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(RESEARCH ARTICLE)

Effect of Slices Thickness on Drying Time and Drying Rate for Okra (*Abelmoscus esculentus L.*) Drying Using Natural Convective Solar Drier

Abdel Moneim O. A. Babiker [1], Mortada H.A. Elhesain [1, *], Mohamed Mahdi Musa [1], Mohammed M. Bukhari [2], SH. E. Idriss [1], Sulieman O. A. Figeada [1], Mohammed Abdalla [1], Mohammed M. Widatalla [1] and S. E. Ehilo [1]

[1] *Department of Food Processing Engineering, Faculty of Engineering and Technical Studies, University of El Imam El Mahdi, Kosti – Sudan.*
[2] *Department of Chemical Engineering, Faculty of Engineering, University of El Imam El Mahdi –Kosti – Sudan.*

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Abstract

This study was conducted at the Department of Food Processing Engineering –Faculty of Engineering and Technical Studies – University of El Imam El Mahdi – White Nile State, Kosti- Sudan. The objective of the present study is to know the effect of slices thickness on the drying time and drying rate of Okra using natural convective solar drier. Three thicknesses of Okra slices were chosen, these are 3mm, 5mm and 7mm. The results show that as the thickness of slices was increased the drying time was increased. The drying time of 3mm, 5mm and 7mm thickness were found to be11, 13 and 15 hours respectively. The drying rate (g of water/g DM.h) depends on the thickness of slices and the drying air temperature; if the temperature of the drying air is higher there is a progressive increase in drying rate. The maximum increase in drying rate of 3mm, 5mm and 7mm slices thickness were found to be 259.48, 141 and 223 (g of water/g DM.h) respectively. The low drying rate of 3mm, 5mm and 7mm slices thickness were found to be 44.46, 38.53 and 0.82 (g of water/g DM.h) respectively.

Keywords: Okra; Slices thickness; Solar drying; Drying time and drying rate

1. Introduction

Drying is one of the oldest and most widely used methods of food preservation. However, it remains a challenging process due to the potential for undesirable changes in product quality. The main purpose of drying is to lower the water activity of foods, thereby inhibiting microbial growth while also reducing physical and chemical deterioration during storage, which ultimately enhances the stability and shelf life of the product. (HA, E, et al., 2021). Drying is the process of removing moisture from a solid material through evaporation. Its primary objectives are to extend the storage life of products, decrease packaging needs, and lower transportation weight and costs. (Abdalla, et al., 2023). Drying is one of the standard methods to reduce water content in food. (Hassan, et al., 2025). Sun drying is one of the most common and widely practiced methods of food preservation worldwide. It is simple, low-cost, and easy to apply. However, this method has several drawbacks, including dependence on weather conditions, exposure to contamination by insects, dust, dirt, and sand, as well as the relatively long time required for the drying process. (Babiker, et al., 2024). The sun drying method can be done at the domestic or farm level for quick and uncomplicated preservation. (Hassan, et al., 2025). Okra (*Abelmoschus esculentus L.* Moench) belongs to Malvaceae family. The fresh fruit is a good source of vitamins, fiber, minerals, phosphorus, calcium and protein. Okra is commonly used for its tender pods. (Meena, et al., 2019). Okra is one of the most popular vegetable crops grown throughout the tropics of the world during spring and summer seasons. It is valued for its edible green seed pods. The plant is cultivated in tropical, subtropical and warm temperate regions around the world. (Mohammad et al., 2017). Slice thickness is one of the most important factors affecting the drying behavior of fruits and vegetables. Thicker slices generally have a lower drying rate because heat and moisture take longer to penetrate the center of the material, resulting in extended drying times. In contrast, thinner

* Corresponding author: Mortada H.A. Elhesain

slices allow faster heat transfer and more efficient moisture removal, which shortens the drying period. However, extremely thin slices may lead to quality issues such as shrinkage, texture degradation, or nutrient loss. Therefore, optimizing slice thickness is essential to achieve a balance between drying efficiency and product quality (Doymaz, 2005; Rahman, 2007). Okra (Abelmoschus esculentus L.) is a perishable vegetable with high moisture content, which makes it deteriorate quickly after harvest. Drying is an effective preservation method, but its efficiency is strongly influenced by slice thickness, especially under natural convective solar drying where conditions are not mechanically controlled. Thicker slices may slow down drying while thinner slices may affect quality. This study aims to evaluate the effect of slice thickness on drying time and drying rate of okra using a natural convective solar dryer, with the goal of identifying the optimum slice thickness for efficient drying and better product quality. Studying the effect of slice thickness on okra drying behavior helps in optimizing drying conditions for better efficiency and product quality.

2. Materials and Methods

This research was conducted at the Department of Food Processing Engineering –Faculty of Engineering and Technical Studies – El Imam El Mahdi University– White Nile State, Kosti- Sudan.

In this study the slices of Okra (*Abelmoscus esculentus L.*) with three thickness 3mm, 5mm, and 7mm were dried using solar drying method

2.1. Equipment

- **Solar dryer:** A previously constructed natural convective solar dryer used for carrying out the drying trials of Okra slices, Plate 1
- **Data logger:** DL 2e Detta logge, At. Delta-T Devices, Cambridge, England. Connected to thermocouples for temperature measurements, Plate 2
- **3- Hygrometer:** A digital hygrometer of Testo GMbH type 6350, made in Germany was used for measuring relative humidity of the air, Plate 3
- **4-Sensitive balance**: A digital sensitive balance of model Yass-620 with capacity of 620 g and accuracy of ±0.01 g. Scale of Yamato make, made in Japan was used for moisture content determination of Okra, Plate 3.4
- **5- Oven:** An oven of Electro Helios make was used for fish moisture content determination and it had a temperature range of 0-200ºC
- **6- Crucibles:** were used for holding the samples in the oven for drying and moisture content determination.

Watch: was used to record the time7 -

Figure 1 Natural convective solar dryer dryer Ddryer PLATE 1

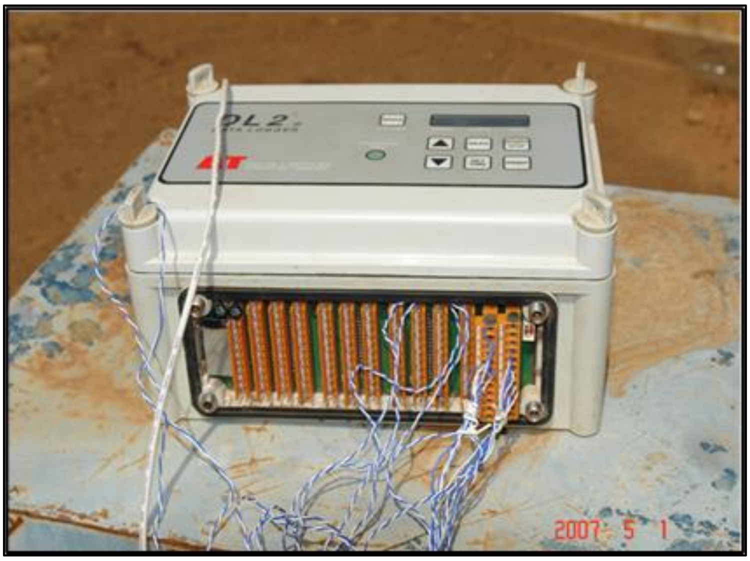

Figure 2 Data Logger to which thermocouples were connected

Figure 3 Digital hygrometer for measuring relative humidity (%)

Figure 4 Sensitive balance for moisture content determination

The dryer was placed on open wide area in order to get a maximum exposure to solar radiation. The dryer consists of three components namely; solar collector (air heater), drying chamber and air duct, for connecting solar collector to the drying chamber

2.2. The preparation of Okra for drying

Fresh Okra that immediately harvested and brought from the farm at EL-Hudab area (south Rabak city) were cut into slices (3mm,5mm and 7mm) using stainless knife, wooden board and ruler . The weight of 30 gram from each thickness (3mm, 5mm and 7mm) were taken and warped with aluminium foil for moisture content determination. The remaining Okra were spread in the tray and put in the drying chamber of the dryer to carry on the drying test using solar dryer. The starting time of drying process was recorded using a hand watch. Initially at zero time the following measurements were recorded.

- Temperature measurement: The temperature was measured at the following locations:
  - Near the entrance of solar collector ambient air temperature
  - At the entrance of the drying chamber (heated air temperature)
  - At the top opening of the drying chamber (exhausted air
  - Temperature
  - Humidity measurements
- Relative

The relative humidity was measured at the following locations:

- Near the entrance of solar collector (ambient air RH%)
- At the entrance of the drying chamber (heated air RH%) RH %)
- At the top opening of the drying chamber (exhausted air

The above-mentioned measurements were recorded at intervals of one hour throughout the experimental period, which took two interrupted by one overnight. At the end of the drying period a representive sample was taken and wrapped with aluminium foil for final moisture content determination using the oven method

2.3. Moisture content determination

Initial and final moisture content was determined according to the method described by (AOAC, 1990). In this method, duplicate samples of fresh and dried Okra were used for initial and final moisture content, respectively. Two aluminium cans were washed and put into the oven for about 3 hours to dry, and then the dishes were taken from the oven and placed into desiccators to cool to get their true weights. The aluminium cans were weighed using a sensitive balance then the samples were placed in the cans and weighed to get the total weighed of the can and the sample. To avoid loss or gain of moisture while weighing aluminium foil were used to wrap the samples. The weighed sample was placed into the oven, and the oven was set at 75 Cº for overnight. After that the samples were taken out and placed into the desiccators and left for about 20 minutes to cool. Then the samples were weighed using the sensitive balance. The moisture content of the samples was calculated using the Following equations:

i) $$MC(w.b.) = \frac{W_w}{W_w + W_d} \times 100 \quad \text{......(1)}$$

ii) $$MC(d.b.) = \frac{W_w}{W_d} \times 100 \quad \text{......(2)}$$

Where:-
MC (w.b.) = Okra moisture content on wet basis, percentage
MC (d.b.) = Okra moisture content on dry basis, percentage
Ww = mass of water, g
Wd = mass of dry matter, g

Drying rate calculation

The drying rate was calculated by using the following equation (Akpinar *et al.*,2003):

$$DR = \frac{M(t+dt)-Mt}{dt} \quad \text{...(3)}$$

Where:
DR= Drying rate, g of water/g DM.h
Mt= moisture content at time t, dry basis (percentage)
M(t+dt) =moisture content at time t+dt, , dry basis(percentage)
dt= the time interval, h

3. Results and Discussions

Table 1 Average initial weight, dry matter (DM), initial moisture content MC (w.b. and d.b.) and drying time for Okra slices solar drying with three thickness 3mm,5mm,7mm

Trial No.	Slices thickness of Okra	Initial wt. (g)	DriedWt. (g)	DM wt. (g)	Initial MC w.b. (%)	Initial MC d.b. (%)	Drying Time (h)
1	3 mm	30	4.73	2.84	90.50	956.34	11
2	5 mm	30	5.68	2.84	90.50	956.34	13
3	7 mm	30	5.68	2.84	90.50	956.34	15

As shown in Table 1 drying of Okra slices start with an average initial weight of 30 gram for representive slices and average initial moisture content wet basis and dry basis of 90.50% and 956.34 % respectively. The total drying time of Okra slices through the two drying days is 11,13, and 15 hours for 3mm, 5mm and 7mm slices respectively. The dry matter (DM) was found to be 2.84 gram for each 30 gram of Okra slices.

Table 2 Variation of weight losses with drying time for three thickness of Okra slices (3mm, 5mm, 7mm) using solar drying method

Drying Period		Average weight of 3mm thickness	Average weight of 5mm thickness	Average weight of 7mm thickness
Time	Hours			
0	8:00 a.m.	30	30	30
1	9:00	23.66	26.55	28.4
2	10:00	17.99	23.66	28.4
3	11:00	13.25	21.36	25.55
4	12:00	11.36	17.99	22.78
5	1:00 p.m.	9.47	16.09	22.72
6	2:00	8.52	15.15	19.88
7	3:00	6.63	13.25	17.04
8	4:00	6.63	10.41	14.2
-	-	overnight	overnight	Overnight
9	8:00 a.m.	6.63	10.41	14.2
10	9:00	4.73	9.47	11.36
11	10:00	4.73	7.57	10.47
12	11:00	4.73	5.68	8.52

13	12:00	-	5.68	6.63
14	1:00 p.m.	-	5.68	5.86
15	2:00	-	-	5.86
16	3:00	-	-	5.86
17	4:00	-	-	-

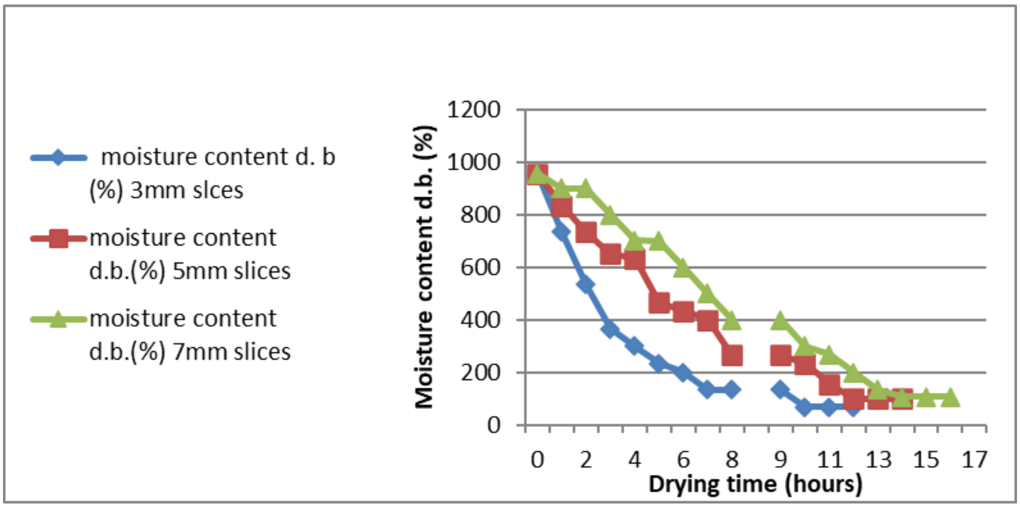

Figure 5 Variation of moisture content with drying time for Okra slices solar drying with thickness of 3mm, 5mm, and 7mm

The Solar Drying Kinetics of Okra slices:

Fig. 1 shows the variation of drying rate with drying time for the two days of the drying. It is clear that, drying process interrupted by one overnight. There is no constant drying rate period in the drying of Okra slices and all the drying process occurs during the falling rate period. This indicates that, the initial moisture content of Okra slices is lower than its critical moisture content and diffusion is the most physical mechanism governing moisture content in the Okra slices. The diffusion takes place in the inner wet region of Okra and water will evaporated as it reaches the surface (negligible resistance to mass transfer).This means that the assumption of movement of water takes place in falling rate period and liquid diffusion governs moisture transfer is also valid. These results were in agreement with (Ayoub, 2006) in her study of mathematical modelling of solar drying of tomato slices

Table 2 and Fig. 1 show the variation of moisture content with time for three thicknesses of Okra slices. As shown in the Figure it is clear that when the thicknesses of slices were increased the drying time was increased also and vice versa. Thinly sliced products dried faster due to reduced distance the moisture travels and increased surface area exposed for a given volume of the product. The slices of 7mm thickness took 15 hours to dry, while the slice of 5mm took 13 hours to dry, but the slice of 3mm took 11 hours to dry. These results were in a good agreement with (Al-Halfi,2007). He found that, the thicker slices the longer the drying time

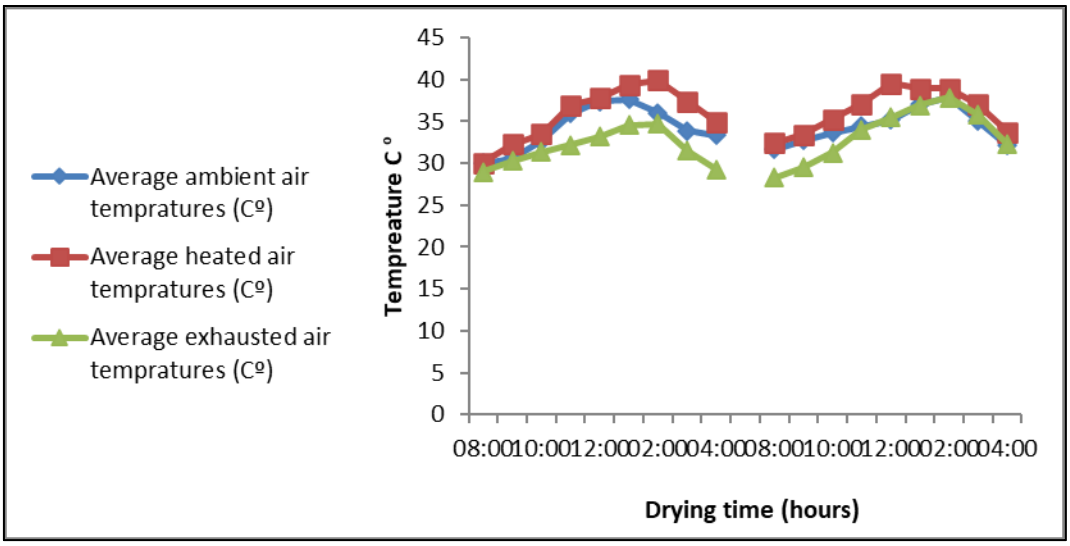

Figure 6 Average Ambient, heated and exhausted air temperatures for Okra slices solar drying

Fig. 2 shows the average ambient air, heated air and exhausted air temperatures plotted versus drying time of Okra slices during two consecutive days. There is a remarkable difference between ambient air and heated air temperatures. Generally, all air temperatures increase to a maximum value at about noon and then fall progressively towards evening period. The increased air temperature inside solar collector (heated air temperature) was attributed to high solar radiation collected inside the solar collector and this resulted in raising the temperature of the drying air in the drying chamber of solar drier. When the drying air passed through the product (Okra slices) in drying chamber there is a simultaneous heat and mass transfer this resulted in exhausted air with low temperatures and high relative humilities.

Table 3 Drying rate (g water/g DM.h) for Okra solar drying with different thickness slices (3mm, 5mm,7mm)

Drying Period		3mm thickness	5mm thickness	7mm thickness
Time	Hours			
0	8:00	259.84	141	143.44
1	9:00	232.37	118.44	12.54
2	10:00	194.27	94.26	193.86
3	11:00	77.46	138.11	223.36
4	12:00	38.93	38.53	81
5	1:00	77.46	77.87	38.95
6	2:00	77.46	116.39	122.95
7	3:00	0	0	0.82
8	4:00	0	38.53	0
-	-	**overnight**	**overnight**	**overnight**
9	8:00	77.87	77.86	109.02
10	9:00	0	77.46	38.93
11	10:00	0	0	0
12	11:00	0	0	77.46
13	12:00	0	0	127.46
14	1:00	0	0	38.93

15	2:00	0	0	0
16	3:00	0	0	0
17	4:00	0	0	0

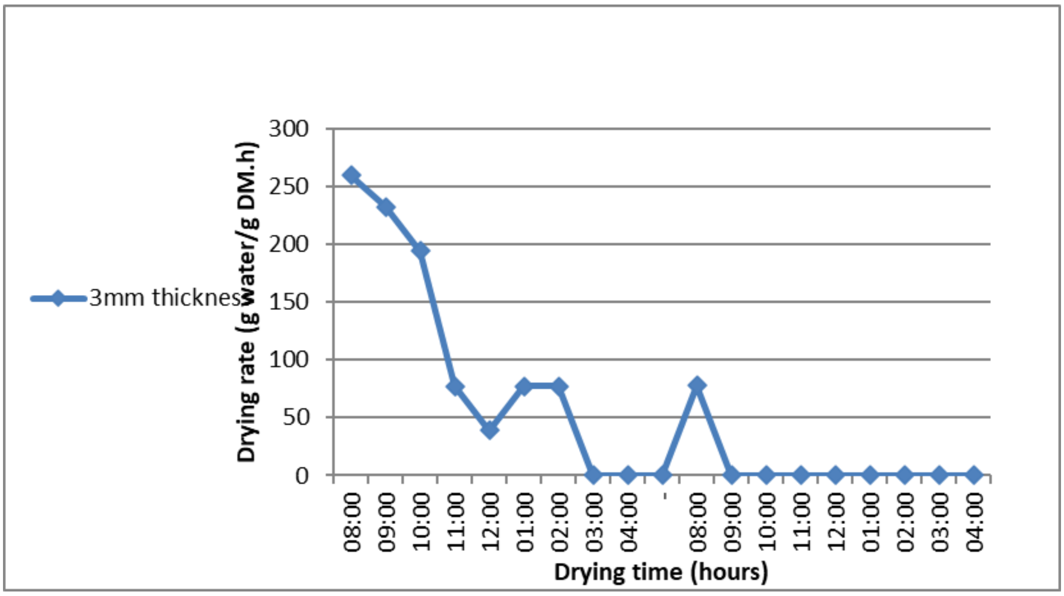

Figure 7 Variation of drying rate with drying time for Okra solar drying slices 3mm thickness

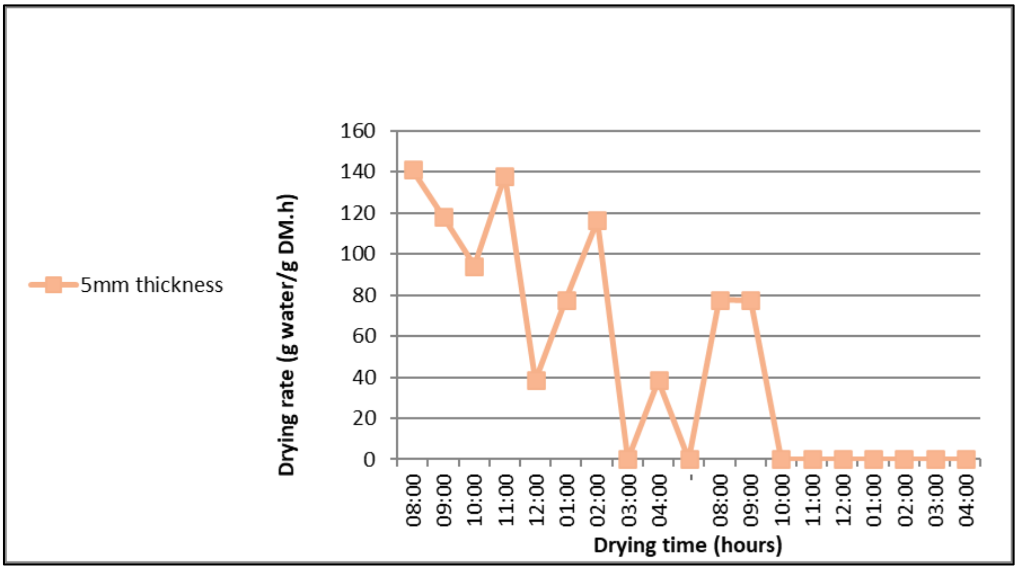

Figure 8 Variation of drying rate with drying time for Okra solar drying slices 5mm thickness

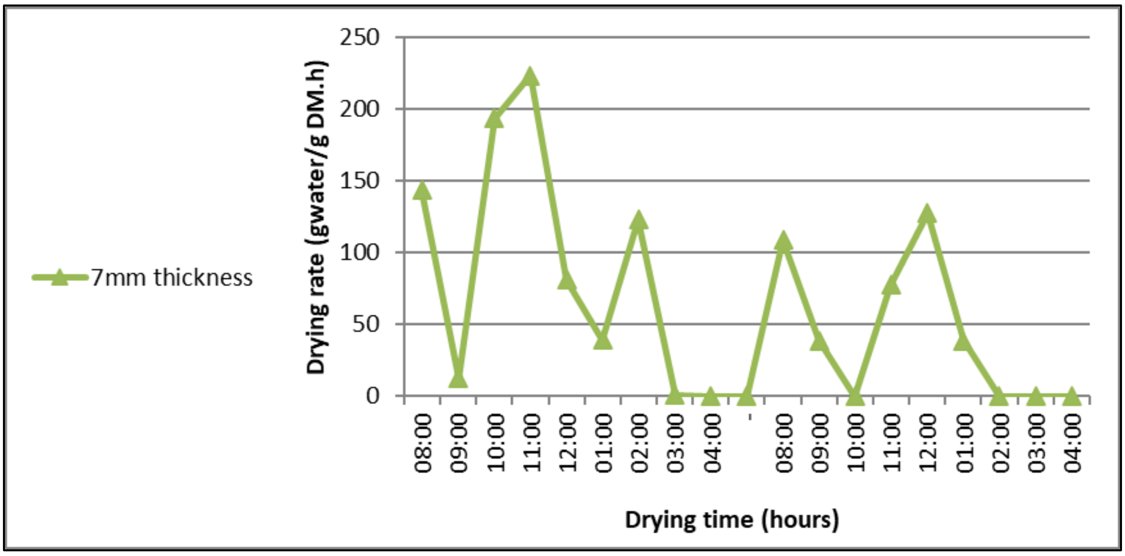

Figure 9 Variation of drying rate with drying time for Okra solar drying slices 7mm thickness

Figs 3,4 and 5 show the variation of drying rates for Okra using solar drying method at different thickness (3mm,5mm,7mm) . In Table 3 and Figs 3,4 and 5, we find that the drying rate increases and decreases with time. This is attributed to the rise and fall of the drying air temperature. The higher the drying temperature, the greater the drying rate, and the lower the temperature, the lower the drying rate. This study is consistent with the study conducted by (Halabo., et al., 2008). It is clear that as the thickness of the product increase the drying time will increase depending on the degree of drying air temperatures so that the curves of drying rate were fluctuated, when the temperatures of drying were higher the drying rates were higher also. The drying rate is higher at the beginning of the drying process and decreased continuously with the advance of drying time. Also, it is clear that, there is no constant drying rate period in the drying of Okra slices and all the drying process occurs during the falling rate period. In Figs 3,4 and 5 the drying rate at the end of the drying process tend to zero, this means that at these drying times , there is no moisture to be removed from internal part of the product i.e this is the end of the drying process. These results were in a good agreement with (Babiker *et. al*., 2024) in their study of effect of solar drying on fish Bayad.

4. Conclusion

When using solar drying method for Okra with different slices thickness, the drying time and drying rate were greatly affected by slices thickness .When drying thickness of Okra slices were increased the drying time was increased considerably, but the drying rate increase with the increasing of slices thickness and heated air temperatures.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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