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Comparative Study between Different Drying Methods Using Thin-layers of Mango Slices (*Mangifera indica L.*)

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ABSTRACT

Solar, oven and open-direct sun drying experiments in thin-layers of mango slices were conducted at the Department of Food Processing Engineering, Faculty of Engineering and Technical Studies, University of El Imam El Mahdi, Rabak, White Nile State Sudan. The objectives of the study, is to compare between different drying methods of mango, these methods are oven, solar, and open-direct sun drying, Some drying characteristics were used for comparison and evaluation, these are drying time and drying rate. Chemical compositions for fresh and dry mango were done. The change in mass of mango slices were recorded continuously every one hour interval. The results indicated that Fresh sample of mango had (78.77, 1.40, 0.32, 0.55, 9.96 and 9.00) % of moisture, protein, ash, fat, fibers and carbohydrates (on dry wet Basis) respectively. Also results showed that, mango slices were dried from an initial moisture content of 78.8 % (w.b.) for all drying methods to the final moisture content of 0% (w.b.) in 24 hours for oven drying method, while The final moisture content of 22.3% (w.b) in solar drying method with drying time of 18 hours, the final moisture content of 46.7%(w.b.) for open-direct sun drying method with drying time of 16 hours. The drying process occurs in the falling rate period for all the drying methods and more change in moisture occurs in the first day of drying. The drying rate for oven, solar and open-direct sun were found to be (0.78, 0.16 and 0.16)% respectively. Quality analysis of (Moisture content, oil content, ash content, crude fiber, protein content and carbohydrate content) for fresh and dried mango revealed that drying reduce the moisture content and increase the dry matter of mango slices and consequently improved their quality.

1. Introduction

Vegetables and fruits are excellent providers of minerals, vitamins (especially A and C), and easily digested carbs. Roughage, or indigestible carbs, is another benefit they offer and is necessary for a regular, healthy digestion. (Salunkh and Kadam, 1955). Fruits and vegetables can be preserved to reduce significant losses and increase their availability at reasonable rates throughout the off-season. The mango (*Mangifera indica L.)* is a highly significant tropical and subtropical fruit. The mango is referred to as "the king of fruits" due to its widespread popularity in tropical areas (Lauricella et al., 2017). It contains high amounts of sugars and considerable amounts of vitamin C and pro-vitamin A. (Akoy et al., 2013) The mango, a highly valuable tropical fruit, is typically collected in its green state and thereafter sold after being stored for a while. (Léchaudel and Joas, 2007). Sudan and any other countries cultivate mangos which are a popular fruit. Fresh or in a variety of various forms (juice, concentrate, pickling, jam

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jelly, and dried slices) could be consumed. Mango tree is the number one fruit tree in terms of production, followed by banana, date palm and lime. Sudan produces about 5.7% (616.5) tons of the total Arab world production. (Elbashir, 2010). Because mango fruit deteriorates quickly after being harvested, it must be eaten within a few days or dried to reduce its moisture content before being stored for an extended period of time. (Akoy et al., 2013). Drying is one of the oldest methods of food preservation, but it's also a difficult food processing process because it makes the dried product's quality poor sometimes. To further improve food durability, drying is one of the most widely used methods. (Abdalla, 2023). One intriguing technique to stop fresh fruit from deteriorating could be drying. Important phases in the food processing business are drying procedures. It is the most traditional technique of preserving food and is a crucial part of food processing. (Doymaz, 2004). The most popular method for preserving food goods worldwide is sun drying. It is an inexpensive and simple procedure. Although this technique is widely used, it has many drawbacks, including soil, dust, insect, and sand particle contamination, as well as weather dependence. Furthermore, the drying time needed can be rather lengthy.. (HA et al., 2021). The objective of this study is to compare different drying methods of mango, these methods are oven drying, direct sun drying and solar drying and to determine some parameters for comparison.

2. Materials and Methods

Location

Drying experiments were carried out using natural convective solar dryer. This dryer was constructed to operate as a free convective solar dryer. It was located at the Department of Food Processing Engineering, Faculty of Engineering and Technical Studies, White Nile State, Rabak, Sudan. It is situated on Longitude of 32.74 ˚E, latitude 13.18˚N and at an elevation of 362 meter above mean sea level. The dryer was placed on an open area in order to get maximum exposure to solar radiation. The dryer consists of three detachable components namely; solar collector (air heater), drying chamber and two air ducts. as shown in Figure 1.

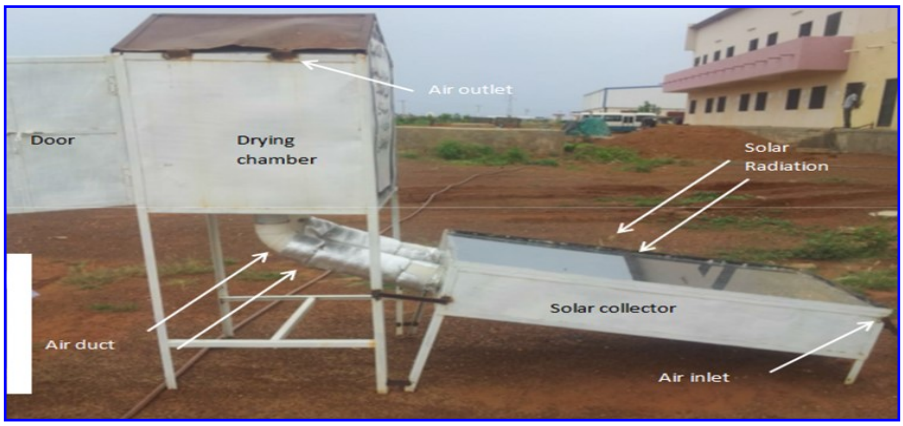

Figure 1. Natural Convective Solar Dryer (Wagas, et al., 2016)

Materials

Mango (*Mangifera Indica L.*) (Baladi) type was bought from Rabak local Market, White Nile State, Sudan; it was used as testing materials for the experiments.

Methods

The methods adopted for carrying out the experiments are as follows:

The preparation of mango for drying

Fresh mango with moisture content 78.76 % (w.b) were peeled and cut into slices (3-5 mm thickness) using stainless steel.

Open- direct sun drying tests

This experiment was conducted for comparison between solar, open-direct sun and oven drying methods using mango slices (*Mangifera indica L.*). A represented sample of the three slices of mango (30 gram for each) was taken from the same samples used for solar drying tests and oven drying A represented sample of the three slices of mango 30g

for each) was taken from the same samples used for solar drying tests and oven drying tests. These samples were put in a wire mesh tray and directly exposed to the sun radiation in an open area near the solar dryer. The starting time of the drying process was recorded using a stop watch. Initially at zero time the initial weight of these samples were recorded, then the lost in weights were recorded at interval of one hour throughout the experimental period, which took two days (16 hours) interrupted by one overnight. At the end of the second day the final weight of these samples was weighed using sensitive balance and the average weight was taken.

Solar drying tests

After mango was arranged and put in the trays for carrying solar drying test. A represented sample of three slices of mango (30 grams for each) were taken from the same samples used for sun drying tests, and oven drying tests, the starting time of drying process was recorded using a stop watch. Initially at zero time the weight of represented samples of mango were recorded. The above-mentioned measurement was recorded at intervals of one hour throughout the experimental period, which took two days (18 hours) interrupted by one overnight for solar drying test. At the end of the drying period. When there is a fixed weight, this means that no further moisture content was removed from the sample the average weight was taken.

Oven drying tests

This experiment was conducted to compare the mango drying by oven with solar and open-direct sun drying methods. A representative sample of three slices of mango (30 grams each) was taken from the same mango used for solar drying and open-direct sun drying tests. These samples were placed in aluminum foil and then in oven shelves, which works at temperatures of 70°C. The start time of the drying process was recorded using a stop watch. Initially, at zero time, the initial weight of this sample was recorded, then the lost in weights were recorded at interval of one hour throughout the experimental period, which took three days (23 hours) interrupted by two overnights, At the end of the third day, these samples were weighed using the sensitive balance and the mean was taken.

Moisture content

Initial and final moisture content were determined according to the method described by (AOAC, 1990). The moisture content of the samples was calculated using the following equations (1 and 2):

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

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

Where:

MC (w.b) = mango moisture content on wet basis, percent (%).

MC (d.b.) = mango moisture content on dry basis, percent (%).

Ww = mass of water, grams.

Wd = mass of dry matter, grams.

Drying rate

The drying rate was calculated using the fallowing equation (3), (Akpinar, et al., 2003).

$$Drying\ Rate\ (DR) = \frac{Mt + dt - Mt}{dt} \quad (3)$$

Where:

DR≡ Drying rate (g of water/g of dry matter).

M_t≡ moisture content at time t, dry basis.

$M_t + d_t$≡ moisture content at time t+ dt , dry basis.

Quality analysis of mango

The quality analysis for mango slices using solar, open-direct sun and oven drying were done by determination the following parameters:

Oil content

Total fat was determined by the AOAC method (1990). The oil content was calculated according to the following equation (4):

$$Fat\ content(\%) = \frac{wt_2 - wt_1}{S} \quad (4)$$

Where:

Wt_1: weight of empty flask.

Wt_2:weight of flask with extracted oil.

S: weight of sample.

Ash content

Total ash was determined according to the AOAC method (1990). Ash content was calculated using the following equation (5):

$$Ash\ content(\%) = \frac{wt_1 - wt_2}{S} \quad (5)$$

Where:

Wt_1 = weight of the crucible with sample.

Wt_2 = weight of the empty crucible.

S = weight of sample.

Crude fiber content

Crude fiber was measured using the AOAC method (1990).

$$Crude\ fiber\ \% = \frac{Loss\ of\ weight\ on\ ignition}{Weight\ of\ sample} \times 100\% \quad (6)$$

Protein content

Nitrogen content was determined by the semi micro-kjeldahl distillation method described by AOAC method (1990).

$$N\ \% = \frac{(ml\ HCl - ml\ blank) \times Normality\ of\ HCl \times 14 \times 100}{mg\ of\ sample} \quad (7)$$

Crude protein % = N% × 6.25

Carbohydrate content:

Total carbohydrate for solar drying, direct sun drying and oven drying methods for mango slices samples were estimated from the following equation (8):

Carbohydrate%=100 - [Moisture content % + Protein% + Ash% + Oil% + Crude fiber % (8)

3. Results and Discussion

Table 1. Hourly samples weight of mango slices for different drying methods oven drying, solar drying and open-direct sun Drying experiments

Time (hours)	Drying test weight (grams)		
	Oven drying	Solar drying	Open-direct sun drying
0	30.00	30.00	30.00
1	19.96	28.56	28.01
2	17.07	27.01	27.59
3	13.65	25.63	26.45
4	11.48	22.21	24.20
5	9.64	18.26	22.86
6	8.64	15.62	19.08
7	8.03	13.71	17.31
8	7.61	11.27	15.27
9	7.40	10.15	14.01
10	7.12	10.01	13.99
Over night			
11	7.12	10.01	13.99
12	6.85	9.26	12.01
13	6.57	9.03	11.98
14	6.52	8.65	11.97
15	6.50	8.42	11.96
16	6.48	8.22	11.96
17	6.46	8.20	-
18	6.45	8.20	-
19	6.43	-	-
20	6.42	-	-
21	6.37	-	-
Over night			
22	6.37	-	-
23	6.37	-	-

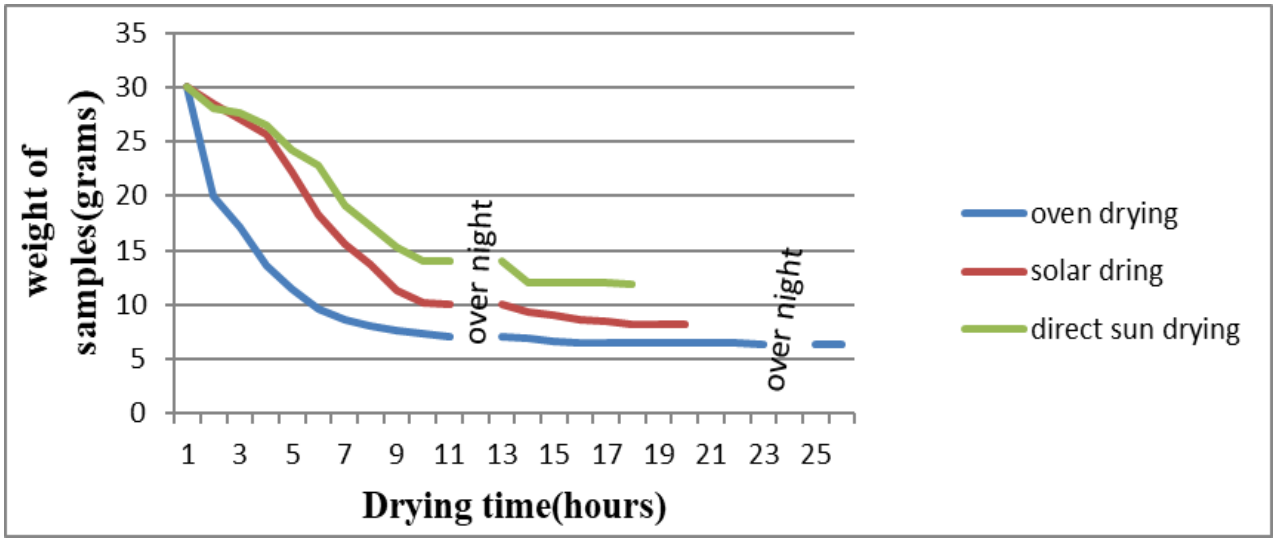

Figure 1. Hourly samples weight of mango slices for oven drying, solar drying and open-direct sun

From Table 1. and Figure 1. The mango started with an average initial weight of 30 gram for all experiments, oven drying, solar drying and open-direct sun drying and then decreased with time. Also the drying time took about 23 hours with final weight (dry matter) of 6.37 gram for oven drying of mango, while the drying time took about 18 hours with final weight of 8.2 gram (1.83 gram moisture) for solar drying of mango, while the drying time took about 16 hours with final weight of 11.96 gm (5.59 gram moisture) for direct sun drying experiments of mango. Although drying time by open-direct sun took less time than oven and solar dryer but it is with high final moisture content. This high moisture content in mango dried by open-direct sun as the result of low air temperature of drying air may affect the storage of mango slices and cause spoilage and reduce the quality of mango. This result was in a good agreement with the findings by (Akoy, 2007), they found that the increase in drying air temperatures of solar dryer, lower the moisture contents of the dried products and this will result in reducing the risk of spoilage in the storage period.

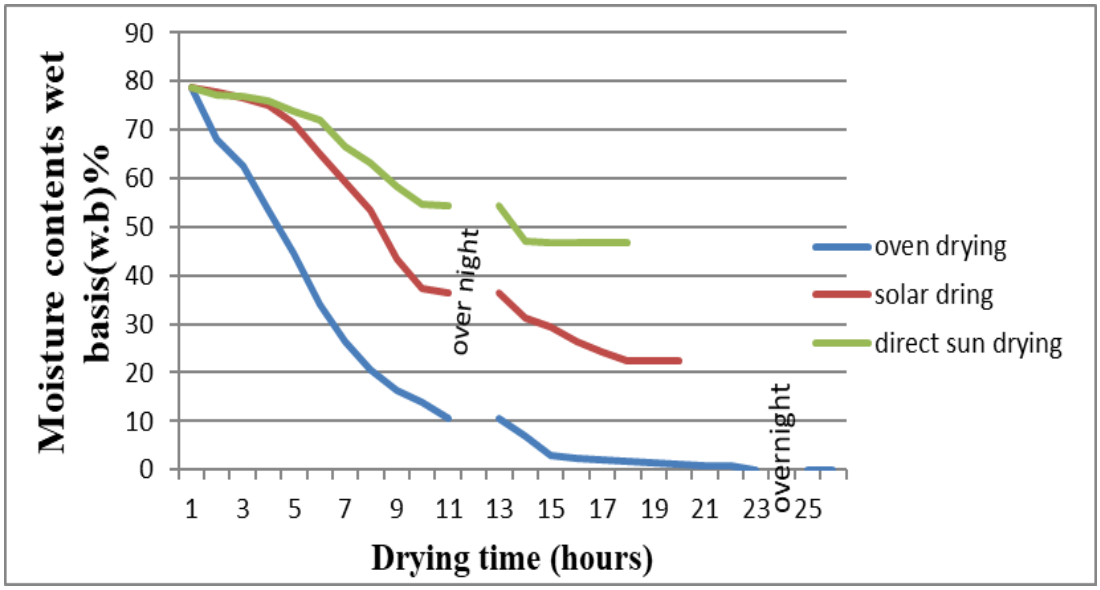

Figure 2. Hourly moisture contents in wet basis (w.b) for oven drying, solar drying and open-direct Sun

Table 2. Hourly decrease in moisture contents (w.b) for oven drying, solar drying and open-direct sun

Time (hours)	Moisture contents % (w.b)		
	Oven drying	Solar drying	Open-direct sun drying
0	78.77	78.77	78.77
1	68.09	77.70	77.26
2	62.68	76.42	76.91
3	53.33	75.15	75.92
4	44.51	71.32	73.68
5	33.92	65.12	72.13
6	26.27	59.22	66.61
7	20.67	53.54	63.20
8	16.29	43.48	58.28
9	13.92	37.24	54.53
10	10.53	36.36	54.47
Over night			
11	10.53	36.36	54.47
12	7.01	31.21	46.96
13	3.04	29.46	46.83
14	2.30	26.36	46.78
15	2.00	24.35	46.74
16	1.70	22.51	46.69
17	1.39	22.41	-
18	1.24	22.32	-
19	0.93	-	-
20	0.78	-	-
21	0.00	-	-
Over night			
22	0.00	-	-
23	0.00	-	-

From Table 2. and Figure 2., it is observed that the mango slices dried with the oven ended with a moisture content of zero percent (0 %) on wet basis. The mango slices dried with the solar dryer started with the same moisture content and finished with a moisture content of 22.3 percent on wet basis , while the mango slices dried with open-direct sun started with the same moisture content and finished with a moisture content of 46.7% on the wet basis, from these results, although the natural direct sun dried in short time (16 hours) than the oven drying (23 hours) and solar drying (18 hours) but with a final moisture content higher than oven and solar dryer, Also oven drying has reached the lowest final moisture content zero percent (0%), but this is considered a dehydration stage (i.e. bone drying). This may be attributed mainly to the ability of hot air to pull the moisture from moist products, as the drying air temperature is higher in case of oven and solar drying and less air temperature in direct sun drying experiments. This result was in a good agreement with (Panchariya et al., 2002) in their studies of thin layer modeling of black tea drying process. The high moisture content of mango dried with direct sun affects the quality of mango during storage because the storage requires less moisture content, so drying with oven dryer is more save for optimum storage of mango and good quality of the product.

Table 3. Hourly drying rate (g water/g dry matter. h) of mango slices for oven, solar and open-direct Sun Drying experiments.

Time (hours)	Drying rate (g water/g dry matter. h)		
	Oven drying	Solar drying	Open-direct sun drying
0	0.00	0.00	0.00
1	157.61	22.61	31.24
2	45.37	24.33	6.59
3	53.69	21.66	17.90
4	34.07	53.69	35.32
5	28.89	62.01	21.04
6	15.70	41.44	59.34
7	9.58	29.98	27.79
8	6.59	38.30	32.03
9	3.30	17.58	19.78
10	4.40	2.20	0.314
	Over night		
11	0.00	0.00	0.00
12	4.24	11.77	31.08
13	4.40	3.61	0.47
14	0.78	5.97	0.16
15	0.31	3.61	0.16
16	0.31	3.14	0.16
17	0.31	0.16	-
18	0.16	0.16	-
19	0.31	-	-
20	0.16	-	-
21	0.78	-	-
	Over night		
22	0.00	-	-
23	0.00	-	-

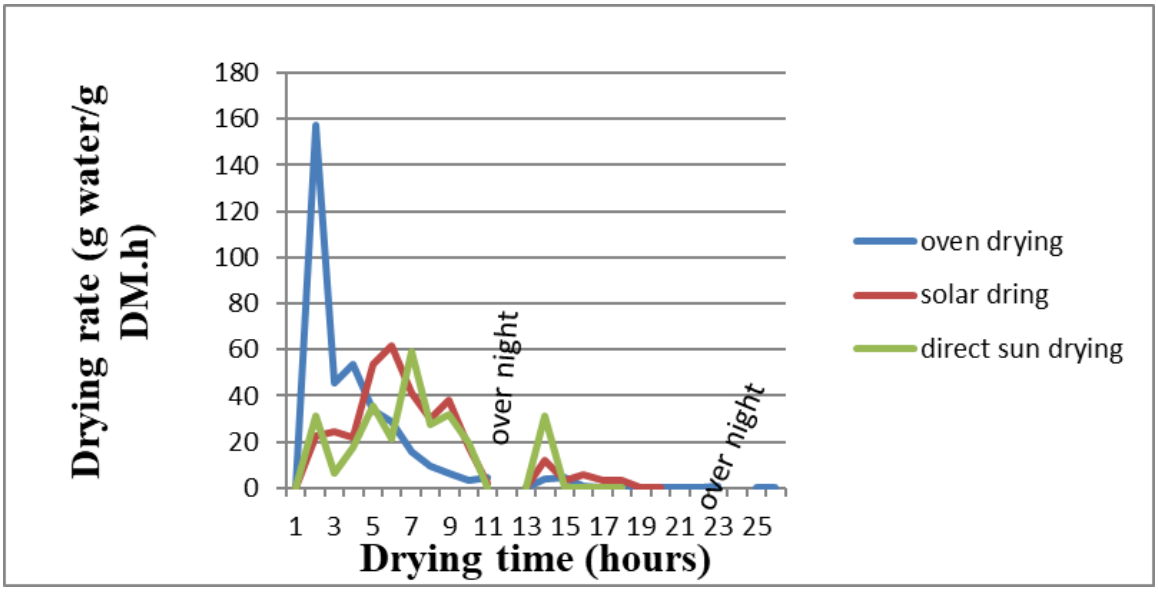

Figure 3. Hourly drying rate (g water/g dry matter. h) for mango slices of oven drying, solar drying and direct sun drying experiments.

From Table 3. and Figure 3., it is clear that the maximum drying speed was performed on the first day of drying and it was reduced in the following days. This is because of high moisture content of the product (sample) in the first day. Also the variation of drying rate with drying time indicated that drying rate decreased continuously with time. In these curves there was no constant drying rate period in the three drying methods (oven, solar and open-direct sun drying methods). All the drying process occurred during the falling rate drying period. This result was in a good agreement with (Togrul and Pehlivan, 2004) in their studies of modeling of thin layer drying kinetics of some fruits under open air sun drying process.

From Table 3. and Figure 3. It is clear that, the drying rate of oven is higher than solar and direct sun. This is because drying temperature was increased significantly in oven as compared with drying air temperature in solar and drying air temperature in direct sun. So that the drying rate (g water/g dry matter, h.) were higher in oven drying. This result was in a good agreement with (Panchariya et al., 2002) in their studies of thin layer modeling of black tea drying process.

Table 4. The final samples weight, final M.C (w.b and d.b)%, drying rate and drying time for three drying methods (oven, solar and open-direct sun drying methods).

	Oven	Solar	Open-direct sun
Final sample weight(grams)	6.37	8.20	11.95
Final M.C in w.b (%)	0.00	22.30	46.70
Final M.C in d.b (%)	0.00	28.70	87.60
Drying rate (g water/g D.M)	0.78	0.16	0.16
Drying time(hours)	24.00	18.00	16.00

From Table 4., it is clear that mango slices dried with oven method drying took 24 hours with final weight of 6.37g and final moisture content is zero (0% d.b) and final moisture content is zero (0% w.b) and final drying rate (0.78 g water/g dry matter. h), while for solar drying method, the drying ended in 18 hours with final weight of 8.2 g and final moisture content 28.7% and 22.3% dry basis and wet basis respectively and final drying rate of (0.16 g water/g dry matter h.) . For direct sun method, the drying ended in 16 hours with final weight of 11.95 g and final moisture content 87.6 % and 46.7 % dry basis and wet basis respectively and final drying rate of (0.16 g water/g dry matter.h). Although drying with oven took long time (23 hours) as compare to other different drying methods, but it is with no moisture content (i.e. bone dry) and high drying rate. This means that using an oven is better than using solar and open-direct sun for drying mango slices. Although the drying took more time in oven method but it pull off all the moisture of mango (i.e. bone dry) due to high temperature, this result was in a good agreement with (Panchariya et al., 2002) in their studies of thin layer modeling of black tea drying process. While the solar took 18 hours, but still there is some moisture 1.83 gram, in case of open-direct sun, drying took 16 hours but still there is some moisture 5.58 gram. This result shows that, oven drying method is more save for optimum storage of mango and good quality of the product.

Table 5. shows the mean values of chemical composition in grams per 100 gram of dry matter for fresh and dried mango slices. These attributes are moisture, protein, fat, fiber, ash and Carbohydrates content. The drying decreased the moisture content as percentage for all the drying methods (open-direct sun, solar and oven). The decrease in moisture result in the increase of dry matter for all the methods of drying. Generally, the increase of dry matter for oven is higher than solar and direct sun drying because the moisture removed by oven dryer is higher

than that removed by solar drying and direct sun drying. This means that drying improve the quality of the products by reducing their moisture contents and increasing their dry matter. The increase in the dry matter increases the amount of protein, ash, fat, fiber and carbohydrates for all the drying experiments. This result was in a good agreement with (Mohamed et al., 2017) in their studies of Effect of Different Drying Methods and Pre-Treatments on Quality Characteristics of Mango Slices

Table 5. Mean values of chemical composition in grams per 100 grams of fresh, solar, open-direct sun and oven drying methods of mango slices

Chemical composition	Fresh sample of mango	Solar drying sample of mango	Direct sun drying sample of mango	Oven drying sample of mango
Moisture content (w.b) (%)	78.77	6.85	8.03	6.31
Protein content (%)	1.40	3.35	4.02	3.20
Ash content (%)	0.32	1.75	1.65	1.88
Fat content (%)	0.55	1.34	1.45	1.24
Fiber content (%)	9.96	9.99	10.20	10.25
(Carbohydrates + others) (%)	9.00	76.72	74.65	77.12
Total (%)	100	100	100	100

4. Conclusion

The three methods of drying are successfully describing the drying process of mango slices, but oven method is the best one. All the drying processes of mango slices occur in the falling rate period and took place during the first day. Drying rate for open-direct sun and solar is less than oven. Drying time for open -direct sun is less than oven and solar but it with high moisture. In the next study, the effect on the physical and thermal properties of the products dried by these three methods will be investigated. Also sensory evaluation to show the effect of drying on the consumer acceptability will be done.

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