Hindawi
Journal of Food Quality
Volume 2023, Article ID 2811491, 12 pages
https://doi.org/10.1155/2023/2811491

WILEY | Hindawi

Research Article

Microwave Drying Modelling of *Stevia rebaudiana* Leaves Using Artificial Neural Network and Its Effect on Color and Biochemical Attributes

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Received 9 November 2022; Revised 16 December 2022; Accepted 20 March 2023; Published 11 April 2023

Academic Editor: Kaavya Rathnakumar

Stevia rebaudiana has grown in popularity and consumption across the world as an excellent natural sweetener due to its 300 times sweetness than sugar. Since Stevia leaves are often used in their dried state, the drying process has an inevitable effect on the attributes of finished product. In this study, Stevia leaves were microwave dried at five different levels of powers ranging from 180 to 900 W to evaluate the influence of power levels on moisture ratio (MR), drying rate and time, effective moisture diffusivity, specific energy consumption (SEC), color, and biochemical characteristics. Among the five selected thin layer models for evaluating the drying behavior, the semiempirical page model described the drying kinetics very well with $R^2 > 0.997$. The effective diffusivity increased from 3.834×10^{-11} to 1.997×10^{-10} m^2/s with increasing microwave power, while SEC first increased till 320 W to a value of 9.77 MJ/kg and then followed a decreasing trend. Furthermore, multilayer feed forward (MLF) artificial neural network (ANN) using backpropagation algorithm was used to predict the moisture ratio of Stevia leaves during microwave drying. The result showed that the ANN model with 15 neurons in 1 hidden layer could predict the MR with a high R^2 value (0.999). Thus, ANN modelling can successfully be used as an effective tool for predicting drying kinetics of samples. Furthermore, the color properties showed significant differences between fresh and dried samples except for the hue angle, and the variation in their values was not affected by the microwave dryer's power output. At 720 W power level, the highest content of stevioside (11.84 mg/g) and rebaudioside A (7.11 mg/g) along with maximum retention of ascorbic acid (~86%) was observed, while the highest total phenol content (56.98 mg GAE/g) and antioxidant capacity (74.22%) was reported in microwave dried samples at 900 W.

1. Introduction

Stevia rebaudiana Bertoni, belonging to the family of *Asteraceae* (Compositae), is a small perennial shrub which is indigenous to Paraguay, Brazil, and Argentina [1]. Stevia leaves, a natural sweetener, are seen as an alternative to artificial sweeteners because of its sweetness which is 300 times higher than sucrose with the added benefits of having no calories, no carbs, and without producing blood sugar spikes [2]. Stevia leaves can be eaten fresh or dried, and crushed or sweet components can be extracted from them. The dried leaves with moisture content of 10–13% are used to make commercial sweetener [3]. Depending upon the variety and growing conditions, the dried leaves have stevioside (sweet component) in the range of 4–20% [4].

Like other medicinal herbs, drying of Stevia leaves is necessary for storage and consumption. The drying involves the reduction of moisture to a limit which allows safe and long storage life. The moisture reduction during drying reduces the volume which minimizes the material required for packaging and space for storage and also reduces the cost of transportation [5]. Lately, microwave type of drying is favored because of short drying time period, uniformity in energy dissipation, enhancement of energy recovery, and quality of final product [6–8]. The microwave is an electromagnetic radiation having a frequency in the range of 300 MHz–300 GHz. The varying electric field causes the rotation of polar particles, and collision of these particles cause friction which emits thermal energy [9, 10]. As a result, significant volumetric heat and gradient of internal vapour pressure are produced within the sample, which pushes moisture towards the surface of the sample from its core. This is the reason that microwave drying substantially completes in less time leading to improved quality of the food product and less energy consumption. This is in contrast to traditional drying, which transfers heat from the sample's surface to its core and lengthen the drying process [11–13].

Theoretical, semitheoretical, and empirical thin layer mathematical models are used to understand drying phenomena. Many of the models provide an acceptable regression to experimental drying data due to their empirical nature; however, they are only confined to processing situations [14]. Due to their learning capabilities and suitability for nonlinear processes, artificial neural networks (ANNs) have a number of advantages over traditional modelling methodologies [15–17]. They are able to model without making any assumptions about the characteristics of the underlying phenomenological mechanisms [14]. Recently, several studies have been reported the application of microwave radiation in drying of leaves of morisa xak (*Amaranthus caudatus*) [18], celery [19], coriander [19], *Laurus nobilis* [5], *Moringa oleifera* [20], and Kaffir lime [21]. The neural network as an approximation approach has been used for microwave drying of thyme leaves [22] and tea leaves [23]. Also, there are not many studies on microwave drying of Stevia leaves in the literature. Those investigations used only single microwave level power (700 or 800 W) [24, 25].

This study is the first (i) to examine how the microwave power level affects the kinetics of drying Stevia leaves and select the best model among five thin layer drying mathematical models, (ii) to determine the effective moisture diffusivity and specific energy consumption, (iii) to develop the ANN model for drying of Stevia leaves at different powers, and (iv) to study the effect of microwave powers on color and biochemical attributes.

2. Materials and Methods

2.1. Plant Material. Fresh leaves of *Stevia rebaudiana* Bertoni were harvested from a local greenhouse located in Ludhiana, Punjab, India. The leaves were meticulously detached from the stem and selected based on visual analysis to have nondestructive appearance and similar green color and size of leaves for the experiment. To preserve the original fresh quality, the plucked leaves were kept in a refrigerator at $5.0 \pm 2^{\circ}C$ until they were utilized in drying trials. The determination of the initial moisture content of fresh leaves was carried out using the method described by the AOAC method [26]. Fresh Stevia leaves had an initial moisture content of 80.66% on a wet basis. The thickness of Stevia leaves were estimated by a calibrated digital caliper (Mitutoyo, model Absolute Digimatic, Japan) and was observed as 0.24 ± 0.005 mm.

2.2. Equipment and Procedure of Drying. The microwave drying of Stevia leaves was carried out using a domestic microwave oven (IFB Industries Limited, 34BC1, China) with maximum output power of 900 W at 2450 MHz. The oven has technical features of 230–240 V and 50 Hz. With a revolving glass plate with a diameter of 30 cm at the base of the oven, the drying chamber had a dimension of 376 mm × 498 mm × 500 mm. In addition, it had a digital control facility for modifying the processing time and could operate at various power levels.

For carrying out the drying trials, samples of 25 g of Stevia leaves were used which were weighed using a digital balance (SP J602, OAHUS Corporation, USA) with a precision of 0.01 g. The samples were dried at varying microwave power output from 180 to 900 W and at each of these power outputs, three replications were carried out. The experiments had a reproducibility of 5% or less. Weighing of samples was carried out at a defined time gap by shifting the glass plate, and in less than 10 seconds, each weighing process was finished. Drying was continued until the weight of the sample reduced to 0.1 g/g·db.

2.3. Moisture Ratio, Drying Rate, and Mathematical Modelling. By drying the fresh Stevia leaves in an oven for 24 hours at 105°C, the moisture content of the leaves was evaluated [26]. These moisture contents were utilised to estimate the moisture ratio using the formula and fitted into five popular thin layer drying models to determine the moisture ratio as a function of drying time, which are shown in Table 1.

The moisture ratio of Stevia leaves was determined using the following equation (1):

$$\mathrm{MR} = \frac{M_t - M_e}{M_0 - M_e}. \quad (1)$$

The drying rate was estimated with experimental moisture content data using following equation (2):

$$\mathrm{DR} = \frac{M_{t+dt} - M_t}{dt}, \quad (2)$$

where MR is the moisture ratio (dimensionless), DR is the drying rate (g water/g dry matter·min), M_0 is the initial moisture content (g/g db), M_e is the equilibrium moisture content (g/g db), M_t is the moisture content at the specific time, and M_{t+dt} is the moisture content (g/g·db) at $t + dt$ [6].

2.4. Effective Moisture Diffusivity. The estimation of the rate of moisture movement during the drying process can be represented with effective diffusivity. Fick's second law of diffusion can be applied to proximate the mass transfer in a sample regardless of the sort of mechanism engaged in drying [27].

$$\mathrm{MR} = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{\mathrm{eff}}}{4L^2}\right) t, \quad (3)$$

where L is the sample's half thickness (m), D_{eff} is the effective moisture diffusivity (m^2/s), and t is the drying time (s). The

Table 1: Statistical factors of different models fit of moisture ratio for microwave drying of Stevia leaves.

Model	Equation	Power (W)	Estimated coefficients	R^2	Adjusted R-square	χ^2	RMSE
Lewis	MR = exp $(-kt)$	180	$k = 0.2153$	0.9690	0.9689	0.0030	0.0543
		360	$k = 0.3848$	0.9849	0.9848	0.0014	0.0373
		540	$k = 0.7508$	0.9974	0.9974	0.0002	0.0143
		720	$k = 1.7050$	0.9943	0.9943	0.0004	0.0204
		900	$k = 2.4763$	0.9992	0.9992	0.0001	0.0087
Page	MR = exp $(-kt^n)$	180	$k = 0.10952$ $n = 1.39671$	0.9970	0.9969	0.0003	0.0169
		360	$k = 0.28767$, $n = 1.25896$	0.9989	0.9989	0.0001	0.0099
		540	$k = 0.75908$, $n = 0.01986$	0.9974	0.9974	0.0002	0.0143
		720	$k = 1.63719$, $n = 0.84917$	0.9993	0.9993	0.0001	0.0072
		900	$k = 2.41135$, $n = 0.95692$	0.9994	0.9994	0.0001	0.0075
Henderson and Pabis	MR = a exp $(-kt)$	180	$k = 0.23591$, $a = 1.10368$	0.9784	0.9784	0.0021	0.0453
		360	$k = 0.41505$, $a = 1.08311$	0.9912	0.9911	0.0008	0.0285
		540	$k = 0.74052$, $a = 0.98617$	0.9975	0.9975	0.0002	0.0140
		720	$k = 1.65553$, $a = 0.97161$	0.9948	0.9948	0.0004	0.0195
		900	$k = 2.46346$, $a = 0.99417$	0.9992	0.9991	0.0001	0.0090
Logarithmic	MR = $a\exp(-k_1 t) + c$	180	$k = 1.15943$, $a = 1.1594$, $c = -0.0949$	0.9878	0.9877	0.0012	0.0341
		360	$k = 1.10756$, $a = 1.1075$, $c = -0.0458$	0.9941	0.9941	0.0005	0.0232
		540	$k = 0.99556$, $a = 0.9955$, $c = -0.0194$	0.9983	0.9983	0.0001	0.0116
		720	$k = 0.96565$, $a = 0.9656$, $c = -0.01243$	0.9955	0.9955	0.0003	0.0181
		900	$k = 0.99468$, $a = 0.9946$, $c = -0.00071$	0.9991	0.9990	0.0001	0.0095
Wang and Singh	MR = $1 + at + bt^2$	180	$a = -0.1565$, $b = 0.0062$	0.9944	0.9943	0.0005	0.0231
		360	$a = -0.2747$, $b = 0.0191$	0.9905	0.9904	0.0009	0.0295
		540	$a = -0.4870$, $b = 0.058$	0.9486	0.9485	0.0041	0.0639
		720	$a = -0.8042$, $b = 0.1480$	0.7764	0.7764	0.0164	0.1279
		900	$a = -1.25736$, $b = 0.3622$	0.8723	0.8722	0.0124	0.1115

RMSE: root mean square error.

aforementioned equation (3) can be expressed as follows in logarithmic form:

$$\ln(\mathrm{MR}) = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 \times D_{\mathrm{eff}} \times t}{4L^2}\right). \quad (4)$$

Plotting experimental drying data as ln(MR) versus drying time (t) yields a straight line with a slope. The slope is further equated equal to $(\pi^2 \times D_{\mathrm{eff}})/4L^2$ and used to calculate the diffusion coefficient.

2.5. Specific Energy Consumption. Specific energy consumption (SEC) is defined as the amount of energy required to remove a unit mass of water from Stevia leaves and is estimated using mathematical formula given as follows[27]:

$$\mathrm{SEC} = \frac{P \times t \times 10^{-6}}{m_W}, \quad (5)$$

where m_w is the mass of water (kg) evaporated from the sample, P is the microwave power (W), t is the drying time, 10^{-6} is the conversion coefficient of J to MJ, and t is the drying time.

2.6. ANN Modelling. Different ANN models to predict the moisture ratio during microwave drying of Stevia leaves were designed and tested using MATLAB software (R2018a, MathWorks, USA). The most common renowned ANNs, multilayer feed-forward with backpropagation learning algorithm were selected. In the supervised training method used by this algorithm, the network weights and biases are firstly initialised at random. There are at least three layers (input-hidden-output) of nodes in MLF. The ANN contained two inputs (microwave power and time of drying) and one output variable (moisture ratio), as shown in Figure 1.

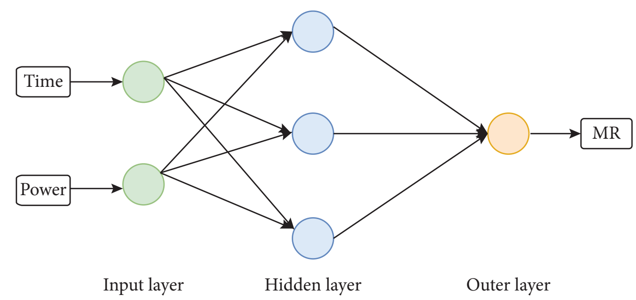

Figure 1: Configuration of artificial neural network model.

Before being divided into subgroups for training, validation, and testing, the experimental statistics was initially shuffled. For estimating the gradient along with training the network weights and biases, 70% of the data were used, while 15% were used for network evaluation and 15% were used for testing. Tansig was employed as the network transfer function in this study, with the Levenberg–Marquardt algorithm serving as the training function. Trial and error was utilised to calculate the number of neurons in the hidden layer in order to produce the optimum ANN model. Finally, three statistical criteria—mean square error (MSE), root mean square error (RMSE), and coefficient of determination (R^2)—were calculated to assess the performance of the ANN model as follows:

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}\left(\mathrm{MR}_{\mathrm{predicted},i} - \mathrm{MR}_{\mathrm{real},i}\right)^2,$$

$$\mathrm{RMSE} = \left[\frac{1}{n}\sum_{i=1}^{n}\left(\mathrm{MR}_{\mathrm{predicted},i} - MR_{\mathrm{real},i}\right)\right]^{1/2}. \quad (6)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(\mathrm{MR}_{\mathrm{predicted},i} - \mathrm{MR}_{\mathrm{real},i}\right)^2}{\sum_{i=1}^{n}\left(\mathrm{MR}_{\mathrm{predicted,\,mean}} - \mathrm{MR}_{\mathrm{real},i}\right)^2}.$$

2.7. Color Characteristics. The different color values (L^*, a^*, and b^*) of the Stevia leaves were measured with a colorimeter (Konica Minolta CR-10 color reader, Japan). The value L^* is the measure of lightness which vary from zero for black to 100 for perfect white, value a^* measures redness when positive/greenness when negative, and value b^* measures yellowness when positive/blueness when negative. These values (L^*,a^*, and b^*) were converted into chroma [28] and hue angle [29] using following equations (7) and (8):

$$\mathrm{Chroma}\left(C^*\right) = \left(a^{*2} + b^{*2}\right)^{1/2}, \quad (7)$$

$$\text{Hue angle}\left(h^*\right) = \tan^{-1}\left(\frac{b^*}{a^*}\right) \text{when } a^* > 0 \text{ and } b^* > 0, \quad (8)$$

$$\left(h^*\right) = 180^\circ + \tan^{-1}\left(\frac{b^*}{a^*}\right) \text{when } a^* < 0 \text{ and } b^* > 0 \text{ or } b^* < 0, \quad (9)$$

$$\left(h^*\right) = 360^\circ + \tan^{-1}\left(\frac{b^*}{a^*}\right) \text{ when } a^* > 0 \text{ and } b^* < 0. \quad (10)$$

2.8. Steviol Glycosides. The method of Ai et al. [30] was used to extract the steviol glycosides from Stevia leaves. A mixture of 0.2 g of powdered dried Stevia leaves and 10 mL of methanol-water solution (6 : 4 v/v) was sonicated (40 kHz, 250 W) at 60°C for 30 minutes followed by centrifugation for 5 min at 5000 × g. The resulting supernatant was diluted with 60% methanol to 50 mL. The repetition of extraction was carried out three times followed by filtration of extracts through a membrane filter (0.45 μm pore size) before being subjected to HPLC (high-performance liquid chromatography) analysis.

The determination of steviol glycoside was carried out using high-performance liquid chromatography (Agilent Technologies 1260, Wilmington, DE) equipped with an ODS2 column (4.6 mm × 150 mm, 5 μm particle size; Agilent Technologies) and fluorescence detector. The mobile phase was a mixture of acetonitrile and phosphate (32 : 68 v/v). The other parameters were as follows: column temperature 25°C, flow rate 1 ml/min, and injection volume 20 μl. The stevioside and rebaudioside A contents were quantified at 210 nm based on peak area, and results were expressed as mg per g sample.

2.9. Ascorbic Acid. The level of ascorbic acid in the samples of Stevia leaves was estimated using the 2, 6-dichloroindophenol titration method [26]. One gram of Stevia leaves sample was grounded with a mortar and pestle using 3% metaphosphoric acid followed by filtration through Whatman No. 1 filter paper. The ascorbic acid solution was titrated against dye solution (2, 6-dichloroindophenol using phenolphthalein as an indicator to an end-point of faint pink color which should persist for at least 15 s). Results were expressed in the form of mg/100 g of each sample.

2.10. Total Phenolic Content. The total phenolic content (TPC) was measured spectrophotometrically (Model: UV-2601 UV/VIS Double Beam, Rayleigh, China) at 765 nm using the Folin–Ciocalteu technique [31]. The calculation of total phenolics of leave samples was carried out using the linear equation generated from the calibration curve plotted by taking gallic acid as standard. The concentration of gallic acid solution was taken in the range of 5–25 μg/ml for preparing the standard curve. The TPC of Stevia leaves was expressed as equivalents of gallic acid/g (mg GAE/g) of dried leaves.

2.11. DPPH Radical Scavenging Activity. The antioxidant activity (AA) of the samples was estimated using 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay according to the method described by Şahin et al. [32]. The proton-donating activity decreased the absorbance which was recorded at a wavelength of 517 nm and inhibition% was calculated using following formula:

$$\text{Inhibition}\,\% = \frac{A_0 - A_s}{A_0} \times 100, \tag{11}$$

where A_0 and A_s stand for the absorbance of control (methanol) and sample, respectively.

2.12. Statistical Analysis. Origin Pro 8.5 software was used to do the nonlinear regression analysis. The reduced chi-square (χ^2), root mean square error (RMSE), and coefficient of determination (R^2) were used to determine how well the drying curve fits performed. Higher R^2 values and lower χ^2 and RMSE values are regarded as indicators for a suitable model [33]. Statistical analysis was carried out using SPSS software version 20 for Windows. The means ± SD for triplicate assays of all parameters were examined for significance using ANOVA with t-test to determine any significant difference between the treatments at $p < 0.05$.

3. Results and Discussion

3.1. Moisture Ratio, Drying Rate, and Modelling of Drying Curves. Figure 2 displays the moisture ratio versus drying time for Stevia leaves dried in a microwave at various levels of microwave power. It is evident that when the microwave power level grew from 180 to 900 W, the drying durations of the leaves were drastically reduced to 2.5 minutes from 15 minutes. For Stevia leaves, it took 15, 9, 5.5, 4, and 2.5 min at 180, 360, 540, 720, and 900 W, respectively, to reach the final moisture level (<10% wet basis). As the level of microwave power raised four times, the average drying time dropped by 6 times. This suggests that mass movement within the leaves occurred faster under larger power level because generation of more heat takes place within the leaves and result in a huge vapour pressure differential between the product's center and surface due to the typical microwave volumetric heating [27]. Similar results have been reported in the literature for microwave drying of different leaves of *Pandanus amaryllifolius* [34], coriander [35], and *Ficus carica* Linn [11]. The drying rate versus time is depicted in Figure 3 for various microwave power levels. The current microwave drying experiment only shows a brief period of acceleration at the start, with no steady rate period. Moreover, it was observed that the increase in microwave power amplified the drying rate. These results are in accordance with findings for microwave drying of different food items such as parsley [36] and mango ginger [14].

The information of drying was used to explain the microwave drying kinetics of Stevia leaves. The nonlinear regression analysis was used to fit the experimental data with commonly used five model equations. The coefficient of determination (R^2), root mean square error (RMSE), and the chi-square (χ^2) between the experimental and projected moisture ratio values were used to assess the model's fitness. The statistical findings for Stevia leaves undergoing microwave drying from all models are displayed in Table 1. Analyzed parameter values included the R^2 value between 0.77643 and 0.9994, χ^2 value between 0.0001 and 0.0164, and RSME value between 0.0072 and 0.1279 for different models. The page model was found to be the most suitable one for all the experimental data with the value of coefficient of determination (R^2) greater than 0.997, root mean square error (RMSE) lower than 0.0003, and the chi-square (χ^2) lower than 0.01 in comparison to the statistical parameters obtained for other models selected for investigation (Table 1). Similar outcomes were noted when drying parsley leaves [36] and *Ficus carica* L. leaves [11] in the microwave. Comparison of experimental data with predicted page model is shown in Figure 2. It is observable that the value of the

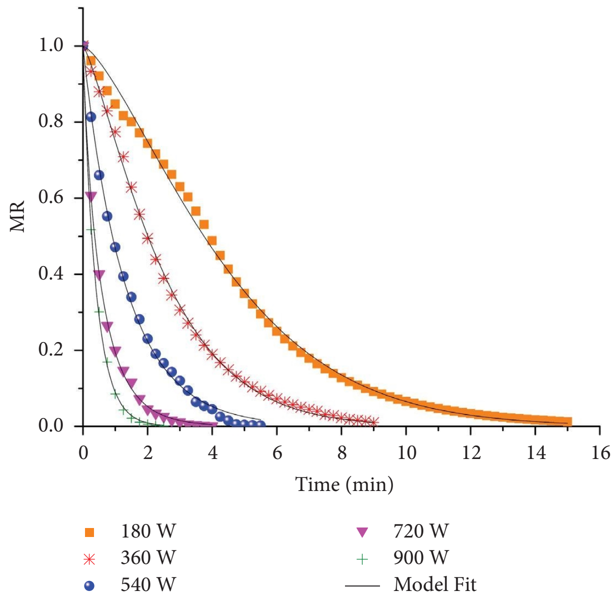

Figure 2: Variation of moisture ratio during microwave drying of Stevia leaves at different powers.

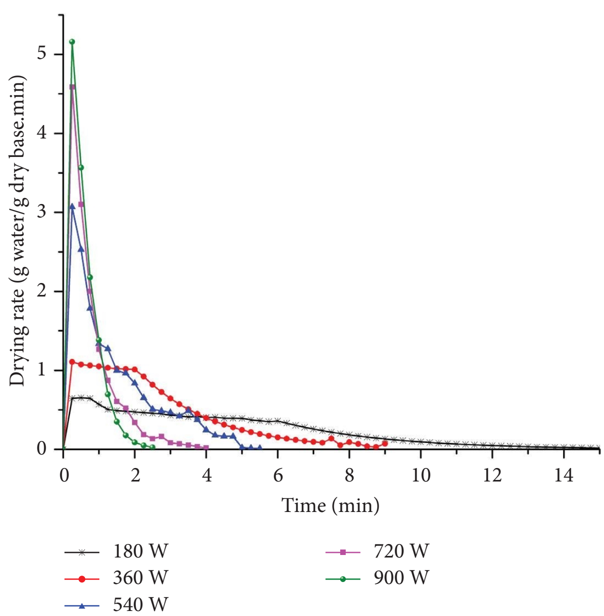

Figure 3: Variation of drying rate during microwave drying of Stevia leaves at different powers.

drying constant k rose together with the growth in the level of microwave power. This indicates that with the increase in microwave power the curve of drying becomes steeper signifying quicker drying of leaves [37].

3.2. Effective Moisture Diffusivity. The method of slopes, which involves graphing ln(MR) versus drying time (t) with regard to data acquired at various microwave power levels, was used to estimate moisture diffusivity. The effective moisture diffusivity values (D_{eff}) and corresponding values of coefficients of determination (R^2) at various power levels are shown in Table 2. In this investigation, D_{eff} values of Stevia leaves ranged from 3.009×10^{-11} to 2.636×10^{-10} m^2/s. Therefore, it was noted the D_{eff} values enhanced with increasing the power level which might be due to the development of a higher moisture gradient between the leaf samples and ambient along with an increment in the driving force of mass transfer and moisture diffusivity [38]. The microwave drying of leaves of purple basil [39] and *Ficus carica L.* [11] had comparable results. Moreover, values of effective diffusivity determined in the current investigation were within the general range 10^{-12} to 10^{-8} m^2/s for food items [27].

3.3. Specific Energy Consumption. The SEC values for various levels of microwave output power, which range from 6.78 to 9.77 MJ/kg water, are shown in the Table 2. This table shows that the final SEC of leaves enhances when microwave power increases from 180 to 360 W. Similarly, initial increase in SEC have been reported in microwave drying of onion slice [40]. In case of microwave drying of peppermint leaves, the SEC increased throughout the microwave power range of 200–600 W [38]. This might be explained by the last phases of the drying's decreased moisture content, which resulted in lower energy absorption by the samples and higher energy requirements for moisture removal [11]. However, The SEC of Stevia leaves decreased with an increase in power from 540 to 900 W which might be due to the decreasing drying time [41]. However, a minor fall in SEC between 540 and 720 W may be due to the fact that these powers (540 and 720 W) have quite closer drying time of leaves (330 and 240 sec, respectively).

3.4. ANN Modelling. Development of an artificial neural network (ANN) was carried out using multilayer feed forward topology and to determine the amount of hidden neurons, these topologies were evaluated. The MSE against the number of hidden neurons was plotted to provide insight into how the number of hidden neurons affects the performance of the artificial neural network, as shown in Figure 4. MSE is an average squared difference between outputs and targets, and lower values are considered for an optimal model. Among the different artificial neural networks, the best network was a three layered topology with 15 neurons in the hidden layer (2-15-1).

The comparison between the experimental and the best ANN model's predicted moisture ratio during the drying procedure is shown in Figure 5. Correlation coefficient (R) predicted by the ANN for training, validation, and testing was 0.99991, 0.99994, and 0.99996, respectively. Figure 6 displays the experimental MR as well as the projected MR by the best ANN for all microwave power levels. The outcomes demonstrated that the ANN is able to predict the drying kinetics of the Stevia leaves with high accuracy when they are dried using microwave energy. For the best ANN, it was discovered that the R^2, MSE, and RMSE values were 0.9999, 1.51×10^{-5}, and 0.039, respectively. Therefore, according to the results obtained in this investigation, a potentially

Table 2: Calculated effective moisture diffusivity values and specific energy consumption for microwave drying of Stevia leaves.

Microwave power level (W)	Effective moisture diffusivity				SEC (MJ/kg water)
	Slope	D_{eff} (m^2/s)	R^2	Adjusted R-square	
180	0.00516	3.834×10^{-11}	0.9920	0.9919	8.14 ± 0180^{c}
360	0.00828	4.470×10^{-11}	0.9920	0.9920	9.77 ± 0.29^{a}
540	0.01768	7.493×10^{-11}	0.9320	0.9319	8.94 ± 0.15^{b}
720	0.02681	1.106×10^{-10}	0.9859	0.9858	8.68 ± 0.21^{b}
900	0.04521	1.997×10^{-10}	0.9967	0.9966	6.78 ± 0.23^{d}

SEC: specific energy consumption and values with same superscript letters in the same column are nonsignificant at $p < 0.05$.

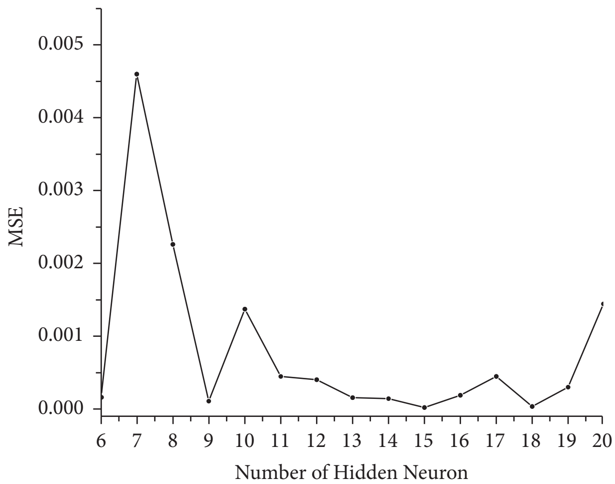

Figure 4: ANN performance evaluation based on the number of hidden neurons for microwave drying of Stevia leaves.

effective method for the prediction of drying kinetics of microwave drying Stevia leaves is ANN modelling.

3.5. Color Characteristics. The color parameters of dried Stevia leaves are depicted in Table 3. The microwave dried leaves showed a significant reduction ($p < 0.05$) in the values of L^*, b^*, and a^* in comparison to the fresh ones. Similarly, the values of chroma of Stevia leaves undergone microwave drying were significantly different from fresh leaves except the values of hue angle. The increase in the level of microwave power from 180 to 900 W did not demonstrate a significant influence ($p > 0.05$) on L^*, b^* and a^*, hue angle, and chroma values. This indicates that the change in parameters of color was not dependent on the level of microwave power. These findings are in good agreement with results of microwave-dried parsley leaves [36] and coriander leaves [35]. It is evident that a nice green tone was maintained even though microwave drying caused some darkening of the leaf color in comparison to the fresh Stevia leaves.

3.6. Steviol Glycosides. The effects of different microwave powers on the steviol glycoside content of Stevia leaves are shown in Table 4. The stevioside and rebaudioside A contents of dried leaves were significantly ($p < 0.05$) reduced in comparison to fresh leaves. The increase in power from 180 to 720 W significantly ($p < 0.05$) enhanced the stevioside and rebaudioside A content in dried leaves. This might be due to the reason that Stevia leaves contain steviol glycoside precursors, which when heated, undergo a chemical reaction to produce the matching sweeteners [42]. The highest content of stevioside (11.84 mg/g) and rebaudioside A (7.11 mg/g) was reported in samples dried at 720 W. Moreover, the increment of power level from 720 to 900 W decreased the content of stevioside and rebaudioside A to 9.01 mg/g and 6.44 mg/g, respectively. When the internal temperature of the material rises during drying, the occurrence of more enzymatic reactions takes place as a result of increased enzyme activity which might have resulted in the decrement of glycoside concentration [43].

3.7. Ascorbic Acid Content. Table 4 compares the ascorbic acid levels of samples of Stevia leaves exposed to different microwave power outputs in comparable to fresh leave sample. The ascorbic content of dried leaves was significantly reduced in comparison to fresh Stevia leaves, while power output also significantly affected the ascorbic acid content of leaves. The lowest value of the ascorbic acid (12.23 mg/100 g) was reported in case of 180 W microwave power which has the longest period of drying. The decline in the content of the ascorbic acid in microwave-dried samples was observed to be linked to the time of drying [44]. The ascorbic acid was retained maximum (~86%) in leaves dried at 720 W. Similar reduction in the values of the ascorbic acid with prolonging of microwave drying were reported for the microwave drying of collard leaves [45]. The ascorbic acid at 900 W was reported as 20.89 mg/100 g which is lesser than the value observed at 720 W. This might be due to the reason that though the drying time is short at 900 W, but the supply of heat is more, which might have led to the significant degradation of the ascorbic acid [46].

3.8. Total Phenolic Content. The total phenolic content of the Stevia leaves dried at different microwave power is depicted in Table 4. The fresh Stevia leaf sample initially estimated for the total phenolic content showed a value of 49.96 mg GAE/g. The total phenolic content of dried samples was significantly ($p < 0.05$) affected by the microwave power. The power of 180 and 360 W showed a significant decline in the content of total phenolics of about 15.55% and 10.58%, respectively, in comparison to that of fresh leaves. This might be due to the reason that phenolic content, being sensitive to the time of drying exposure, degraded at lower power (180 and 360 W) as a period of drying was larger at these powers.

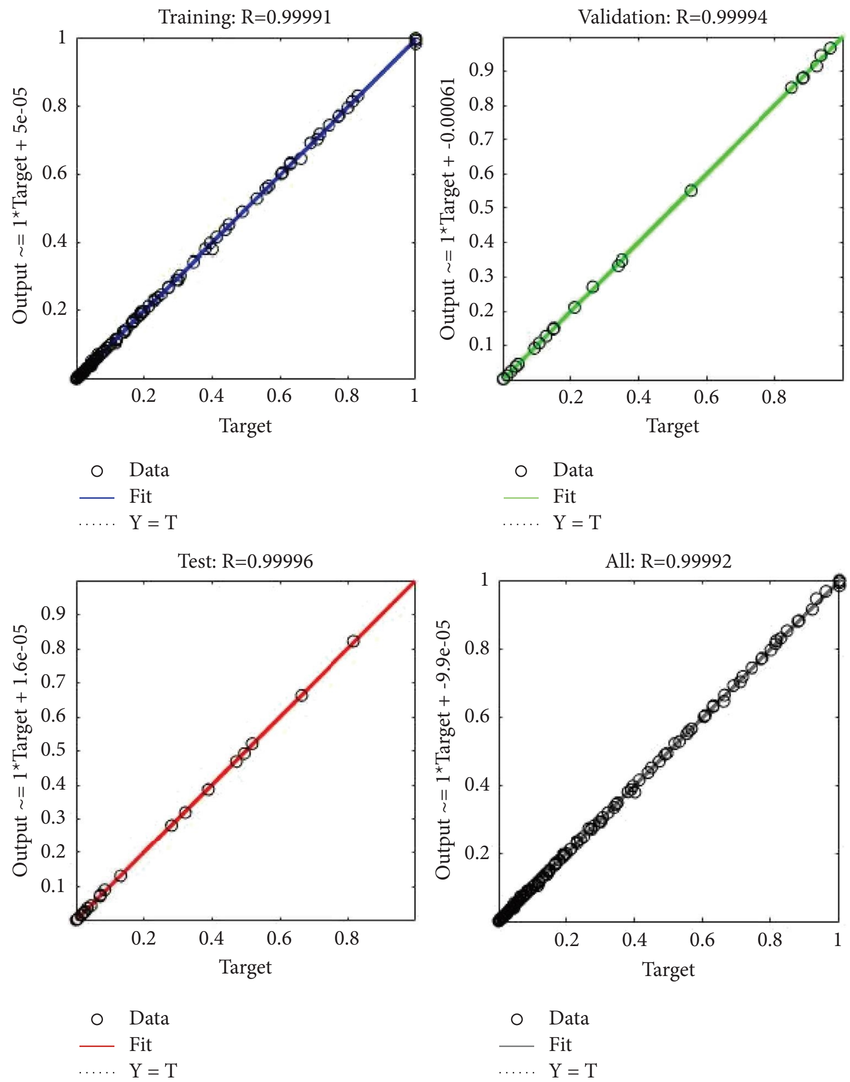

Figure 5: Comparison between experimental and predicted moisture ratios during training, validation, and testing of the best ANN model.

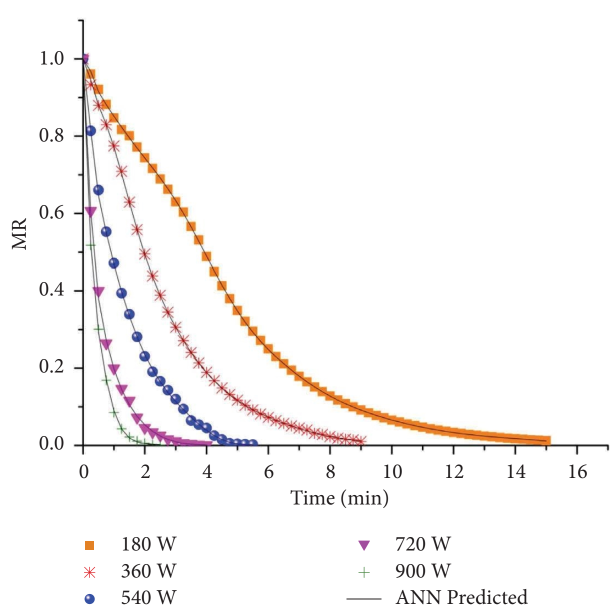

Figure 6: Best ANN model prediction and experimental data for microwave drying of Stevia leaves.

Table 3: Variation of color characteristics for the microwave drying of Stevia leaves.

Microwave power (W)	L^*	b^*	a^*	Hue angle	Chroma
Fresh leaves	41.30 ± 0.17^{a}	-11.10 ± 0.12^{e}	19.55 ± 0.53^{a}	119.60 ± 0.91^{a}	22.48 ± 0.42^{a}
180	38.20 ± 0.79^{b}	-10.20 ± 0.42^{d}	18.40 ± 0.79^{b}	119.01 ± 0.55^{ab}	21.03 ± 0.17^{b}
360	37.30 ± 0.50^{bc}	-9.50 ± 0.29^{cd}	17.90 ± 0.06^{bc}	117.95 ± 0.65^{bc}	20.26 ± 0.24^{bc}
540	36.50 ± 0.18^{cd}	-8.90 ± 0.01^{bc}	17.30 ± 0.28^{cd}	117.23 ± 0.38^{cd}	19.45 ± 0.06^{cd}
720	35.40 ± 0.84^{de}	-8.20 ± 0.25^{ab}	16.70 ± 0.13^{de}	116.15 ± 0.85^{d}	18.60 ± 0.18^{de}
900	34.20 ± 0.71^{e}	-7.90 ± 0.32^{a}	16.20 ± 0.50^{e}	115.99 ± 0.85^{d}	18.02 ± 0.18^{e}

Values with same superscript letters in the same column are nonsignificant at $p < 0.05$.

Table 4: Variation in biochemical parameters of Stevia leaves dried at different levels of microwave power.

Microwave power (W)	Steviol glycosides		Ascorbic acid (mg/100 g)	Total phenolic content (mg GAE/g)	Radical scavenging activity (inhibition %)
	Stevioside (mg/g)	Rebaudioside A (mg/g)			
Fresh leaves	12.56 ± 0.15^{a}	9.22 ± 0.29^{a}	25.30 ± 0.02^{a}	49.96 ± 0.09^{d}	79.09 ± 0.26^{a}
180	6.22 ± 0.21^{f}	4.97 ± 0.19^{f}	12.23 ± 0.48^{f}	41.19 ± 0.15^{f}	59.20 ± 0.13^{d}
360	7.71 ± 0.10^{e}	5.82 ± 0.11^{e}	15.35 ± 0.22^{e}	44.72 ± 0.36^{e}	50.14 ± 0.94^{e}
540	10.15 ± 0.53^{c}	7.11 ± 0.23^{c}	19.61 ± 0.70^{d}	52.54 ± 0.18^{c}	65.02 ± 0.70^{c}
720	11.84 ± 0.55^{b}	8.53 ± 0.01^{b}	21.75 ± 0.25^{b}	54.82 ± 0.09^{b}	69.55 ± 0.11^{bc}
900	9.01 ± 0.31^{d}	6.44 ± 0.24^{d}	20.89 ± 0.47^{c}	56.98 ± 0.03^{a}	74.22 ± 0.20^{b}

GAE: gallic acid equivalent and values with same superscript letters in the same column are nonsignificant at $p < 0.05$.

Similar findings related to the phenolic content degradation were reported for the microwave drying of kiwi slices [47]. With the increase of microwave power from 540 to 900 W, the total phenolic content increased from 52.54 to 56.98 mg GAE/g. This might be due to the reason that the increment in the microwave power generates high vapor pressure and temperature inside the tissue of plant which disrupts the polymer cell wall of plant and releases the phenolic components from cell walls along with bound phenolic compounds [48]. Similar trend of first decrease followed by an increase in the total phenolic content with increasing power was also observed in microwave drying of pineapple slices [49]. In another study on microwave drying of coriander leaves, the total phenolic content enhanced when the microwave was increased [50].

3.9. DPPH Radical Scavenging Activity. The change in the antioxidant capacity of the microwave-dried Stevia leaves obtained by using different microwave power is given in Table 4. The microwave drying significantly affected the radical scavenging activity of Stevia leaves. The DPPH inhibition percentages varied from 79.09 to 50.15%. Increasing the microwave power from 180 to 360 W led to the significant decrement in the radical scavenging activity of dried leaves in comparison to that of fresh leaves. The degradation of antioxidant compounds during drying is the cause of this decline. Similar decrement of antioxidant capacity was observed in the microwave drying of pineapples when microwave power was increased from 120 to 350 W [49]. In comparison to fresh Stevia leaves, the superior radical scavenging activity was observed at 900 W with a value of 74.22%. A nonsignificant difference was observed among the values of DPPH inhibition percentages at 540, 720, and 900 W. Similarly, the microwave drying of lemon myrtle leaves showed no significant difference for DPPH for three microwave power levels of 720 W, 960 W, and 1200 W [51]. For the microwave power above 360 W, the increase in the percentage of DPPH might be due to the growth of antioxidant characteristics of naturally formed components or products of the Maillard reaction with antioxidant activity [52].

4. Conclusion

Stevia leaves were dried in a microwave drier at different power levels (180, 360, 540, 720, and 900 W) to evaluate drying kinetics, effective moisture diffusivity, specific energy consumption, color changes, and biochemical attributes. The increase in the power levels led to the increment of dry rate and decrement of drying time. Regarding goodness of fit indices (R^2, χ^2, and RMSE), page model gave the best fit to the experimental data among five differently selected models. At all microwave power levels tested, this model predicted very well the moisture content as a function of drying time. The values of effective moisture diffusivity enhanced from 3.009×10^{-11} to 2.636×10^{-10} m^2/s with increment of the power level. Specific energy consumption (SEC) firstly increased and then decreased with increasing the power levels from 180 to 900 W. In order to describe microwave drying of Stevia leaves, a feed-forward artificial neural network using a backpropagation algorithm was also found to accurately predict the moisture content. The final selected model, 2-15-1 successfully showed the relationship between input and output parameters with $R^2 > 0.999$. The ANN has so demonstrated that it could be a viable substitute for Stevia leaves thin layer drying modelling due to its acceptable capabilities and simplicity. The color estimation demonstrated a significant ($p < 0.05$) change in color parameters of microwave-dried leaves in comparison to fresh leaves, though a good green color was maintained. Moreover, color values of dried levels were not dependent on the power level. Stevia leaves dried at 720 W showed the highest content of stevioside (11.84 mg/g) and rebaudioside A (7.11 mg/g) and maximum (~86%) retention of ascorbic content. The highest total phenol content (56.98 mg GAE/g) and antioxidant capacity (74.22%) were observed in microwave-dried samples at 900 W.

Data Availability

All data pertaining to this work are available within the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Baldev Singh Kalsi was involved in investigation, conceptualization, methodology, formal analysis, software provision, writing of the original draft, data curation, and review and editing. Sandhya Singh was involved in conceptualization, methodology, supervision, project administration, validation, review, and editing. Mohammed Shafiq Alam was responsible for software provision, data curation, formal analysis, review, and editing. Surekha Bhatia was responsible for formal analysis, review, and editing.

Acknowledgments

The authors are thankful to AICRP (All India Coordinated Research Project) on Post-Harvest Engineering & Technology for financial assistance. The authors also like to thank the Punjab Agricultural University for facilities.

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