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ORIGINAL PAPER

Microwave assisted convective drying of bitter gourd: drying kinetics and effect on ascorbic acid, total phenolics and antioxidant activity

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Abstract

Bitter gourds were dried by convective drying (CD) at 40, 50 and 60 °C and by microwave assisted convective drying (MACD) at 40, 50 and 60 °C combined with microwave power at 320, 400, and 480 W. In MACD, temperature and microwave power were applied synchronously. Quality of dried products in terms of ascorbic acid content, total phenolic content, total flavonoid content, vitamin A, DPPH radical scavenging activity, rehydration ratio, and total color change were compared. The drying rate increased with an increase in air temperature and microwave power. The MACD technique shortened the drying time compared to the CD. Prolonged drying time caused more deterioration of ascorbic acid and antioxidant activity than higher temperatures. In MACD, the total phenolic content and total flavonoid content did not degrade at elevated temperatures due to faster and homogenous drying. Moreover, the application of microwave power resulted in less reduction of Vitamin A and better retention of the surface color of the bitter gourd. Considering the drying time and quality attributes, microwave assisted convective drying would be a very promising alternative drying technique for bitter gourd.

Keywords Bitter gourd · Ascorbic acid · Total phenolic content · Antioxidant activity · Drying kinetics

Introduction

Bitter gourd (*Momordica charantia L.*) which belongs to the family Cucurbitaceous is widely grown in India, China, Malaysia, Taiwan, Indonesia, Vietnam and Africa [1]. Bitter gourd has received growing interest because of the presence of important antioxidant compounds such as phenolic acids, flavonoids, ascorbic acid and carotenoids which impart various health benefits [2]. In terms of food application, fresh bitter gourd can be traditionally used as a vegetable for direct cooking. The dried bitter gourd chips, dried bitter gourd powder and bitter gourd pickles are some of the value-added products obtained from the bitter gourd [3]. Like other perishable crops, fresh bitter gourd also deteriorates rapidly after harvest due to its excess moisture content [4]. Therefore, to widen its shelf life and to expand the possibility of offseason availability of bitter gourd, immediate preservation becomes a vital requirement.

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Drying is recognized as one of the ancient food processing techniques, and today it is broadly used in food industries for fruit and vegetable preservation. The basic concept involved in drying is the lowering of moisture content up to a definite threshold value that prevents deterioration and subsequent decay within a definite period. The increasing reluctance of consumers to the foods, preserved by the use of chemicals and the growing demand of high quality fast-dried food products has led to the fast expansion of the market for the additive-free dried alternatives [5].

Hot air drying is a common food preservation method that results in dried foodstuffs that have an enlarged shelf life. However, it suffers from a major drawback of production of low quality food due to prolonged drying time and elevated temperatures used [6]. Other methods such as microwave drying, a relatively new form of drying, could be considered faster and more efficient than conventional air drying. However, microwave drying application alone results in some serious drawbacks such as overheating and charring of material because of non-uniform heating, improper microwave energy conversion to the heat at reduced amount of water and restricted microwave entry through the food product [7]. Moreover, because of the costly affairs of microwave drying of food products, it cannot compete with hot air drying.

Nowadays, growing concerns about the quality as well as cost of production has boosted the researchers to select the combined drying techniques. Various combined techniques such as microwave enhanced or microwave assisted drying could be successfully applied to overcome these problems. In microwave assisted drying technique, heat is not disseminated from the surface of the food product to the inside, but it is produced in a food product being dried. In this technique, hot air eliminates the free water from the surface of the product and the moisture from the inner parts of the product is removed by microwave energy. Microwave assisted convective drying not only improves drying rate predominantly in the falling rate period but also yield the product of better quality [8].

Several studies on microwave assisted convective drying were carried out in different fruits and vegetables such as red pepper [9], Okra [10] and blue berries [11]. However, as reported in literature, bitter gourd has been mostly dried by using hot air and radio frequency assisted hot air [12], sun and solar drying [4]. According to our knowledge, microwave assisted convective drying of bitter gourd has not been carried out until now. Furthermore, the originality of the research comes from the application of microwave assisted convective drying technique to acquire acceptable quality of dried bitter gourd. Therefore, in the present research, convective drying in combination with microwave was used to examine the drying kinetics of bitter gourd and to analyze the effect of microwave power and air temperature on the ascorbic acid content, total phenolic content, total flavonoid content, DPPH radical scavenging activity, Vitamin A, rehydration ratio and color change.

Materials and methods

Sample preparation

Fresh and good quality bitter gourds were procured from the local market of Aligarh, India. The bitter gourds which had similar skin color, size and maturity were selected for this particular study. After cleaning and washing of bitter gourds with tap water, the vegetables were kept in a refrigerator (4–5 °C) until further study. The samples were cut into the 3 mm thick slices and, seeds and stems were removed. Moisture content of fresh bitter gourd was estimated by drying the bitter gourd sample at 70 °C in a hot air oven for 14–16 h. [13]. The initial moisture content of the bitter gourd varied from 91 to 92% (w.b).

Microwave assisted convective drying

Drying was carried out in a microwave assisted convective dryer prototype, fabricated and installed at the Department of Post-harvest Engineering and Technology, AMU, Aligarh, India. A schematic diagram and picture of the working setup are given in Fig. 1a, b respectively. The setup for all the experiments were the same i.e. in MACD, the magnetron of the microwave oven (Kenstar, KE 20 CMGJ-MJK, India) was kept ON continuously, while in convective drying (CD), the magnetron of the oven was kept OFF throughout the treatment. The rear wall of microwave oven was made perforated by drilling numerous openings of 2 mm diameter to allow the entry of air inside the oven cavity. From outside, the air convection system was connected to rear wall of microwave oven by means of screws using galvanized iron

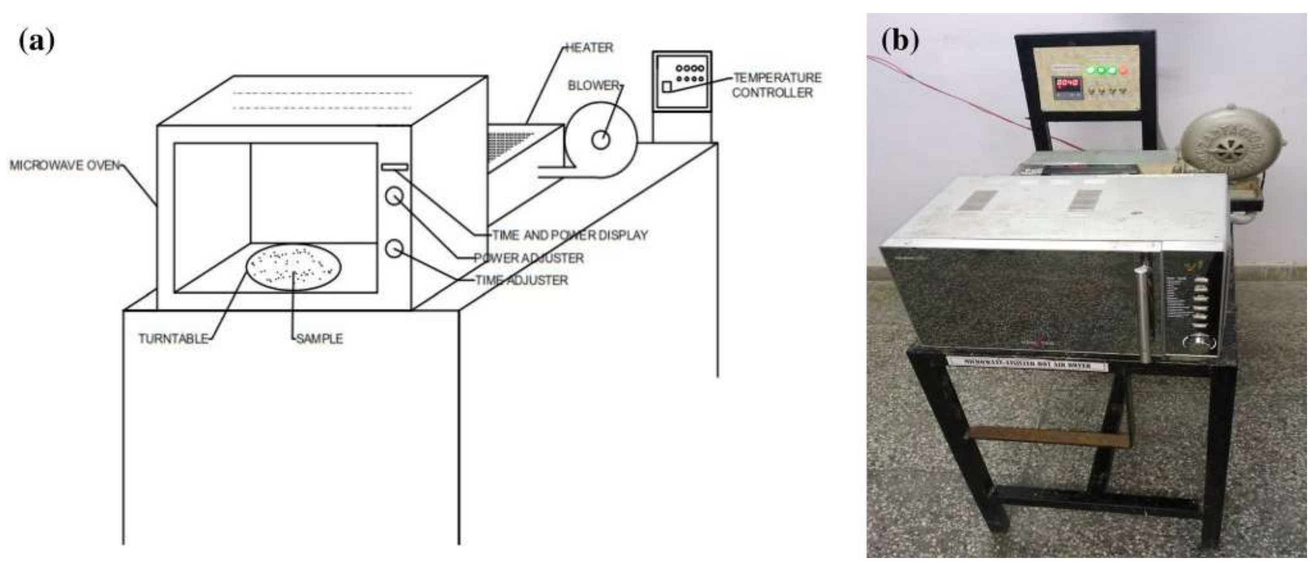

Fig. 1 Experimental apparatus (Microwave assisted convective drying system) (**a**) schematic diagram (**b**) in a working condition

sheet duct of 100 mm length, 220 mm width and 60 mm depth with proper packing. Another end of the duct was connected to a room heat convector (2 kW heating load) and the heaters were connected to power source. The original blower of room heat convector was replaced by an external higher capacity air blower (Lama Electricals, New Delhi, India). The inlet air temperature was controlled and monitored by digital display and magnetic relay type controller unit with the probe inserted between the ducts and perforated rear wall of oven. The whole setup was connected to AC power supply via a constant voltage stabilizer (3 KVA).

Drying procedure

For each experiment, approximately 250 g weight of the bitter gourd sample was taken and uniformly spread on centrally located rotating glass tray which was subjected to an air flow speed of 2.0 ± 0.1 m/s. The drying system had a provision for setting air temperature according to the drying requirements at 40, 50 and 60 °C. The levels of microwave power were set at 320, 400 and 480 W. The glass turntable containing bitter gourd sample continuously rotated during the drying process in order to achieve the homogenous microwave energy distribution in the product sample, and to affirm uniform drying of the product. The samples were weighed periodically during the drying process to record the weight loss of the product. For this purpose, the microwave was switched OFF, and the sample was then immediately weighed on an electronic balance. In the similar manner, the samples were again exposed to drying (particular set of air temperature and microwave power) as explained above until two consecutive observations recorded equal sample weight.

The dried sample so obtained was further cooled in a desiccator. When the temperature reached to the normal, the sample was packed in the low density polyethylene packets and heat sealed. The dried sample was then used for the assessment of various quality parameters.

Quality parameters

Ascorbic acid content

The ascorbic acid content was estimated according to the method of Ranganna [13] and as done by Yousuf and Srivastava [14]. Briefly, 5 g of dried sample was blended with 3% metaphosphoric acid (HPO_3) solution, followed by filtration. The filtrate was made up to 50 ml with 3% HPO_3. The dye solution was prepared by dissolving 50 mg of the sodium salt of 2,6- dichlorophenol indophenol in 150 ml of hot glass distilled water containing 42 mg of sodium bicarbonate. The solution was cooled and then diluted with distilled water to 200 ml. An aliquot of 3 ml of HPO_3 sample extract was then titrated with a standard dye solution to the pink end point. Standardization of the dye was done by titrating with a standard ascorbic acid solution and the titre value was noted. Content of ascorbic acid expressed as mg per 100 g of dry weight was determined using the following formula.

$$\text{Ascorbic acid (mg/100 g DW)} = \frac{Titre \times Dye\,factor \times volume\ made\ up \times 100}{Aliquot\ taken\ for\ estimation \times weight\ of\ sample\ taken}$$

Total phenolic content

Total phenolic content was estimated by the procedure of Chun et al. [15] with some modifications. Methanolic extract solution was prepared by homogenizing 2 g of bitter gourd tissue in 20 ml of methanol. The homogenate was left undisturbed for 12 h at 4 °C and was then centrifuged at 10,000×*g* for 15 min at 4 °C. In brief, an aliquot of 0.2 ml of methanolic extract solution was transferred to a glass tube; 1.5 ml of Folin–Ciocalteau reagent and 1.2 ml of 7.5% Na_2CO_3 was added. After vigorous shaking of the mixture, the mixture was left undisturbed for 2 h at room temperature. Finally, absorbance was measured at 765 nm using a double bean UV–VIZ Spectrophotometer and was then compared to a gallic acid standard curve. Total phenolic content was expressed as mg of gallic acid equivalents (GAE) per 100 g of dry weight.

Total flavonoid content

Total flavonoid content determination was performed by a method of Chang et al. [16]. 1 ml of methanolic solution of sample was mixed with 3 ml of 95% methanol followed by the addition of 0.2 ml of 10% aluminum chloride, 0.2 ml of 1 M potassium acetate and 2.6 ml water. Substitution of 10% aluminum chloride volume was done by the same amount of distilled water in blank. The mixture was left undisturbed for 30 min at room temperature and then absorbance at 415 nm was measured. Quercetin (Sigma, Germany) was used for preparation of standard curve and the total flavonoid content was expressed as mg of quercetin equivalents (QE) per 100 g DW.

Vitamin A

Beta-carotene determination was performed by a procedure previously reported by Mehta et al. [4]. Briefly, acetone and petroleum ether mixture in the ratio of 1:1 (v/v) was used to extract a 5 g of the sample by using mortar and pestle. The upper layer was collected and then mixed with crude extracts after being washed with water repeatedly. The extract obtained was made up to the volume of 100 ml using petroleum ether. Beta-carotene was estimated with a spectrophotometer taking petroleum ether as blank and recording absorbance at 452 nm

$$\text{Beta} - \text{ carotene } (\mu g/100g) = \frac{O.D \times 13.9 \times 10^4 \times 100}{weight\ of\ sample(g) \times 560 \times 1000}$$

$$\text{Vitamin A (I.U.)} = \text{Beta} - \text{ carotene } (\mu g/100g)/0.6$$

DPPH radical scavenging activity

Antioxidant activity was estimated according to the method of Horuz et al. [17]. 5 ml of 0.1 mM methanol solution of DPPH was mixed with 0.1 ml of several concentrations of methanol extract of fresh and dried bitter gourd samples. After vigorous shaking of the reaction mixture, the mixture was left undisturbed for 20 min at 27 °C. The absorbance was read at 517 nm in a spectrophotometer. Percent inhibition of DPPH radical was determined as:

$$\%\ \text{Inhibition} = \frac{A_{control} - A_{sample} \times 100}{A_{control}}$$

Where A_{control} = absorbance of control; A_{sample} = absorbance of sample.

Rehydration ratio

As suggested by the Horuz et al. [17], the following method was used for the estimation of rehydration ratio (RR) of dried bitter gourd samples. The dried sample weighing 2 g was soaked in 20 ml of distilled water at 30 °C for 120 min. The water was drained and the sample was withdrawn and then weighed. The rehydration ratio was calculated as the ratio of weight of rehydrated bitter gourd sample to the weight of dried bitter gourd.

Total color change

The surface color measurements of bitter gourd samples were carried out using Hunter Lab Colorimeter (Mini Scan XE plus, Hunter Associates Laboratory, Inc, Reston, USA) according to the CIELAB system. Before color measurements, calibration of the instrument was done with standard white and black plates. The sample color was expressed in terms of L^* (lightness), a^* (redness/greenness and b^* (yellowness/blueness). The total color change (ΔE) was calculated by using the following formula as done by Yousuf and Srivastava [18].

$$\Delta E = \left[(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2 \right]^{1/2}$$

where, L_0, a_0 and b_0 are the initial values of bitter gourd and, L, a, b are the dried bitter gourd samples values.

Statistical analysis

All the experiments were repeated three times and the data reported is mean of three determinations ± standard deviation (SD). Statistical analysis of the data was carried out by analysis of variance (ANOVA) and Duncan's multiple-range test by using SPSS software (version 17.0 for Windows, SPSS Inc., Chicago, U.S.A.). Statistical differences were defined at $p < 0.05$.

Results and discussion

Drying kinetics

The variation of the moisture content with time during the MACD of bitter gourd are shown in Fig. 2a, b, while Fig. 2d represents the variation of moisture content with drying time during convective drying. From the figures, it could be seen that as drying time progressed, moisture content decreased till a constant value was achieved. Moisture content decreased rapidly during the initial period of drying which is noticeable from the figures by the steeper slope and then the curve slope begins to be flatter as the drying progressed, pointing out slower drying. The drying time decreased with increase in microwave power and temperature. This could be due to the generation of larger vapor pressure difference between the interior and exterior surface of the product which results in rapid heat transfer within the product at higher temperature and microwave power. The convective drying took much longer time of 220, 160 and 140 at 40, 50 and 60 °C respectively (Fig. 2d), as compared to the MACD which took only 50–70 min depending on the drying conditions (Fig. 2a–c). This reduction in drying time mainly comes from the microwave energy, however temperature during drying was slightly dominant than microwave power, mainly at lower microwave power levels [17].

The drying rates were calculated from the change of moisture content with drying time and plotted against drying time as shown in Fig. 3a–d. It could be seen from the figures, that drying occurred in falling rate period and the constant rate period was not observed, suggesting that intrinsic properties mainly govern the water removal from the product. The faster drying rates were observed at higher temperature ascribed to faster heat and mass transfer. However, at the initial period of drying, drying rate was faster in MACD as compared with the convective drying. This could be attributable to the high content of moisture available in the sample which resulted in more absorption of microwaves and hence increased moisture diffusivity. On the other hand, absorption of microwaves is lesser at last stage of drying due to the presence of lower moisture content. Consequently, air drying became extra influential on the drying rate [19].

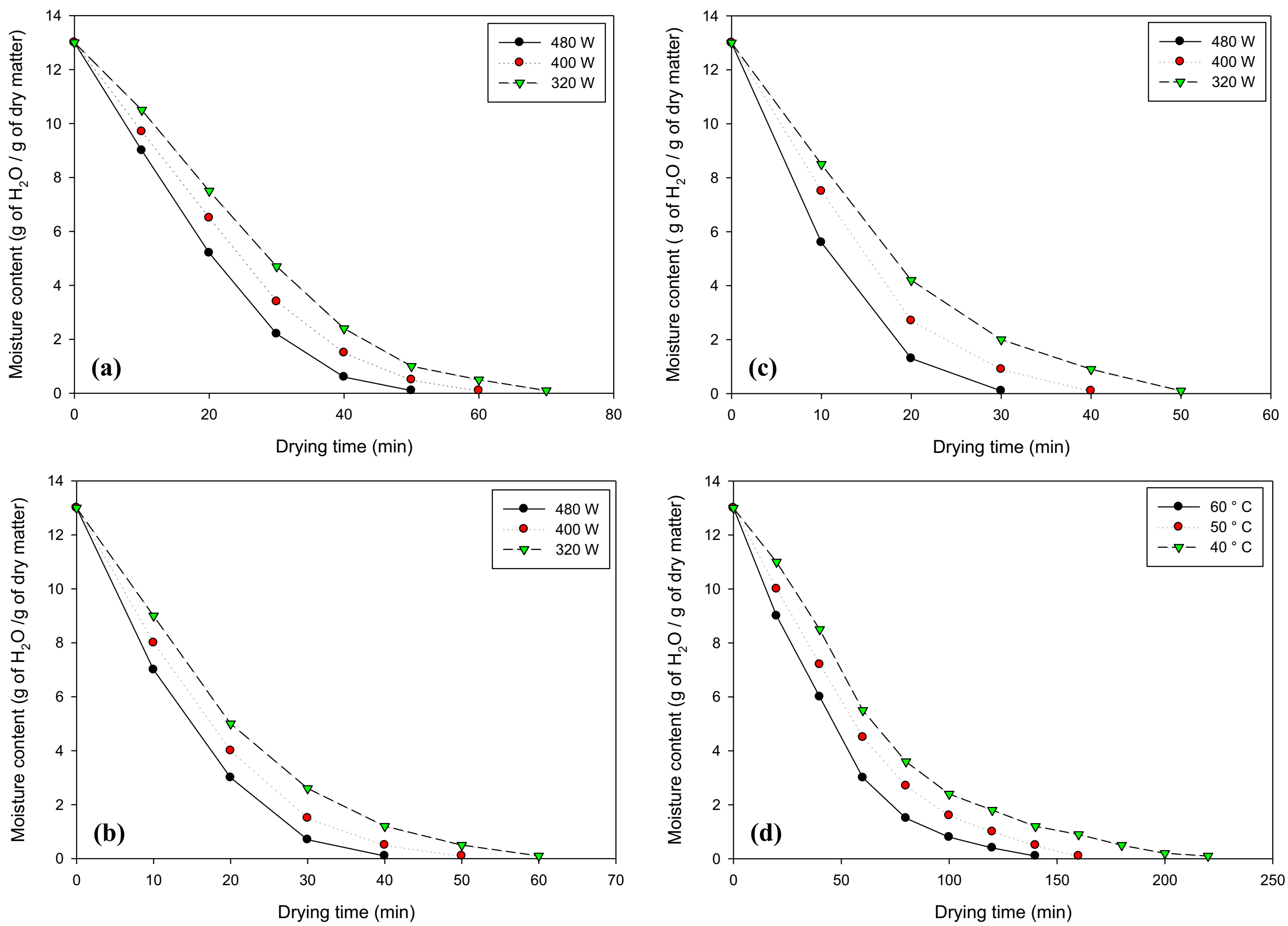

Fig. 2 Effect of drying temperature on moisture content at **a** 40 °C, **b** 50 °C, **c** 60 °C, **d** convective drying

Quality attributes

Ascorbic acid content

Ascorbic acid is an indispensable nutrient for humans and quality indicator of dried food products, because of its heat and light sensitivity. Time and temperature are the dominant factors that affect the degradation of ascorbic acid in various food processes [20]. In this study, fresh sample contained about 64.27 mg of ascorbic acid per 100 g. The ascorbic acid content decreased significantly ($p < 0.05$) in both convective and microwave assisted convective dried samples under all drying conditions. The ascorbic acid content of convective dried samples varied from 29.96 to 37.06 mg/100 g which means more than 53% of ascorbic acid was lost during convective drying.

The heat application also had significant negative effect in samples dried by MACD under all conditions of drying. However, in MACD, the ascorbic acid loss was lower than convective drying. The effect of drying temperature and microwave power on ascorbic acid of dried bitter gourd is shown in Fig. 4. It was noticed from the figure, that lower temperature (40 °C) caused more ascorbic acid loss in convective dried samples than elevated temperature (60 °C). Similar trend was observed for the samples dried by microwave assisted convective drying. This could be due to the longer drying times facilitating the ascorbic acid oxidation. Moreover, increase in microwave power at high and low temperatures increased the ascorbic acid content of dried bitter gourd. However, ascorbic acid content of dried bitter gourd was only affected by air temperatures at higher microwave power. Furthermore, higher temperature caused inactivation of ascorbic acid oxidase, an enzyme that catalyzes the oxidation of ascorbic acid [21].

Total phenolic content

The total phenolic content (TPC) of fresh bitter gourd was found as 141.20 mg GAE/100 g. Total phenolic content of the dried samples ranged from 26.13 mg/100 g to 71.20 mg/100 g, means 49.50–81.40% loss occurred during drying (Fig. 5). However, loss of TPC was more in

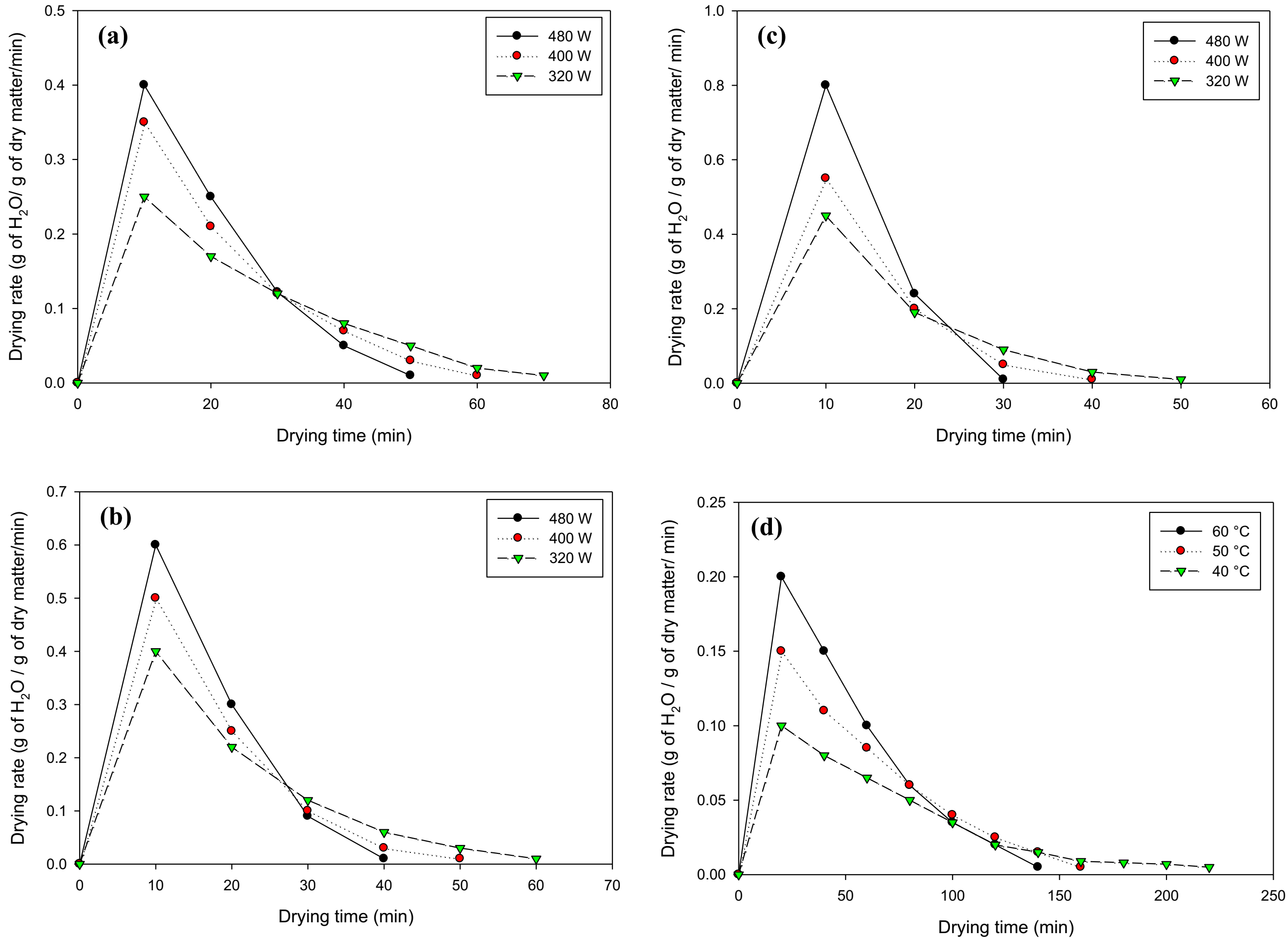

Fig. 3 Effect of drying temperature on drying rate at **a** 40 °C, **b** 50 °C, **c** 60 °C, **d** convective drying

convective drying than microwave assisted convective drying of bitter gourd. The reduction of TPC in convective drying at 40, 50 and 60 °C were 81.40, 80.02 and 79.26% respectively. The reason could be the deterioration of the phenolic compounds due to the prolonged heat exposure at lower drying temperature.

In MACD, the total phenolic content of the dried bitter gourd was more than convective drying. The total phenolic content significantly increased with increase in air temperature and microwave power. The situation may be due to the reduction of drying time because of the application of microwave power. Faster and shorter heating inactivated oxidative enzymes during MACD and helps in the better retention of phenolics. Similar results were found by Wojdyło et al. [22], reporting that degradation of phenolic compounds was lesser in vacuum microwave drying compared to the convective drying. Furthermore, presence of phenolic molecule precursors (by non-enzymatic interconversion between phenolic molecules) at higher temperatures results in the formation of phenolic compounds [23].

Total flavonoid content

Flavonoids are important phytochemicals that are responsible for the defensive effect of vegetables. In this study, the total flavonoid content of fresh bitter gourd was 11 mg QE/100 g DW. Total flavonoid content (TFC) of dried samples varied from 2.10 to 4.82 mg/100 g (Fig. 6). The total flavonoid content decreased in both convective as well as in microwave assisted convective dried samples under all drying conditions. However, the loss of total flavonoids was more than 80% in convective drying (Fig. 6). This could be clarified by the instability of flavonoids against oxygen during long drying times. Furthermore, C- glycoside bonds of flavonoids that exist as dimers and oligomers result in the formation of monomers by the hydrolysis of C- glycosides bonds upon prolonged drying times in convective drying [24].

In MACD, effect of microwave power and temperature on total flavonoid content of dried bitter gourd could be visualized from Fig. 6. The total flavonoid significantly

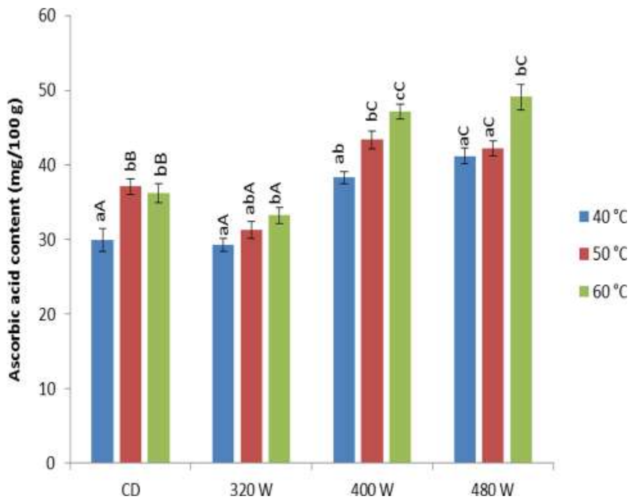

Fig. 4 Effect of microwave power and temperature on ascorbic acid content (mean of three replicates ± standard deviation) of dried bitter gourd. Different lower case letters represent statistical difference ($P < 0.05$) for different microwave powers at same temperature. Different upper case letters represent statistical difference ($P < 0.05$) for different temperatures at same microwave power

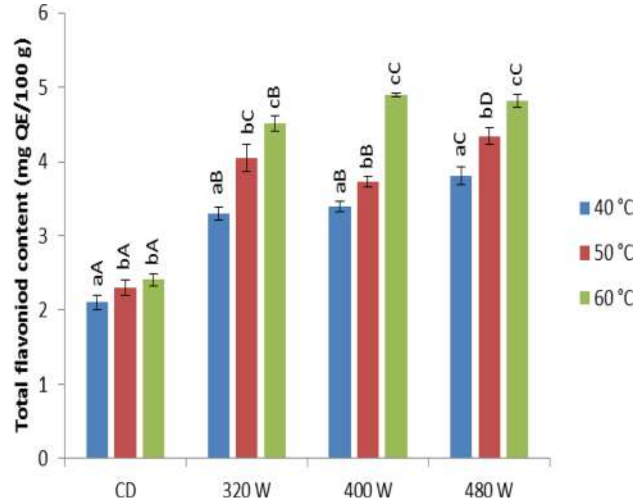

Fig. 6 Effect of microwave power and temperature on total flavonoid content (mean of three replicates ± standard deviation) of dried bitter gourd. Different lower case letters represent statistical difference ($P < 0.05$) for different microwave powers at same temperature. Different upper case letters represent statistical difference ($P < 0.05$) for different temperatures at same microwave power

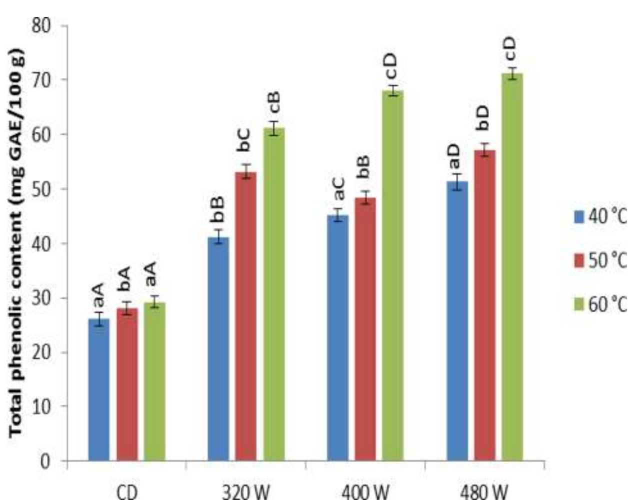

Fig. 5 Effect of microwave power and temperature on total phenolic content (mean of three replicates ± standard deviation) of dried bitter gourd. Different lower case letters represent statistical difference ($P < 0.05$) for different microwave powers at same temperature. Different upper case letters represent statistical difference ($P < 0.05$) for different temperatures at same microwave power

($p < 0.05$) increased with increase in temperature and microwave power. The maximum TFC was found at a microwave power of 400 W and temperature of 60 °C, and bitter gourd dried at this combination retained maximum amount of total flavonoids. This could be due to the higher microwave power and temperature caused the breakdown of the cell wall and cell membrane leading to increased availability of flavonoids [25].

DPPH radical scavenging activity

DPPH radical scavenging activity method was used for the determination of antioxidant activity of bitter gourd. The antioxidant activity of fresh bitter gourd was found to be 40.6%. Both CD and MACD methods negatively affected the antioxidant activity of bitter gourd (Table 1). However, the reduction of antioxidant activity was more in convective dried samples than microwave assisted convective dried ones. The reduction of antioxidant activity in convective drying was 74.55, 72.51, and 71.60% at 40 °C, 50 °C and 60 °C, respectively. The drying at higher temperature and power showed retention higher antioxidant activity rather than at lower temperature. This probably may be due to the lower temperatures necessitates longer drying time that resulted in a decrease in antioxidant activity. Moreover, the formation of maillard reaction products at higher temperatures and microwave power shows free radical scavenging activity that could enhance the antioxidant properties [26].

Vitamin A

The vitamin A content of fresh bitter gourd was found to be 140 I.U. Vitamin A content of both convective and microwave assisted convective dried samples are shown in Table 1. Drying process negatively affected the vitamin A of dried bitter gourd. The vitamin A content of the dried

Table 1 Effect of microwave power and drying temperature on DPPH radical scavenging activity and Vitamin A content of dried bitter gourd

Drying method	Power (Watt)	Temperature (°C)	DPPH radical scavenging activity (%)	Vitamin A (I.U.)
CD		40	10.33 ± 0.41^{aA}	25.20 ± 0.62^{bA}
		50	11.16 ± 0.56^{abA}	23.93 ± 0.90^{aA}
		60	11.53 ± 0.47^{bA}	28.03 ± 0.65^{cA}
MACD	320	40	18.40 ± 0.55^{aB}	34.13 ± 0.51^{aB}
	320	50	18.96 ± 0.55^{aB}	40.20 ± 0.62^{bB}
	320	60	24.16 ± 0.56^{bB}	45.10 ± 0.55^{cB}
	400	40	20.20 ± 0.62^{aC}	37.98 ± 0.42^{aD}
	400	50	22.06 ± 0.40^{bC}	40.10 ± 0.55^{bB}
	400	60	30.03 ± 0.45^{cC}	50.00 ± 0.40^{Cd}
	480	40	21.43 ± 0.45^{aD}	35.91 ± 0.54^{aC}
	480	50	27.03 ± 0.35^{bD}	42.16 ± 0.47^{bC}
	480	60	31.13 ± 0.41^{cD}	48.06 ± 0.40^{cC}

CD Convective drying; *MACD* Microwave assisted convective drying

Values represent mean of three observation ± standard deviation

Different lower case letters represent statistical difference ($P < 0.05$) for different microwave powers at same temperature

Different upper case letters represent statistical difference ($P < 0.05$) for different temperatures at same microwave power

bitter gourd varied from 25.20 to 50.0 I.U. In CD, vitamin A content of dried bitter gourds ranged from 25.20 to 28.03 I.U. meaning that more than 80% of vitamin A was lost during convective drying. The vitamin A content significantly ($p < 0.05$) increased with increase in microwave power and temperature, and the bitter gourd dried at 400 W microwave power and 60 °C temperature retained maximum vitamin A. Higher temperatures resulted in less reduction of vitamin A. This could be due to the increased beta-carotene solubility at elevated temperatures. Furthermore, degradation of beta-carotene is attributed to the oxidation with air and longer drying exposure. Longest drying times of 140–220 min caused higher beta-carotene losses during convective drying. Karabulut et al. [27] studied the effect of temperatures on beta-carotene of apricot in which they reported that beta carotene increased with increase in temperature from 50 to 80 °C and elevated temperature resulted in less reduction of beta carotene content in dried samples. Cui et al. [28] also found in their study that shorter drying times and faster drying rates reduced the activity of lipoxygenases, an enzyme responsible for the degradation of beta carotene.

Rehydration ratio

Rehydration is foremost quality characteristic of the dried products and it depends mostly upon structural changes caused during drying in cells of food product. The effect of drying conditions on the rehydration ratio of dried bitter gourd is shown in Table 2. The rehydration ratio of both convective and MACD samples increased significantly with increase in microwave power and temperature. This could be due to the tissue structural damage caused at higher microwave power and temperature, and the retention of the water in the spaces generated by the damaged tissues.

Microwave assisted convective dried samples showed higher rehydration ratio, mainly at higher microwave powers. This could be due to the engendering of enormous internal stresses during drying at higher microwave power. Horuz et al. [17] dried the sour cherry using convective and microwave convective drying and reported that microwave convective dried sour cherries exhibited higher rehydration ratio than convective drying. They further concluded that microwave convective drying improved the rehydration ratio of the dried sample.

Total color change

Color is an important quality attribute of the dried product, and at the point of sale, it is the first impact created by the consumer on the food. So, it's highly desirable to have a specific and uniform color of the dried product. The hunter scale values, L*, a* and b* have been broadly used to monitor the color changes due to thermal processing. Chromatic coordinates for the dried bitter gourd samples ranged from 41.32 ± 0.064 to 49.73 ± 0.071, -3.95 ± 0.13 to -5.72 ± 0.04 and 26.42 ± 0.083 to 28.33 ± 0.18 for L*, a* and b*, respectively. The L* value of dried samples increased with an increase in air temperature, meaning that dried product becomes brighter at higher temperatures. This trend was also reported by Samoticha et al. [29] in their study. A significant decrease ($p < 0.05$) in a* value was observed with an increase in

Table 2 Effect of microwave power and drying temperature on rehydration ratio and total color change of dried bitter gourd

Drying method	Power (Watt)	Temperature (°C)	Rehydration ratio	Total color change
CD		40	3.63 ± 0.11^{aA}	19.42 ± 0.05^{aD}
		50	3.80 ± 0.20^{aA}	20.73 ± 0.04^{bD}
		60	3.70 ± 0.10^{aA}	21.86 ± 0.05^{cD}
MACD	320	40	4.21 ± 0.08^{aB}	15.70 ± 0.11^{aC}
	320	50	4.52 ± 0.13^{bB}	18.13 ± 0.12^{cC}
	320	60	4.63 ± 0.07^{bB}	17.24 ± 0.13^{bB}
	400	40	4.41 ± 0.12^{aC}	14.36 ± 0.20^{aB}
	400	50	4.45 ± 0.12^{aB}	16.13 ± 0.06^{bB}
	400	60	4.82 ± 0.12^{bC}	16.49 ± 0.06^{cA}
	480	40	4.60 ± 0.10^{aC}	13.80 ± 0.10^{aA}
	480	50	4.70 ± 0.10^{abC}	15.24 ± 0.16^{bA}
	480	60	4.90 ± 0.10^{bC}	16.53 ± 0.15^{cA}

CD Convective drying; *MACD* microwave assisted convective drying

Values represent mean of three observation ± standard deviation

Different lower case letters represent statistical difference ($P < 0.05$) for different microwave powers at same temperature

Different upper case letters represent statistical difference ($P < 0.05$) for different temperatures at same microwave power

drying temperature and decrease in microwave power. Similarly, b* values increased with an increase in air temperature and, the samples dried by using convective drying exhibited more yellow color nuance due to prolonged drying time at higher temperatures [30]. The color change of convective and microwave assisted convective dried samples at different conditions of drying is shown in Table 2. The color change of the dried products ranged from 13.80 to 21. 86. The highest color change of 21. 86 was found in the convective dried sample. However, the color change did not show any huge difference for most of the dried samples. In convective drying, the color degradation increased with increase in temperature. This could be due to the degradation of green color and maillard reaction initiation which results in little browning of the dried bitter gourd. However, in our study, none of the dried product evinced prominent brown color. Miranda et al. [31] also reported that higher temperature during drying resulted in higher values of color change due to the high temperature effect on heat sensitive compounds.

The lowest color change was found in microwave assisted convective dried sample at 480 W microwave power and 40 °C temperature. Since, the bitter gourd contains high moisture content, and microwave application pushes the liquid into the surface which then gets converted into the vapour without causing the overheating of the surface [32]. Therefore, the better surface color preservation was found in the microwave assisted convective dried samples than convective dried ones.

Conclusion

The results of the study confirm the efficacy of the microwave assisted convective drying over conventional convective drying. The effect of combined drying methods on drying kinetics and quality attributes were discussed. The temperature and microwave power were the critical factors affecting the drying of bitter gourd. Drying occurred in the falling rate period and the constant rate period was not observed. Both the drying parameters and drying methods had a significant effect on the quality of dried products. The MACD method better retained the quality of the bitter gourd compared to the CD. The highest ascorbic acid content, TPC, TFC, vitamin A, DPPH radical scavenging activity, rehydration ratio, and the lowest color change was observed in microwave assisted convective drying method. Experiments with bitter gourd samples showed that microwave assisted convective drying method could be used for the preservation of high-quality products in reasonable drying time with lower energy consumption.

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