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EFFECT OF DIFFERENT DRYING METHODS ON THE DRYING KINETICS AND PROXIMATE COMPOSITION OF GARDEN EGG

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This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Garden egg *(Solanum aethiopicum L.)* is a perishable crop as a result of high moisture content which necessitates its conversion to a shelf-stable product using appropriate preservation techniques such as drying. Therefore, this study evaluated the effect of drying methods on the drying kinetics of dried garden egg slices. The garden eggs were washed, sorted, and cut transversely into slices (3.0, 6.0 and 9.0 mm) and dried using the sun, solar and cabinet (60 ºC) drying. Drying kinetic, effective moisture diffusivity and the activation energy were determined. Proximate composition (moisture content, crude protein, crude fiber, crude fat and ash) was determined for both dried and fresh samples. Drying took place entirely in the falling rate period. Effective moisture diffusivity (D_{eff}) increased with an increase in slice thickness. Effective moisture diffusivity varied from 3.641×10^{-10} to 1.062×10^{-9} for sun drying, 2.467×10^{-10} to 1.083×10^{-9} for solar drying and 2.487×10^{-10} to 1.213×10^{-9} for cabinet drying. The activation energy for cabinet drying was 14.93, 17.01 and 19.55 $kJmol^{-1}$ for slice thicknesses of 3.0, 6.0 and 9.0 mm, respectively. The moisture content ranged from 4.02 to 8.02% for all analyzed samples, crude protein (17.5 - 20.13%), crude fibre (12.01 - 20.02%), crude fat (2.00 - 2.03%) and ash content (4.01 - 6.03%). The moisture content and ash content of sun-dried samples were higher compared to solar and cabinet-dried samples. The crude protein content, crude fiber content and crude fat content of solar-dried samples were higher compared to sun and cabinet dried samples. In conclusion, this study has shown that garden eggs subjected to solar drying and cabinet drying (at 60°C) gave a better result in terms of moisture content, crude protein, crude fibre, crude fat and ash content. Samples with lower slice thickness and higher temperature dry faster. D_{eff} increases with an increase in slice thicknesses.

Keywords: Garden egg; drying; slice thickness; sun; solar; cabinet dryer.

1. INTRODUCTION

Garden egg (*Solanum aethiopicum L.*) is a type of eggplant that originated from Tropical Africa [1]. It is an economic flowering plant that belongs to the family of *Solanaceae*, about 1,400 species found throughout the temperate and tropical regions of the world [2]. The name "garden eggplant" was originated based on the shape of some fruits which are white and shaped like chicken eggs. It is a vegetable plant that is well known throughout the world [3]. This crop has many varieties with different shapes and

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colours of which some are yellow with green stripes; yellow with white stripes and flat ribbed green types among others [2].

Series of names are given to different species depending on the country and these common names include aubergine, brinjal, scarlet eggplant, African eggplant or garden egg [4] Garden egg also known as aubergine and brinjal is more domesticated in South East Asia [5] while the scarlet garden egg is indigenous in Tropical Africa, and the crop is extensively grown in both northern and southern Africa [1]. This crop contains some essential vitamins, minerals, and phytochemicals which make it be used in treating certain diseases [6].

According to Sabo and Dia (2009), the garden egg contains water (92.5%), protein (1%), fat (0.3%), and carbohydrates (6%). It contains between 30 to 50% of iron (Fe), fiber, potassium (K), manganese (Mn), copper (Cu), and vitamins: (vitamin B_1, B_2, B_3, $B_{6,}$ and B_9). Garden egg also contains phyto-nutrients such as nasunin and chlorogenic acid [7]. The plant can be regarded as brain food because it contains anthocyanin phytonutrient that is present in its skin, also nasunin (a potent antioxidant) with chlorogenic acid as a predominant compound [8-9]. These substances are substrates for polyphenol oxidase enzyme that resulted in rapid browning of cut or injured tissues [10]. The crop is an essential raw material for canning industries in the production of the garden–egg paste, sautéed garden-egg and other products. The garden egg with its bitter taste and spongy texture could make an amazing pot of stew with a nice aroma [9].

Because of high nutrient content and its post-harvest losses, and being a seasonal fruit with high moisture content, there is a need to make the fruit available at all times and also to prevent the post-harvest losses by further processing of the fruit and one way forward is by the production of dried garden egg. Drying is a process of moisture removal due to simultaneous heat and mass transfer phenomena [11-12]. It is one of the methods of food preservation that bring about longer shelf- life, lighter weight for essay transportation and smaller space for storage [13].

Studies have shown that post-harvest loss has been a bane to food security. According to Majumder *et al.* [14] it has been stated that about 20 - 40 percent of fruit and vegetable production goes to waste. Kumar *et al*. [15] also stated that the losses do not only affect the output but reduce farmers' income all over the world.

Although several works have been conducted on the effect of drying on fruit and vegetables: Oni *et al*. [16] during the drying of banana peel; Ogunlakin *et al*. [17] during the drying of waterleaf; Olajire *et al.* [12] during the drying of okro; and Gurlek *et al*. (2009) during the drying of tomato but there is limited information on the effect of different drying methods on some nutritional quality of the dried garden egg. Therefore, this work aims to determine the effect of drying methods on drying kinetics and the proximate composition of dried garden egg slices.

2. MATERIALS AND METHODS

2.1 Materials

Garden egg was purchased from a local farmer in Ogbomoso, Oyo State, Nigeria and brought to the Department of Agronomy Teaching and Research Centre Ladoke Akintola University of Technology for proper identification of the variety. The equipment (cabinet and solar dryers) and other apparatus (vernier caliper, sensitive weighing balance, and stainless steel knife, thermometer, bowl, tray and distilled water) used for this research work are obtained from the Food Processing Laboratory of Food Engineering Department.

2.2 Sample Preparation

The garden egg was sorted and washed to remove extraneous materials. The samples were cut using a sharp knife into slice thicknesses of 3, 6 and 9 mm and were divided into two portions. The first portion of the sample saves as the control according to ElKhodiry *et al.* [18] and Khan *et al.* [19]). The second portion of the samples was used for drying experiments and was dried using three different drying methods (sun, solar and cabinet at 60 ^{o}C).

2.3 Drying Procedure

For sun drying methods, 1000 g of the sliced samples were spread on the drying trays and were directly placed under the sun. The duration of the drying was between 11 am – 5 pm daily (which represented the sunlight hour). The weight of the samples was measured hourly and the drying was continued until three consecutive readings were constant.

Sliced samples of 1000 g were spread on the drying trays that were placed inside the solar dryer and were placed directly under the sun. The duration of the drying was from 11 am – 5 pm daily which represented the sunlight hours. The samples were weighed every hour until three consecutive readings were constant.

Garden egg samples of slice thicknesses 3, 6 and 9 mm weighing 1000 g each, spread on the drying trays which were loaded into the cabinet dryer. The dryer was allowed to run for about 30 min before loading of samples to reach the set drying air temperature condition and the drying experiment was carried out at 60 ºC. The drying trays were removed at regular intervals of 1 h until three consecutive weights were constant, indicating equilibrium drying conditions.

2.4 Drying Kinetics

Moisture Content: The moisture content (MC), expressed as g water/g material was calculated as a function of time using Equation 1

$$MC = \frac{W_i - W_d}{W_i} \times 100 \quad (1)$$

where, w_i is the initial mass of the sample before drying and w_d is the mass of the sample at a time t.

Moisture Ratio: The moisture ratio (MR) was calculated by expressing the moisture in the following dimensionless form as presented in Equation 2:

$$MR = \frac{M - M_e}{M_i - M_e} \quad (2)$$

where MR is the moisture ratio, M, M_e and M_i is the moisture content at any time t, equilibrium moisture content and initial moisture content, respectively.

But, MR was turned to M/M_i instead of using Equation 2 this was as a result of relative humidity that occurred in the drying air [20]. The MR was then expressed as

$$MR = \frac{M}{M_i} \quad (3)$$

Effective Moisture Diffusivity and Activation Energy: Effective moisture diffusivity (D_{eff}) was calculated using Fick's second equation of diffusion as reported by Velic *et al.* [21] with Fick's second law of diffusion all these assumptions were made; moisture migration is only by diffusion, shrinkage is relatively small, constant temperature and diffusion coefficients and long drying time [22].

$$MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff}}{4L^2} t\right) \quad (4)$$

where, MR is the moisture ratio, D (m^2s^{-1}) is the effective moisture diffusivity, L(m) is the sample thickness and t is the drying time (s).

Equation 4 which involved a series of exponents can be simplified to Equation 5

$$InMR = \frac{-\pi^2 D_{eff}}{4L^2} t + \frac{In8}{\pi^2} \quad (5)$$

Equation 5 was used to obtain the effective diffusivity (D_{eff}) at each temperature from the slope of the plot of ln(MR) against time for corresponding temperature data. The activation energy was calculated by using an Arrhenius equation [23].

$$D_{eff} = D_0 e^{\frac{-E_a}{Rg(T+273.15)}} \quad (6)$$

where D_o is the maximum diffusion coefficient, Ea is the activation energy ($kJmol^{-1}$), T is the temperature (ºC) and R_g is the gas constant.

$$\ln D_{eff} = \left[-\frac{1}{Rg(T+273.15)}\right] E_a + \ln D_0 \quad (7)$$

In the same manner, as D_{eff}, the Activation energy was obtained as the slope of $\ln D_{eff}$ against $-\frac{1}{Rg\ (T+273.25)}$

2.5 Proximate Analysis

Moisture content determination: The moisture content of each sample was determined by the method described by the AOAC [24]. The sample (2 g) was weighed into a previously weighed crucible and then transferred into the oven with the temperature maintained at 150 ºC for 3 h. The crucible was removed from the oven and placed in the desiccator at room temperature. The moisture content was calculated as:

$$\%\ \text{Moisture} = \frac{M_1 - M_2}{M_1 - M_0} \times 100 \quad (8)$$

where, M_0 =Weight of empty crucible, M_1=Weight of crucible + sample before drying, M_2=Weight of crucible + oven dried sample

Ash content determination: The ash content of each sample was determined using the method described by AOAC [24]. The sample (2 g) was weighed into a weighed crucible, which would have been dried in an oven and cooled in the desiccator. It was heated over an electric heater to char organic matter and was transferred into a muffle furnace at 600 ºC for 6 h. The crucible with the sample was cooled in the desiccator before it was weighed.

$$\%\ Ash\ content = \frac{(weightofcrucible + ash) - (weightofemptycrucible)}{weightofsample} \quad (9)$$

Crude fat content determination: The crude fat content was determined by the method described by AOAC [24]. The sample (1 g) each was weighed into a fat-free extraction tumble and was blocked lightly with cotton wool. The timble was placed in the extractor and was fitted up with a reflux condenser. A 250 ml soxhlet flask that had been dried in the oven, cooled in the desiccators was weighed. The soxhlet flask was filled to ¾ of its volume with petroleum ether (boiling point of 40 – 60 ºC). The flask, extractor with the condenser set was placed on the heater for 6 h with constant running with ether lacks, and the heat source was adjusted appropriately for ether to bril gently. The timble and distillation will continue until the flask practically dries. The flask containing the fat and oil was detached. Its exterior was cleaned and dried to a constant weight in the oven.

$$\% \, crudefat = \frac{w_1 - w_0}{weig\square tofsampletaken} \times 100 \quad (10)$$

where W_o is the initial weight of oven soxhlet flask and W_1 is the final weight of oven-dried flask + oil/fat.

Crude protein determination: The crude protein of each sample was determined using the Kjeldahl Nitrogen method described by AOAC [24]. The sample, 0.5 g each were carefully weighed into the kjeldahl digestion tubes to ensure that all materials get to the bottom of the tubes. Two grams (2 g) of kjeldahl catalyst and 10ml of concentrated H_2SO_4 was added before setting in the appropriate hole of the digestion block heaters in a fume cupboard for 4 h. The digest was cooled and water was carefully transferred into a 100 ml volumetric flask thoroughly rinsing the digestion tube distilled water. The digest (5 ml) portion was pipetted into the distillation apparatus and 5 ml, 40% (W/V) NaOH was added. The mixture was steamed distilled for 2 min into 500 ml of the conical flask containing 10 ml of 2% boric acid with mixed indicator solution and placed at the receiving top of the condenser. The solution was then titrated against 0.01N HCl in a 50 ml burette.

$$\% \, Nitrogen = \frac{Titrevalue \times AtomicmassofNitrogen \times V_f}{W \times V_d} \times 100 \quad (11)$$

$$\% \, CrudeProtein = \%Nitrogen \times 6.25$$

where, M =molarity of HCL used, V_f=volume of the flask containing the digest, W=weight of the sample digested, V_d=volume of the digest for steam distillation.

Crude fiber determination: The sample (2 g) was weighed into a 600 ml beaker and 200 ml hot 1.25% was added and placed in digestion apparatus with pre-heated plates. It was allowed to boil and reflux for 30 min to hydrolyze the carbohydrates and protein. This was followed by filtering through Whatman paper and washing the residue with distilled water until the filtrate was neutral. The residue was transferred into the beaker and 200 ml NaOH was added before returning to the digestion apparatus to boil and reflux for 30 min (this affected the saponification of fat). It was filtered and washed with distilled water until the filtrate was neutral. The residue was then transferred into the crucible and dried at 100 ºC overnight. It was cooled in the desiccators and weighed (A) before placing in the furnace at 600 ºC or a period of 6 h. It was cooled and weighed as B.

$$\%\text{Crude Fibre} = \frac{A - B}{Weig\square tofsample} \times 100 \quad (12)$$

Carbohydrate determination: Carbohydrate was obtained by the different methods as described by Onyeike and Omubo-Dede [25]. That is, total carbohydrate (%) = 100 – (%Moisture + % Ash + %crude protein + %crude fat).

2.6 Statistical Analysis

The raw data collected (triplicate) were analyzed using one-way analysis of variance (ANOVA) to find out whether there were any significant variations of the means ($p \leq 0.05$). The statistical program used was Genstat version 5, Release 3.2 (Lawes Agriculture Trust Roth Amsted experimental station, USA).

3 RESULTS AND DISCUSSION

3.1 Determination of Drying Curve and Drying Rate Curve

Fig. 1 show the drying curve (moisture content against drying time) for drying garden egg samples using different drying methods (sun, solar and cabinet drying at 60 ºC).

Garden egg samples which contain moisture content of 92.5 g water/g material were dried to a final moisture content of 1.33, 1.33 and1.33 for sun-drying; 1.43, 1.43 and 2.82 for solar drying while 1.32, 2.59 and 2.59 g water/g material for cabinet and at a slice thickness of 3, 6 and 9 mm, respectively. From the curve, it was observed that, a gradual decrease in moisture content with a corresponding increase in drying time, with the drying curve forming a sloppy downward curve. Furthermore, moisture loss was higher at the begging of the drying experiment due to the evaporation of free water in garden egg samples. Subsequently, there is a reduction in moisture content in the latter drying periods. This shows that the free water has been evaporated from the garden egg samples leaving the bound water. This result was in line with the observation of Kabiru *et al.* [26] and Olajire *et al.* [12]during the drying of mango slice and okro slice, respectively. The time to reach the final drying time were 12, 14 and 16 h for sun-drying; 9, 12 and 14 h for solar drying while 8, 10 and 12 h for cabinet drying at a slice thickness of 3, 6 and 9 mm, respectively. The effect of slice thickness on the drying of garden egg samples was that the smaller the sample thickness the faster it dry (Fig. 2). This is because the sample with a smaller slice thickness takes a short distance for the water molecule to travel from the core of the sample to the outer layer where evaporation will take place while for a larger thickness the distance is long and take a longer distance. From the graph, (Fig. 2) there is a decrease in drying rate as drying progresses. This is due to bound water that is remaining in the dried sample which is difficult to remove. The drying rate also increased with an increase in drying air temperature which agreed with the findings of Ndukwu [27] in the drying of the cocoa bean. The reason is that higher air temperatures lead to greater diffusion of water which increases the rate at which water is evaporated from the surface of the garden egg samples.

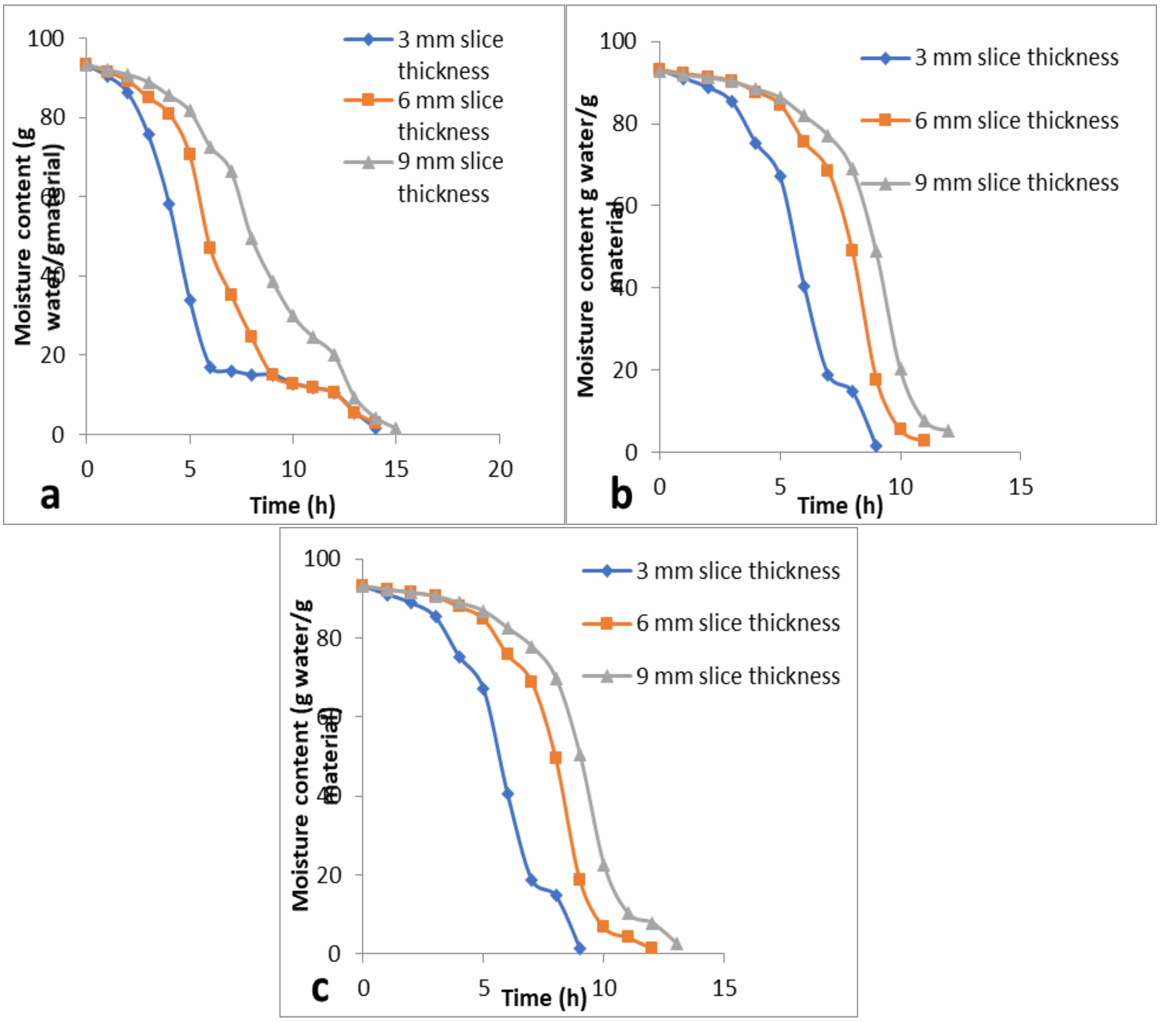

Fig. 1. Moisture content against time for different garden egg slice thickness dried using (a) sun, (b) solar and (c) cabinet at 60 ºC

3.2 Effective Moisture Diffusitivity (D_{eff}) and Activation Energy

The drying experiment is of greater importance because it is used to determine moisture migration in food samples and provide an accurate result from the drying kinetics data [28]. The D_{eff} values were obtained from the gradient of the linear graph of lnMR against time from Fig. 3 using Equation 6. The values of D_{eff} for drying the garden egg using different drying methods are as presented in Table 1. From the graph, it was observed that drying of garden egg occurred in falling rate period, and therefore the curves are straight line. Furthermore, as temperature increase D_{eff} increase with an increase in slice thickness. This was in line with the report of Samimi *et al.* [29] that D_{eff} increased with increase in slice thickness from 1.58×10^{-9} m^2/s at 0.5 m/s air velocity for 3 mm slice thickness to 6.98×10^{-9} m^2/s at 2 m/s air velocity for 7 mm slice thickness. Generally, the value of moisture diffusivity (D_{eff}) changes in the range of 10^{-11} – 10^{-9} m^2/s for food materials [30,23,31]. Activation energy is needed to initiate the moisture diffusion within the slice and is a function of temperature sensitivity. The activation energy for cabinet drying of the garden egg was 14.93, 17.01 and19.55 $kJmol^{-1}$ for slice thickness of 3.0, 6.0 and 9.0 mm which was obtained from the slopes of the linear plot in Fig. 4 according to Equation 7.

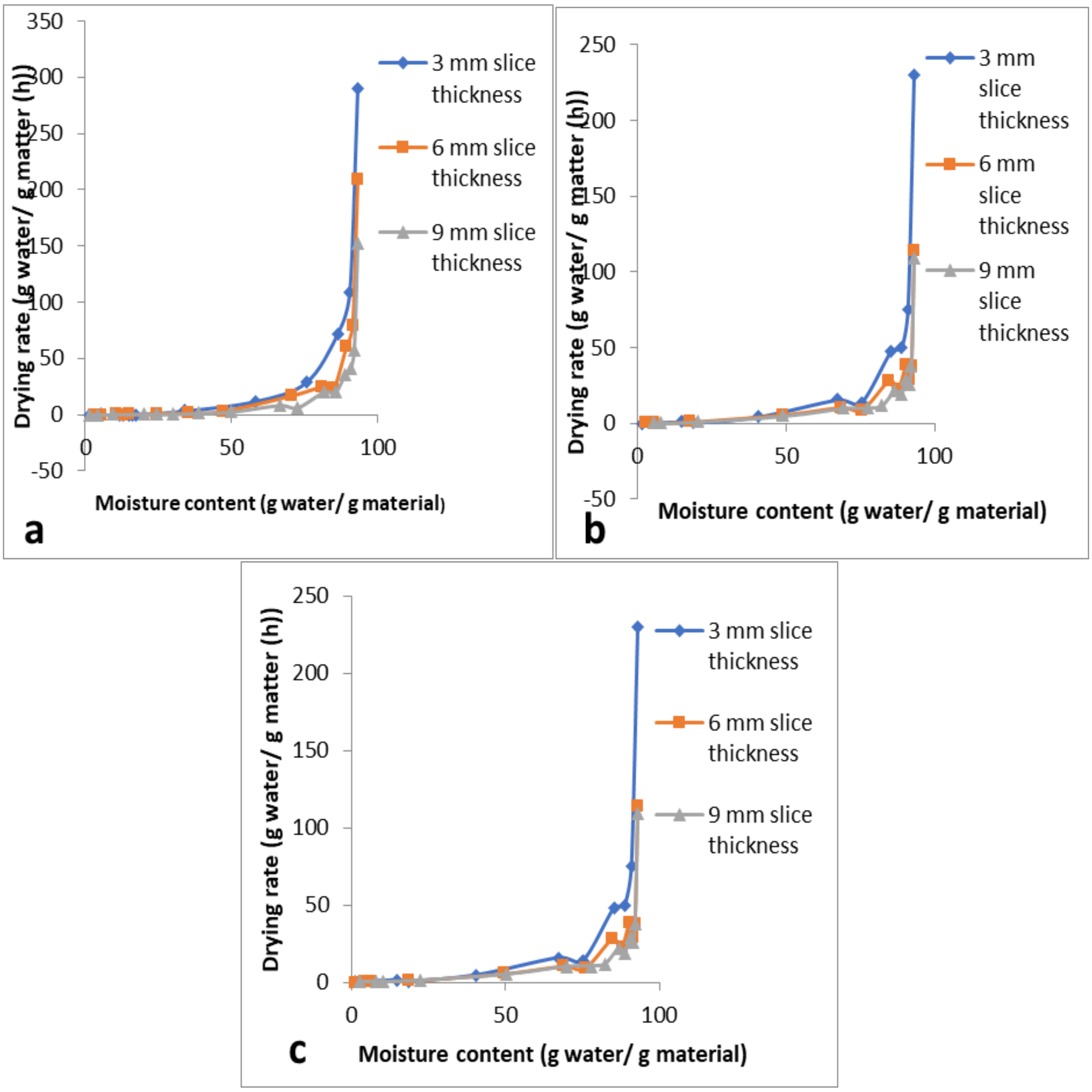

Fig. 2. Drying rate curve for drying garden egg slices using (a) sun, (b) solar and (c) cabinet at 60 ºC

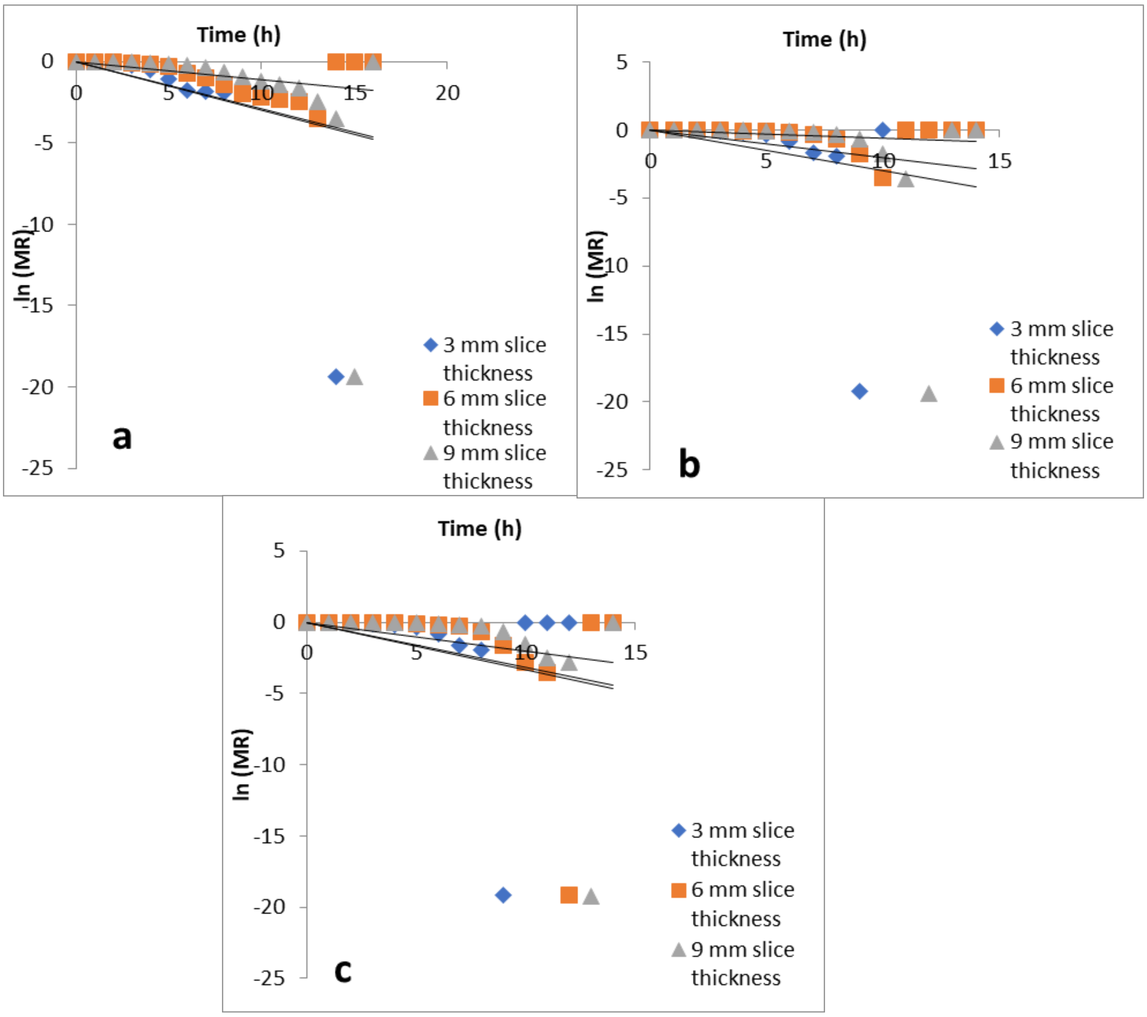

Fig. 3. Estimation of moisture diffusivity for (a) sun, (b) solar and (c) cabinet at 60 °C

Table 1. Effective moisture diffusivity (m^2/s) of the different drying processes of garden egg

Slice Thickness (mm)	Effective Moisture Diffusivity (m^2/s)		
	Sun	Solar	Cabinet
3.0	2.241×10^{-10}	2.467×10^{-10}	2.487×10^{-10}
6.0	4.062×10^{-10}	4.144×10^{-10}	7.702×10^{-10}
9.0	1.062×10^{-9}	1.083×10^{-9}	1.213×10^{-9}

3.3 Proximate Analysis

The result of the proximate analysis of moisture content, crude fat, crude fibre, crude protein and ash content are shown in Table 2. The result revealed that the garden egg samples in this study have high moisture content. The moisture which was determined on the fresh garden egg sample was 90.02%, other researchers recorded similar values for various varieties in the Solanaceae family. Chinedu *et al.* [32] reported 92.5% for *Solanum macrocarpum* (*gboma* eggplant) whereas Akoto *et al.* [33] obtained 86.23% for *Solanum torvum* fruits from Ghana while Sam *et al.* [34]) mentioned 85.5% for *Solanum verbascifolium* (African garden egg). The high moisture content accounts for its low dry matter content and its high perishability according to Edem *et al.* [35] and Chinedu *et al.* [32]. The moisture content on a dry basis after drying ranged between 4.02 to 8.02% with 9 mm slice thickness of sun-dried sample having the highest moisture content and 3 mm slice thickness of solar-dried sample having the lowest moisture content. This is as a result of a slightly higher temperature in the solar-dried sample compare to the sun-dried sample. Also, a sample with a lower slice thickness will not be able to retain more water compared to a sample of larger slice thickness because of the closeness of the core of the sample to the outer layer where evaporation will take place in the sample of lower slice thickness. There was a significant difference ($p \leq 0.05$) in the values of moisture content for all the dried samples.

Crude protein ranged between 17.50 to 20.13% with the least in the 3 mm slice thickness of sun-dried sample, 9 mm slice thickness of the cabinet-dried sample and the highest in 9 mm slice thickness of the solar-dried sample. There was a significant difference between ($p \leq 0.05$) the dried sample. It is believed that protein content increases after drying due to moisture loss resulting in concentration of the solid content, in which some protein structures get broken down by heat to release more detectable nitrogen [36]. Protein helps in maintaining proper growth and repair of body tissues [35].

Food high in fiber helps in lowering cholesterol, preventing constipation and improving digestion [37]. The samples in this study have high fiber content which ranged between 12.01 and 22.00% with a sun-dried sample of slice 3 mm having the lowest fiber while solar-dried of 3 mm has the highest values. There is a significant difference between the value in all the drying methods and slice thicknesses. Compare this result with other researchers, it was in line with that of Edem *et al*. [35] which recorded 11.75 -14.87%, for dried *S. verbascifolium*. It was observed that crude fiber for a fresh sample was small compared to that of dried samples is due to moisture remover from the samples which resulted in a concentration of the nutrient.

The ash content for dried garden eggs ranges from 4.01to 6.03%. The least ash was recorded in the 3 mm slice thickness of the sun-dried sample and the highest in the 3 mm slice thickness of the solar-dried sample. There was no significant difference ($p \leq 0.05$) between all the samples except the sun-dried sample at a slice thickness of 3 mm. Ash contents give clear information about the inorganic content which comprises the totality of all minerals in the food material. Samples with high percentages of ash contents are expected to have high concentrations of various mineral elements as reported by Bello *et al.* [38-39].

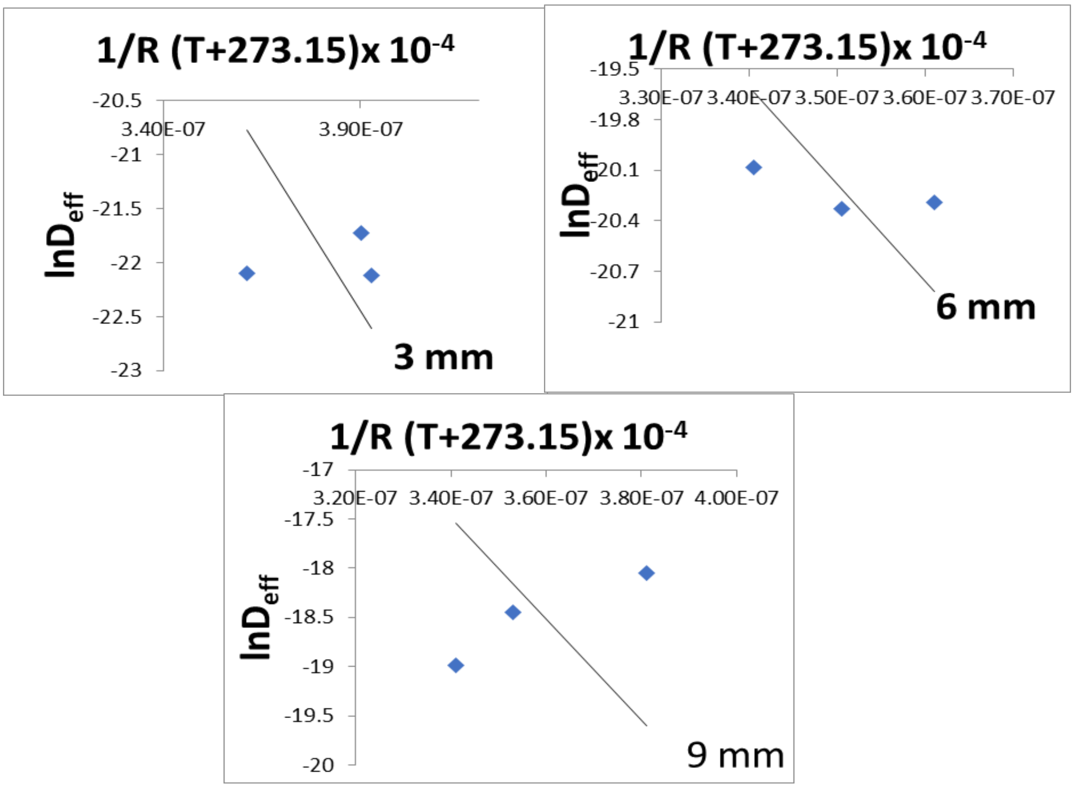

Fig. 4. Graph of ln(D_{eff}) against $\frac{1}{R(T+273.15)} \times 10^{-3}$ at different thicknesses

Table 2. Proximate composition of garden egg

Sample	Crude protein (%)	Crude fibre (%)	Ash (%)	Crude fat (%)	Moisture content (%)
Fresh	**2.63**	**2.10**	**0.01**	**4.00**	**90.02**
3 mm sun	17.50^{a}	12.01^{e}	4.01^{b}	2.00^{a}	6.03^{c}
6 mm sun	18.38^{c}	20.02^{c}	6.03^{b}	2.02^{a}	8.00^{c}
9 mm sun	19.25^{d}	16.00^{d}	6.01^{c}	2.03^{a}	8.02^{c}
3 mm solar	18.38^{b}	22.00^{f}	6.02^{b}	2.01^{a}	4.02^{a}
6 mm solar	19.25^{c}	14.03^{b}	6.00^{b}	2.03^{a}	6.01^{b}
9 mm solar	20.13^{d}	18.01^{d}	6.10^{b}	2.03^{a}	8.01^{c}
3 mm cabinet	18.38^{b}	20.02^{e}	6.01^{b}	2.00^{a}	6.03^{b}
6 mm cabinet	19.25^{c}	14.02^{b}	6.00^{b}	2.10^{b}	6.02^{b}
9 mm cabinet	17.50^{a}	14.01^{b}	6.03^{b}	2.02^{a}	6.00^{b}

Values represent means of triplicate reading, follow by different lowercase letter
Means within the same row with different alphabets are significantly different ($p \leq 0.05$)

The fat content of the samples ranged from 2.00 to 2.03%. Samples of 3 mm slice thickness of the sun-dried sample, slice thickness, 3 mm of solar-dried sample recorded the lowest fat content while samples of 9 mm slice thickness of sun-dried samples and 9 mm slice thickness of solar-dried sample recorded the highest value of fat content. It is also evident that the fat content of the 3 mm slice thickness of the sun-dried sample and cabinet-dried sample is not significantly different.

4. CONCLUSION

The results of the study indicated that subjecting garden eggs to different drying methods affects the moisture content, drying rates, effective moisture diffusivity and proximate composition present in the garden egg slices. The moisture content decreased as drying time increased. The lowest moisture contents were obtained in the sun-dried and cabinet-dried sample having a slice thickness of 3 mm while the highest moisture contents were obtained in the sun-dried sample having a slice thickness of 9 mm. The drying rate decreased as drying progressed and it increased with an increase in drying time. The effective moisture diffusivity also increased with an increase in slice thickness. Degradation of crude fat was observed whereas, crude protein, crude fibre and ash content increased for all slice thickness and the drying methods used.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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