

Influence of Microwave Pretreatment on Drying Kinetics, Rehydration and β -Carotene Retention of Carrot Slices

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Abstract - Microwave pretreatment of carrot slices was investigated at microwave power levels of 90, 180, 600 and 900 W, followed by convective drying at 60°C. Drying time ranged from 10 to 22 min, with the highest microwave power (900 W) producing the most rapid initial moisture removal, reducing moisture content from 623% to 32.56% (dry basis). During subsequent convective drying, the greatest reduction in moisture content was observed for samples pretreated at 600 W, reaching a final moisture content of 4.87% (dry basis). The highest rehydration ratio was also obtained at 600 W, whereas β -carotene retention was highest at 180 W and lowest at 900 W. Considering moisture removal, rehydration characteristics, and β -carotene retention, microwave pretreatment at 600 W followed by convective drying at 60°C was identified as the selected drying condition for carrot slices.

Keywords: *Microwave pretreatment, convective drying, drying kinetics, rehydration ratio, β -carotene,*

1. INTRODUCTION

Carrot (*Daucus carota* L.), belonging to the family Apiaceae, is an important root vegetable cultivated widely across the world. It is valued for its attractive colour, characteristic flavour, dietary fibre, vitamins and a range of bioactive compounds, particularly carotenoids. In India, carrot is widely consumed as a fresh vegetable and is also used in various processed products. Recent national horticultural statistics indicate that carrot production in India reached approximately 2.78 million tonnes from about 0.125 million ha during 2023–24, highlighting its considerable potential for processing and value addition.

The nutritional and functional significance of carrot is largely attributed to its carotenoid content, particularly β -carotene, which serves as an important precursor of vitamin A, along with phenolic compounds and other antioxidants [1]. Recent studies and reviews have emphasized the nutritional and functional potential of carrot and the importance of selecting appropriate processing technologies to preserve its valuable bioactive constituents. With increasing consumer demand for

nutritious, convenient and shelf-stable vegetable products, dehydration offers considerable potential for extending the usability and value of fresh carrot.

Drying is one of the most widely employed methods for preserving fruits and vegetables, as moisture removal reduces water activity and thereby limits microbial growth and several deteriorative reactions [2]. Among various techniques, convective drying is the most widely used at the industrial scale [3]. However, conventional hot-air or convective drying often involves prolonged drying periods and exposure to elevated temperatures, which may adversely affect the colour, texture and heat-sensitive nutritional and bioactive constituents of product. Consequently, there is a need for improved drying technologies that can enhance drying efficiency while minimizing quality deterioration.

Microwave drying has been of great interest as an alternative or complementary technology, since microwave energy generates heat volumetrically within the food material, which facilitates rapid moisture migration and reduces the drying time. However, too much microwave energy can result in localized overheating and undesirable changes in color and nutritional quality [4]. In contrast, convective drying offers relatively controlled and uniform heating but at the expense of longer processing times. Hence microwave pretreatment before convective drying has the potential to combine the advantages of rapid internal heating of microwave energy with controlled environment of convective heating, thereby improving drying efficiency while maintaining desirable product quality [5]. This type of approach is especially relevant for carrot, where the development of a dehydrated product requires an appropriate balance between the drying rate and quality parameters such as color, final moisture content and rehydration properties.

In view of these considerations, the present study was undertaken to investigate the drying behaviour of carrot pieces using microwave and convective drying and to evaluate the quality characteristics of the resulting dehydrated products. The study aims to provide useful information for identifying suitable drying conditions that can improve processing efficiency while maintaining the desirable quality of dehydrated carrot pieces.

2. MATERIALS AND METHODS

Fresh carrots were washed properly, peeled by hands and sliced into 0.5 cm thickness with a knife. The process flow chart for producing dehydrated carrot slices is given in the Fig 1. After initial steps, carrot pieces were dried using a laboratory microwave oven (LG (MG – 583MCG)), at 4 different power levels of 180, 360, 600 and 900 watt. The mass of the sample was recorded at every 2 min intervals for all the power levels. After initial drying by microwave oven, the carrot slices were dried in the convective tray dryer at a temperature of 60°C till moisture content goes below 10% for safe storage. The weight of the sample was taken at every 30 min intervals for convective drying to determine the moisture content.

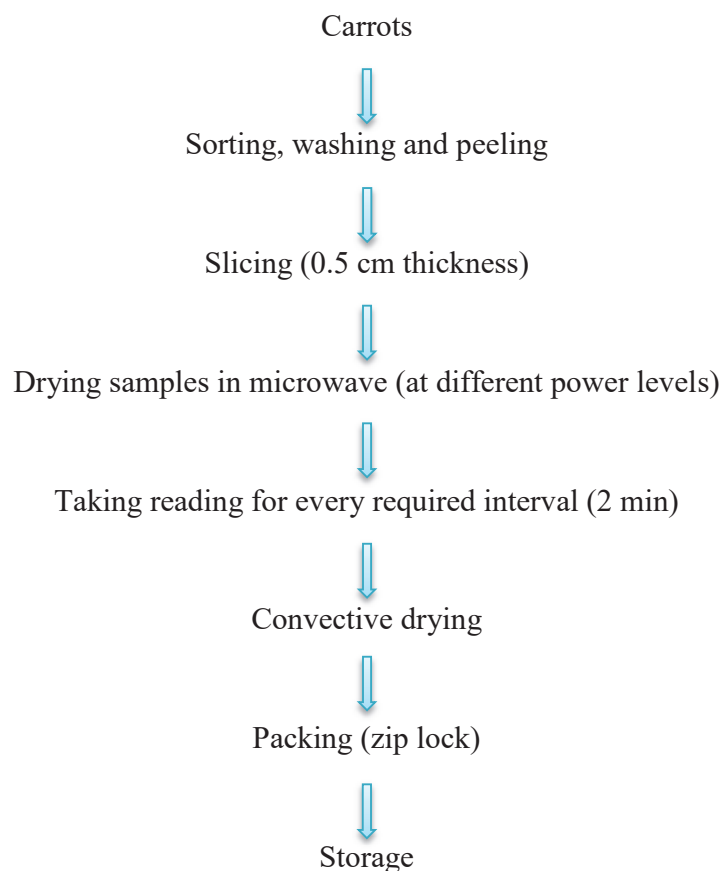


Fig.1. Process flow chart for dehydration of carrot pieces

2.1 Drying kinetics

The initial and final moisture contents of the sample were determined by using standard AOAC procedures and were noted as change in sample weight with respect to the drying time. Moisture content of the carrot (g H₂O/g dry matter) was determined using the Equation:

$$M = \frac{(W_o - W) - W_i}{W_i}$$

where, M is the moisture content of the carrot (in g H₂O/ g dry matter), W_o is initial weight of sample, W is the amount of water removed, W_i is dry matter present in the sample. Drying rate (R) was calculated using Equation:

$$DR = \frac{(W_o - W_t) * 100}{t \times W_i}$$

where, W_o is the initial weight, 't' is time, W_t is the drying weight at time t and W_i is the dry matter present in the sample.

2.2 β -Carotene content

β -Carotene content was determined using 2 g of fresh and dried carrot samples. Each sample was extracted overnight at room temperature with 30 mL of acetone–distilled water mixture (80:20, v/v) in a tightly covered test tube. An identical solvent mixture was used as a blank. The extracts were subsequently transferred to a separatory funnel containing 15 mL each of benzene and sodium bisulphite solution and shaken thoroughly. After phase separation, the lower layer was discarded and the upper layer was collected for analysis. Absorbance was measured at 452 nm using a Varian Cary 50 Bio UV–Visible spectrophotometer. Total carotene content was calculated using the following equation:

Total carotenoids mg/ 100 g

$$= \frac{OD \times 13.9 \times 10000 \times 100}{\text{Wt. sample mass (g)} \times 560 \times 1000}$$

Where, OD is Optical density (absorbance) of the solution recorded by spectrophotometer at 452 nm.

2.3 Rehydration ratio

Approximately 2 g of each dried sample was weighed for the rehydration study. The samples were immersed in 400 mL of distilled water in a beaker and maintained at room temperature. The samples were removed at 10-min intervals, gently blotted to remove excess surface water, and weighed until a constant weight was attained. The rehydration ratio was calculated using the following equation:

$$\text{Rehydration} = \frac{\text{Mass after rehydration}}{\text{Mass before rehydration}}$$

3. RESULTS

3.1 Variation in Moisture Content

The variation in moisture content with time during microwave pretreatment is presented in Fig.2. It is evident from the graph that moisture content decreased continuously with drying time at all microwave power levels (180, 360, 600 and 900 W). The rate of moisture removal increased with increasing microwave power, resulting in a shorter drying time at higher power levels. At 900 W, moisture content decreased rapidly from about 623% to 32.5% (d.b.) within 10 min. At 600 W, it decreased to 52.3% in 14 min, while at 360 W, the moisture content reached about 46.3 % in 20 min. The 180 W treatment exhibited the slowest moisture removal, requiring approximately 22 min to reach about 48%. Thus, increasing microwave power enhanced moisture removal and reduced the overall drying time, with 900 W providing the fastest drying among the treatments.

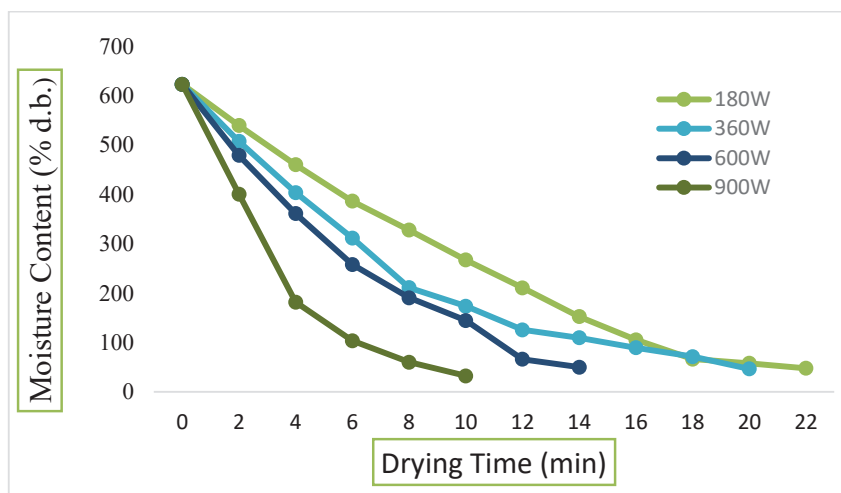


Fig. 2. Variation in moisture content with time during microwave pretreatment

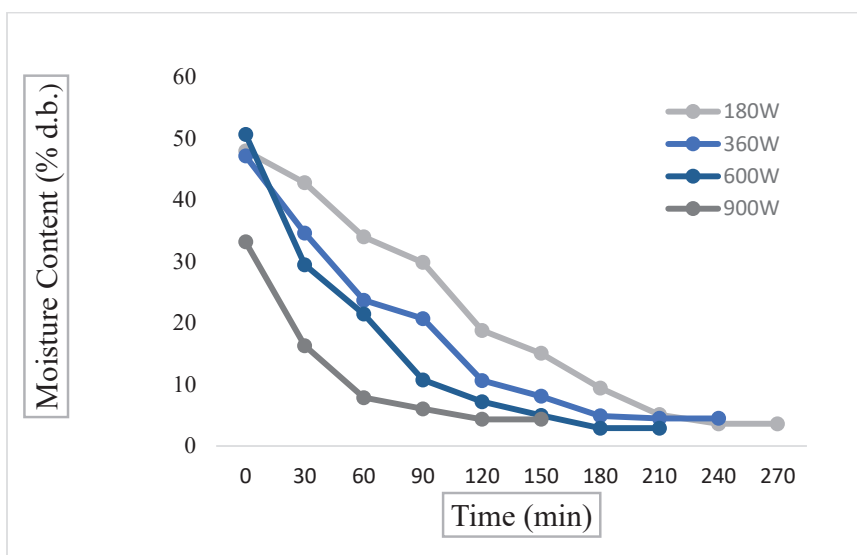


Fig. 3. Variation in moisture content with time during convective drying

The change in moisture content of carrot samples during hot-air drying at 60°C, is presented Fig. 3. The results indicate that microwave power significantly influenced the drying rate and the time required to attain final equilibrium moisture content. Among the treatments, samples dried at 900 W reached equilibrium moisture content in the shortest time (150 min), whereas those dried at 180 W required the longest drying time (270 min) during convective drying. This indicates that an increase in microwave power enhanced the rate of moisture removal from the carrot samples during hot air drying.

The drying curves exhibited the characteristic pattern commonly observed during the drying of food materials. A relatively rapid reduction in moisture content was observed during the initial stage of drying, followed by a gradual decrease as drying progressed. During the later stages, the

rate of moisture removal became considerably slower and approached equilibrium, indicating the progressive reduction in the availability of free moisture for evaporation.

3.2 Variation in Drying Rate

The variation in drying rate with average moisture content during microwave treatment and hot air drying are presented in Fig. 4 and Fig.5. The drying rate decreased continuously with average moisture content for both the cases. The moisture content of the material was very high during the initial phase of the drying which resulted in a higher absorption of microwave power and higher drying rates due to the higher moisture diffusion. As the drying progressed, the loss of moisture in the product caused a decrease in the absorption of microwave power and resulting in a fall in the drying rate. Similar finding was also reported for radiofrequency drying of peanut where the drying was accomplished in falling rate period [6].

For hot air drying, no constant rate of drying period was observed and all the drying operations occurred in the falling rate period and hence drying rate was controlled by diffusion of moisture from the interior of the solid to the surface.

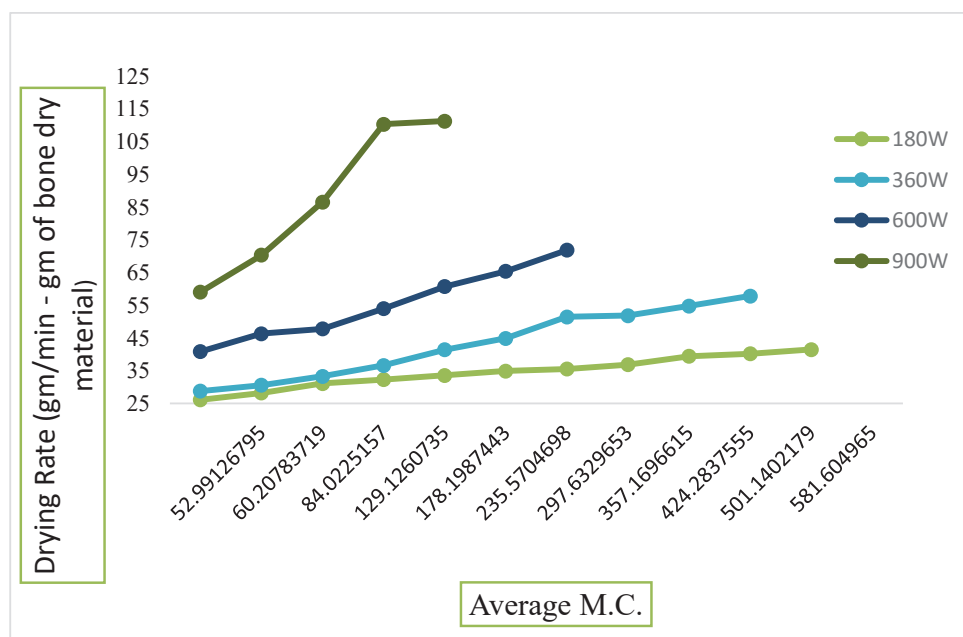


Fig. 4. Variation in drying rate with average m.c. for microwave drying

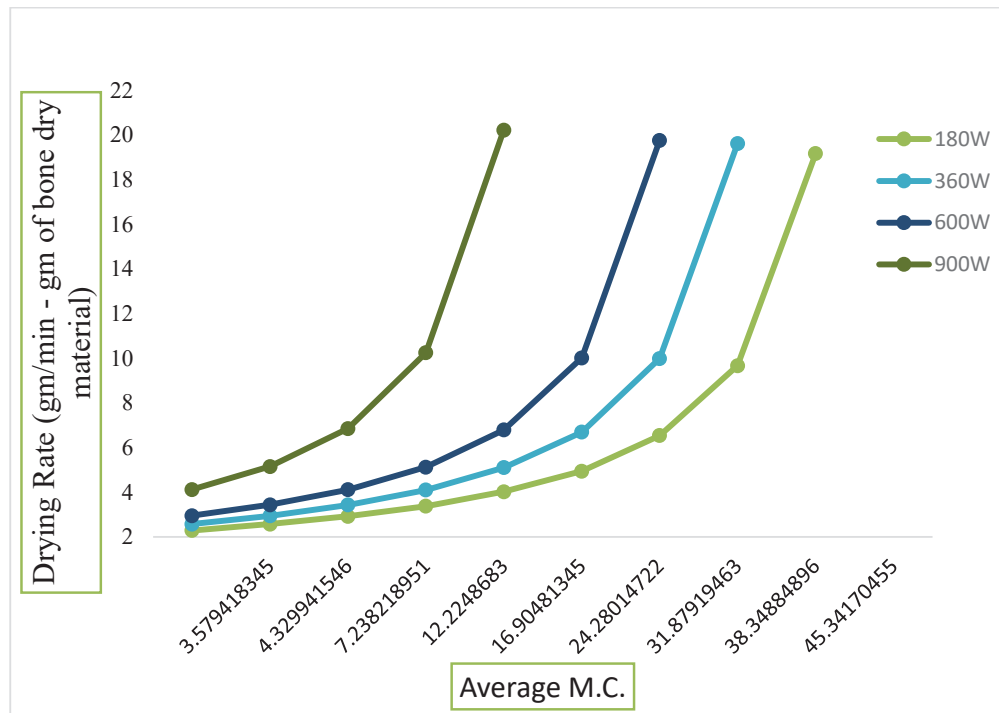


Fig. 5. Variation in drying rate with average m.c. for convective drying

3.3 Rehydration Ratio

Rehydration ratios were almost close to 5 for all the samples irrespective of drying condition. This was due to the fact that all the samples were dried upto almost same equilibrium moisture content ($4 \pm 2\%$) during hot air drying. However, for convective drying of microwave pretreated zucchini, rehydration was found to increase by 14.7% with the increase in microwave power [7].

Table1. Rehydration ratio of dehydrated samples

Drying condition	Time	Rehydration Ratio
180W, 60°C	150	5.205
360W, 60°C	150	4.98
600W, 60°C	150	5.455
900W, 60°C	150	4.95

3.4 β -Carotene Content

Beta carotene content (mg/100g) of dried carrot slices are given in Table 2. The reduction of Beta carotene content was highest for the samples dried at 900W and 60°C.

Table 2. β -Carotene content of dehydrated samples

β -Carotene values at wavelength 452 nm			
Drying Condition	Weight of sample (g)	Optical Density (O.D)	β -Carotene (mg/100g)
180W, 60°C	2.062	0.0426	0.51279964
360W, 60°C	2.06	0.04142	0.499079404
600W, 60°C	2.061	0.03923	0.472462224
900W, 60°C	2.06	0.03813	0.459437413

4. CONCLUSION

On the basis of the results obtained from the present investigation it can be concluded that drying characteristics of carrot slices were greatly influenced by microwave power levels. Based on experimental data analysis, microwave drying at power level of 600 W along with convective drying at 60°C was found to be the best drying condition for carrot slices. The produced carrot slices with this drying condition showed highest rehydration ratio and maximum reduction in moisture content.

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