# DRYING KINETICS AND INFLUENCE ON THE CHEMICAL CHARACTERISTICS OF DEHYDRATED OKRA (*ABELMOSCHUSESCULENTUS*) USING CABINET DRYER

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## ABSTRACT

This study investigated the drying kinetics and effects of drying on the chemical properties of okra (*Abelmoschusesculentus*) using cabinet dryer. Fresh okra was sorted, cleaned and sliced into 2.0 mm thickness with FUTA Slicer. They were spread in a thin layer in a cabinet dryer and dried at varying temperatures of 40, 50 and 60$^{o}$C until constant weights were obtained.. The resulting dried okra slices were milled into grit for further analyses. Each sample was analyzed for proximate composition, mineral content, viscosity, anti-nutrients and anti-oxidants. The drying data were fitted into eight models to predict a suitable one. Results obtained showed that protein content followed a decreasing order for samples dried at 40 $^{o}$C (24.54%), 50 $^{o}$C (21.20%) and 60 $^{o}$C (17.28%). The crude fibre content of dried okra samples increased significantly at ($p<0.05$) as shown by okra sample dried at 40$^{o}$C (15.17%), samples dried at 50$^{o}$C was (12.86%), while that dried at 60$^{o}$C had (11.72%). It was also observed that the sample dried at the temperature of 40$^{o}$C had the highest values of the entire minerals analyzed. The viscosity of okra samples dried at varying temperatures with different particle sizes were significantly different at ($p<0.05$). The sample with a very fine particle size had the highest mucilage retention property. Tannin and flavonnoid contents of the okra samples were not significantly different from one another. β-carotene content of the dried okra grits was decreasing with increasing temperature. The vitamin C content of the okra reduced significantly at ($p<0.05$) from 0.26% to 0.02%. The samples dried at 60$^{o}$C had the least vitamin C content of (0.02%). It was concluded that drying of okra at 40 $^{0}$C was better to retain its nutritional qualities and Modified Page model was found most suitable to describe the drying patterns within the temperature range under study.

**Keywords**: Okra, Drying, Models, Antioxidants, Mucilage.

## INTRODUCTION

Okra; mucilaginous plant, which gives off a slippery/sticky substance when cut, is among the fruits and vegetables which are seasonal and perishable. Okra is popular in human diet for the vitamins and minerals they supply, their medicinal value, taste and texture especially when fresh. The economic importance of Okra cannot be overemphasized. Okra contains carbohydrates, proteins and vitamin C in large quantities (Aworh *et al.*, 1980; Ene, 1995; Brown, 1999; USDA, 2010). Okra is a rich source of many nutrients, including fiber, vitamin B6 and folic acid (FAOSTAT, 2008). The essential and non essential amino acids that Okra contained are comparable to that of soybean. Hence it plays a vital role in human diet (Ononogbu, 1998 Adetuyi *et al.*, 2011). The abundant slimy mucilage in okra binds and inhibits the absorption of cholesterol, bile acids and toxins. It also helps alleviate the irritation, swelling and pain in the throat associated with common cold and cough.(Siemonsma and Kouame, 2004).

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Okra undergo spoilage shortly after harvest, leading to gross post harvest losses which posses a great danger on Nigeria's food security (Sam, 1999).Studies have also shown that the use of low temperature storage is inappropriate for many crops of tropical and subtropical origin such as okra due to its susceptibility to chilling damage resulting in discolouration and rottening. To meet the demand during the entire year in all areas, the commodities are preserved using different techniques and their processing may however lead to loss of some of the characteristics which initially made them consumer delights.

The technique of drying is probably the oldest method of food preservation practiced by mankind. The removal of moisture prevents the growth and reproduction of microorganisms causing decay and minimizes many of the moisture meditated deterioration reaction. It brings about substantial reduction in weight and volume minimizing packing, storage and transportation cost and enables storability of the product under ambient temperatures (Orishagbemi *et al.*, 2000). The drying process not only decreases the water content of the product, but also affects other physical and chemical properties, which will change the shape, crispness, hardness, aroma, flavor and nutritive value of the food produce. Okra is easily dried for later use; a little dried okra in prepared dishes produces much the same results as does the fresh product (Sam, 1999; Eklou *et al*., 2006).

The concept of drying kinetic involved the use of mathematical equation to describe the characteristic behaviors of a drying process (Chukwuma and Ozoma, 2006). One obvious advantage of the use of kinetic models in the production and analysis of drying system lies in saving cost and time that would otherwise have been expended on expensive experiments and construction of pilot plants (Turner and Mujumdar, 1996).

It is of great necessity therefore to investigate and recommend the proper drying temperature range at which nutritional, antioxidants and sensory attributes of okra will not be compromised and to predict the drying model suitable for such temperature range.

## MATERIALS AND METHODS

### Samples Preparation and Drying of Okra

Fresh okra fruits (Iwo varieties) were bought at Shasha market in Akure Ondo state. The fruits were sorted, washed with clean water and drained. They were then sliced with FUTA slicer to 2.0mm thickness. A portion weighing 1 kg was loaded into tray and inserted into the drying chamber of the cabinet dryer (model 85mo64 Shandom, UK) at mean air velocity of 1.68 m/s. The dryer was pre-set at 40 $^{o}$C for 15 minutes before loading to allow stabilized temperature. At intervals of 60 minutes the weight of the okra sample was being taken until constant weight was obtained. The dried sample was milled and packaged in polythene. This same processing operation was also repeated at temperatures of 50 and 60 $^{o}$C using the same cabinet dryer.

### Analyses Carried Out

### Chemical Analyses

The proximate compositions of the samples were determined following the procedures of Association of Official Analytical Chemists AOAC (1995) method. Average of three replications was used. The mineral compositions of the samples were determined using an Atomic Absorption Spectrophotometer following the manufacturer's specifications. The viscosity and Specific gravity were determined using A.O.A.C (1990) methods. The samples were screened for antinutritional factors; spectrophotometric method of Brunner (1984) was used for saponin determination, total flavonoid content was determined using the method of Meda *et al.*, (2005) and tannin was determined according to the method of Makker & Good-child (1996). The determination of β-carotene was done using the spectrophotometric method as described by Ameny and Wilson, (1997) and determination of ascorbic acid compositions was done using the standard of AOAC (1995).

## Analytical Modeling

In order to describe the drying behavior of okra under different drying conditions, thin layer drying models were used. The simple type of drying models assumes that rate of exchange in moisture content is proportional to the difference between moisture content and equilibrium moisture content (EMC) of the material. Seven thin layer drying models were used (Table 1)

**Table 1: Some selected thin layer drying models.**

| MODEL | NAME | REFERENCE |
|---|---|---|
| MR = exp(-kt) | Newton | Liu and BakkerArkema (1997) |
| MR = exp(-kt$^n$) | Page | Zhang and Litchfield (1991) |
| MR =a exp((-kt)$^n$) | Modified Page | Overhults et al; (1973) |
| MR =a exp(-kt) | Handerson and Pabis | Handerson and Pabis (1961) |
| MR =a exp(-kt)+c | Logarithmic | Yaldiz et al; (2001) |
| MR =a exp(-k$_0$t)+b exp(-k$_l$t) | Two term | Raghavan et al; (1998) |
| MR = 1+at+bt$^2$ | Wangh and Sing | Wang and Singh (1998) |

The experimental values for moisture content were converted to moisture ratio using Equation 3 which has been simplified to Equation 4 (Togrul and Pehlivan, 2004). These data were fitted to the thin layer drying models of Table 1 to select the best model that can suitably predict the drying characteristics of okra in sliced form, dried in a cabinet dryer. The correlation coefficient ($R^2$) was the primary criterion for selecting the best model to describe the drying characteristics. In addition to $R^2$, the reduced chi square ($x^2$), the mean bias error (MBE) and the root mean square error (RMSE) were used as the statistics for the modeling. They were calculated using:

$$R^2 = \frac{\sum_{i=1}^{N}(MR_i - MR_{pred.i})\sum_{i=1}^{N}(MR_i - MR_{exp.i})}{\sqrt{\sum_{i=1}^{N}(MR_i - MR_{pred.i})}.\sqrt{\sum_{i=1}^{N}(MR_i - MR_{exp.i})}} \text{---------------------------(1)}$$

$$X^2 = \frac{\sum_{i=1}^{N}(MR_i - MR_{predi})^2}{N-Z} \text{-----------------------------------------------(2)}$$

$$\text{RMSE} = \left[ {}^{1}\!/_{N} \sum_{i=1}^{N}(MR_{predi} - MR_{expi})^2 \right]^{1/2} \text{-----------------------------(3)}$$

$$\text{MBE} = \frac{1}{N}\sum_{i=1}^{N}(MR_{predi} - MR_{expi}) \text{-----------------------------------------(4)}$$

where MRexpi is the experimentally observed moisture ratio, MRpredi the *i*th predicted moisture ratio, N the number of observation and n the number of constants. The regression was carried out using sigma plots 10.0 software

**Validation of the established model**

The established model was validated by plotting the moisture ratio against time for the experimented and the predicted values of the established model for a each experimental run.

**Statistical Analysis**

Means of triplicate readings and their corresponding standard errors of mean (SEM) were determined. The readings were subjected to Analysis of Variance (ANOVA) while means were separated using Duncan's Multiple Range Test. All the procedures were carried out using the statistical package for social scientist,(SPSS) version 18.

**RESULTS AND DISCUSSION**
**Effect of Drying on the Proximate Composition of Okra**

The proximate compositions of the okra grits at varying temperatures (Table 2) showed that the samples after being subjected to drying was significantly affected (at $p<0.05$). For the ash content, which is an indication of the total mineral element according to Aleiro and Abdullahi (2009), the samples dried at 40$^o$C had the highest value of ash (13.47%), followed in a decreasing order by the samples dried at 50$^o$C (11.42%) and samples dried at 60$^o$C had (11.11%). Heat processing of the okra samples at high temperature of 60$^o$C enhanced the fat content as it was found to be the highest value with (4.39%), when compared to other dried samples, it was significantly higher than the other samples. Samples dried at 50$^o$C had the value of (3.66%), while that of 40$^o$C was (3.33%).

Proteins are extremely important components of living cells in that they regulate metabolism, act as structural molecules and in some products represent storage forms of carbon and nitrogen (Kays, 1991). The protein content ranged between (17.28%) for samples dried at 60$^o$C and (24.54%) for samples dried at 40$^o$C. Fresh okra samples had a protein content of (28.00%), but after being subjected to drying, had the lowest content of (17.28%) for samples dried at 60$^o$C followed on an increasing order by samples dried at 50$^o$C,(21.20%) and (24.54%) for samples dried at 40$^o$C showing that processing at a higher temperature denatures the protein.

Dietary fibers are constituents of many fruits and vegetables. Fibers are also general term for plant cell wall components that are poorly digested by humans such as cellulose and lignin (Ensminger *et al.*, 1995). Though dietary fibers cannot be digested, they aid digestion (Eva, 1983). The crude fiber content of dried okra samples increased significantly ($p<0.05$), as shown by okra samples dried at 40$^o$C with (15.17%), samples dried at 50$^o$C was (12.86%) while the ones dried at 60$^o$C had the value of (11.72%). It is an indication that heat processing of okra at a low temperature enhanced its fiber content. Current evidence also suggests that an increase intake of dietary fiber may prevent or treat a variety of ailments ranging from diabetes to arteriosclerosis and colon cancer (Nimenibo-Uadia, 2001).

**Effect of Drying on the Mineral Composition of Okra**

The result of the mineral analysis (Table 3) indicated that okra was high in mineral content such as calcium which is paramount for teeth and bone formation as well as for development. It was also observed that the samples dried at the temperature of 40 $^{o}$C had the highest value of the entire minerals analyzed. It had the calcium content of 99 mg/100g, magnesium content of 739 mg/100, iron content of 824 mg/100g, sodium content of 1418 mg/100g and potassium content 2731 mg/100g among others.

Comparison of the above mineral contents with that of the fresh sample showed that the fresh sample had the least mineral content in all the mineral elements analyzed. This implied that dry processing of okra at a moderate temperature increased the mineral contents per gram of okra.

**Table 2: The proximate composition of okra (*Abelmoschusesculentus*) samples**

| Samples | % Moisture | % ash content | % crude fat | % crude protein | % crude fibre | % carbohydrate |
|---|---|---|---|---|---|---|
| **OK$_{FR}$** | 90.00$^{a}$±0.01 | 22.50$^{a}$±0.01 | 15.50$^{a}$±0.11 | 28.00$^{a}$±0.01 | 11.00$^{d}$±0.01 | 23.00$^{d}$±0.01 |
| **OK$_{40}$$^{o}$C** | 13.00$^{b}$±0.01 | 13.47$^{b}$±0.59 | 3.33$^{d}$±0.01 | 24.54$^{b}$±0.01 | 15.17$^{a}$±0.21 | 43.16$^{c}$±0.01 |
| **OK$_{50}$$^{o}$C** | 12.50$^{c}$±0.01 | 11.42$^{c}$±0.01 | 3.66$^{c}$±0.01 | 21.20$^{c}$±0.01 | 12.86$^{b}$±0.01 | 50.86$^{b}$±0.01 |
| **OK$_{60}$$^{o}$C** | 10.00$^{d}$±0.01 | 11.11$^{c}$±0.01 | 4.39$^{b}$±0.01 | 17.28$^{d}$±0.01 | 11.72$^{c}$±0.01 | 55.50$^{a}$±0.41 |

Values represent means of triplicate readings SEM followed by different lowercase letter
Values with the same letters along the columns are not significantly different ($P<0.05$)

**Table 3: The mineral (g/100g) composition of okra samples**

| Sample | Calcium | Magnesium | Iron | Manganese | Sodium | Potassium | Copper | Phosphorus |
|---|---|---|---|---|---|---|---|---|
| Ok$_{FR}$ | 59.08$^{d}$±0.56 | 51.83$^{f}$±0.00 | 56.31$^{e}$±0.02 | 50.42$^{f}$±0.11 | 71.22$^{b}$±0.13 | 94.26$^{a}$±0.34 | 26.21$^{g}$±0.00 | 65.28$^{c}$±0.6 |
| OK$_{40}$$^{o}$c | 996$^{c}$±0.15 | 739$^{e}$±0.05 | 824$^{d}$±0.09 | 710$^{f}$±0.03 | 1418$^{b}$±0.12 | 2731$^{a}$±0.40 | ND | 679$^{g}$±0.00 |
| OK$_{50}$$^{o}$c | 863$^{c}$±0.73 | 681$^{e}$±0.01 | 746$^{d}$±0.002 | 669$^{f}$±0.92 | 924$^{b}$±0.56 | 2082$^{a}$±0.14 | ND | 639$^{f}$±0.36 |
| OK$_{60}$$^{o}$c | 667$^{c}$±0.10 | 574$^{e}$±0.04 | 599$^{d}$±0.27 | 568$^{f}$±0.18 | 806$^{b}$±0.73 | 1901$^{a}$±0.99 | ND | 595$^{d}$±0.85 |

Values represent means of triplicate readings SEM followed by different lowercase letter
Values with the same letters along the columns are not significantly different ($P<0.05$)

**KEY**
OK$_{FR}$ = Fresh Okra sample
OK$_{40}$$^{o}$C = Okra dried at 40$^{o}$C
OK$_{50}$$^{o}$C = Okra dried at 50$^{o}$C
OK$_{60}$$^{o}$C = Okra dried at 60$^{o}$C

**Effect of Drying on the Viscosity Values of Okra**

One of the main properties of okra is its mucilaginous nature which is measured in terms of its viscosity. Mucilage content of okra pods is a reflection of the carbohydrate content.

Mucilage are composed of a wide cross-section of sugar sub-units, they are polymers and may be found free in the cytoplasm and in some cases sequestered in specialized cells (Kays, 1991). The viscosity of okra samples dried at varying temperatures with different particle sizes were significantly different at ($p<0.05$) (Table 4). The sample with a very fine particle size had the highest mucilage retention property, even when dried at the same temperature; this agrees with the findings of Komolafe and Idah (2008). .

Considering the samples with particle size 0.2mm for instance which had the finest of the particle sizes considered, the samples dried at 40$^{o}$C had the least value of (17.30%), for that of 50$^{o}$C it had (18.31%) while the ones dried at 60$^{o}$C had the highest value of (18.57%) and the fresh sample was (3.30%).

This indicated that the higher the temperature, the more the drying and the higher the bulkiness such that whenever it is reconstituted or rehydrated with an amount of water, it absorbs more water, become heavy or bulky and the more viscous it will also become relative to the particle size. The finer the size, the higher the viscosity as shown by the result, where the samples dried at 40 $^{o}$C with varying sizes reduced significantly at ($p<0.05$), the samples with size 0.2mm had the value of (17.30%), for those with 0.3mm at the same temperature of 40 $^{o}$C, it had (12.80%) while the least value was with the coarse particle size of 0.4 mm, (8.33%). The same principle applied to all the other samples.

**Effect of Drying on the anti-nutritional Constituents of Okra**

The anti-nutrient contents of okra include saponin, tannin and flavonoid. The saponin contents of the samples were significantly different at ($p<0.05$) from one another. The sample dried at 40 $^{o}$C had the highest value of (4.80%), followed in a decreasing order by the sample dried at 50 $^{o}$C, (3.08%) and (2.68%) for the ones dried at 60 $^{o}$C, indicating that saponins are better reduced at high temperatures during heat processing. On the other hand, the tannin content of the okra samples had no significant difference at ($p<0.05$) as shown in Table 5, with samples dried at 40 $^{o}$C having the value of (0.02%), that of 50 $^{o}$C was also (0.02%) and likewise that of 60 $^{o}$C had (0.02%) and even the fresh sample was (0.02%) indicating that the heating process does not have effect on the tannin content, likewise the flavonnoid content was not affected.

**Effect of Drying on the Anti-Oxidant Content of Okra**

Table 6 showed the results of anti-oxidants contents of the okra samples. Vitamin C is the most heat labile of all vitamins and therefore the main parameter in assessing the effect of heat on fruits and vegetables. The vitamin C content of okra samples reduced significantly ($p<0.05$) from 0.26% to 0.02%. The samples dried at 40 $^{o}$C had the value of (0.09%), due to the fact that it took longer time to get dried although at a lower temperature while the one dried at 50 $^{o}$C was (0.26%), it dried at a shorter time. The sample dried at 60 $^{o}$C had the lowest vitamin C content (0.02%), because of the high temperature which adversely affected the vitamin C level. This showed that the longer the heating process and the higher the temperature, the more the adverse effect on the vitamin C content.

β-carotene is one of the most important phytochemicals present in okra and it is suggested to protect one against cataracts by decreasing the level of oxidative damage in the body. It has also been shown that it reduces the incidence of angina in a test conducted using a small sample of men who had previously had heart attack (Sivasankar, 2007). Results of the analysis showed that β-carotene content of okra was highest for samples dried at 40 °C with (2422.45%), the samples dried at 50 °C was (2023.03%) and the least value was that of 60 °C with (1880.21%). This result is in harmony with Sivasankar (2007), who suggested that exposure of vegetable to high temperature or sunlight destroys β-carotene and that better retention can be obtained from drying with low temperature or under shade.

**Table 4: Viscosity values of okra samples**

| Samples | Viscosity (cp) | | |
|---|---|---|---|
| | **Particle size 0.2 mm** | **Particle size 0.3 mm** | **Particle size 0.4 mm** |
| $OK_{FR}$ | $3.30^{d}$±0.00 | $1.22^{d}$±0.1 | $10.90^{d}$±0.02 |
| $OK_{40}$°C | $17.30^{c}$±0.01 | $12.80^{c}$±0.01 | $8.33^{c}$±0.01 |
| $OK_{50}$°C | $18.31^{b}$±0.0.3 | $16.01^{b}$±0.03 | $10.55^{b}$±0.02 |
| $OK_{60}$°C | $18.57^{a}$±0.21 | $17.26^{a}$±0.14 | $12.35^{a}$±0.16 |

Values represent means of triplicate readings SEM followed by different lowercase letter
Values with the same letters along the columns are not significantly different (P<0.05)

**Table 5: The anti-nutrients constituents of okra samples (mg/ml)**

| Samples | Saponin | Tannin | Flavonoid |
|---|---|---|---|
| $OK_{FR}$ | $5.39^{a}$±0.00 | $0.023^{a}$±0.00 | $0.015^{a}$±0.00 |
| $OK_{40}$°C | $4.80^{b}$±0.00 | $0.022^{b}$±0.00 | $0.13^{b}$±0.00 |
| $OK_{50}$°C | $3.08^{c}$±0.00 | $0.021^{c}$±0.00 | $0.010^{c}$±0.00 |
| $OK_{60}$°C | $2.68^{d}$±0.00 | $0.020^{c}$±0.00 | $0.008^{d}$±0.00 |

Values represent means of triplicate readings SEM followed by different lowercase letter
Values with the same letters along the columns are not significantly different (P<0.05)

**KEY**
$OK_{FR}$ = Fresh Okra sample
$OK_{40}$°C = Okra dried at 40°C
$OK_{50}$°C = Okra dried at 50°C
$OK_{60}$°C = Okra dried at 60°C

**Table 6: The anti-oxidant contents of okra samples**

| Samples | Potency of β-Carotene (units/g) | Vitamin C |
|---|---|---|
| $OK_{FR}$ | $2883.74^{a}$±0.12 | $0.31^{a}$±0.00 |
| $OK_{40}$°C | $2422.45^{b}$±0.03 | $0.09^{d}$ ±0.00 |
| $OK_{50}$°C | $2023.03^{c}$±0.02 | $0.26^{b}$±0.00 |
| $OK_{60}$°C | $1880.21^{d}$±0.02 | $0.02^{c}$ ±0.00 |

Values represent means of triplicate readings SEM followed by different lowercase letter
Values with the same letters along the columns are not significantly different (P<0.05)

**Evaluation of the Drying Models of Okra Samples**

The best model describing the thin layer drying characteristics of okra slices was obtained with $R^2$ above 0.9 and the lowest average of the values of RMSE, MBE and $X^2$ (Tables 7 – 9) At 40 $^0$C, $R^2$ ranged from 0.6218 - 0.9872; $X^2$ from 0.001666 - 0.039451 and RMSE from 0.03481 - 0.189378 and MBE from -0.01337 - 0.035118 Modified Page has the highest $R^2$ (0.9872) and least average of $X^2$, RMSE and MBE (0.001666, 0.03481 and 0.000818 respectively). At 50 $^0$C, $R^2$ ranged fom 0.6556 - 0.9745; $X^2$ from 0.004854- 0.054609 and RMSE from 0.052667 - 0.193365 and MBE from -0.01079 - 0.030914 Modified Page has the highest $R^2$ (0.9745) and least average of $X^2$, RMSE and MBE (0.004854, 0.052667 and 0.005271respectively). At 60 $^0$C, $R^2$ ranged fom 0.7138 - 0.9751; $X^2$ from 0.005191814 - 0.046593187and RMSE from 0.054782 - 0.185556 and MBE from -0.01377 - 0.0228 Modified Page has the highest $R^2$ (0.9751) and least average of $X^2$, RMSE and MBE (0.005251914, 0.054782 and 0.013877 respectively). These results showed that Modified Page is the established model for drying okra (*Abelmoschusesculentus*) within the range of 40 - 60 $^0$C.

The established model was used to predict the moisture ratio of okra. Therefore the validation was done by comparing the predicted moisture ratio with the experimented as shown in Figures 1, 2 and 3. There were good agreement between the experimental and predicted variables which indicates that the Modified Page model could be used satisfactorily to predict the thin layer hot-air drying of okra between drying temperatures of 40 – 60 $^0$C

**Table 7: The best fit of the selected thin layer models on the drying of okra at 40$^o$C**

| MODEL | $R^2$ | COEFFICIENTS | EQUATION | $X^2$ | RMSE | MBE |
|---|---|---|---|---|---|---|
| HAND & PAB | 0.7415 | a=1.2889<br>k=0.0019 | ***MR***=1.29exp(-0.002***t***) | 0.029972 | 0.156597 | -0.0077 |
| LOGARITHMIC | 0.8240 | a=3940.9002<br>k=3.8182E-007<br>c= -3939.6631 | ***MR***=3940.90exp(3.8182E-7***t***)+(-3939.66) | 0.018361 | 0.115556 | 9.09E-06 |
| MODIFIED PAGE | 0.9872 | a=0.9600<br>k=0.0018<br>n=5.0037 | ***MR***=0.96exp[-(0.0018***t***)^5] | 0.001666 | 0.03481 | 0.000818 |
| NEWTON | 0.6218 | a=1.0000<br>k=0.0012 | ***MR***=exp(-0.0012***t***) | 0.039451 | 0.189378 | 0.035118 |
| PAGE | 0.9816 | k=0.0018<br>n=4.4140 | ***MR***=exp(-0.0018***t***^4.41) | 0.002138 | 0.041826 | -0.01337 |
| TWO TERM | 0.7415 | a=1.2889<br>b=3.9727E-009<br>$k_0$=0.0019<br>$K_1$=0.1288 | ***MR***=1.29exp(-0.0019***t***)+3.97E-9(0.1288***t***) | 0.038536 | 0.156597 | -0.0077 |
| WANGH AND SING | 0.9711 | a=0.0005<br>b=-2.7986E-006 | ***MR***=1-0.0005***t***-2.7986E-6***t***$^2$ | 0.003343 | 0.052303 | -0.0054 |

**Table 8: Best fit of the selected thin layer models on the drying of okra at 50$^o$C**

| MODEL | $R^2$ | COEFFICIENTS | EQUATION | $X^2$ | RMSE | MBE |
|---|---|---|---|---|---|---|
| HAND & PAB | 0.7845 | a=1.3731<br>k=0.0036 | ***MR***=1.37exp(-0.0036***t***) | 0.032765 | 0.152983 | -0.01039 |
| LOGARITHMIC | 0.8972 | a=3852.6344<br>k=6.7527E-007<br>c=-3851.3872 | ***MR***=3852.63exp(6.7527E-7***t***)+(-3851.39) | 0.019533 | 0.105649 | 7.93E-18 |
| MODIFIED PAGE | 0.9745 | a=0.9477<br>k=0.0030<br>n=4.5303 | ***MR***=0.95exp[-(0.0030***t***)^4.53] | 0.004854 | 0.052667 | 0.005271 |
| NEWTON | 0.6556 | a=1.0000<br>k=0.0023 | ***MR***=exp(-0.0023***t***) | 0.043622 | 0.193365 | 0.030914 |
| PAGE | 0.968 | k=0.0030<br>n=3.8387 | ***MR***=exp(-0.003***t***^3.84) | 0.004874 | 0.059006 | -0.01079 |
| TWO TERM | 0.7845 | a=1.3731<br>b=1.1216E-007<br>$k_0$=0.0036<br>$k_1$=2.3570 | ***MR***=1.37exp(-0.0036***t***)+1.12E-7(2.357***t***) | 0.054609 | 0.152983 | -0.01039 |
| WANGH AND SING | 0.9452 | a=0.0002<br>b=-5.7404E-006 | ***MR***=1-0.0002***t***-5.74E-6***t***$^2$ | 0.008326 | 0.077119 | -0.00017 |

**Table 9: Best fit of the selected thin layer models on the drying of okra at 60$^o$C**

| MODEL | $R^2$ | COEFFICIENTS | EQUATION | $X^2$ | RMSE | MBE |
|---|---|---|---|---|---|---|
| HAND & PAB | 0.834 | a=1.4244<br>k=0.0046 | ***MR***=1.42exp(-0.0046***t***) | 0.027955912 | 0.14131 | -0.01377 |
| LOGARITHMIC | 0.9209 | a=1433.1299<br>k=1.9364E-006<br>c=-1431.9312 | ***MR***=1433.13exp(1.9364E-6***t***)+(-1431.93) | 0.016648395 | 0.097536 | 0.0000 |
| MODIFIED PAGE | 0.9751 | a=0.9376<br>k=0.0035<br>n=4.1052 | ***MR***=0.94exp[-(0.0035***t***)^4.11] | 0.005251914 | 0.054782 | 0.013877 |
| NEWTON | 0.7138 | a=1.0000<br>k=0.0031 | ***MR***=exp(-0.0031***t***) | 0.040169637 | 0.185556 | 0.0228 |
| PAGE | 0.9692 | a=0.0035<br>k=3.3191 | ***MR***=exp(-0.0035***t***^3.32) | 0.005191814 | 0.060897 | -0.00316 |
| TWO TERM | 0.834 | a=1.4244 | ***MR***=1.42exp(-0.0046***t***)+1.90E-6(-39.08***t***) | 0.046593187 | 0.14131 | -0.01377 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | b= 1.9024E-006<br>$k_0$=0.0046<br>$K_1$=39.0801 | | | | |
| WANGH AND SING | 0.9122 | a=-0.0009<br>b=-3.5948E-006 | $\underline{\textit{MR}}=1-0.0009\underline{t}-3.595E-6\underline{t}^2$ | 0.014795758 | 0.102803 | 0.008643 |

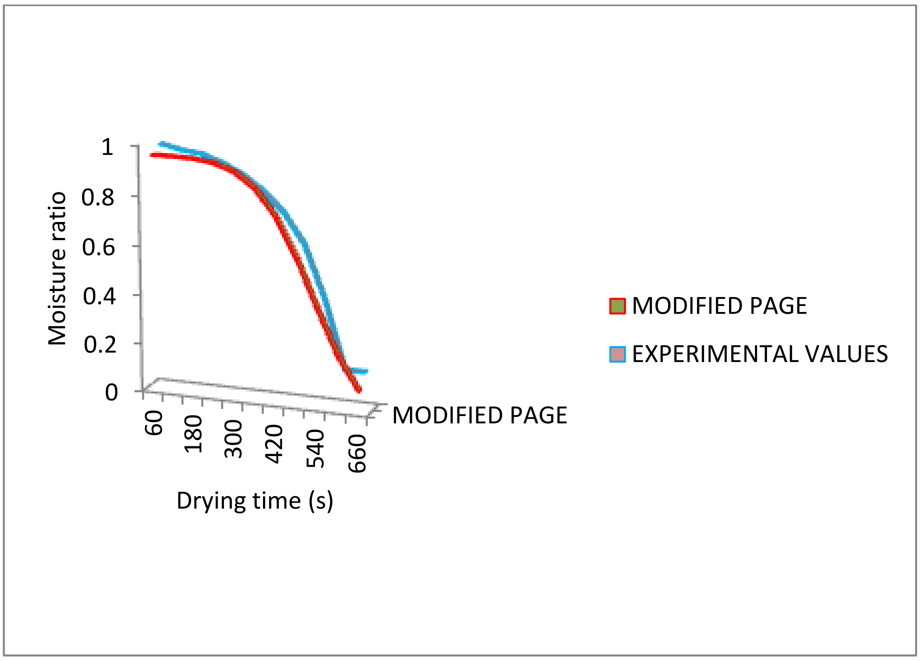


Figure 1: Comparison of experimental and predicted moisture ratio against drying time for okra dried at 40°C

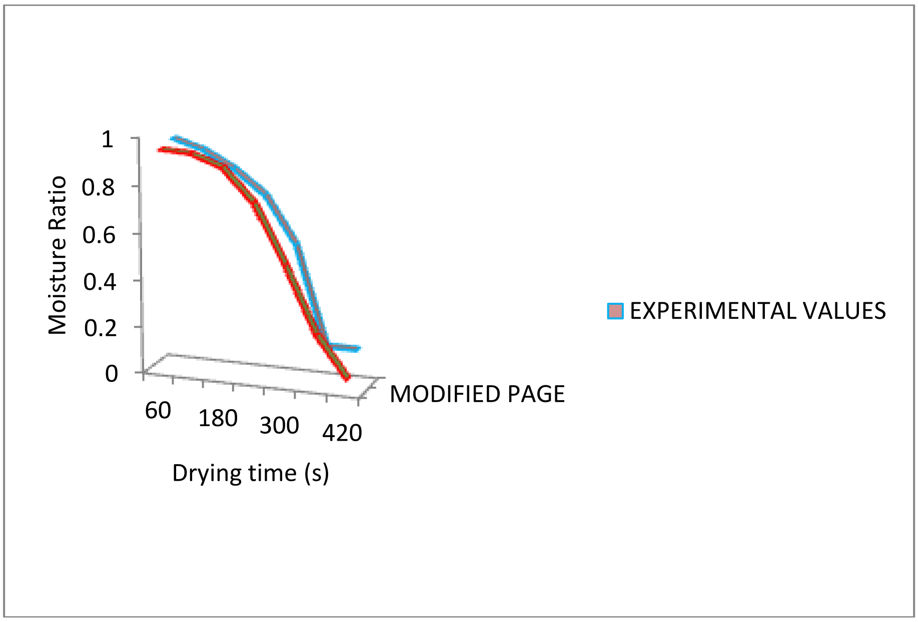


Figure 2**:** Comparison of experimental and predicted moisture ratio against drying time for okra dried at 50°C

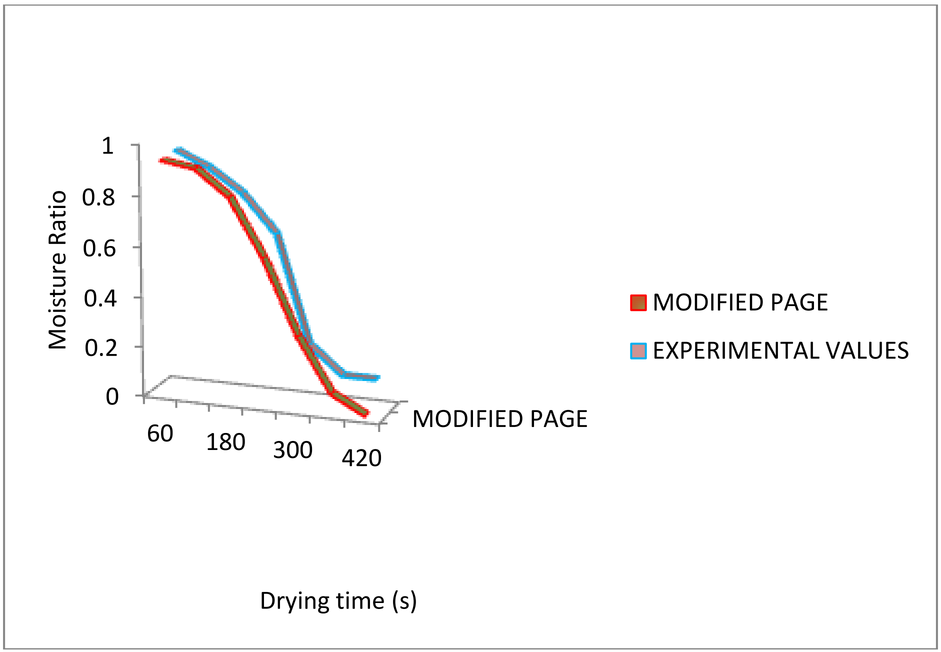


Figure 3**:** Comparison of predicted moisture ratio against experimental for okra dried at 60°C

## CONCLUSION

The high demand for okra arises for a need of processing of okra into powder in order to preserve the product for use when it is out of season or to add value for extra income. These studies have shown that a nutritionally acceptable shelf-stable powder can be produced from okra using mild heat treatment. .Results obtained indicate that there are beneficial effects on the nutritive content of the fruit. Drying also made some nutrients more available i.e the removal of moisture generally increases the concentration of the nutrients.

It could be concluded that 40 °C was the best temperature for drying of okra as it gave the highest nutrients especially in terms of proximate composition, anti-oxidant constituents and mineral contents. However, 50 °C was best in terms of vitamin C content probably because the longer time it spent in the oven degraded the vitamin C when drying at 40 $^0$C.The result of viscosity measurement showed that the best mucilage retention capacity is with the one with a very fine particle size.

The principle behind a model is that the higher the correlation coefficient ($R^2$), the lower the chi square ($X^2$) and root mean square error (RMSE) values indicate that the model is best fitted. Based on these criteria, the modified page model was found best to describe the drying curves

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