



INVESTIGATION OF OPTIMAL DRYING MEDIA FOR SELECTED AGRICULTURAL PRODUCE IN NIGERIA

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Abstract

The study was carried out in the raining season to investigate the optimal drying medium for the four-selected agricultural crops common in the South-Western Nigeria. The four different crops used in the research were unripe plantain (*Musa paradisiaca*), okra (*Abelmoschus esculentus* L.), white yam (*Dioscorea rotundata*) and pepper (*Capsicum annum*). All the samples except pepper were sliced to obtain a uniform thickness of 9, 5 and 3 mm for yam, plantain and okra, respectively. They were subjected to drying in an oven, solar dryer and open – sun for five days. The weight loss of each sample and temperature variations were taken as drying process progressed. The assessment of the crops in the oven, solar dryer and open – sun gave an average drying rate (g/hr); okra (7.29, 3.57 and 3.37), pepper (1.35, 1.08 and 0.86), yam (9.97, 5.69 and 6.26) and plantain (7.50, 4.81 and 4.16). Hence, the use of electric oven was found to be most effective while the open-sun medium is the least effective.

Keywords: Agricultural produce, solar dryer, oven, open sun, moisture loss

Introduction

The tropical food crops are plants which are cultivated and managed to obtain food, profit, satisfaction and to increase the social values. Importantly, they are primary source of all nutrients for people (Benke and Bruce, 2017). The agricultural systems must be ensured to provide enough products during all seasons. Among the tropical food crops are okra, yam, cassava, cocoyam, plantain and pepper. Yam (*Dioscorea spp.*) is cultivated in the tropics and it is important staple food in Sub-Sahara Africa. It is a rich source of carbohydrate to the people in this region (Alamu *et al.*, 2014). There are many different edible species of yams, they are usually recognized by the range and colour of their leaves and tubers as well as by the direction of their stem twinning as they climb (Epping and Laibach, 2020). Example of these species is white yam (*Dioscorea rotundata*) usually associated with high digestibility (Epping and Laibach, 2020). Water yam (*Dioscorea alata*) is another example, known to be very high yielding with high moisture content (Oko and Famurewa, 2015). It is higher in protein and mineral content than white yam. Chilli (*Capsicum annum* Linn.) is an important spice and vegetable crop used all over the world in many forms. It is also known as red pepper, it constitutes an important commercial crop

used as condiment, culinary supplement or as a vegetable. Chilli is planted mainly in tropical and subtropical countries namely, Mexico, Africa, India, Japan, Turkey and USA. In India, among the spices consume (per capita consumption) is dried chilli, which contributes a major share (Raji *et al.*, 2017). Chilli which contains high moisture content (300-400% d.b.) after harvest, it is highly perishable and hence its processing and storage are of considerable importance to the farmers, processors and consumers (Raji *et al.*, 2017).

Also, Okra (*Abelmoschus esculentus* L) belongs to the family *Malvaceae*. It is highly grown as a vegetable crop in the tropics, sub-tropics and warmer temperate areas. It is a plant of African Origin, *Abelmoschus esculentus* which was earlier designated as *Hibiscus esculentus* was established by Carlos Lineaus in 1737. In Nigeria, it is known as “Ila” in “Yoruba”, “Kubewa” in “Hausa” and “Okwale” in “Igbo” land (Hussein *et al.*, 2018). Okra is a prominent fruit and leafy vegetable grown for domestic consumption of the highly nutritious immature leaves and fruits in Nigeria (Gemedede *et al.*, 2015). According to Food and Agriculture Organization (FAO) of the United Nations in 2007, okra production all over the world was about

5,941 million tonnes. The major producer countries include India, Nigeria, Sudan, Pakistan, Iraq and Ghana (FAO, 2009). Okra can be consumed as a fresh vegetable, cooked vegetable or an additive for soups, salads and stews (Aamir and Boonsupthip 2017).

The last crop selected in this study is Plantain (*Musa paradisiaca*), it is extensively cultivated in the tropics, and serves as a staple crop for over 70 million people of the sub-Saharan Africa (Louis and Peter, 2009). It is commonly used for its carbohydrate content and can be consumed as unripe fruit or when ripe (Louis and Peter, 2009). Traditional processing methods require boiling, roasting or frying. When processing into flour, it can be used as a component of baby food (Odeku, 2013). Unripe dried plantain pulp consists of 83% starch (Bezera et al., 2013), hence the rheological properties of plantain are determined by the nature of the starch materials.

The major challenge of these tropical food crops is how to preserve them during the raining period when they are abundant such that, there would be enough reservation for their consumption during the dry season. Since these food crops are highly perishable after harvest, drying was employed for preserving them to make them available throughout the year. Previous researches revealed that various agricultural produce have different moisture contents and one of the main problems facing Nigerian farmers has remained the lack of convenient method of preserving the agro-produce which is usually produced in larger quantities during harvest. It's therefore important to know which method of drying best suite this preservation process. These crops were subjected to drying in an oven, solar dryer and open – sun for five days to determine the

appropriate drying medium for various specific agricultural products.

Materials and Methods

This research experimentation was conducted during the raining season. Four agricultural products were used for the experiment. The four agricultural produce were purchased from the Oje market, Ibadan, Oyo State, Nigeria. Each crop was thoroughly washed to remove the dirt and foreign impurities after which the plantain and yam were peeled. All the samples except pepper were sliced to obtain a uniform thickness of 9, 5 and 3 mm for yam, plantain and okra respectively using kitchen knife. Samples of all the four-investigated produce were divided into three groups; A, B and C, the initial mass of each group was measured by means of a digital balance. The initial moisture content of the plantain, yam, pepper and okra samples were 65%, 68%, 63% and 88% (db), respectively. The samples were also weighed after the drying periods with a digital balance to determine the weight (moisture) loss of each sample.

Drying Process

The samples in the group A were dried in a solar dryer accessed at the Institute of Agriculture Research and Training (IAR&T), Apata Area, Ibadan, Nigeria between 10am to 3pm for five days. Also, the samples in group B were dried in an open sun between 10am to 3pm for five days as the weather dictated. In the same way, the samples in group C were dried in an electric oven maintained at a constant temperature of 45°C for period of 3hours per day. Clinical thermometers were used to measure the temperature in the drying chamber of the solar dryer and the ambient temperature of the open sun. The fresh samples of the selected crops and solar dryer were presented in Figures 1-3.



Figure 1: Fresh samples of the crops



Figure 2: Front elevation of the solar dryer



Figure 3: Isometric view of the solar dryer



Figure 6: Sample of plantain dried in a solar dryer



Figure 4: Sample of plantain dried in open sun



Figure 5: Sample of dried plantain in an oven



Figure 7: Sample of yam dried in open sun



Figure. 8: Sample of yam dried in a solar dryer



Figure 9: Sample of yam dried in an oven



Figure 10: Okra sample dried in open sun



Figure 11: Okra sample dried in an oven



Figure 12: Okra sample dried in the solar dryer

Results and Discussion

Figures 4 –12 presents dried samples. Table 1 displayed the properties of the solar dryer while the results of average drying rate and the percentage

moisture content for okra, pepper, yam (sliced) and plantain (sliced) of the tests were recorded in Tables 2-13, respectively. The maximum temperature recorded in the solar dryer was 49°C.

Table 1: Location (Ibadan, Nigeria) and Solar Dryer Properties

Solar dryer properties	Measurement taken
Average incident sun intensity	20 MJ/m ² day
Latitude and longitude	07°22'N and 03°8'E
Air density	1.2754 Kg/m ³
Specific capacity of air	1.00 KJ/KgK
Solar collector area (total)	0.476 m ²

The Table 2 showed a similar reduction in the average drying rate and the percentage loss in moisture content of the okra sample dried in the solar dryer from the first day till the fifth day. On the first day, average drying rate

was 8.18 g/hr and reduced to 3.57 g/hr on the fifth day. Similarly, moisture content followed the same trend with 29.38% reduction.

Table 2: Okra Sample Inside the Solar Dryer

Day	Initial mas M_i (g)	Final mass M_f (g)	Diff. in mass $M_i - M_f$ (g)	Average drying rate	Moisture content (%)	Ambient temp. ($^{\circ}\text{C}$)	Dryer Temp. ($^{\circ}\text{C}$)
1	170.00	129.10	40.90	8.18	24.06	40	47
2	112.10	97.90	14.20	5.51	12.67	40	48
3	87.50	73.70	13.80	4.59	15.77	34	47
4	66.50	55.00	11.50	4.02	17.29	38	43
5	51.80	43.00	8.80	3.57	16.99	42	49

Also, in the open sun medium as shown in Table 3, the maximum ambient temperature recorded was 40°C

and the average drying rate was ranged to be $9.04 \text{ g/hr} - 3.37 \text{ g/hr}$ from the first day to the fifth day with 50% moisture loss.

Table 3: Okra Sample in Open Sun

Day	Initial mas M_i (g)	Final mass M_f (g)	Diff. in mass $M_i - M_f$ (g)	Average drying rate	Moisture content (%)	Ambient temp. ($^{\circ}\text{C}$)
1	170.00	124.80	45.20	9.04	26.59	40
2	105.00	91.50	13.50	5.87	12.86	40
3	82.50	72.70	9.80	4.57	11.88	34
4	66.70	58.20	8.50	3.85	12.74	38
5	54.20	47.00	7.20	3.37	13.28	42

In the same way, the results for an okra sample dried in an oven as shown in Table 4 revealed that the average drying rate was 14.4 g/hr on the first day, 13.63 g/hr on

the second day and followed the same trend till the fifth day when the value 6.67 g/hr was recorded. Similarly, moisture content reduced to 73.75%.

Table 4: Okra Sample in Oven

Day	Initial mas M_i (g)	Final mass M_f (g)	Diff. in mass $M_i - M_f$ (g)	Average drying rate	Moisture content (%)	Oven temp. ($^{\circ}\text{C}$)
1	170.00	126.80	43.20	14.40	25.41	45
2	120.00	81.40	38.60	13.63	32.17	45
3	78.50	59.70	18.80	11.18	23.94	45
4	54.70	49.20	5.50	8.84	10.05	45
5	48.00	44.80	3.20	7.29	6.67	45

Figure 13 showed the drying rate of okra sample as a function of the drying time. As seen from the curve, the drying rate of the sample in the oven is far higher than similar drying rate of the solar and open-air drying. The lower drying rate observed in the solar and open-

sun drying process may be attributed to the low intensity of the sun. However, (Eze and Agbo, 2011) reported a higher drying rate in solar dryer compared to open sun drying. This may be attributed to the fact that the two media are solar radiation dependent.

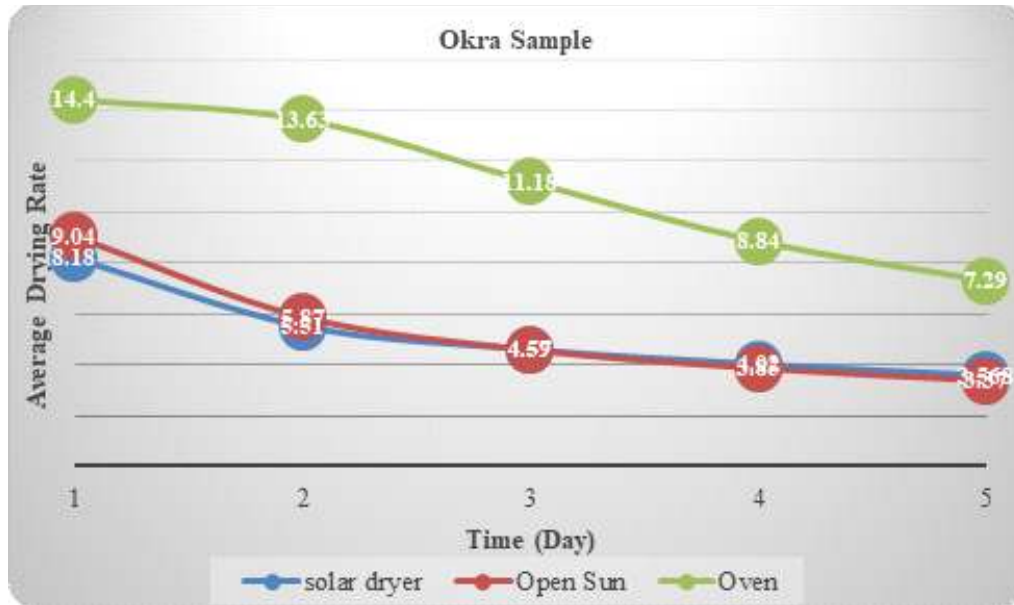


Figure 13: Drying Curve for okra sample

Also, Figure 14 presented the moisture loss in the okra sample in the three media. There was high moisture loss in the sample dried in an oven on the first and second day of drying. This could be attributed to the low solar intensity in these days, these lines with the earlier finding (Rashidi *et al.*, 2021). There was

reduction in moisture loss in the sample dried in an oven on the third day, a little amount of moisture loss was recorded on the fourth day and the fifth day in the oven compared to the other two media. The reason may be the sample in the oven gets dried, the moisture loss reduces.

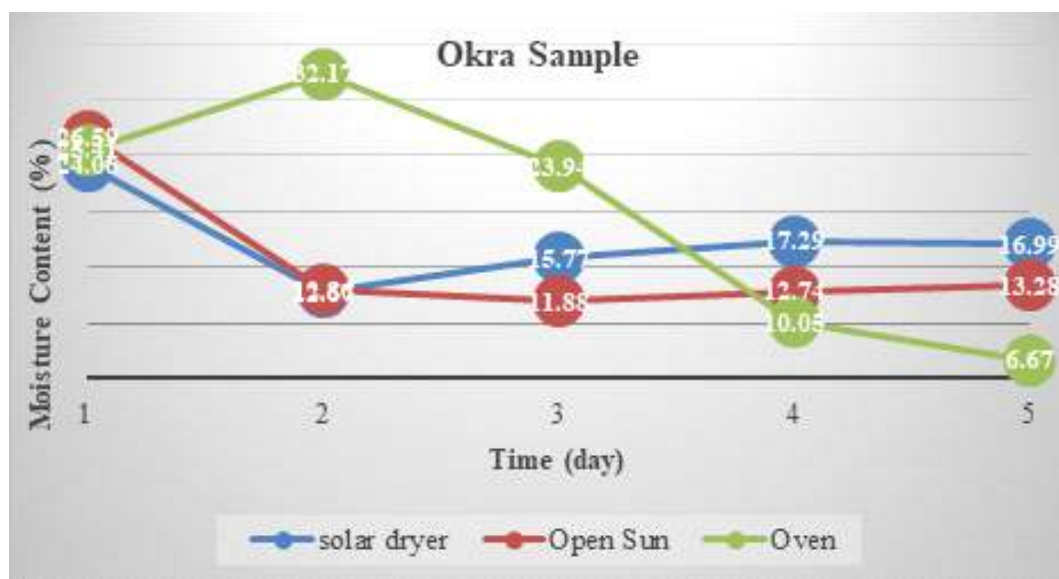


Figure 14: Drying curve for okra sample

Table 5 showed the pepper sample dried inside the solar dryer with the maximum temperature of 49°C. The sample had the average drying rate of 1.78 g/hr,

1.6 g/hr, 1.30 g/hr, 1.18 g/hr and 1.08 g/hr on the first, second, third, fourth and fifth day, respectively while the percentage moisture content ranged from 9.89 to 8.31 from the first day to the fifth day.

Table 5: Pepper Sample Inside the Solar Dryer

Day	Initial mas M _i (g)	Final mass M _f (g)	Diff. in mass M _i -M _f (g)	Average drying rate	Moisture content (%)	Ambient temp. (°C)	Dryer Temp. (°C)
1	90.00	81.10	8.90	1.78	9.89	40	47
2	76.20	69.10	7.10	1.60	9.32	40	48
3	64.60	61.10	3.50	1.30	5.42	34	47
4	53.30	49.20	4.10	1.18	7.69	38	43
5	40.90	37.50	3.40	1.08	8.31	42	49

Also, the results obtained from the pepper sample dried in an open sun are presented in Table 6 with average drying rate of 1.48 g/hr, 1.16 g/hr, 1.02 g/hr, 0.93 g/hr and 0.86 g/hr on the first, second, third, fourth and fifth

day, respectively while the percentage moisture content was ranged from 8.22 to 5.82 from the first day to the fifth day with the maximum temperature of 42°C.

Table 6: Pepper sample in the Open Sun

Day	Initial mas M _i (g)	Final mass M _f (g)	Diff. in mass M _i -M _f (g)	Average drying rate	Moisture content (%)	Ambient temp. (°C)
1	90.00	82.60	7.40	1.48	8.22	40
2	80.00	76.00	4.20	1.16	5.24	40
3	71.30	67.60	3.70	1.02	5.19	34
4	62.00	56.70	3.30	0.93	5.32	38
5	49.80	46.90	2.90	0.86	5.82	42

The results of the pepper sample dried in an oven as presented in Table 7 revealed that the average drying rate was 2.37 g/hr on the first day, 2.12 g/hr on the

second day and followed the same trend till the fifth day when the value was 1.35 g/hr. Similarly, the percentage moisture content reduced from 7.89 on the first day to 4.72 on the last day.

Table 7: Pepper Sample in The Oven

Day	Initial mas M _i (g)	Final mass M _f (g)	Diff. in mass M _i -M _f (g)	Average drying rate	Moisture content (%)	Oven temp. (°C)
1	90.00	82.90	7.10	2.37	7.89	45
2	80.40	74.80	5.60	2.12	6.97	45
3	75.30	71.00	4.30	1.89	5.71	45
4	60.20	56.60	3.60	1.72	5.98	45
5	50.80	48.40	2.40	1.35	4.72	45

Figure 15 showed the drying rate of the pepper sample. From the curve, it was obvious that the drying rate of the oven is far greater than that of the solar dryer and

the open – sun. The three curves virtually followed the same trend. The results obtained agreed with earlier finding (Nidhul *et al.*, 2020).

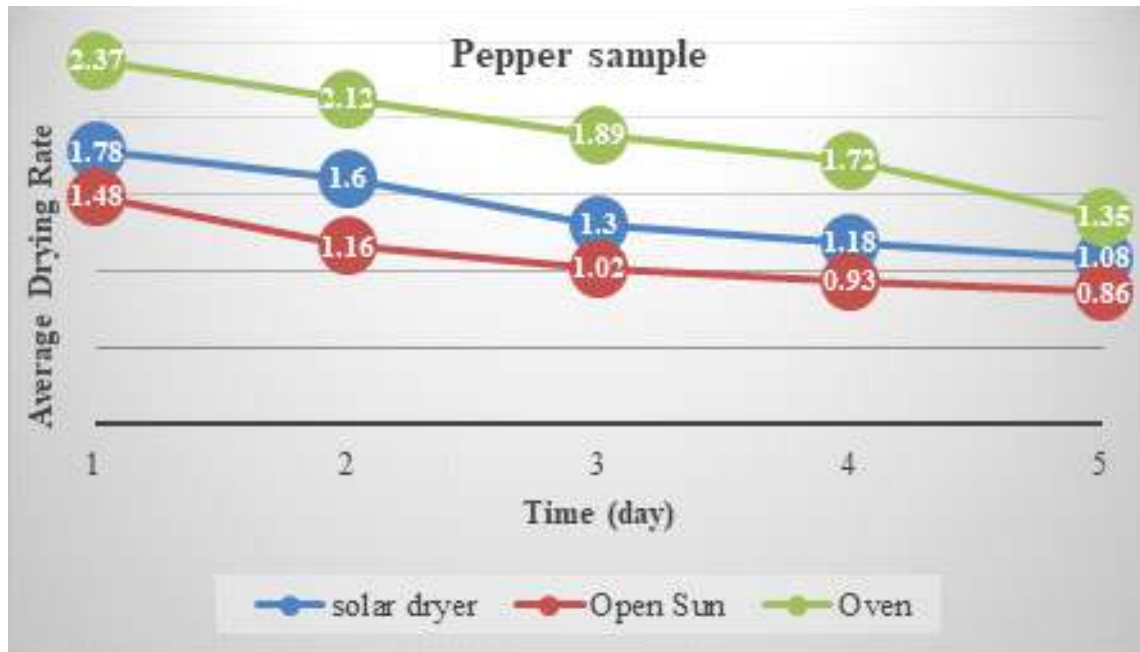


Figure 15: Drying curve for pepper sample

Figure 16 presented the moisture loss rate of the pepper sample. The moisture loss was steady in the oven for the first three days. However, on the fifth day,

the lowest moisture loss was recorded in oven ryer due to the higher rate of drying in the oven when compared to the other two media (Zarein et al., 2015).

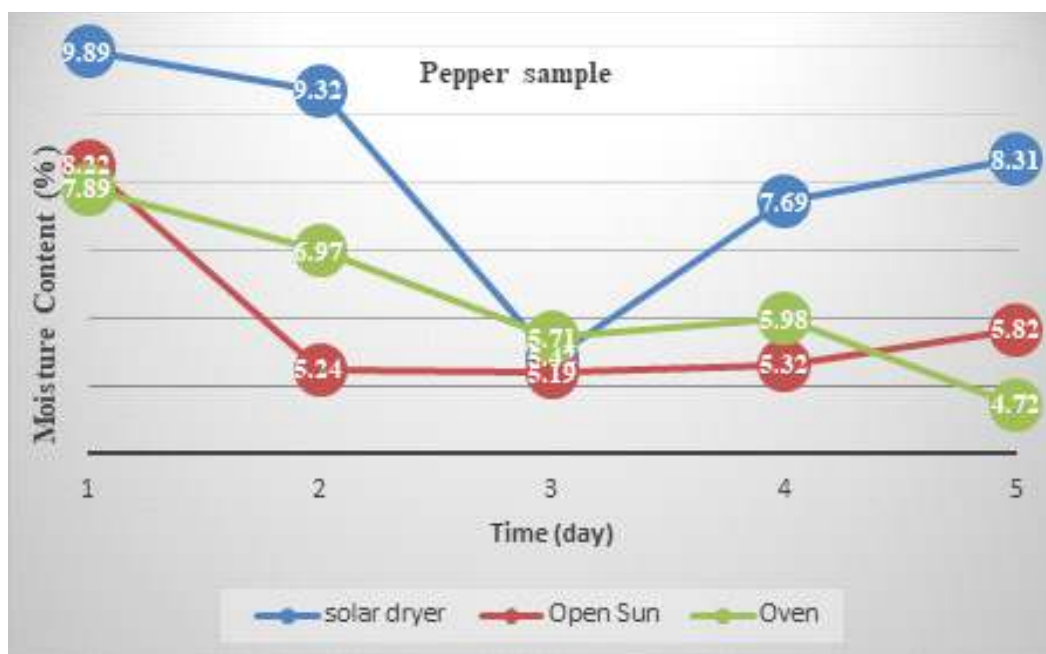


Figure 16: Drying curve for pepper sample

Table 8 presented the result obtained from the yam sample dried in a solar dryer which had the average drying rate of 11.38, 9.10, 7.46, 6.37 and 5.69 (g/hr) on

the first, second, third, fourth and fifth day respectively while the percentage moisture content of 17.78 to 13.32 from the first day to the fifth day was recorded with a maximum temperature of 49°C.

Table 8: Yam (sliced) Sample Inside the Solar Dryer

Day	Initial mas M_i (g)	Final mass M_f (g)	Diff. in mass $M_i - M_f$ (g)	Average drying rate	Moisture content (%)	Ambient temp. ($^{\circ}\text{C}$)	Dryer Temp. ($^{\circ}\text{C}$)
1	320.00	263.10	56.90	11.38	17.78	40	47
2	230.00	196.80	33.20	9.01	14.43	40	48
3	166.80	145.00	21.80	7.46	13.06	34	47
4	125.30	109.80	15.50	6.37	12.37	38	43
5	96.10	81.30	14.80	5.69	13.32	42	49

The results obtained for the yam sample dried in an open sun were presented in Table 9 with the average drying rate of 10.76 g/hr on the first day, 9.50 g/hr on the second day and followed the same trend till the

fifth day when the value was 6.26 g/hr. Similarly, the percentage moisture content reduced from 16.81 on the first day to 12.42 on the fifth day with maximum temperature of 42°C .

Table 9: Yam (sliced) Sample in the Open Sun

Day	Initial mas M_i (g)	Final mass M_f (g)	Diff. in mass $M_i - M_f$ (g)	Average drying rate	Moisture content (%)	Ambient temp. ($^{\circ}\text{C}$)
1	320.00	266.20	53.80	10.76	16.81	40
2	245.10	203.90	41.20	9.50	16.81	40
3	178.00	148.50	29.50	8.30	16.57	34
4	129.50	109.20	20.30	7.24	15.68	38
5	94.20	82.50	11.70	6.26	12.42	42

In the same way, the results obtained for the yam sample dried in an oven are also presented in Table 10 with the average drying rate of 19.20 g/hr on the first day, 15.72 g/hr on the second day and followed the

same trend till the fifth day when the value was 9.97 g/hr. Similarly, the percentage moisture content reduced from 18.00 on the first day to 13.51 on the fifth day.

Table 10: Yam (sliced) Sample in the Oven

Day	Initial mas M_i (g)	Final mass M_f (g)	Diff. in mass $M_i - M_f$ (g)	Average drying rate	Moisture content (%)	Oven temp. ($^{\circ}\text{C}$)
1	320.00	262.40	57.60	19.20	18.00	45
2	237.10	200.40	36.70	15.72	15.48	45
3	182.20	158.30	23.90	13.13	13.12	45
4	140.90	124.60	16.30	11.21	11.58	45
5	111.80	96.70	15.10	9.97	13.51	45

Figure 17 showed the drying rate of the yam sample in the three media. From the curve, though the drying rate of the sample in the oven was greater than that in the solar dryer at the initial stage, the reverse was the case

at the end of the drying period. The drying rate in the open- sun was far lower than the other two media. This was in accordance with the previous report (Babu *et al.*, 2018).

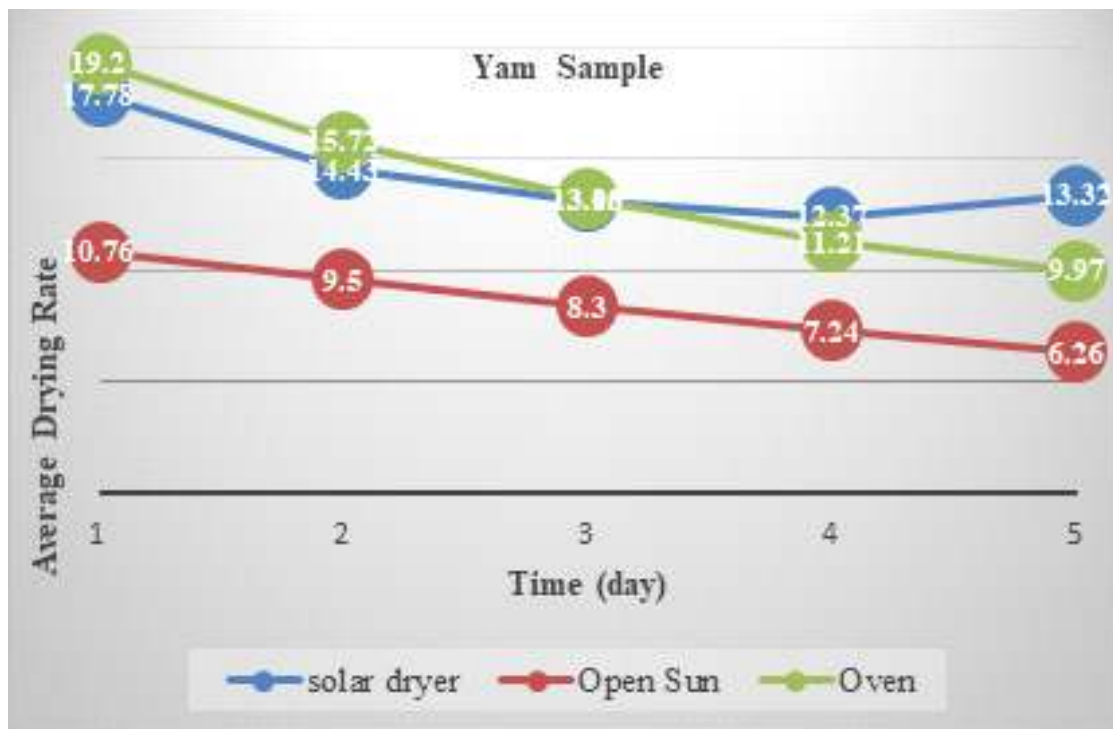


Figure 17: Drying curve for yam sample

Also, Figure 18 showed the moisture loss in the yam sample during the drying period. The curve looked

alike for the solar and oven dried samples but differs for that of the open – sun dried sample.

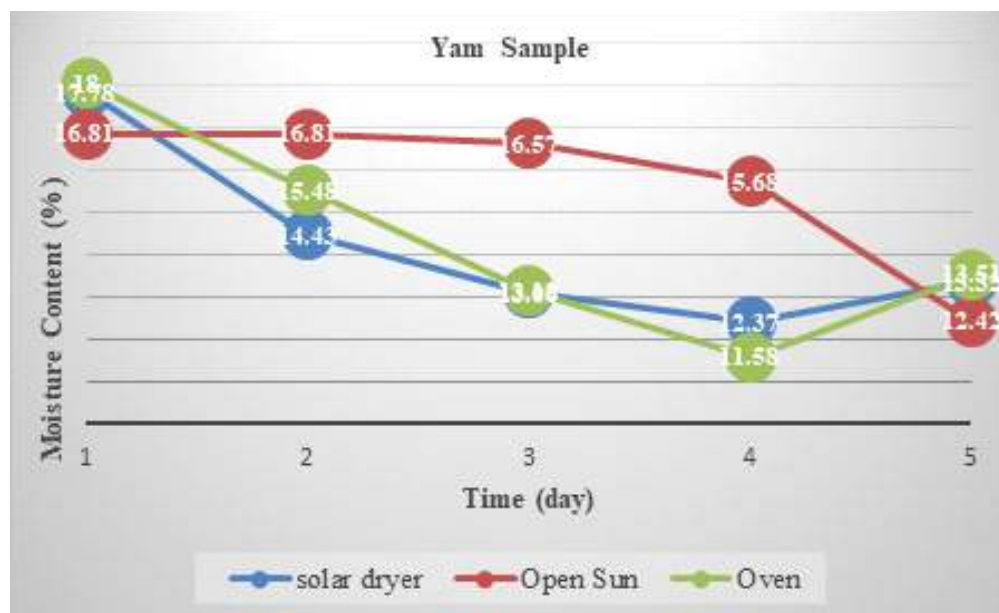


Figure 18: Drying curve for yam sample

Table 11 presented the results obtained from the plantain sample dried in the solar dryer with the average drying rate of 9.38g/hr on the first day, 6.91g/hr on the second day and followed the same trend till the fifth day when

the value was 4.81g/hr. Similarly, the percentage moisture content reduced from 21.32 on the first day to 14.98 on the fifth day. The maximum temperature recorded was 49°C.

Table 11: Plantain (Sliced) Sample Inside the Solar Dryer

Day	Initial mas M_i (g)	Final mass M_f (g)	Diff. in mass $M_i - M_f$ (g)	Average drying rate	Moisture content (%)	Ambient temp. ($^{\circ}\text{C}$)	Dryer Temp. ($^{\circ}\text{C}$)
1	220.00	173.10	46.90	9.38	21.32	40	47
2	168.20	146.00	22.20	6.91	13.20	40	48
3	136.80	114.90	21.90	6.07	16.01	34	47
4	104.40	82.90	17.50	5.43	16.76	38	43
5	78.10	66.40	11.70	4.81	14.98	42	49

Table 12 presented the results obtained for the plantain sample dried in an open with the maximum temperature of 42°C and average drying rate of 8.76 g/hr on the first

day, 6.52 g/hr on the second day and following the same trend till the fifth day when the value was 4.16 g/hr. Similarly, the percentage moisture content reduced from 19.90 on the first day to 12.22 on the fifth day.

Table 12: Plantain (Sliced) Sample in the Open Sun

Day	Initial mas M_i (g)	Final mass M_f (g)	Diff. in mass $M_i - M_f$ (g)	Average drying rate	Moisture content (%)	Ambient temp. ($^{\circ}\text{C}$)
1	90.00	82.60	7.40	1.48	8.22	40
2	80.00	76.00	4.20	1.16	5.24	40
3	71.30	67.60	3.70	1.02	5.19	34
4	62.00	56.70	3.30	0.93	5.32	38
5	49.80	46.90	2.90	0.86	5.82	42

In the same trend, the results obtained for the plantain sample dried in an oven were shown in Table 13 with the average drying rate of 14.27g/hr on the first day, 12.32g/hr on the second day and following the same

trend till the fifth day when the value was 7.57g/hr. Similarly, the percentage moisture content reduced from 19.45 on the first day to 14.30 on the fifth day.

Table 13: Plantain (Sliced) Sample in the Oven

Day	Initial mas M_i (g)	Final mass M_f (g)	Diff. in mass $M_i - M_f$ (g)	Average drying rate	Moisture content (%)	Oven temp. ($^{\circ}\text{C}$)
1	220.00	177.20	42.80	14.27	19.45	45
2	158.00	126.9	31.10	12.32	19.68	45
3	112.30	95.80	16.50	10.04	14.69	45
4	90.10	78.90	11.20	8.47	12.43	45
5	76.20	65.30	10.90	7.50	14.30	45

Figure 19 showed the drying rate of plantain sample in the three media in question. The drying rate in the oven was far greater than that in the other two media. This also may be attributed to the low intensity of the sun during this period. Though the drying rate in the solar

and the open - sun look alike, yet the drying rate in the solar was higher than that of the open – sun. This is in accordance with the report (Eze and Agbo, 2011) who submitted a higher drying rate in solar dryer compared to open sun drying.

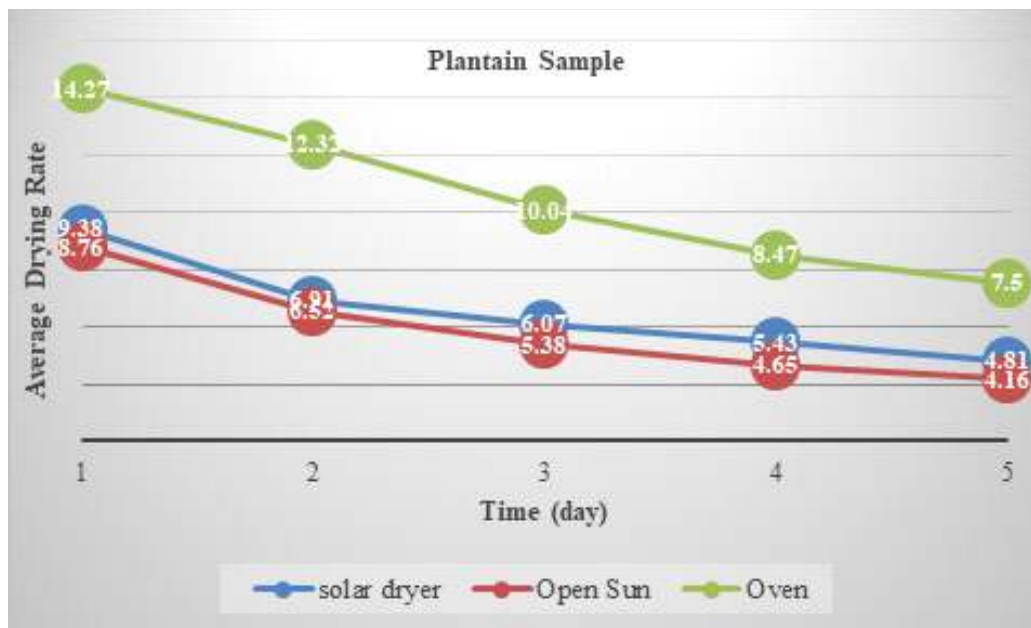


Figure 19: Drying curve for plantain sample

Figure 20 showed the curve of the percentage moisture loss in the plantain sample. The moisture loss was higher in the solar dryer on the first day of drying but drops drastically on the second day. This could be due to lower solar intensity on the second day. The moisture loss was a bit higher in the oven dried sample on the

second day. The reason may be because this medium was maintained at a constant temperature. The moisture loss reduces in the oven dried sample on the third and fourth day. The reason for this could be because the moisture loss reduces as the samples get dried up.

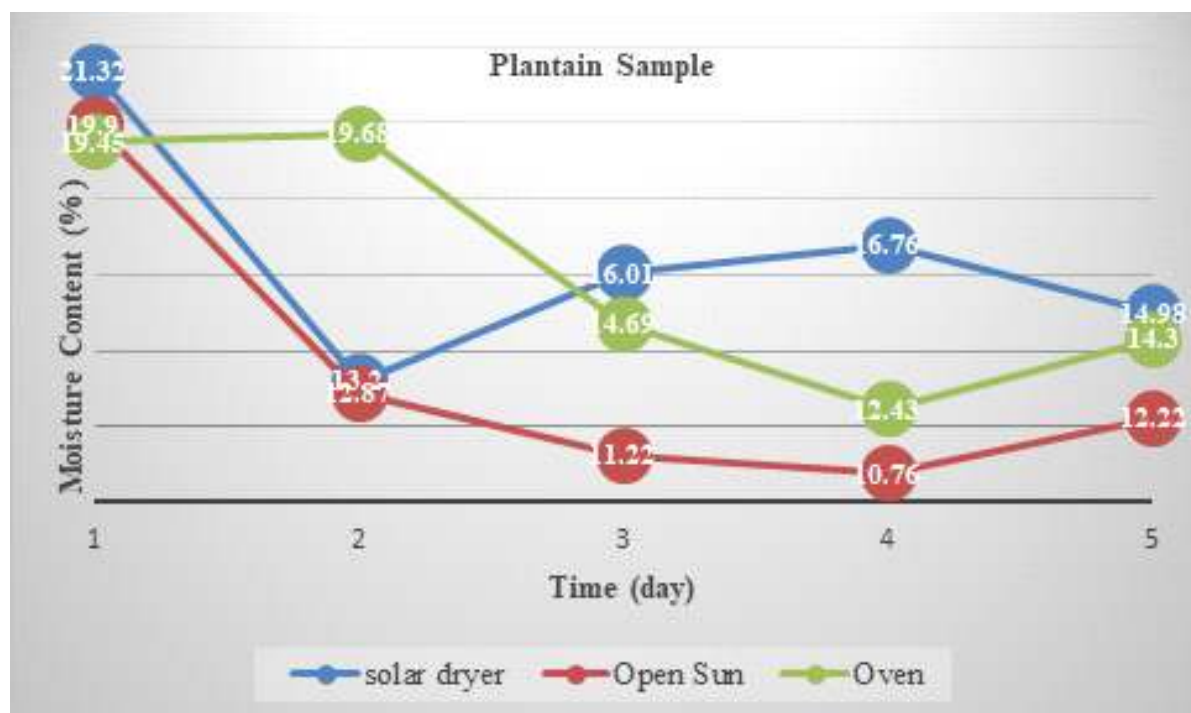


Figure 20: Drying Curve for Plantain Sample

Conclusion

Crop drying in an oven and solar dryer reduced the contamination of the crop by dirt, fungi, insects and animals. The study of the drying process has shown that the oven drying technique was the most effective followed by the solar dryer, this may be attributed to the low intensity of solar radiation in the period of the research experimentation. However, the crops dried via oven process were brown in colour, this may be due to the little or no air circulation in the oven compared to the solar and open-sun drying.

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