara seeds can be accurately predicted using Midilli model and the model proved to be a better fit in predicting drying behavior of bambara beans with the highest R² value of 0.9971 and the root mean square error value of 0.0149 respectively. The moisture transfer could be described by diffusion where the effective diffusivities were within the ranges of other seeds. The Midilli model was employed to fit the drying curves of the effective moisture diffusivity ranging from 5.886 x 10^{-10} m²/s to 5.358 x 10^{-10} m²/s respectively.

REFERENCES


