The Journal of Phytopharmacology 2021; 10(4):242-248
Online at: www.phytopharmajournal.com

Research Article

ISSN 2320-480X
JPHYTO 2021; 10(4): 242-248
July- August
Received: 18-05-2021
Accepted: 09-06-2021

doi: 10.31254/phyto.2021.10405

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Comparative Evaluation of Drying Kinetics of Carrot Slices in Hot air and Microwave Drying

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ABSTRACT

Carrot is most the important vegetable grown throughout the World. It is also a very good source of β-carotene, α-carotene and zeaxanthin. The post-harvest losses because of having high moisture content limit the utilization of carrot. In the present investigation, the comparative analysis was done between hot air drying and microwave drying for different thickness of carrot slices. The quality analysis for both the dried products was performed and compared. The drying time was varied between 3.5 h to 10 h for try drying whereas for microwave drying it was 240 sec to 681.6 sec. The drying time reduces drastically in case of microwave drying in comparison to hot air drying. The moisture ratio for both dried techniques was found to decreasing with an increase in drying time. The microwave dried samples showed a better rehydration ratio than the hot air dried sample. Also, the dehydration ratio of dried carrot sample using microwave drying was found to be lowest compared to the hot air dried sample. The microwave dried carrot slices showed a better sensory score in terms of colour and shape than hot air dried sample. Therefore, microwave drying may be recommended to dry carrot slices to have better energy efficiencies.

Keywords: Hot air drying, Microwave drying, drying kinetics, sensory score.

INTRODUCTION

Carrot (*Daucus carrota* L.), a major cultivated vegetable is commonly used among all the vegetable products and grown throughout the World. The composition of raw carrot is mainly comprised of water (88%), carbohydrates (9%), protein (0.9%), fiber (2.8%), ash (1%) and fat (0.2%) [1]. The bright orange colour of carrot is due to presence of β-carotene, α-carotene and zeaxanthin. Apart from above, it is rich in vitamins like vitamin K and Vitamin B6. Carrot is generally consumed in the raw form and also dried to be used in soups [2]. The post-harvest losses due to the higher moisture content limits the utilization of carrot. Several techniques are being used to control the deterioration of carrot after harvesting. Among the techniques, drying is one of the oldest method to preserve the any food products. Drying of food is a method of food preservation by removing moisture content to a predetermined level [3]. After drying, the microbiological spoilage is greatly reduced because of the reduced moisture content [4]. The rate of drying is dependent on drying air temperature, velocity of air, diffusion of moisture, product thickness and surface area of drying. Different drying methods are followed like freeze drying, hot air, vacuum, sun drying, solar drying, microwave drying etc [5, 6]. Each methods of drying have its merits and demerits. Sun drying is most traditional methods of drying used for agricultural products preservation but it is dependent on the weather conditions [7, 8]. Hot air drying is also being used extensively for drying but it consumed lots of time. The eliminate all the above stated issues, the used of microwave and infrared drying is being promisingly used recently [9, 10]. The electromagnetic waves in microwave drying are in the range of 300-3000 megahertz. Microwave causes volumetric heating (throughout the product heating) whereas the traditional hot air drying dries product by surface heating phenomenon. Use of microwave in food processing have a lot of advantages like shorter heating time, retains better colour, texture when compared with conventional heating methods [11, 12]. Considering all the above discussed drawbacks of conventional heating and benefits of microwave heating, the current research was carried out with aim to compare the quality characteristics of carrot slice dried in hot air drying as well as microwave drying.

MATERIAL AND METHODS

Sample collection

The carrot was purchased from the local market of Paralakhemundi, Odisha. The samples taken for the research work were washed using clean Tap water and wiped with towel to remove the surface water. The initial moisture content of carrot was determined using the hot air oven and was found to be 89.13 % wet basis [13].

Hot air drying

A convective tray dryer was used for the present study (Fig. 1). It consists of 6 number of shelfs, the heating section, a blower and a displaying units showing temperature of air and air velocity. A door is fixed in the front side for opening and closing of the dryer during the experiments. The hot air dryer was run for 30 min before starting of each experiments to achieve the desired temperature and air velocity. The experiments were designed in the Design Expert 10.0 (Statease, Minneapolis) using CCRD (Central Composite Randomized Design) design having total 20 experimental runs (Table 1) [14]. The experiments using hot air drying were carried out by taking different combinations of parameters such as temperature (°C), slice thickness (mm) and air velocity (m/s). The carrots were peeled using a hand peeler and it was cut into the predetermined slice thickness using a kitchen knife before the experiments. The cut sliced carrot samples were uniformly spread in the tray in a single layer to avoid any over lapping. The sample weight was taken at 5 min intervals initially, then at 10 min and 30 min intervals during the entire drying period using a precision weighing balance. The drying experiment was continued until no change in the weight of the sample was reached. After completion of drying, the dried sample was taken out from the tray dryer and then the slices were sealed and packed and kept in the desiccators for further quality analysis.

(a)

(b)

Figure 1: (a) Hot air dryer **(b)** Carrot sample in the tray

Table 1: Experiential design for hot air drying of carrot slices

Sample No.	Air Temperature (˚C)	Air velocity (m/s)	Slice thickness (mm)
R1	50	1.25	3
R2	33.18	1.25	3
R3	50	1.25	3
R4	40	1	2
R5	50	1.25	3
R6	50	0.83	3
R7	60	1.5	4
R8	40	1.5	2
R9	40	1.5	4
R10	50	1.25	3
R11	60	1	2
R12	50	1.25	4.68
R13	66.82	1.25	3
R14	50	1.67	3
R15	60	1	4
R16	50	1.25	3
R17	60	1.5	2
R18	50	1.25	1.32
R19	40	1	4
R20	50	1.25	3

Microwave drying

A domestic microwave oven (Morphy Richards, 20MBG) available in the laboratory having maximum power rating of 1000W was used throughout the experiments (Fig. 2). The height, width and depth of the microwave oven was 280 mm, 300 mm and 210 mm, respectively. Different parts like a 28 cm diameter of glass turntable, fan, grill arrangements, a control panel for controlling the power level, treatment time etc. are attached in the microwave oven within the microwave. The experiments were planned by taking different power densities, slice thickness and microwave heating time. The power density was defined as the ratio of power level and weight of the sample (watt/gram). The experiments were designed in the Design Expert 10.0 (Statease, Minneapolis) using CCRD (Central Composite Randomized Design) design having total 20 experimental runs (Table 2) [14].

The experimental design involves different power densities, thicknesses and different time periods. Before, starting of the experiments, the carrots were peeled using a hand peeler and it was cut into the predetermined slice thickness using a kitchen knife before the experiments. The carrot slices were uniformly spread in the tray in a single layer to avoid any over lapping.

Weights of the samples had taken at regular intervals. The sample weight was taken at 10 sec intervals initially, then at 30 sec intervals during the entire drying time using a precision weighing balance. After completion of drying, the microwave dried sample was taken out from the microwave oven and then the slices were sealed and packed and kept in the desiccators for further quality analysis.

(a)

(b)

Figure 2: (a) Microwave oven **(b)** Dried carrot slices

Table 2: Experiential design for microwave drying of carrot slices

Sample No	Power density (w/g)	Sample Thickness (mm)	Drying Time (sec)
R1	0.8	2	360
R2	1.6	3	480
R3	1.6	1.32	480
R4	0.8	4	360
R5	1.6	3	480
R6	1.6	4.68	480
R7	2.4	4	600
R8	1.6	3	480
R9	1.6	3	681.6
R10	1.6	3	480
R11	2.4	2	360
R12	0.8	4	600
R13	0.8	2	600
R14	2.4	4	360
R15	1.6	3	240
R16	2.4	2	600
R17	1.6	3	480
R18	1.6	3	480
R19	0.25	3	480
R20	2.95	3	480

Quality analysis of tray dried samples

Drying calculation

Drying rate: The time and temperature were noted down from the individual drying experiments. The removal of water with time as mentioned against each drying temperature was observed regularly. The rate of drying was calculated for each time interval for each drying temperature. It is expressed as the amount of water removed per unit time for the respective time interval.

$$\text{Drying Rate} = \frac{\text{Amount of water removed}}{\text{Time taken} * \text{Amount of bone dry material}} * 100 \ldots (1)$$

Moisture ratio: The moisture ratio was by the following formula:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \ldots (2)$$

Where, Moisture Ratio is M_t/M_0
M_t= Moisture content (% db) at that particular time M_0 =Moisture content (% db) at time, t=0

Several mathematical empirical models in exponential forms were developed by several authors [15, 16]. In these expressions the moisture ratio has been simplified to M_t/M_0 instead of $(M_t - M_e)/(M_0 - M_e)$ because of the fact M_e is quite small as compared to M_t and M_o and RH of drying air is continuously fluctuating. Here the moisture ratio M_t/M_0 has been calculated and plotted against drying time for different drying conditions.

Rehydration ratio

The quality analysis was performed for tray dried and microwave dried carrot samples. The analysis was done by the determining the rehydration and dehydration ratios of 20 experimental samples. For determination of rehydration ratio, water is taken in a beaker up to 40˚C. The initial weight of the sample was taken and noted as W1. Then the sample was dipped in the heated water for 4-5 min to regain its shape and size. The rehydration ratio was calculated by using the following equation:

$$\text{Rehydration ratio} = \frac{W_2}{W_1} \ldots (1)$$

Where, W_1 is weight of sample before rehydration (g) and W_2 is weight of sample after rehydration (g).

Dehydration ratio

The dehydration ratio of the tray and microwave dried carrot samples is estimated by taking the ratio of final weight of the sample after drying to initial weight of carrot sample before drying.

$$\text{Dehydration ratio} = \frac{W_2}{W_1} \ldots (2)$$

Where, W_1 is initial weight of the carrot sample before drying (g) and W_2 is final weight of the carrot sample after drying (g).

Sensory evaluation

The sensory evaluation was done for both the dried sample by a 12 panel expert having different ages and different habit of eating. 9-point hedonic scale method was followed to evaluate the sensory score of tray dried and microwave dried sample [8]. The sensory evaluation was conducted for colour and shape by using 9-point

hedonic scale i.e. 9 for like extremely, 8 for like very much, 7 for like moderately, 6 for like slightly, 5 for neither like nor dislike, 4 for dislike slightly, 3 for dislike moderately, 2 for dislike very much and 1 for dislike extremely.

RESULT AND DISCUSSION

Estimation of the drying yield and drying time

The initial moisture content of the carrot was 819.96 % db and the final moisture content after drying was in the range of 73.11 to 191.03 % db for all the 20 combinations. The drying time and the moisture content % db at the end of hot air drying is given in Table 3. The drying time was varied between 3.5 h to 10 h for try drying. The lowest drying time was found at 3.5 h for sample no 17. It may be due to the higher temperature of 60°C and higher air velocity of 1.5 m/s which ultimately decreases the drying time. The drying time with moisture ratio for hot air drying is shown in Fig. 3 (a-b) for all the 20 runs. From Fig. 3, the moisture ratio was found to be decreased with the increase in drying time. Similarly, the drying kinetics data for microwave drying of carrot slices is given in Table 4. The drying time was fixed for microwave drying which was in the range of 240 sec to 681.6 sec. The final moisture content after drying for all the 20 runs was found to be in the range of 91.66 % db to 175.69 % db. The results revealed that the similar range of moisture content was achieved in microwave drying in very short period time. Also, the higher microwave power density level leads to lower range of moisture content. It was due to the volumetric effect of microwave heating which is advantages over conventional hot air drying. The similar results were also reported by Wang and Xi [17] for two-stage microwave drying of carrot slices. Fig. 4 (a-b) shows the relationship between drying time with moisture ratio for microwave dried slices. The decrease trend of moisture content with drying time was also observed like in case of hot air drying.

Table 3: Drying kinetics data for hot air drying of carrot slices

Sl. no.	Air Temperature (˚C)	Air velocity (m/s)	Slice thickness (mm)	Drying time (h)	MC %db, at the end of drying
1	50	1.25	3	10	73.11
2	33.18	1.25	3	8.5	159.34
3	50	1.25	3	4.5	115.71
4	40	1	2	5	85.11
5	50	1.25	3	5	191.03
6	50	0.83	3	5	143.63
7	60	1.5	4	5.5	147.23
8	40	1.5	2	6.5	137.32
9	40	1.5	4	9	180.54
10	50	1.25	3	6	132.64
11	60	1	2	5	117.18
12	50	1.25	4.68	8.5	146.31
13	66.82	1.25	3	4	146.05
14	50	1.67	3	5.5	133.18
15	60	1	4	5	154.53
16	50	1.25	3	5	150.32
17	**60**	**1.5**	**2**	**3.5**	**135.23**
18	50	1.25	1.32	4	110.26
19	40	1	4	9	158.13
20	50	1.25	3	4.5	138.77

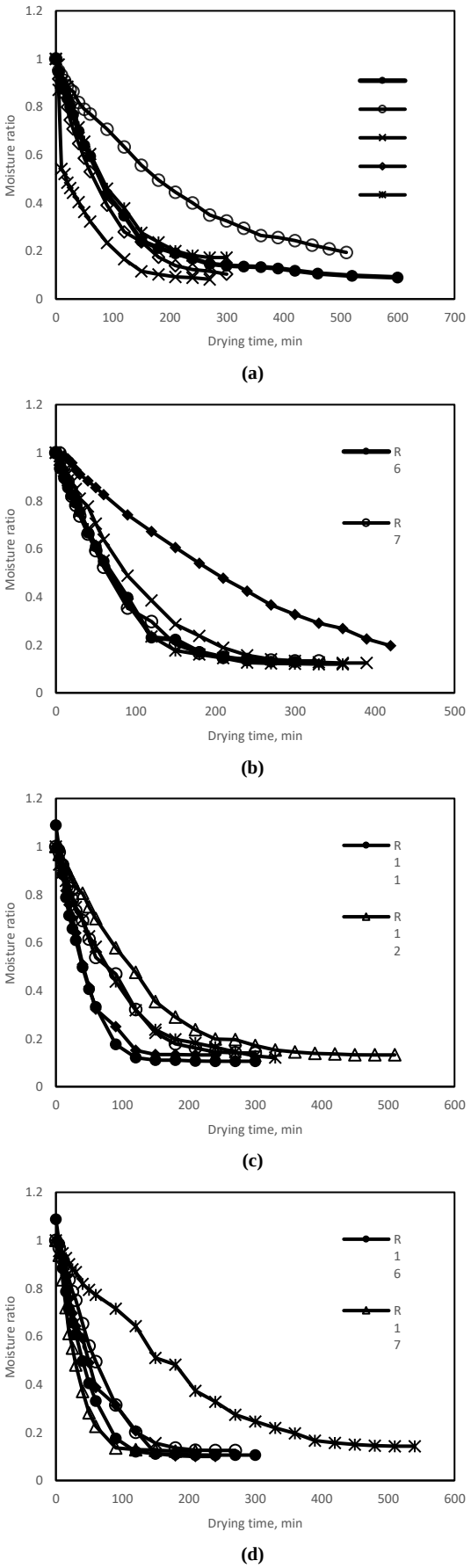
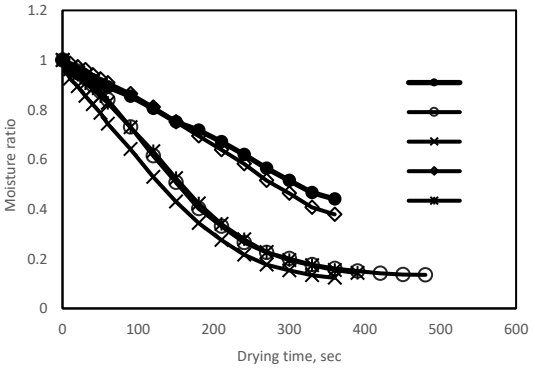


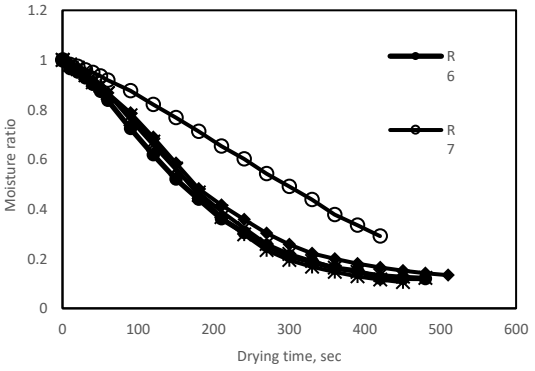
Figure 3: Variation of moisture ration with drying time for hot air dried sample **(a)** sample no R1-R5 **(b)** sample no R6-R10 **(c)** sample no R11-R15 **(d)** sample no R16-R20

Table 4: Drying kinetics data for microwave drying of carrot slices

Sample No	Power density (w/g)	Sample thickness (mm)	Drying time (sec)	MC % db at the end of drying
R1	0.8	2	360	161.06
R2	1.6	3	480	110.89
R3	1.6	1.32	480	91.66
R4	0.8	4	360	110.42
R5	1.6	3	480	99.8
R6	1.6	4.68	480	98.553
R7	2.4	4	600	126.79
R8	1.6	3	480	100.04
R9	1.6	3	681.6	91.204
R10	1.6	3	480	83.829
R11	2.4	2	360	150.67
R12	0.8	4	600	161.68
R13	0.8	2	600	121.9
R14	2.4	4	360	163.64
R15	1.6	3	240	126.49
R16	2.4	2	600	121.68
R17	1.6	3	480	106.66
R18	1.6	3	480	86.266
R19	0.25	3	480	116.53
R20	2.95	3	480	175.69



(a)



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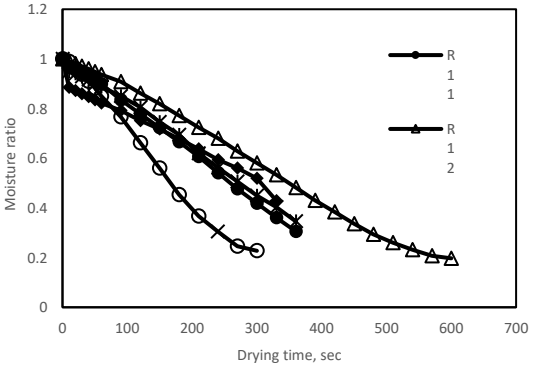

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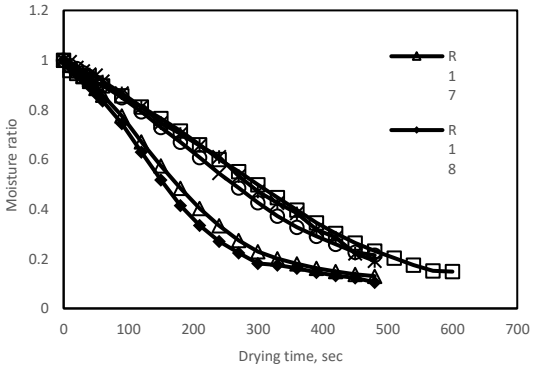

(d)

Figure 4: Variation of moisture ration with drying time for microwave dried sample **(a)** sample no R1-R5 **(b)** sample no R6-R10 **(c)** sample no R11-R15 **(d)** sample no R16-R20

Effect of drying methods on rehydration ratio

The rehydration ratio of dried carrot samples using both hot air drying and microwave drying sample was analyzed and is given in Table 5. The rehydration ratio varied between 1.59 to 2.98 for hot dried sample whereas the minimum value was 1.16 and maximum was 3.36 for microwave dried sample. From the results, it was revealed that the microwave dried samples showed better rehydration ratio than the hot air dried sample. The reason behind this result depend on the shrinkage which was found to be more in hot air drying compared to microwave drying.

Table 5: Rehydration ratio of hot air and microwave dried samples

Sample No.	RR, hot air dried	RR, microwave dried
R1	2.00	1.23
R2	1.68	2.21
R3	2.27	3.36
R4	2.57	1.24
R5	2.15	2.23
R6	2.16	2.15
R7	1.97	1.81
R8	2.82	1.35
R9	1.59	2.47
R10	2.54	2.31
R11	2.13	1.61
R12	1.95	1.55
R13	2.66	2.24
R14	2.09	1.32
R15	1.85	1.74
R16	2.05	2.55
R17	2.98	2.09
R18	2.01	2.25
R19	1.73	1.16
R20	2.83	1.74

Effect of drying methods on dehydration ratio

The dehydration ratio of dried carrot sample using both hot air and microwave drying was analyzed and is given in Table 6. The

dehydration ratio varied between 0.094 to 0.154 for hot dried sample whereas the minimum value was 0.001 and maximum was 0.379 for microwave dried sample. The microwave dried samples showed lowest dehydration ratio compared to the hot air dried sample. By comparing both the drying, the volumetric heating of microwave at higher power density level helped in decreasing the moisture content in microwave drying than hot air drying. In the same time, in sample no R4, the dehydration ratio of microwave dried sample was high compared to hot air drying. It may be due to the high sample thickness (4 mm) and lower drying time (360 sec) (Table 4).

Table 6: Dehydration ratio of tray and microwave dried samples

Sample No	Dehydration ratio, hot air dried samples	Dehydration ratio, microwave dried samples
R1	0.133	0.440
R2	0.145	0.135
R3	0.140	0.112
R4	0.104	0.379
R5	0.154	0.122
R6	0.128	0.120
R7	0.126	0.001
R8	0.118	0.122
R9	0.156	0.111
R10	0.114	0.102
R11	0.097	0.306
R12	0.128	0.197
R13	0.123	0.162
R14	0.122	0.339
R15	0.139	0.227
R16	0.133	0.148
R17	0.115	0.123
R18	0.094	0.105
R19	0.141	0.149
R20	0.121	0.214

Effect of drying methods sensory properties

The sensory evaluation was performed by taking colour and shape of the dried carrot slices into consideration. The likeness for the shape was done by taking minimum shrinkage and the for colour it was close to the original colour (orange). The sensory evaluation score for both the sample dried in hot air and microwave is given in Table 7. The hot air dried sample exhibited low sensory score (5 to 8) compared to microwave dried samples (6 to 8.5). The shrinkage in hot air dried sample was more compared to microwave drying due to higher drying time which may have affected the sensory score (shape). Also, the colour of the hot air dried sample became light orange at the end of drying time. This may be due to the degradation of β-carotene occurred due to exposed to high temperature for a longer time. Similar findings were also reported by Suvarnakuta *et al.*, [18] for drying of carrots under different conditions. The microwave dried sample scored significantly higher sensory score in terms of shrinkage (shape) and colour.

Table 7: Effect of drying methods on sensory properties

Sample No	Tray dried carrot slices		Microwave dried carrot slices	
	Colour	Shape	Colour	Shape
R1	6.5	6	6.7	7.1
R2	7.8	7.3	6.5	6.2
R3	6.8	6.7	6.9	7.1
R4	5.9	5.2	6.2	6.5
R5	7.3	7.4	6.8	6.9
R6	8.1	8.2	6.9	6.4
R7	7.9	8.1	7.2	7.4
R8	5	5.2	7.3	7.4
R9	8.1	8.5	7	6.9
R10	7.3	7.5	6.1	6.2
R11	6.7	6.5	8.2	8.1
R12	6.9	7.1	8.4	8
R13	6.2	7.3	7.8	8.1
R14	7.1	7.2	8.6	8.4
R15	8.3	8.5	7.9	7.6
R16	8.1	8.2	6.9	6.5
R17	8.1	8.3	7.2	7.5
R18	6.5	6.7	6.4	6.7
R19	7.1	6.9	7.1	7.3
R20	7.6	7.5	8.5	8.4

CONCLUSION

The comparative study between hot air drying and microwave drying was done for different thickness of carrot slices. The quality analysis of dried carrot samples by using both drying techniques was performed and compared. The drying time was varied between 3.5 h to 10 h for try drying whereas for microwave drying it was 240 sec to 681.6 sec. The drying time of dried samples by microwave drying reduces drastically than hot air drying. The moisture ratio was found to be decreased in both drying techniques as drying time increases. The microwave dried samples showed better rehydration ratio in comparison with hot air dried sample. Also, the dehydration ratio of carrot dried sample using microwave drying was found to be lower than the hot air dried sample. The microwave dried carrot slices showed better sensory score in terms of colour and shape than hot air dried sample. Therefore, microwave drying may be recommended to dry carrot slices to have better energy efficiencies.

Acknowledgement

The authors are very thankful to the support provided by School of Agricultural and Bio-Engineering, Centurion University of Technology and Management, Paralakhemundi, Odisha, India.

REFERENCES

1. USDA (2020). Nutrition facts for carrots, raw [Includes USDA commodity food A099], per 100g, USDA Nutrient Database for Standard Reference, version SR-21.

2. FAO. Faostat agriculture data. Available from http://faostat.fao.org/faostat/collections. 2003.
3. Toğrul H. Suitable drying model for infrared drying of carrot. J Food Eng. 2006; 77(3):610-619.
4. Sutar PP, Prasad S. Modeling microwave vacuum drying kinetics and moisture diffusivity of carrot slices. Drying Technol. 2007; 25(10):1695-1702.
5. Kumar N, Sarkar BC, Sharma HK. Mathematical modelling of thin layer hot air drying of carrot pomace. J Food Sci. Technol. 2012; 49(1): 33-41.
6. Yan WQ, Zhang M, Huang LL, Tang J, Mujumdar AS, Sun JC. Studies on different combined microwave drying of carrot pieces. Int. J Food Sci. Technol. 2010; 45(10):2141-2148.
7. Akpinar EK. Mathematical modelling of thin layer drying process under open sun of some aromatic plants. J Food Eng. 2006; 77(4):864-870.
8. Behera G, Rayaguru K. Comparative evaluation of the quality characteristics of the osmo-dehydrated star fruit slices using hot air, solar and sun drying. J Pharmacogn Phytochem. 2020; 9(4):433-439.
9. Behera G, Sutar PP. Development of a new pre-drying method of accelerated water absorption and partial gelatinization of starch in paddy using pulsed microwave-water applications in a microwave rotary drum dryer. Drying Technol., 2019; 37(6):707-721.
10. Cui ZW, Xu SY, Sun DW. Microwave–vacuum drying kinetics of carrot slices. J Food Eng. 2004; 65(2):157-164.
11. Behera G, Sutar PP, Aditya S. Development of novel high power-short time (HPST) microwave assisted commercial decontamination process for dried turmeric powder (*Curcuma Longa* L.). J Food Sci. Technol. 2017; 54(12):4078-4091
12. Arballo JR, Campañone LA, Mascheroni RH. Modeling of microwave drying of fruits. Part II: Effect of osmotic pretreatment on the microwave dehydration process. Drying Technol. 2012; 30(4): 404-415.
13. AOAC. Official methods of analysis. Association of Official Analytical Chemists Inc. 15th edn. Arlington, Virginia, USA, 1990.
14. Montgomery DC. Design and Analysis of Experiments (2nd ed.). John Wiley and Sons: New York, 1984.
15. Yaldýz O, Ertekýn C. Thin layer solar drying of some vegetables. Drying Technol. 2001; 19(3-4):583-597.
16. Mehta RR, Jain S, Garg MK. Thin Layer Shade Drying of Liquorice (*Glycyrrhiza glabra*). J Agricul. Eng. 2005; 42(1):23-26.
17. Wang J, Xi YS. Drying characteristics and drying quality of carrot using a two-stage microwave process. J Food Eng. 2005; 68(4):505-511.
18. Suvarnakuta P, Devahastin S, Mujumdar AS. Drying kinetics and β-carotene degradation in carrot undergoing different drying processes. J Food Sci. 2005; 70(8):520-526.

HOW TO CITE THIS ARTICLE
Behera G, Madhumita M, Aishwarya J, Gayathri V. Comparative Evaluation of Drying Kinetics of Carrot Slices in Hot air and Microwave Drying. J Phytopharmacol 2021; 10(4):242-248. doi: 10.31254/phyto.2021.10405