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Microwave assisted fluidized bed drying of bitter gourd: Modelling and optimization of process conditions based on bioactive components

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ABSTRACT

Bitter gourds were dried under varied drying conditions in a microwave assisted fluidized bed dryer, and the process was optimized using response surface methodology. Microwave power, temperature and air velocity were used as process variables for drying and the process parameters were varied between 360 and 720 W, 40–60 °C and 10–14 m/s, respectively. The responses determined for deciding the optimal criteria were vitamin C, total phenolics, IC_{50}, total chlorophyll content, vitamin A content, rehydration ratio, hardness and total color change of the dried bitter gourd. Statistical analyses were done by using response surface methodology, which showed that independent variables affected the responses to a varied extent. The optimum drying conditions of 550.89 W microwave power, 55.87 °C temperature, and 13.52 m/s air velocity were established for microwave assisted fluidized bed drying to obtain highest desirability for the dried bitter gourd. At optimum conditions, validation experiment was done to ensure the suitability of models. Temperature and drying time plays an important role in the deterioration of bioactive components. Faster and shorter heating led to the greater retention of bioactive components. Taking the aforesaid results into consideration, our study recommended MAFBD as a promising technique with minimum changes in quality attributes of bitter gourd.

1. Introduction

Consumers increasingly demand vegetables that are high in bioactive compounds such as ascorbic acid, phenolics, carotenoids, and dietary fibres while being low in sugars.. Bitter gourd is a popular source of bioactive compounds and has numerous medicinal properties among vegetables.(Chakraborty et al., 2020).Bitter gourd *(Memordica charantia L.)* belongs to the family Cucurbitaceae and is extensively cultivated in Asia, South America, East Africa, and America. Bitter gourd is called by different names such as bitter melon, Karela, or balsam pear and has been used as a food and medication for several diseases (Yan et al., 2019). The consumption of bitter gourd has enormously increased everyday not for its nutritional value but also their curative value. Bitter gourd revealed adequate source of catechins, gallic acid, chlorogenic acid, and gentisic acid (Yan et al., 2021). Bitter gourd has been noted to own antilipolytic, analgesic, antiviral, antimutagenic, and hypoglycemic properties (Farooqi et al., 2018). The consumption of bitter gourd reduced the body weight gain and blood glucose levels and increased the level of energy metabolism in high fat diet fed mice, as reported by Kubola and Siriamornpun (2008). Other use of this vegetable can be seen in the recent review (Sorifa, 2018; Sun et al., 2021). Like other vegetables, fresh bitter gourd is vulnerable to degradation because of its higher water content. In order to lower moisture content and microbial activity of the material, drying might be an important food preservation

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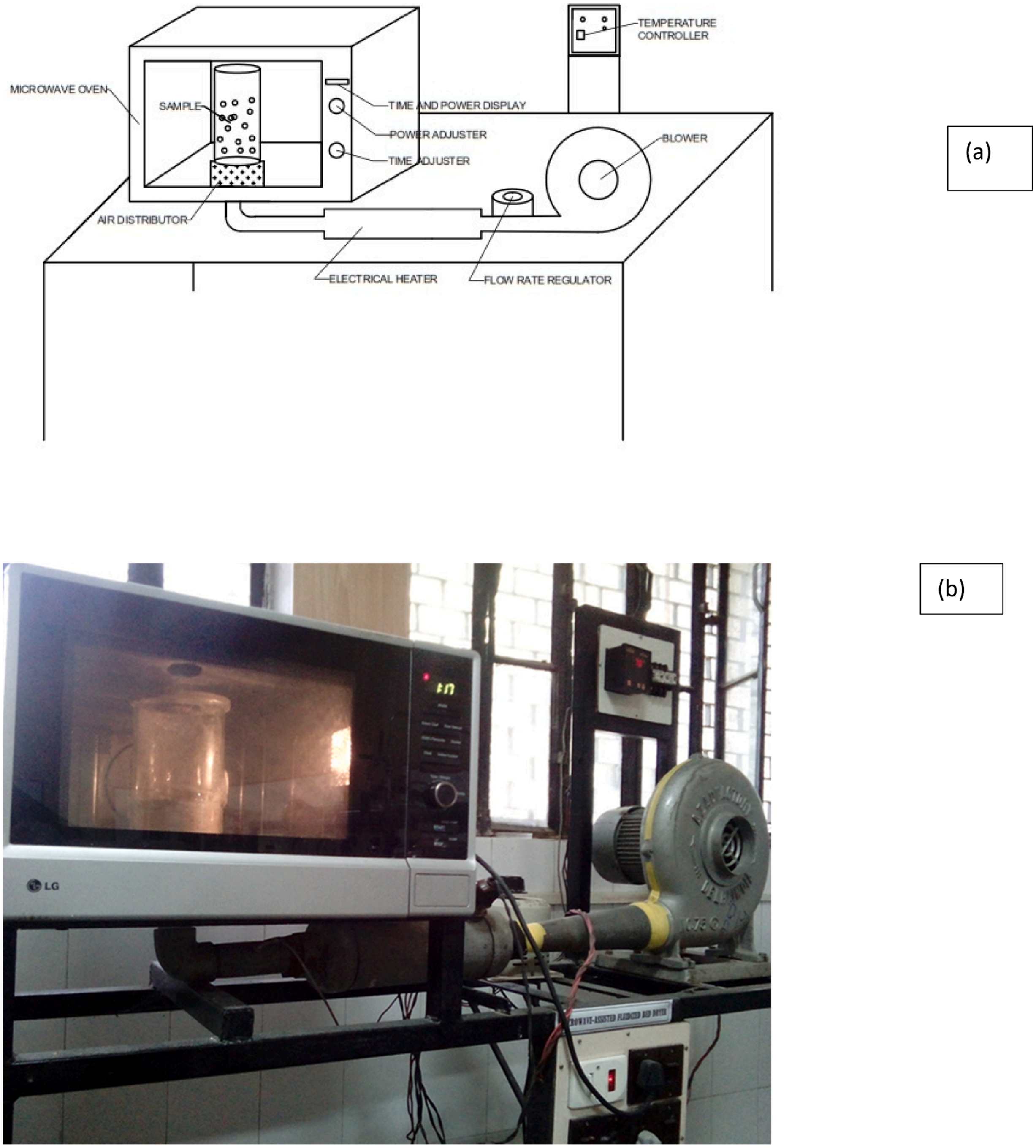

Fig. 1. Experimental apparatus (Microwave assisted fluidized bed drying system) (a) schematic diagram (b) in a working condition.

method, enhancing food stability and lowering transportation and storage costs (Yan et al., 2019).

Drying is a food preservative technique that reduces the moisture content and the bulk of a food material, which is an important criterion for shelf life and during transportation. Various drying techniques like convective drying (Singh and Talukdar, 2020; Delfiya et al., 2022), fluidized bed drying, conventional drying (Kumar et al., 2022; Jeevarathinam et al., 2021), solar drying (Singh & Agrawal, 2021), microwave drying etc., are used for different sectors of the food industry. Among all, the conventional hot air drying method produces serious effects in quality attributes and physico-chemical properties of food product due to its less efficiency and drying time (Lv et al., 2016, Singh & Talukdar, 2020; Pandiselvam et al., 2021).

Thus, microwave drying in conjunction with fluidized bed drying is suggested to reduce the individual limitations of microwave drying and convective drying and can significantly increase product quality and shelf life. Combining microwave and fluidized bed drying has the potential to overcome both drying methods' limitations while increasing the drying rate. The application of fluidization, which agitates the product and uniformly exposes it to microwaves, can correct the non-uniform heating of the product caused by microwave drying. On the other hand, the addition of microwaves to a fluidized bed dryer can reduce drying time because it enhances moisture diffusion rate. Previous research has shown that using a microwave-assisted fluidized bed dryer results in shorter drying times and higher dried product quality in various food products such as soybean (Anand et al., 2021), *Cuminum cyminum L.* (Babakiet al., 2020), strawberries (Jiang et al., 2021), rice (Nanvakenariet al., 2022; Sanisoet al., 2020; Saniso et al., 2021),

Table 1
Coded and actual levels of factors.

S.No.	Point type	Coded value	Microwave power (W)	Air temperature (°C)	Inlet air velocity (m/s)
1	Factorial	(−1, −1, −1)	360	40	10.00
2	Axial	(0, 0, −1)	540	50	10.00
3	Factorial	(1, −1, −1)	720	40	10.00
4	Axial	(0, −1, 0)	540	40	12.00
5	Factorial	(−1, 1, −1)	360	60	10.00
6	Axial	(−1, 0, 0)	360	50	12.00
7	Factorial	(1, 1, −1)	720	60	10.00
8	Centre	(0, 0, 0)	540	50	12.00
9	Factorial	(−1, −1, 1)	360	40	14.00
10	Axial	(1, 0, 0)	720	50	12.00
11	Factorial	(1, −1, 1)	720	40	14.00
12	Axial	(0, 1, 0)	540	60	12.00
13	Factorial	(−1, 1, 1)	360	60	14.00
14	Axial	(0, 0, 1)	540	50	14.00
15	Factorial	(1, 1, 1)	720	60	14.00

nutmeg mace (Singh & Talukdar, 2020), red lentil seeds (Taheri et al., 2020), *Cordyceps militaris* (Wu et al., 2019), and red bell pepper (Zahoor & Khan, 2021).Microwave assisted fluidized bed dryers provide excellent product mixing during drying and can achieve higher heat and mass transfers than more conventional dryers. Because of volumetric heating, the addition of microwave energy increases internal moisture transfer. As a result, the product dries evenly and quickly. MWFB dryers are known for their shorter drying times, lower energy consumption, and higher quality dried products. The various studies on microwave assisted fluidized bed drying revealed that a combination of both these techniques offers several benefits like uniform moisture, heat and mass transfer, low processing temperature, decreased drying time, easy to control microwave power, saving energy, and high efficiency (Zahoor & Khan, 2021).

The modeling and optimization of the drying system can aid in the design and minimize the dryer's energy requirements (Lin et al., 2022).

Table 2
Experimental results of investigated responses obtained under different drying conditions.

Run	Independent variables			Response							
	Temperature (°C)	Power (W)	Velocity (m/s)	Vitamin C (mg/100 g)	TPC (mg GAE/100 g)	IC_{50} (mg/ml)	Vitamin A (I.U.)	Total chlorophyll (μg/ml)	Rehydration ratio	Hardness (g)	Total Color Change
1	40	360	10	42.60	42.11	2.21	9.03	1.12	4.20	320.02	20.00
2	60	360	10	35.85	64.04	1.42	16.44	1.72	5.10	367.11	17.55
3	40	720	10	48.50	53.79	1.91	13.42	1.78	4.53	348.56	17.5
4	60	720	10	37.98	70.33	0.73	18.63	1.58	5.44	394.43	19.13
5	40	360	14	42.65	46.56	2.16	10.02	1.48	4.27	328.30	20.20
6	60	360	14	44.27	65.23	1.37	16.16	1.72	5.17	371.72	15.32
7	40	720	14	40.33	59.37	1.72	15.23	1.55	4.70	355.35	17.85
8	60	720	14	39.11	71.14	0.59	19.10	1.27	5.57	396.22	19.40
9	40	540	12	52.00	51.22	1.94	15.30	1.65	4.48	345.18	11.83
10	60	540	12	51.10	67.73	0.84	23.00	1.64	5.23	381.56	10.27
11	50	360	12	47.95	55.00	1.90	12.08	1.80	4.33	347.23	15.50
12	50	720	12	50.98	73.14	1.20	16.30	1.90	5.28	380.43	16.00
13	50	540	10	55.28	55.33	1.83	20.00	2.18	4.60	350.33	10.33
14	50	540	14	56.11	60.38	1.63	22.60	2.12	4.90	357.57	9.27
15	50	540	12	61.23	62.39	1.53	20.01	2.10	5.00	364.26	8.36

Table 3
Estimated regression coefficients of the second order polynomial model for responses (in coded units).

Regression Coefficient	Response							
	Vitamin C	Total Phenolic Content	IC_{50}	Vitamin A	Total chlorophyll	Rehydration ratio	Hardness	Total color change
β_0	59.94	62.10	1.56	19.47	2.16	4.85	362.01	8.86
Linear								
β_1	−1.78[a]	8.55[a]	−0.50[a]	3.06[a]	0.036	0.43[a]	21.36[a]	−0.57[a]
β_2	0.36	5.49[a]	−0.29[a]	1.86[b]	0.024	0.24[a]	14.06[a]	0.13
β_3	0.23	1.72[a]	−0.063[a]	0.51	−0.024	0.074	2.87[a]	−0.25
Cross Product								
β_{12}	−0.83	−1.55	−0.091[a]	−0.53	−0.16[a]	−0.0025	−0.47	1.13[a]
β_{13}	2.21[a]	−1.02	0.0055	−0.33	−0.055[a]	−0.005	−1.08	−0.31[a]
β_{23}	−1.94[a]	−0.080	−0.029	0.17	−0.11	0.020	−0.54	−0.33[a]
Quadratic								
β_{11}	−6.98[a]	−2.05	−0.17[a]	−0.68	−0.45[a]	−0.056	2.31	2.03[a]
β_{22}	−9.06[a]	2.54	−0.022	−5.68[a]	−0.25[a]	−0.0059	2.77	6.73[a]
β_{33}	−2.83[a]	−3.67[a]	0.16[a]	1.62	−0.049	0.049	−7.11[a]	0.78[a]

[a] Significant at 0.05 level.

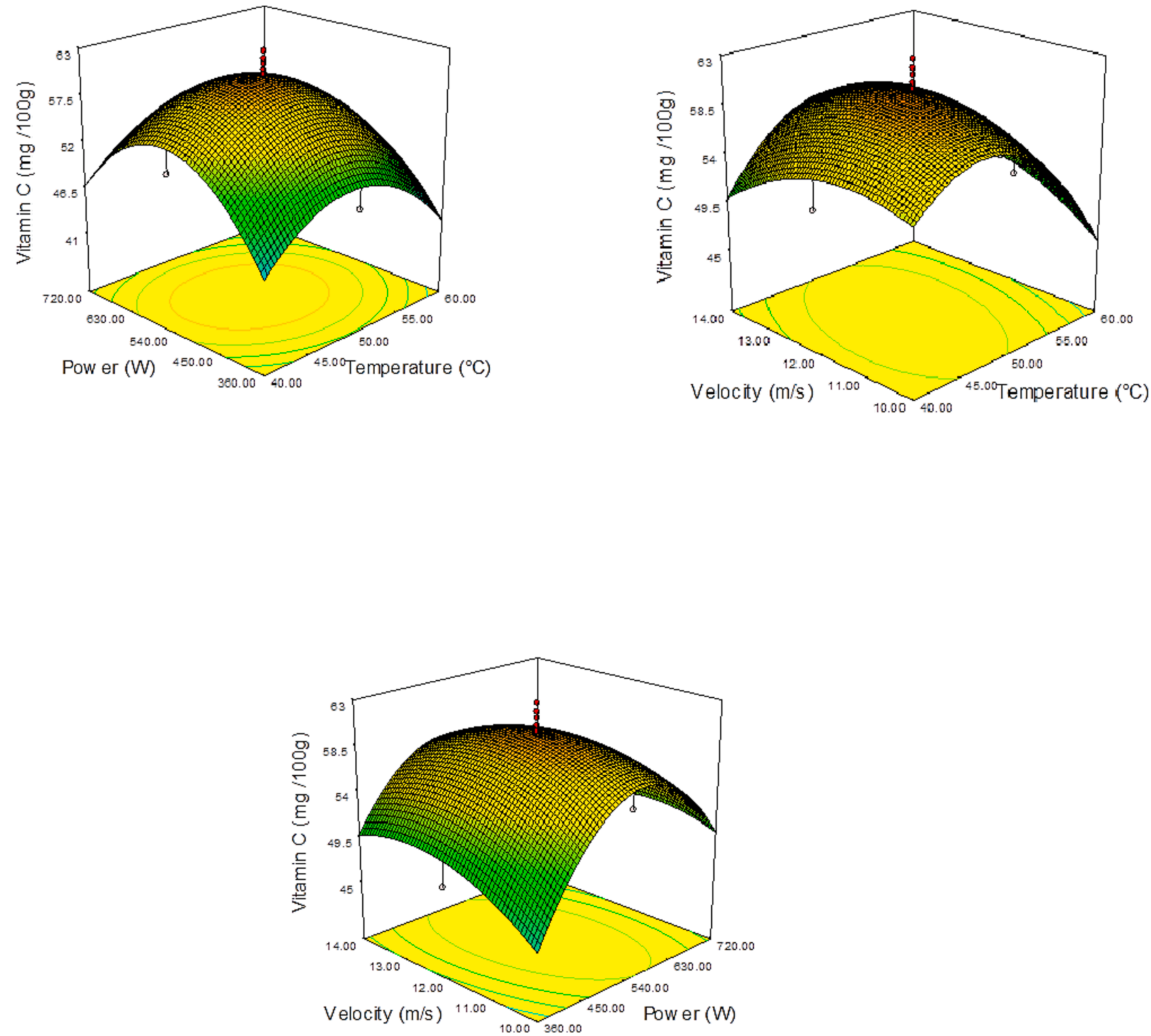

Fig. 2a. Response surface plots showing combined effect of microwave power, temperature and inlet air velocity) on ascorbic acid content.

The microwave drying of bitter gourd and optimization of MAFBD of bitter gourd using response surface methodology have not been studied. The objective of this study is to investigate the effect of various parameters such as air temperature (AT), microwave power (MWP), and air velocity (AV) on the quality characteristics of bitter gourd and to optimize the process variables of microwave assisted fluidized bed drying.

2. Materials and methods

2.1. Raw material

Bitter gourd (Momordica charantia var. charantia) was purchased from the local market of Aligarh, India. The procured vegetables were of same size, appearance, and maturity during purchase. Mature (green, 16–22-day fruit age) fruits were harvested, as judged by fully green colour. Bitter gourd were washed in order to eliminate the dust and dirt and were then stored at 4 °C till further analysis. By using a hot air oven, the initial moisture content of fresh bitter gourd was calculated at 105 °C for 24 h and a moisture content of 94.5 % (w.b) was recorded.

2.2. Microwave assisted fluidized bed drying (MAFBD)

MAFBD prototype was designed and installed at the Department of Post-Harvest Engineering and Technology, AMU, Aligarh, India. The image and representational picture of the prototype are presented in [Fig. 1(a) and (b)].Experimental studies were conducted by using a digital domestic microwave oven with an input and output power of 1950 W and 900 W, respectively, and a magnetron that operates at 2450 MHz frequency and converts electric energy into microwave power. The dimensions of oven (L × W × D) were 376 mm × 574 mm × 505 mm, with a centrally mounted rotating glass and fan. Inside a microwave oven cavity, air was blown through drying column by motorized air blower for fluidization. Also, heater was used to heat up the air flowing through the drying column. Both the air and temperature are being maintained and controlled. The velocity of air was determined by

Table 4
Analysis of Variance (ANOVA) of the fitted second order polynomial model for various responses.

Source	Sum of squares	DF	Mean square	F-value	p-value
Vitamin C					
Model	1454.78	9	161.64	46.20	<0.0001
Residual	34.98	10	3.50		
Lack of Fit	26.11	5	5.22	2.94	0.1307
Pure Error	8.88	5	1.78		
Cor Total	1489.76	19			
$R^{2,a}$ = 0.9765; CV[b] = 3.70 %					
Total Phenolic Content					
Model	1169.17	9	129.91	25.71	<0.0001
Residual	50.53	10	5.05		
Lack of Fit	37.03	5	7.41	2.74	0.1462
Pure Error	13.50	5	2.70		
Cor Total	1219.70	19			
R^2 = 0.9586; CV = 3.72 %					
IC_{50}					
Model	3.56	9	0.40	152.39	<0.0001
Residual	0.026	10	0.0025		
Lack of Fit	0.021	5	0.0042	4.23	0.0697
Pure Error	0.0049	5	0.00099		
Cor Total	3.59	19			
R^2 = 0.9928; CV = 3.32 %					
Vitamin A (I.U.)					
Model	272.41	9	30.27	17.32	<0.0001
Residual	17.48	10	1.75		
Lack of Fit	4.19	5	0.84	0.32	0.8846
Pure Error	13.29	5	2.66		
Cor Total	289.89	19			
R^2 = 0.9397; CV = 7.73 %					
Total chlorophyll					
Model	2.18	9	0.24	33.85	<0.0001
Residual	0.072	10	0.00716		
Lack of Fit	0.052	5	0.010	2.60	0.1593
Pure Error	0.020	5	0.0039		
Cor Total	2.25	19			
R^2 = 0.9947; CV = 0.65 %					
Rehydration Ratio					
Model	2.54	9	0.28	5.52	0.0067
Residual	0.51	10	0.051		
Lack of Fit	0.18	5	0.035	0.53	0.750
Pure Error	0.34	5	0.067		
Cor Total	3.06	19			
R^2 = 0.9682; CV = 4.61 %					
Hardness					
Model	6776.28	9	752.92	110.74	<0.0001
Residual	67.99	10	6.80		
Lack of Fit	51.12	5	10.22	3.03	0.1245
Pure Error	16.87	5	3.37		
Cor Total	6844.27	19			
R^2 = 0.9901; CV = 0.72 %					
Total color change					
Model	392.93	9	43.66	278.50	<0.0001
Residual	1.57	10	0.16		
Lack of Fit	1.26	5	0.25	4.05	0.0756
Pure Error	0.31	5	0.062		
Cor Total	394.50	19			
R^2 = 0.9960; CV = 2.90 %					

[a] Coefficient of determination.
[b] Coefficient of variance (%).

Anemometer ranging from 4 to 30 m/s. Moreover, microwave oven has an air vent cavity at the crown from where the evaporated vapors can escape. Likewise, the perforated bottom allows the flow of air for fluidization into the column.

2.3. Experimental design for microwave assisted fluidized bed drying

The experimental design was based on RSM applying a CCRD to incorporate three independent variables i.e. microwave power (360–720 W), air temperature (40–60 °C) and inlet air velocity (10–14 m/s). Minimum and maximum levels of independent factors were selected based on the available literature and preliminary trials (Babaki et al., 2020; Srinivas et al., 2020; Zahoor & Khan, 2021). Design overall yields five different levels for every variable and allows an improved assessment of their quadratic effects.

The influence of independent factors was investigated using quadratic models on response variables using Statistical Software Design Expert v.7 Trail (Stat- Ease, Minneapolis, MN, USA).The drying conditions were optimized to dry the bitter gourd in the minimum duration and with less quality change. The initial microwave power density was selected using equation given below:

$$D = P/m \tag{1}$$

where, D is the microwave power density (W/g); P is the chosen microwave power level (W); m is the total initial mass of bitter gourd (g).

To perform regression analysis, data were fitted to a second-order polynomial model with p-values less than 0.05, as shown in the equation below. Analysis of variance (ANOVA) using Minitab software was used to determine the significance of regression ($p \leq 0.05$) and lack of fit (>0.05).The generalized form of the quadratic model is presented in Eq. (2).

$$Y_K = \beta_{KO} + \sum_{i=1}^{3} \beta_{ki} X_i + \sum_{i=1}^{3} \beta_{kij} X_i^2 + \sum_{iij}^{3} \beta_{kij} X_i X_j \tag{2}$$

where β_{ko}, β_{ki} and β_{kij} are the constants, linear, quadratic, and cross product regression coefficients respectively and X_i, X_j are the coded independent variables of microwave power, temperature, and inlet air velocity.

The ideal criteria for each independent response variable were determined by picking a design goal such as maximize, minimize, target, within range, none, and to an exact value. The objectives were then combined into a general desirability function presented in Eq. (3).

$$D = \left(d_1^{r1} x d_2^{r2} x2\right) = \left(d_n^m\right)^1 / \sum ri = \left(\sum_{j=1}^{n} d_j^{ri}\right)^1 / \sum ri \tag{3}$$

Where n is the total number of the responses and ′s are the values according to which goals for each response were set.

2.4. Evaluation of functional properties of dried bitter gourd

2.4.1. Quantification of vitamin C

The Vitamin C was measured according to the procedure of Zahoor and Khan (2019). In brief, 5 g material was mixed with 3 % metaphosphoric acid solution, accompanied by filtering of the solution. The

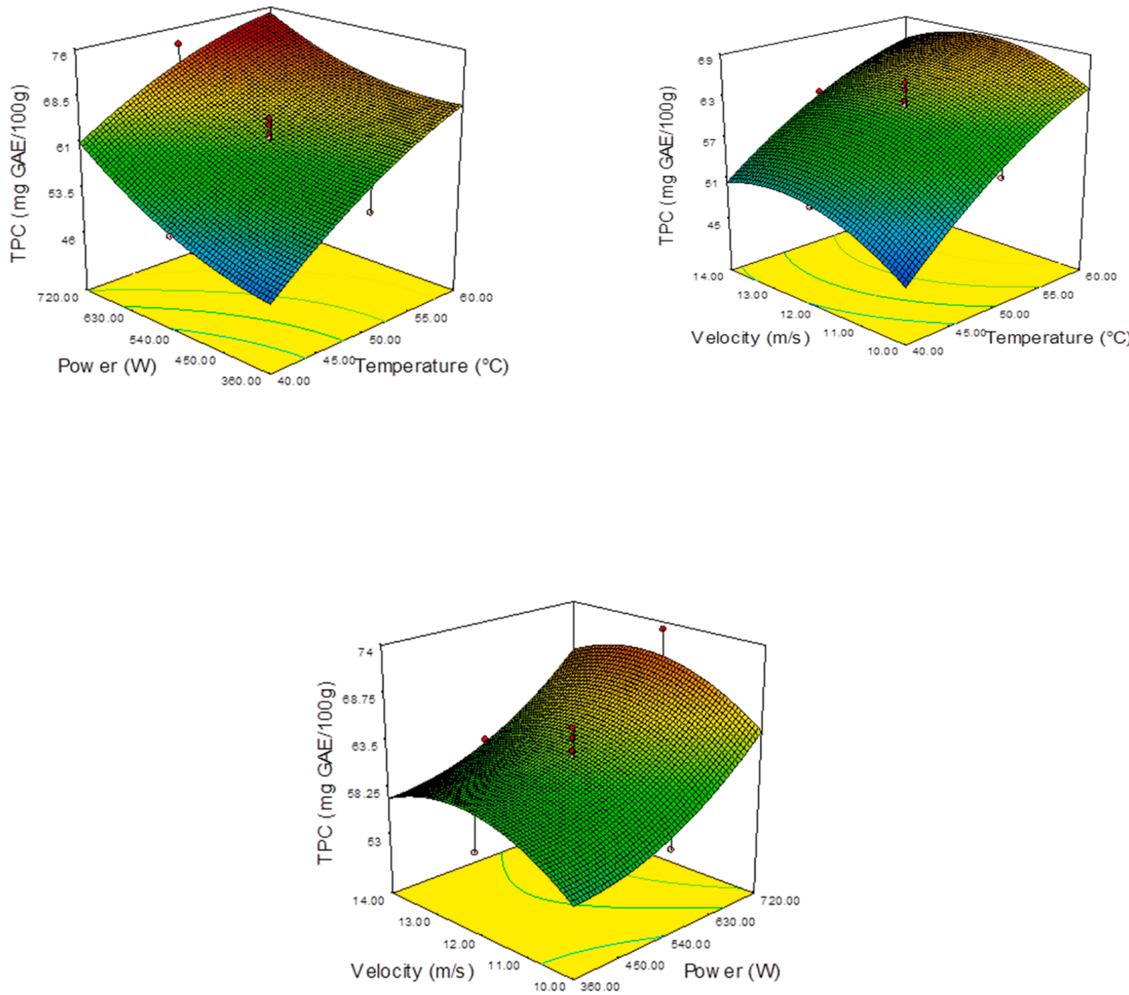

Fig. 2b. Response surface plots showing combined effect of microwave power, temperature and inlet air velocity) on total phenolic content.

standard ascorbic acid solution was used for the standardization of the dye, and the titre value was recorded. The vitamin C content was indicated as mg of vitamin C per100 g of dry weight. All the experiments were carried out in triplicate, and Vitamin C was calculated using Eq. (4).

$$AA\left(\frac{mg}{100\ g\ DW}\right) = \frac{Titre \times Dye\ factor \times vol\ made\ up \times 100}{Aliquot\ taken\ for\ estimation \times sample\ weight} \tag{4}$$

2.4.2. Quantification of total phenolics

The procedure of Sharma and Rao (2015) was used to calculate the total phenolics in dried samples with some modifications. Methanol as solvent was used for the extraction process. 2gm of dried bitter gourd were homogenized in 20 ml of methanol. The homogenate was then kept undisturbed for 12 h. The obtained mixture was centrifuged at 10,000g for 15 min. After centrifugation, 0.2 ml of aliquot is mixed with 1.5 ml of Folin-Ciocalteau reagent and 1.2 ml of 7.5 % of Na_2CO_3. The mixture was then placed aside for 2 h at 25 °C. Lastly, the absorbance was measured by spectrophotometer at 765 nm. A calibration curve was made by gallic acid and the TPC was indicated as mg GAE/100g of dry sample. All the experiments were carried out three times.

2.4.3. Quantification of antioxidant activity

DPPH was measured by the procedure of Horuz et al. (2018) with slight modification. Methanol was used to prepare 0.1 mM of DPPH solution. Different concentrations were extracted, followed by adding 5 ml of DPPH solution and mixed properly. The mixture was left undisturbed in the dark for about 20 min under ambient conditions. The absorbance of the sample was recorded at 517 nm. DPPH radical scavenging activity was determined by the Eq. (5).

$$\%\ Inhibition = \frac{A_{control} - A_{sample} \times 100}{A_{sample}} \tag{5}$$

where $A_{control}$ and $A_{sample}$is the absorbance of control and sample respectively.

The antioxidant activity was expressed as IC_{50} which is the required solution concentration in order to obtain a 50 % radical scavenging activity. All the experiments were carried out three times.

2.4.4. Quantification of vitamin A

Vitamin A was measured by the method given by Abbas et al. (2015). Dried samples were weighed and 10–15 ml of acetone, petroleum ether and few crystal of anhydrous sodium sulphate were added to crushed sample. This procedure was again repeated and the supernatant obtained was mixed with10-15 ml of petroleum ether, so as to get two separate layers. The bottom layer was removed and the volume of upper layer was made up to100mL with petroleum ether. O.D was measured at 450 nm and Vitamin A was quantified using Eqs. (6) and (7).

$$\beta\text{-carotene (mg/100 g)} = \text{O.D.} \times 13.9 \times 10^4 \times 100/\text{weight of sample (g)} \times 560 \times 1000 \tag{6}$$

$$\text{Vitamin A (I.U.)} = \text{Beta-carotene } (\mu g/100g)/0.6 \tag{7}$$

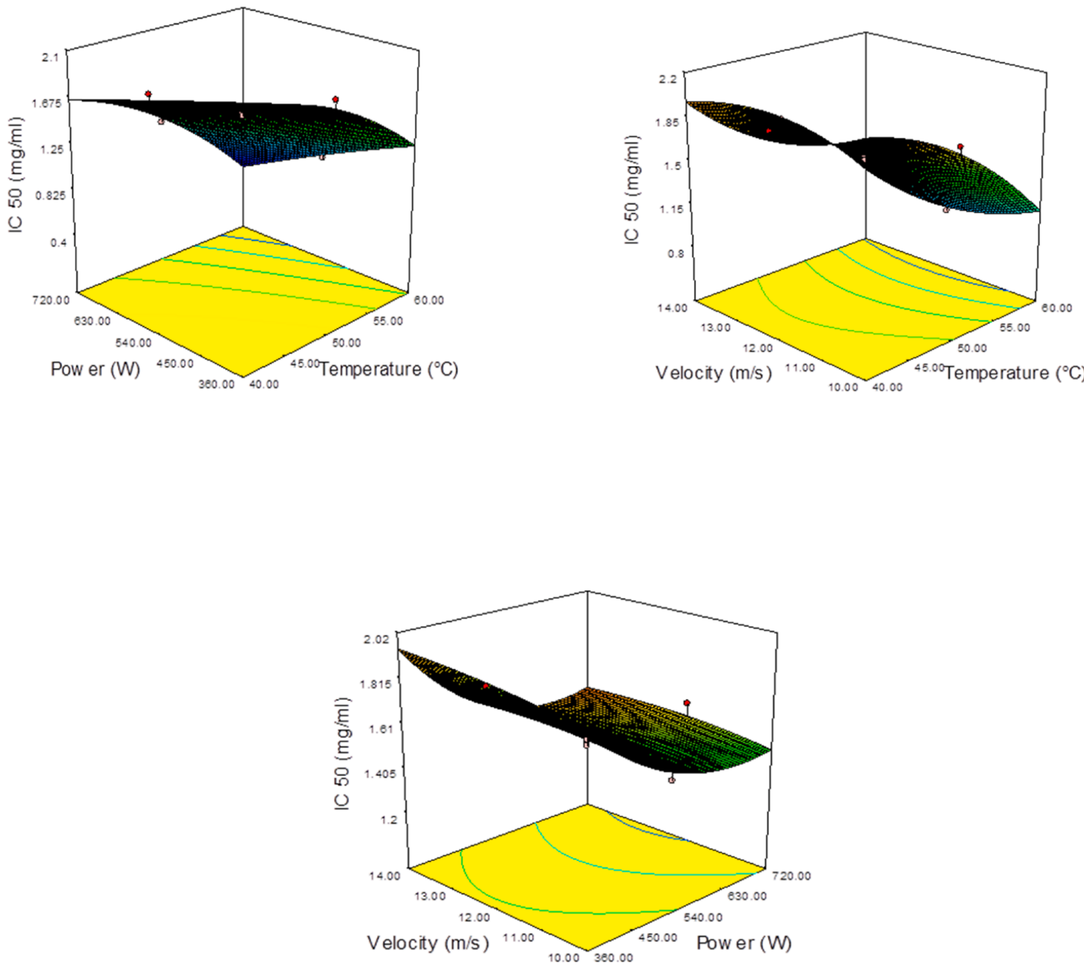

Fig. 2c. Response surface plots showing combined effect of microwave power, temperature and inlet air velocity) on DPPH radical scavenging activity.

2.4.5. Method for measurement of chlorophyll content

The chlorophyll was measured in accordance with ARNON method described by Mehta et al. (2017). Using a mortar and pestle, samples were finely ground in 20 ml of 80 g/dl acetone. The procedure was carried out four times until residues became completely colorless. Acetone was used for volume made up to 100 ml. The experiments were carried put three times and the absorbance was determined in spectrophotometer against a blank at 645 and 663 nm. The total chlorophyll was determined by applying Eq. (8) and was expressed as μg/ml

$$\text{Total chlorophyll}\ (\mu\text{g/ml}) = 20.2(A_{645}) + 8.02\ (A_{663}) \tag{8}$$

A_{645} and A_{663} are the absorption values at 645 nm and 663 nm, respectively.

2.5. Evaluation of physical properties of dried bitter gourd

2.5.1. Hardness of dried bitter gourd

The hardness of dried bitter gourd slices was determined after rehydration using Texture Analyzer (Stable Micro Systems., TA-HD plus Surrey, UK). Stainless steel needle probe (2 mm) was used to measure the hardness. The pre-test and post-test speed of 2 mm/s and the test speed of 1 mm/s were used and the force was measured during compression. The force required for a needle probe to penetrate the sample was measured in grams. Hardness was measured by taking an average of three observations.

2.5.2. Color change of dried bitter gourd

The color assessment of dried bitter gourd was accomplished by applying the method of Yousuf and Srivastava (2017). The total color change of the samples was determined from L*, a* and b*values of fresh and dried bitter gourd according to Eq. (9).

$$\Delta E = \left[(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2\right]^{1/2} \tag{9}$$

where, ΔE is the total color change, $L_{0,}$ $a_{0,}b_0$ and, L, a, b are the initial and dried values of bitter gourd.

2.5.3. Rehydration ratio (RR) of dried bitter gourd

The procedure of Zhang et al. (2016) was adopted for the calculation of rehydration ratio of bitter gourd. 6 g of dried bitter gourd was immersed in 60 ml of water for 120 min at 30 °C. The sample was withdrawn, followed by water evacuation and weighing of sample. The RR was calculated as the weight of rehydrated bitter gourd divided by the weight of dried bitter gourd (See Table 1).

4. Results and discussions

4.1. Effect of drying process parameters on vitamin C

Vitamin C is one of the main unstable bioactive molecules that are easily degraded during drying process. Therefore, drying process should be performed in such a way that the maximum amount of vitamin C is retained in the dried product. Furthermore, its preservation in dried products might be used as a drying process quality indicator. The

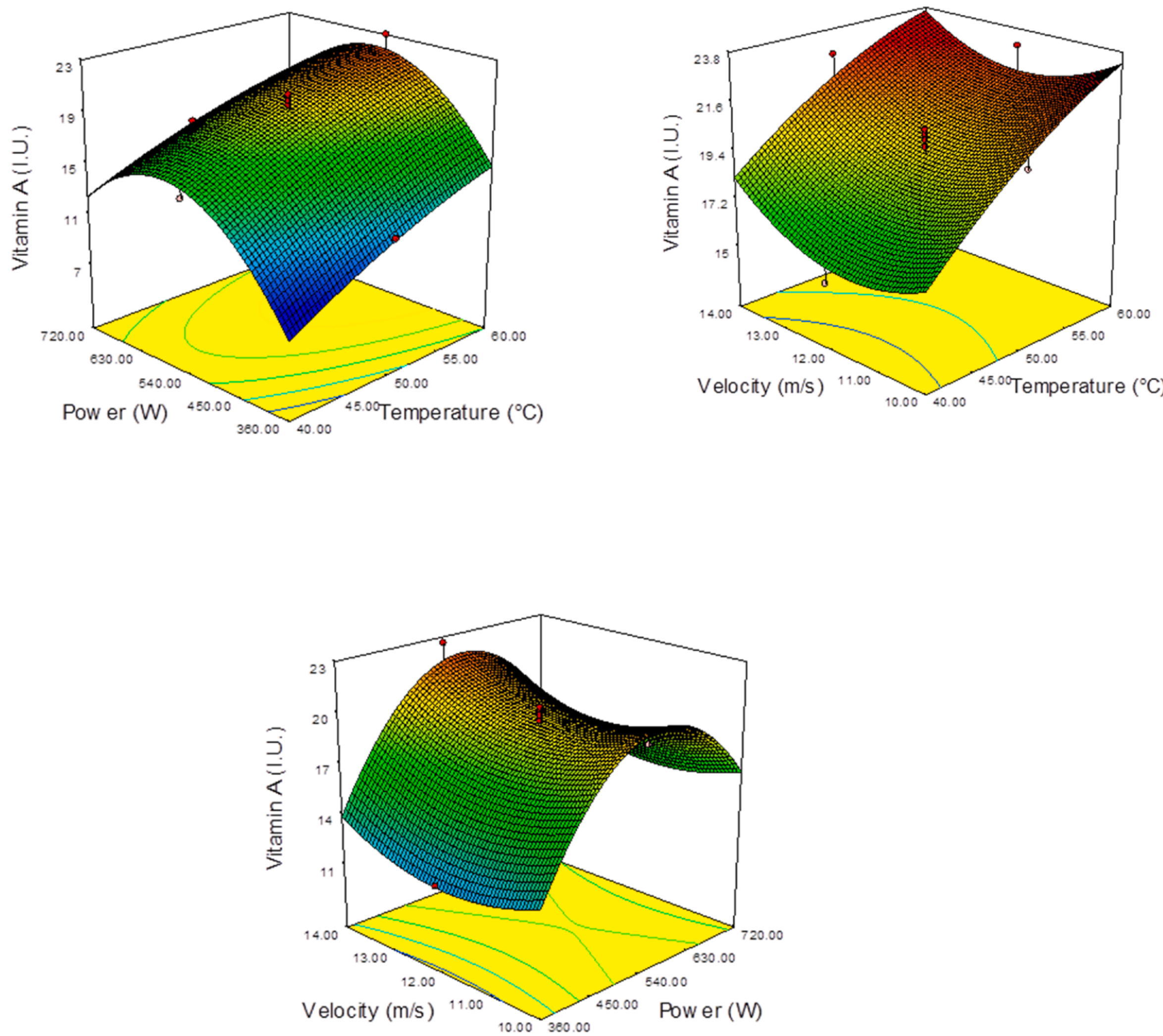

Fig. 2d. Response surface plots showing combined effect of microwave power, temperature and inlet air velocity) on vitamin A.

vitamin C of dried bitter gourd varied between 35.85 and 62.60 mg/100 g (Table 2). According to the data from Table 3, linear term of AT, quadratic terms of AT, MWP and AV exhibited a remarkable influence on vitamin C. During the drying process, the interaction between temperature and velocity, as well as microwave power and velocity, had a significant impact on vitamin C retention. The regression equation obtained for vitamin C in terms of coded levels of drying parameters is shown in Eq. (10).

$$\text{Vitamin C} = 59.94 - 1.78X_1 + 0.36X_2 + 0.23X_3 - 0.83X_1X_2 + 2.21X_1X_3 - 1.94X_2X_3 - 6.98X_1^2 - 9.06X_2^2 - 2.83X_3^2 \tag{10}$$

Visualization of parameter influence can be accomplished by the chart presented in Fig. 2(a). The vitamin C increased with increment in temperature and MWP up to 50 °C and 540 W and then further increase in these parameters leads to decrease in vitamin C in dried bitter gourd. The breakdown of vitamin C is mostly caused by oxidation and thermolabillity. Ascorbic acid oxidation is accelerated by the heating process. Vitamin C content was also harmed by longer drying durations caused by low process temperature and microwave power. Pham et al. (2018) linked this phenomenon to the degradative chemical processes of natural bioactive chemicals catalyzed by heat and ascorbic acid oxidase enzyme liberated from ruptured cell membranes during the drying process. The maximum content of vitamin C of 61.23 mg/100 g was observed at 50 °C, 540 W and 12 m/s of temperature, power and air velocity, respectively, this is a reasonably mild condition with a quick overall drying time. However, minimum vitamin C content of 35.85 mg/100 g was found at 60 °C, 360 W and 10 m/s of temperature, MWP and AV, respectively. This outcome affirms the thermal sensitivity of the vitamin C at rigorous drying conditions and extended drying process (See Table 4).

4.2. *Effect of MAFBD process parameters on total phenolic content*

In foods, phenolic chemicals serve a range of purposes, including acting as antioxidants. The phenolic content of dried bitter gourd ranged from 42.00 to 73.14 mg GAE/100 g. According to the statistical analysis (Table 3), all the linear terms of temperature, MWP, and AV were found to have a significant impact on total phenolic content. Nevertheless, the interaction of these variables had no significant effect on total phenolics. The relationship between total phenolic content and independent variables of temperature, MWP and AV attained in terms of coded variables is shown in Eq. (11).

$$\text{Total phenolic content} = 62.10 + 8.55X_1 + 5.49X_2 + 1.72X_3 - 1.55X_1X_2 - 1.02X_1X_3 + 0.080X_2X_3 - 2.05X_1^2 + 2.54X_2^2 - 3.67X_3^2 \tag{11}$$

The temperature, microwave power and air velocity caused positive influence which could be visualized from Fig. 2(b). The total phenolic

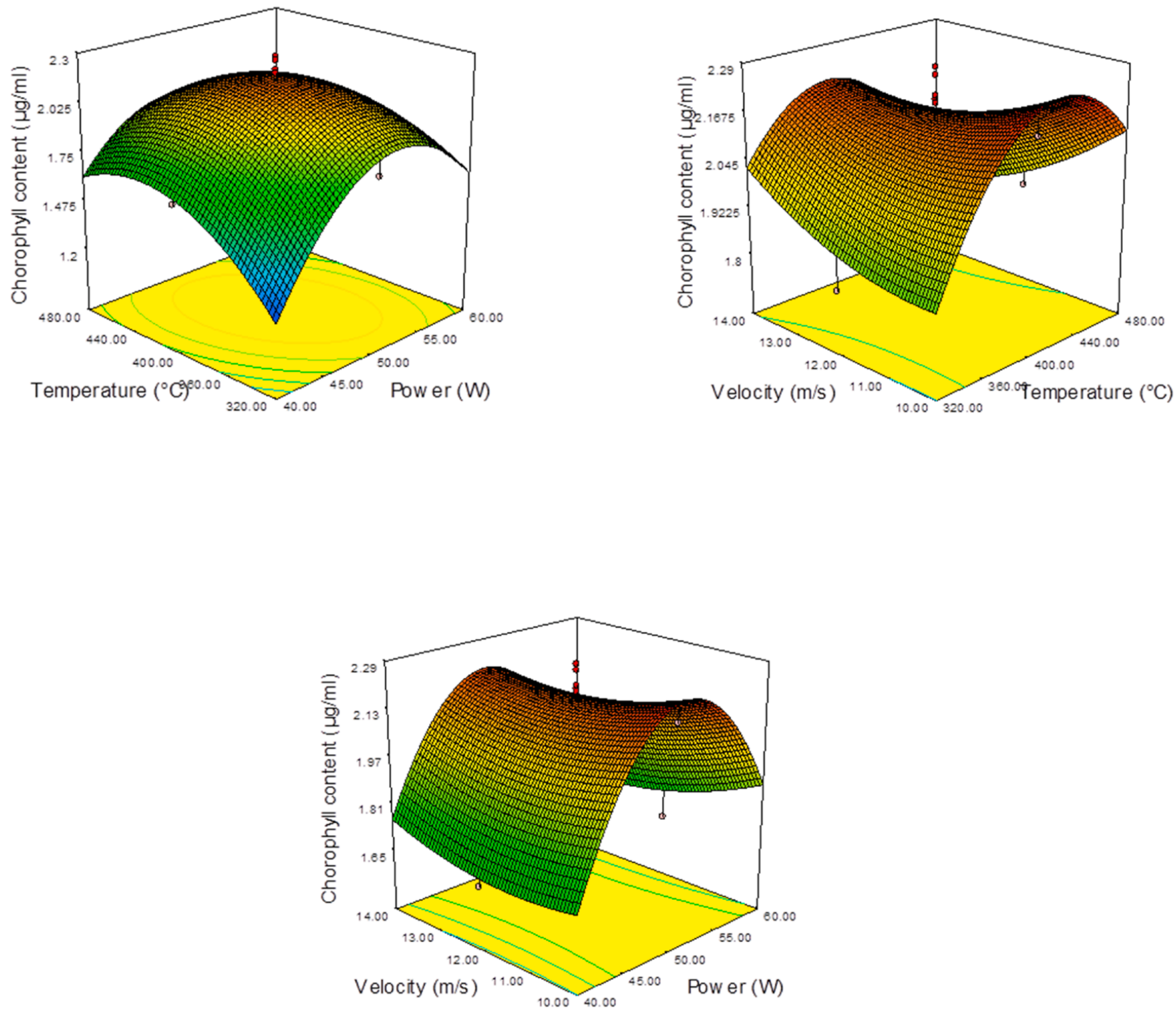

Fig. 2e. Response surface plots showing combined effect of microwave power, temperature and inlet air velocity) on chlorophyll content.

content rose as the temperature and microwave power increased and maximum content of total phenolics was observed at 50 °C, 720 W and 12 m/s of temperature, microwave power and air velocity, respectively. This could be due to the elevated temperatures induced by the microwave radiation immobilize oxidative enzymes, shorten oxygen contact time and improve phenolic component preservation (Horuz et al., 2017).Our outcome also demonstrate that the amount of total phenolic preservation is higher at intensive drying, which further confirms that the total phenolics are less thermal sensitive than that of vitamin C.

4.3. Effect of MAFBD process parameters on antioxidant activity

The free radical scavenging ability of several samples has been tested using DPPH, a free radical molecule. The IC_{50} values of the dried bitter gourd varied between 0.59 and 2.21 mg/ml (Table 2). MWP, drying temperature, and AV all had a significant effect on the dried bitter gourd's antioxidant activity. The antioxidant activity of bitter gourd was significantly affected by all linear terms of power, temperature, and AV, as well as the quadratic effects of temperature and AV. (Table 3). Moreover, interaction between microwave power and temperature also exerted significant influence on antioxidant activity of dried bitter gourd. The regression equation obtained for antioxidant activity of bitter gourd in terms of coded level of drying parameters is presented in Eq. (12).

$$\begin{aligned}\text{Antioxidant activity} = {} & 1.56 - 0.50\,X_1 - 0.29\,X_2 - 0.063\,X_3 - 0.091\,X_1X_2 \\ & + 0.0055\,X_1X_3 - 0.029\,X_2X_3 - 0.17\,X_1^2 - 0.022\,X_2^2 \\ & + 0.16\,X_3^2\end{aligned} \tag{12}$$

The temperature, power and air velocity showed negative effect on IC_{50} (positive on antioxidant activity). TheIC_{50} values decrease with increase in microwave power which means higher antioxidant activity [Fig. 2(c)]. A similar trend occurred with increase in temperature where IC_{50} decreases, which means increase in antioxidant activity. As has been reported by Samoticha et al. (2016), the production of melanoidins, which have antioxidant properties, at higher temperatures could account for the rise in antioxidant activity.

4.4. Effect of MAFBD process parameters on vitamin A content

Vitamin A levels in dried bitter gourds ranged from 9 to 23 I.U. (Table 2). The drying parameters exerted significant effect on vitamin A of bitter gourd. The linear terms of temperature, MWP and quadratic terms microwave power exhibited significant influence on the vitamin A (Table 3). The interaction between temperature and MW Palso had a significant effect on the vitamin A. The following regression equation was obtained for vitamin A in terms of coded levels of drying parameters (Eq. (13)).

Fig. 2f. Picture of the dried bitter gourd before and after rehydration.

$$\text{Vitamin A (I.U)} = 19.76 + 2.78\,X_1 + 1.92\,X_2 + 0.15\,X_3 - 0.60\,X_1\,X_2 - 0.26\,X_1\,X_3 + 0.10\,X_2X_3 - 3.38\,X_1^2 - 5.27\,X_2^2 + 3.53\,X_3^2 \quad (13)$$

The drying temperature and microwave power exerted significant effect, which was positive for both the parameters which could be seen in Fig. 2(d).The amount of vitamin A in the dried product rose as the drying temperature and microwave power increased. The maximum content of vitamin A was observed at 60 °C, 540 W and 12 m/s while as minimum content was observed at 40 °C, 360 W and 10 m/s. Vitamin A levels were reduced less at upper temperatures and microwave power. This could be related to beta carotene's enhanced solubility at higher temperatures. Furthermore, the activity of lipooxygenases, an enzyme involved in beta carotene degradation, was lowered by higher drying

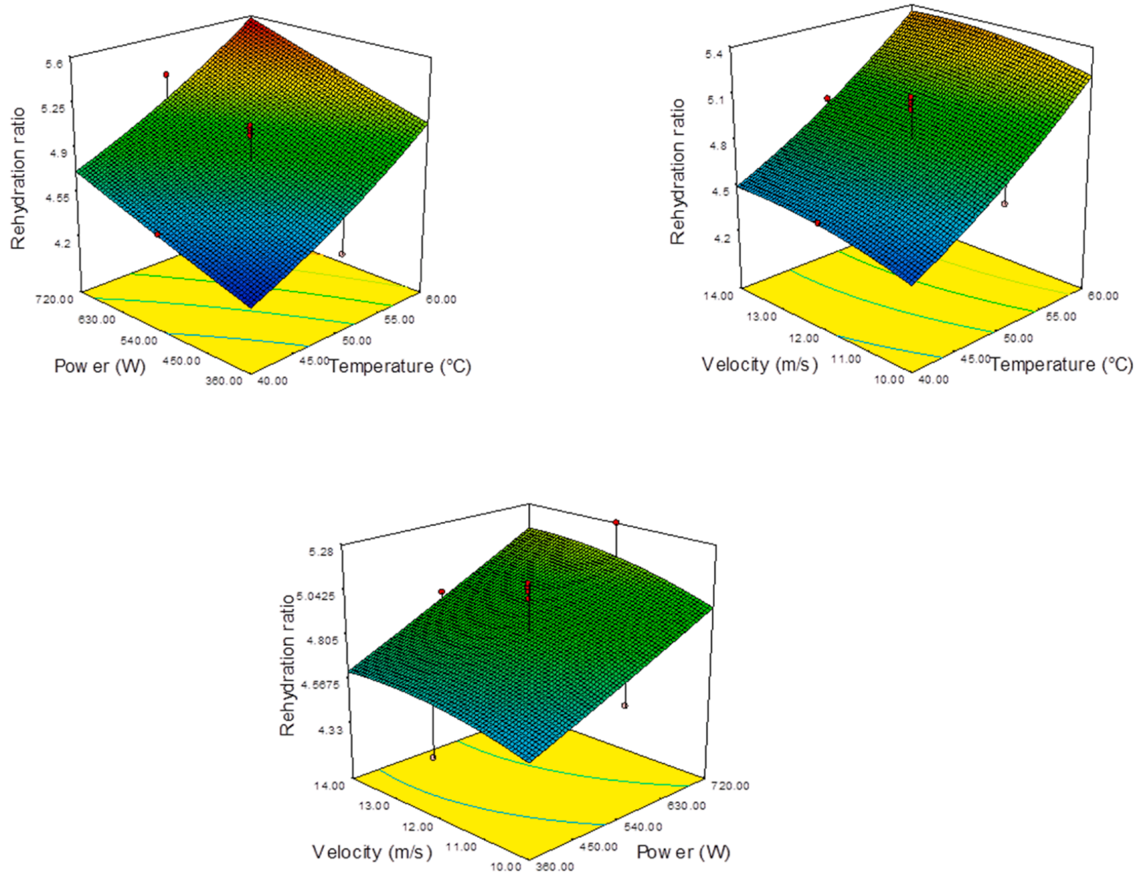

Fig. 2g. Response surface plots showing combined effect of microwave power, temperature and inlet air velocity) on rehydration ratio.

rates and shorter drying durations (Cui et al., 2004).

4.5. Effect of MAFBD process parameters on chlorophyll content

The amount of chlorophyll in a green colour show is quite essential. The chlorophyll content of dried bitter gourd ranged from 1.12 to 2.28 μg/ml (Table 2).The linear terms of temperature, MWP and inlet air velocity did not show any significant effect on chlorophyll content of bitter gourd (Table 3). However, the interaction between temperature and microwave power and interaction between MWP and AV exhibited a significant influence on chlorophyll content of bitter gourd. The quadratic terms of temperature and microwave power also exhibited a significant influence on chlorophyll content of bitter gourd. The regression equation obtained for chlorophyll content in terms of coded levels of drying parameters is presented in Eq. (14).

$$\text{Chlorophyll} = +2.16 + 0.036\,X_1 + 0.024\,X_2 - 0.024\,X_3 - 0.16\,X_1X_2 - 0.055\,X_1X_3 - 0.11\,X_2X_3 - 0.45\,X_1^2 - 0.25\,X_2^2 + 0.049\,X_3^2 \tag{14}$$

The individual effect of temperature, MWP and AV and combined effect of these process conditions on chlorophyll content can be seen in Fig. 2(e). From the figures, it can be seen that amount of chlorophyll in the sample rose as the temperature and MWP increased up to 50 °C and 400 W, respectively, after which chlorophyll content showed decreasing trend again. The maximum content of chlorophyll content was found at combination of 50 °C, 400 W and 12 m/s of temperature, microwave power and inlet air velocity, respectively. While as minimum content was found at 40 °C, 320 W and 10 m/s of temperature, microwave power and inlet air velocity, respectively. This could be due to the color-related enzymes were inactivated by drying, resulting in the colour and chlorophyll concentration of dried bitter gourd remaining unchanged. However, intensive drying conditions, on the other hand, may have torn the vegetable membrane, resulting in chlorophyll loss (Huang & Zhang, 2016).

4.6. Rehydration ratio of microwave assisted fluidized bed dried bitter gourd

The rehydration ratio is a key quality indicator for dried materials, indicating the physical and chemical changes in structure and composition that occur as a result of drying. The amount of water absorbed by the dried product affects its sensory properties and preparation time. So, dried products should have higher rehydration capacity, mainly because of consumer acceptability. The rehydration ratio of the dried samples varied from 4.20 to 5.57 (Table 2). The picture of the dried bitter gourd before and after rehydration is shown in Fig. 2(f). The linear terms of temperature and MWP had notable effect on the rehydration ratio. However, quadratic terms of these parameters and interaction effect of these parameters did not show any remarkable influence on the rehydration ratio (Table 3). The following regression equation obtained for the rehydration ratio in terms of coded levels of parameters is presented in Eq. (15).

$$\text{Rehydration ratio} = 4.85 + 0.43\,X_1 + 0.24\,X_2 + 0.074\,X_3 - 0.0025\,X_1X_2 + 0.005\,X_1X_3 + 0.020\,X_2X_3 + 0.0560\,X_1^2 + 0.0059\,X_2^2 - 0.049\,X_3^2 \tag{15}$$

The temperature and microwave power exerted remarkable influence on rehydration ratio which was positive for both the parameters. The rehydration ratio rose as the temperature and microwave power increased [Fig. 2(g)]. The highest rehydration ratio was obtained at 60 °C, 720 W and 14 m/s, while as lowest value was observed at 40 °C,

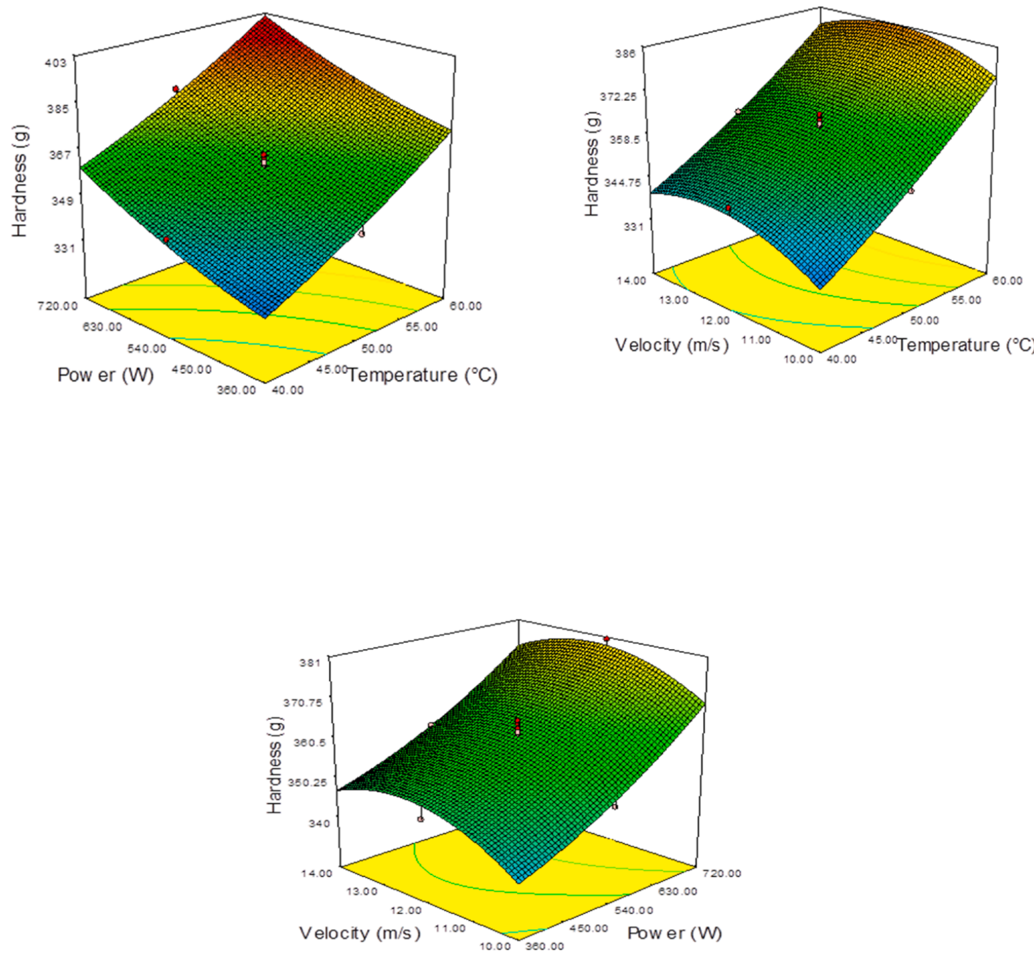

Fig. 2h. Response surface plots showing combined effect of microwave power, temperature and inlet air velocity) on hardness.

360 W and 10 m/s of temperature, microwave power and air velocity, respectively. This could be owing to elevated temperatures and microwave energy causing tissue collapse and cell deformation which further lead to water retention in the spaces left by wounded cells. Furthermore, application of microwave energy might have intercellular spaces that allow significant amounts of water to be absorbed during rehydration. (Contreraset al., 2012).

4.7. Texture analysis (Hardness) of dried bitter gourd

Texture is an important parameter for evaluating a food structure's sensory expression as well as how it reacts to force. Mastication exerts force during the feeding process, which is defined as hardness. Hardness was defined by the peak force during the first compression cycle (Hardness is a critical parameter used to investigate case hardening in dried foods. The softer the dried foods the higher the quality of the dried product. The higher temperature and long drying time causes local desiccation, which is in turn results in harder texture (Jin et al., 2018). The hardness of dried samples ranged from 320.02 to 396.22 g. The drying conditions exerted significant effect on the texture of dried product. The texture was significantly influenced by the linear terms of MWP, temperature and AV (Table 3). However, interaction effects of all the combinations did not exhibited any notable influence on the hardness of the dried bitter gourd. The regression equation obtained for the rehydration ratio in terms of coded levels of parameters is shown in Eq. (16).

$$\begin{aligned}\text{Hardness} =& 362.01 + 21.36\,X_1 + 14.060\,X_2 + 2.87\,X_3 - 0.47\,X_1X_2 \\ & - 1.08\,X_1X_3 - 0.54\,X_2X_3 + 2.31\,X_1^2 + 2.77\,X_2^2 - 7.11\,X_3^2\end{aligned} \tag{16}$$

All the linear terms of temperature, MWP and AV showed positive effect on the hardness. The hardness of the material grew when the power and temperature were raised [Fig. 2(h)]. The greatest hardness was observed at a combination of 720 W, 60 °C and 14 m/s of MWP, AT and AV, respectively, while as its minimum value is found at 360 W, 40 °C and 10 m/s of air velocity. This could be due to a build up of solutes on the skin's surface during drying, which results in hard, dry skin. Furthermore, microwave application can enhance solute migration from the interior to the surface, as well as accelerate solute build up on the surface (Horuz et al., 2018).

4.8. Color change in of dried bitter gourd

Customer acceptability of processed products is influenced by colour and product quality is first appraised visually. Pigment degradation, enzymatic activity, and Maillard non-enzymatic browning processes can all have an impact on colour during drying. Picture of the dried bitter gourd sample before and after microwave assisted fluidized bed drying are shown in Fig. 2(i). The color change (ΔE) of the dried product varied from 8.36 to 20.33 (Table 2). The linear and quadratic terms of temperature, MWP and AV exerted remarkable influence on color change (Table 3). Moreover, interaction between microwave power and air velocity also exhibited notable effect on color change of dried bitter gourd samples. The equation obtained for the color change in terms of

(a) Fresh Bitter gourd

(b) Dried bitter gourd

Fig. 2i. Picture of dried bitter sample before and microwave assisted fluidized bed drying.

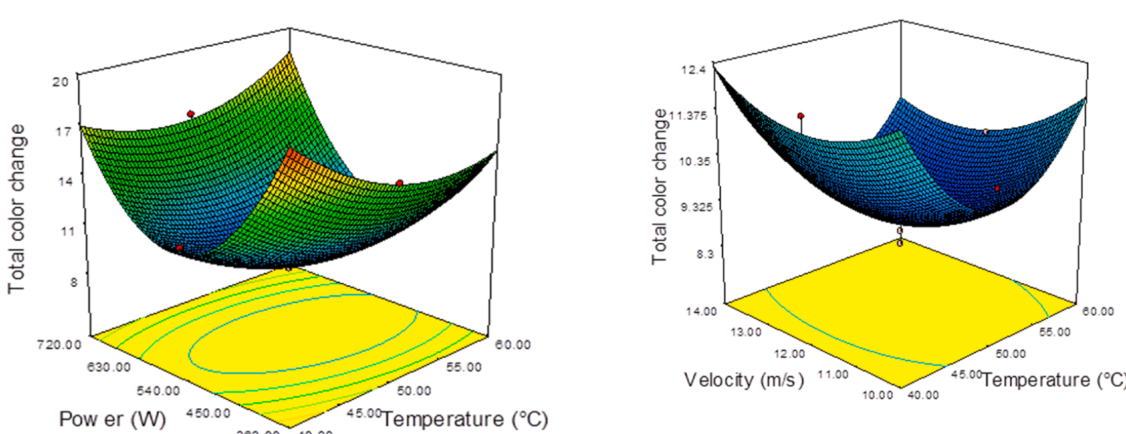

Fig. 2j. Response surface plots showing combined effect of microwave power, temperature and inlet air velocity) total color change.

Table 5
Simultaneously optimized microwave assisted fluidized bed drying conditions with target and predicted values of investigated responses.

Response	Target	Predicted
Vitamin C	Maximized	55.87
Total Phenolic Content	Maximized	65.44
IC_{50}	Minimized	1.22
Vitamin A	Maximized	22.29
Chlorophyll content	Maximized	2.19
Rehydration ratio	Maximized	5.16
Hardness	Minimized	373.79
Total Color Change	Minimized	9.44

Optimized Conditions: 55.88 °C; 551.05 W; 13.52 m/s, D[a] = 0.670.
[a] Desirability function.

Table 6
Comparison of experimental values with predicted values.

Response	Predicted value	Experimental value [a]	Standard error	Mean difference	Sig. (2 tailed)
Vitamin C	55.87	55.74 ± 0.84	0.37	−0.12	0.760
Total Phenolic Content	65.44	65.61 ± 1.18	0.52	0.17	0.756
IC_{50}	1.22	1.88 ± 0.542	0.242	0.66	0.052
Vitamin A	22.29	22.88 ± 0.73	0.326	0.594	0.143
Chlorophyll content	2.19	1.82 ± 0.53	0.237	−0.364	0.200
Rehydration ratio	5.16	5.55 ± 0.544	0.243	0.183	0.392
Hardness	373.79	373.15 ± 0.567	0.253	−0.643	0.064
Total Color Change	9.44	10.23 ± 0.871	0.389	0.794	0.111

[a] Mean values ± s.d.

coded levels of parameters is given below (Eq. (17)).

$$\text{Total color change}(\Delta E) = 8.86 - 0.57X_1 + 0.13X_2 - 0.25X_3 - 1.31X_1X_2 - 0.31X_1X_3 + 0.33X_2X_3 + 2.03X_1^2 + 6.73X_2^2 + 0.78X_3^2 \tag{17}$$

The colour change (ΔE)was reduced when the temperature and microwave power increased up to 50° C and 540 W while further increase in these parameters cause increase in color change[Fig. 2(j)]. The drying time and drying temperature are the parameters that influence color exhibitions of the final product. Furthermore, microwaves also generated a quick colour change in the samples due to the high heat effect and browning reactions that occurred during drying. However, extended dying time associated with lower drying temperatures also had negative effect on the color because prolonged exposure to the drying environment accelerated the browning reaction.

4.9. Optimization of microwave assisted fluidized bed drying

Each component and reaction had a separate aim, and each target was given a varied weight depending on the dehydrated product's relative preference and desirability. (Table 5). Temperature of 55.88 °C, microwave power of 551.05, and velocity of 13.52 m/s were the optimum process factors for the maximum desirability function (0.670). Under these optimum conditions, the predicted responses were vitamin C of 55.87 mg/100 g, total phenolics of 65.44 mg GAE/ 100 g, IC_{50} of 1.22 mg/ml, total chlorophyll content of 2.19 μg/ml, vitamin A content of 22.29 I.U., rehydration ratio of 5.16, hardness of 373.79 g and total color change 9.44. The data was validated by repeating the trials five times and analyzing the quality response of the created items under the derived optimum circumstances (Table 6). The null hypothesis was that the actual and optimized values were not significantly different. There were no significant variations between projected and actual values.

5. Conclusion

Bitter gourds were dried under various drying conditions in a microwave-assisted fluidized bed dryer. RSM was used to analyse and optimize the effect of microwave aided fluidized drying parameters on product quality using the fewest number of experiments possible. The quadratic model fit the experimental data well for the majority of answers, with high R^2 values. Temperature and microwave power had the greatest impact on the quality measures, followed by air velocity. Based on the quality of the dried bitter gourd, the drying parameters of microwave power, temperature and air velocity were optimized using a central composite face centered design. The statistical as well as graphical analysis showed that drying parameters (microwave power, temperature and air velocity) had significant effect on the investigated responses of dried bitter gourd. The experimental response values were found to be quite near to the expected values from the fitted models. With a small number of experiments, it is possible to investigate the impact of various microwave aided fluidized bed drying settings on product quality and the process optimized using response surface methodology (RSM).

CRediT authorship contribution statement

Insha Zahoor: Conceptualization, Methodology, Investigation, Writing – original draft. **Aamir Hussain Dar:** Investigation, Writing – original draft. **Kshirod Kumar Dash:** Methodology, Investigation. **R. Pandiselvam:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Alexandru Vasile Rusu:** Formal analysis, Resources, Data curation, Writing – review & editing. **Monica Trif:** Formal analysis, Resources, Writing – review & editing. **Punit Singh:** Software, Formal analysis, Resources, Writing – review & editing. **G. Jeevarathinam:** Methodology, Software, Resources, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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