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Original research

The effect of infrared on *Bacillus cereus* in paprika powder: Modeling through genetic algorithm-artificial neural network

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A B S T R A C T

In this study, the effect of infrared (IR) on decontamination of *Bacillus cereus*, color, weight losses, and temperature profiles at paprika powder was determined in difference IR radiation power (100, 200, and 300 W), different sample distances from a radiation source (5, 10, and 15 cm), and various holding times. The most reduction of *B. cereus* count (2.3 log CFU/g) was achieved after 1 min holding time at 200 W IR power and 5 cm distance. The highest D-value (0.18 min) was achieved after a holding time of 0.5 min at 300 W IR power and 5 cm distance. The a* value of paprika powder was slightly affected and the highest color change was observed at 100 W IR power, 10 cm distance, and 8 min resulting in a decrease of a* from 42.537 ± 0.201 to 38.645 ± 0.429. Data were analyzed to predict the antibacterial effects of IR on *B. cereus* in paprika powder through an artificial neural network (ANN) model. The developed GA-ANN, which included 20 hidden neurons, could predict the *B. cereus* population with R^2 = 0.9561. The results indicated that the GA-ANN model could give a good prediction for the population of *B. cereus*. Sensitivity analysis results showed that IR irradiation time was the most sensitive factor for the prediction of the *B. cereus* population.

Keywords: *Bacillus cereus*; Paprika powder; Genetic algorithm; Infrared heating; Microbial decontamination

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1. Introduction

Herbs and spices are necessary food ingredients, and they participate affirmatively in the food's sensory properties. They also mostly have a microbial hazard owing to poor sanitation during storage, drying, growth, and harvest. Spices and herbs have extensively various bacteria such as *Escherichia coli*, *Clostridium perfringens*, *Salmonella*, and *Bacillus cereus* are often found (Sagoo et al., 2009; Banerjee & Sarkar, 2003). *B. cereus* is a mostly bacteria in spices that contamination generally attaining 6–8 log_{10} colony-forming unit per g (CFU/g) (McKee, 1995). Generally, 10^5 CFU/g is indispensable to cause illness however European Food Safety Authority (2005), short reportage on *B. cereus* in food the minimum numbers in food that resulted in food poisoning outbreak were given as 10^3 to 10^4 CFU/g.

For decontamination of foodborne indicators in dried products, including gamma irradiation (Arici et al., 2007; Rahayu et al., 2016), electron beam irradiation (Van Calenberg et al., 1998; Nieto-Sandoval et al., 2000), X-ray irradiation (Van Calenberg et al., 1998; Park et al., 2014), ultraviolet (UV) irradiation (Erdoğdu & Ekiz, 2011; Sharma-Shivappa & Demirci, 2003), dry heating (Baron et al., 2003), steam decontamination (Schneider, 1993), microwave (Eliasson et al., 2015; Legnani et al., 2001) and infrared (IR) radiation (Shavandi et al., 2020a; Shavandi et al., 2018).

IR irradiation has wavelengths of range between 0.76 µm – 1 mm, with wavelengths between ultraviolet and microwave radiation that section of the electromagnetic spectrum. IR irradiation classification as near-IR (0.76 to 2 µm), medium-IR (2 to 4 µm), and far-IR (4 to 1000 µm) and interacts with foodstuff due to it depends on the effect of radiation (transmission, reflection, penetration depth, absorption, IR wavelength, and scattering), and the type of food (product thickness, food composition, and water activity) (Ginsburg, 1969).

In recent years, artificial neural networks (ANNs) than conventional modeling, has more offer real advantages (Funes et al., 2017). ANNs for each independent variable have 1 input layer containing 1 node, 1 or more hidden layers, where the data are

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processed, and 1 output layer, including 1 node for each dependent variable. ANNs in a parallel structure are made of nodes or artificial neurons (Gonçalves et al., 2005). Many reports have said the advantages of the application of technical ANNs compared to other statistical methods (Atsamnia et al., 2017; Kavuncuoglu et al., 2018). ANNs are helpful tools for quality analyses, and food safety such as predicting spectroscopic data, microbial growth, and predicting functional, physical, and chemical properties of foods (Shavandi et al., 2020c; Kavuncuoglu et al., 2018).

One of the most consumed spices is paprika powder in the world and has high economic and export value. The main objectives of this study were to evaluate the effects of IR on the *B. cereus* population, GA-ANN modeling of decontamination as well as color changes, weight losses, and D-values in paprika powder.

2. Material and Methods

2.1. The raw material preparation

The paprika powder (*Capsicum annum*) with a water activity of 0.374 and a moisture content of 8.62% was prepared from Sabzevar, Iran, and stored at 20°C in plastic bags. *B. cereus* (ATCC 11778) as a lyophilized from American type culture collection was purchased. Activation of foodborne indicator *B. cereus* was done in two consecutive days in BHI Broth (Merck, Germany) medium (24 hours incubation at 37 °C). Then its population was adjusted to 10^9 CFU/ml. The final bacteria population in the paprika powder after contamination was 7.26 $\log_{10}$ CFU/g.

2.2. IR treatment of the paprika powder

In this study, an experimental stainless steel chamber (45×45×40 cm) was designed for the IR irradiation system, and an aluminum waveguide with an IR lamp (1000 w, and 350 mm) were used (Shavandi et al., 2020b). The paprika powder a thin layer in a glass petri dish was set below the IR source. The treatments were applied at the IR power irradiation (100, 200, and 300 W) and sample distance from the IR lamp (5, 10, and 15 cm), and different holding times (depending on treatment conditions from 0 to 15 min) on the microbial inactivation kinetics were investigated.

2.3. Microbiological analysis

The effect of IR treatments on the *B. cereus* population in paprika powder by spread plating method was determined. Following IR treatments paprika powder was aseptically weighed and then their serial ten-fold dilutions were spread on Chrom agar (Merck, Germany). After 24 h incubation at 37°C, colonies that appeared were enumerated. Microbial enumerations as the log of reduction (CFU/g) were expressed. The survival (N) was also calculated, where N is the surviving bacteria number after treatments.

2.4. Determination of color changes

Color changes of the paprika powder were determined by analysis of L^* (lightness), a^* (redness), and b^* (yellowness) values through image J software. Different samples were scanned (HP Scanjet G2710), and then the scanned pictures were analyzed (Eliasson et al., 2014; Shavandi et al., 2022).

2.5. Determination of D-values

D-values at different treatments were determined using linear regression of *B. cereus* reduction curves. Calculations were performed using two fixed points in the graph (Staack et al., 2008; Shavandi et al., 2020b).

2.6. Weight loss percentage

After and before IR treatments, the paprika powder was aseptically weighed and then the weight loss percentage was calculated (Erdoğdu & Ekiz, 2011).

2.7. Statistical analysis

Results as the standard deviation and mean of 3 independent replicates were expressed. All the data were statistically analyzed utilizing one-way analysis of variance (ANOVA) using Duncan post hoc in $p < 0.05$. All of the statistical analyses utilizing SAS software version 9.3 were performed (SAS Institute Inc.).

2.8. GA-ANN model

ANN is a popular type of artificial intelligence and the multi-layer feed-forward neural network is the most popular, where the neurons are arranged into 3 layers output, hidden, and input (Yolmeh et al., 2014). A description of the these layers network structure used in this study consists input layer (IR power, sample distance from radiation source, and time), hidden layer (input neurons, hidden neurons, and output neurons), and output layer (*B. cereus* population). The performance of an ANN depends severely on its topology. The input neurons number and the output neurons number correspond to the input variables number in the neural network and the target output variables number, respectively. At least 1 hidden layer that can have any neurons number, there is between the output and the input layers and depends on the application of the network. Usually, by error and trial method, determination of the optimum hidden layer neurons number is done (Salehi et al., 2012; Bahram Parvar et al., 2013).

The genetic algorithm (GA) optimization technique, is a method for overcoming the inherent limitation of ANNs. The GA mimics the mechanism of biological evolution and is a search technique for optimal value (Morimoto, 2006).

The net input (xj) to node j in output layers and the hidden, is of the form:

$$X_j = \sum_{i=a}^{n} W_{ij} y_i + b_j \quad (1)$$

where b_j is the bias associated with node j, n is the number of nodes, y_i is the inputs, and w_{ij} is the weights associated with each input/node connection (Soleimanzadeh et al., 2018).

In this study, because Levenberg–Marquardt technique is faster and more powerful than the conventional gradient descent technique, for ANNs training was used (Sagdic et al., 2012). All data were randomly divided into three partitions: training (60%), validating (15%), and testing data (25%). For designing the GA-ANN model has used the Neurosolution software (release 6.01, NeuroDimension, Inc., USA).

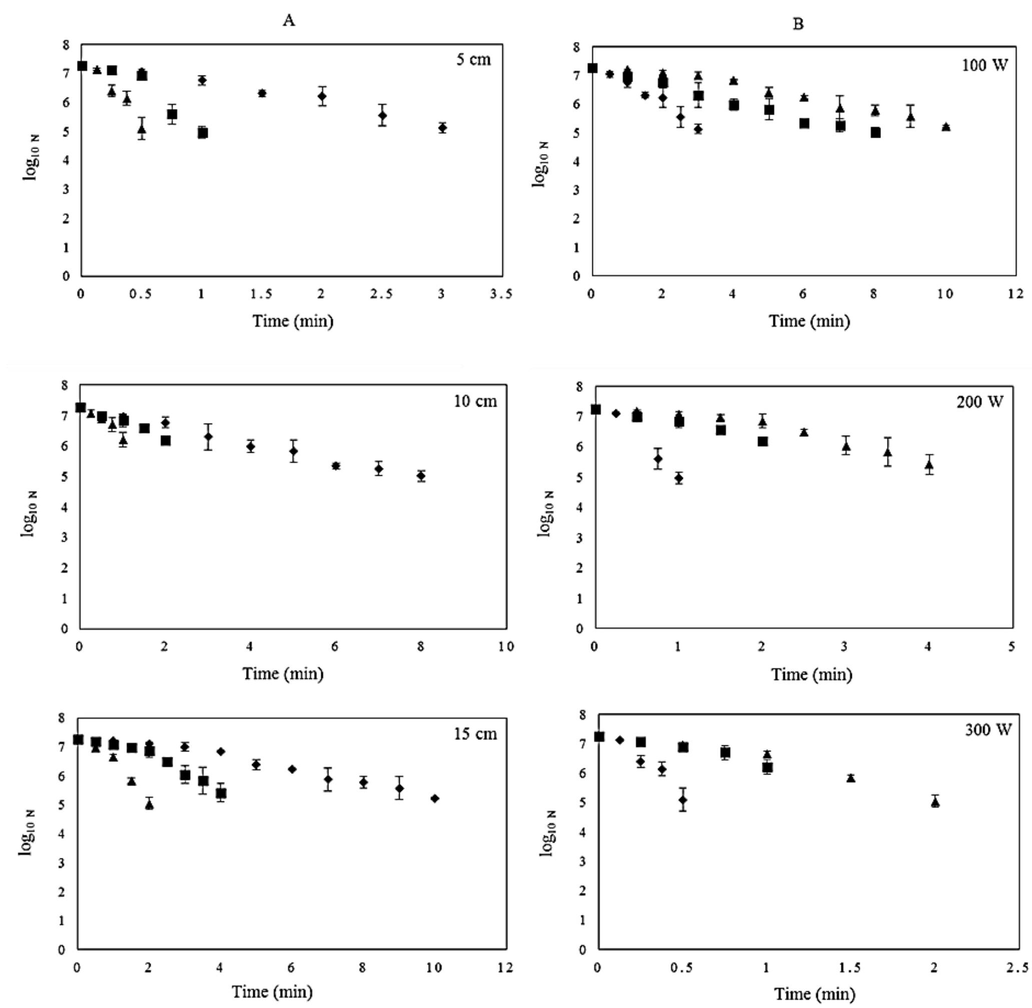

Fig. 1. The effect of different IR power- 100 W (♦), 200 W (■) and 300 W (▲)- at constant distance from IR lamp (A) and the effect of different distances from IR lamp- 5 cm (♦), 10 cm (■) and 15 cm (▲)- at constant IR power (B) on log N of *B. cereus* in paprika powder.

3. Results and Discussion

3.1. Decontamination of microorganisms

The difference between the inactivation effects of different IR powers at constant distances of the IR lamp during the time, as well as various distances from the IR source at fixed IR power during the time is shown in Fig. 1.(A and B), respectively. According to the results, the highest rate of decontamination of paprika powder 2.3 log CFU/g was obtained at 200 W IR power, 5 cm distance, and 1 min time. The minimum decontamination of paprika powder of 1.055 log CFU/g was obtained at 300 W IR power, 10 cm distance, and 1 min time. It was observed that the increase in lamp power, the decontamination of paprika powder was significantly increased ($p < 0.05$). This happened because of the difference in temperature produced by the IR lamp and absorbed by the sample due to shorter wavelengths (thus more energy). Decreasing the sample distance from the IR source, the decontamination of *B. cereus* in the paprika powder was significantly increased ($p < 0.05$). This effect may be due to the increase of IR absorption by *B. cereus* and the increase in sample temperature due to the decrease in distance. It was reported that an increase in the IR power generates more energy and energy absorbed by microorganisms increases that leading to microbial decontamination (Krishnamurthy et al., 2008).

In a study, IR radiation was used for the inactivation of *A. flavus* and *A. niger* in mung beans. The physical disruption and surface disorders of spores coat are the leading causes behind the decontamination of IR-treated fungal spores and increase of IR temperature, decontamination of mung been was increased (Meenu et al., 2018). The effect of the IR inactivation of *Staphylococcus aureus* by scanning electron microscope and Fourier-transform infrared spectroscopy was investigated. The effect of IR on mesosome collapse, subsequent intracellular leakage, cell wall damage, and the cytoplasmic membrane was observed (Krishnamurthy, 2006). In a similar study, IR was used at different sample distances (90, 110, 130, 150, and 170 mm) to remove the *Penicillium sp.* and *Cladosporium sp.* isolated from peaches at culture media. Decreasing sample distance from the IR lamp due to rapid heating sample, the number of fungal spore removal increased (Trivittayasil et al., 2013).

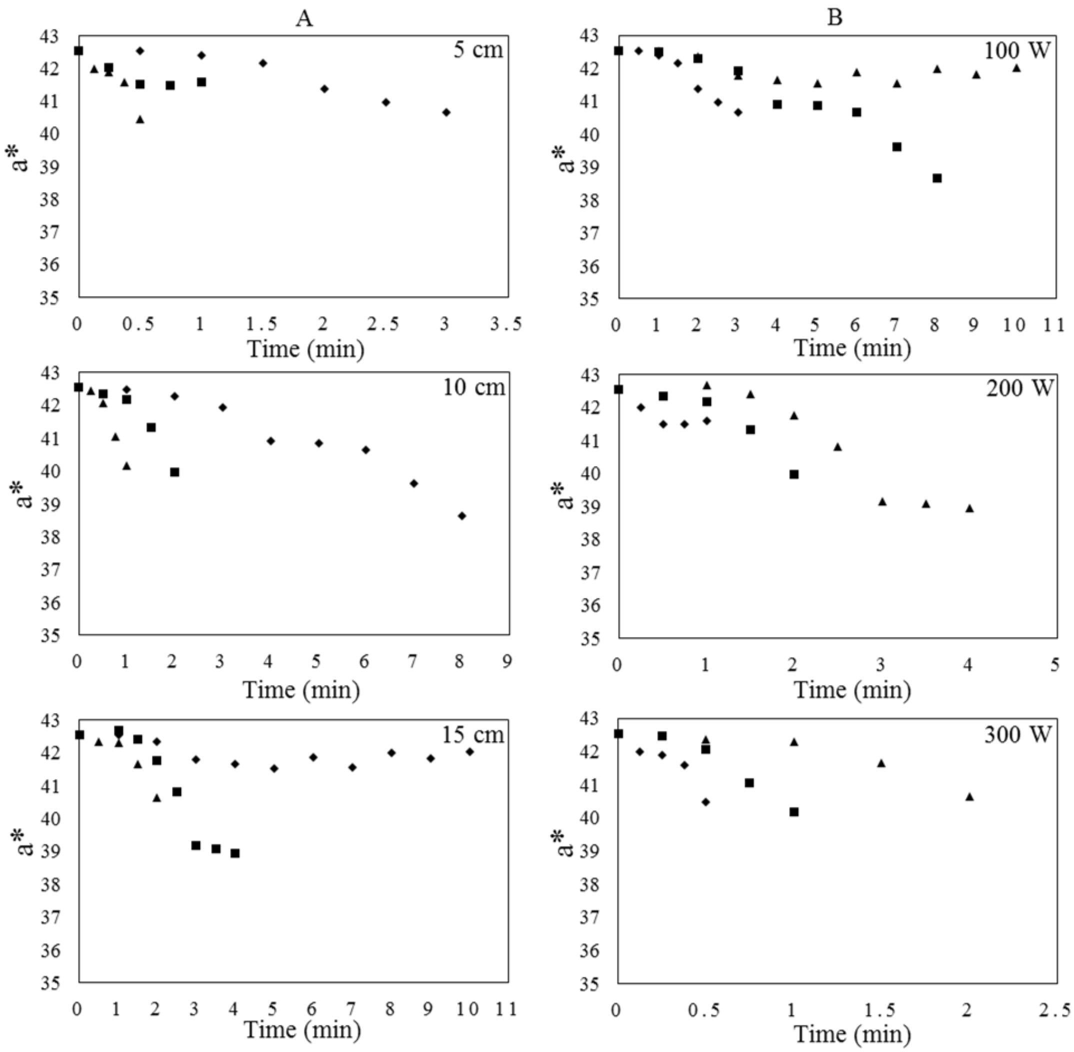

Fig. 2. The effect of different IR powers- 100 W (♦), 200 W (■) and 300 W (▲)- at constant distance from IR lamp (A) and the effect of different distances from IR lamp- 5 cm (♦), 10 cm (■) and 15 cm (▲)- at constant IR power (B) on a* value in paprika powder.

3.2. *Color changes*

L* and b* values had no significant change, so they did not show. The number of color changes (a* value) in treated samples at different IR power and constant distance, as well as the various distances from IR source at fixed IR power during the time, is shown in Fig. 2.(A and B), respectively.

It was observed that with increased time and IR power, the greenness increased and redness decreased in paprika powder (The reduction of distance, a* value was significantly increased). The highest IR power (temperature) and time had the most excellent effect on the color, but this effect was minuscule given the range of time and temperature studied. The highest color changes of paprika powder were observed at 100 W, 10 cm, and 8 min and changed a* (redness decrease) from 42.537 ± 0.201 to 38.645 ± 0.429. Increasing the IR power, the color change was also increased.

It was reported that a higher effect in the change of color was higher temperatures and longer times (Schmalko et al., 2005; Steet & Tong, 1996). Color is an important quality characteristic, affecting consumers' acceptance, and soon, minimizing color changes during any thermal process is crucial. Furthermore, with increasing time and temperature, the color change increased (Eliasson et al., 2014). In another study, color changes of the black pepper seeds treated by FIR were determined by using the LAB method. It was reported that the FIR treatment did not cause any change in lightness and yellowness, but with increased time and temperature, a slight increase happened in redness with the FIR treatment (Erdoğdu & Ekiz, 2013).

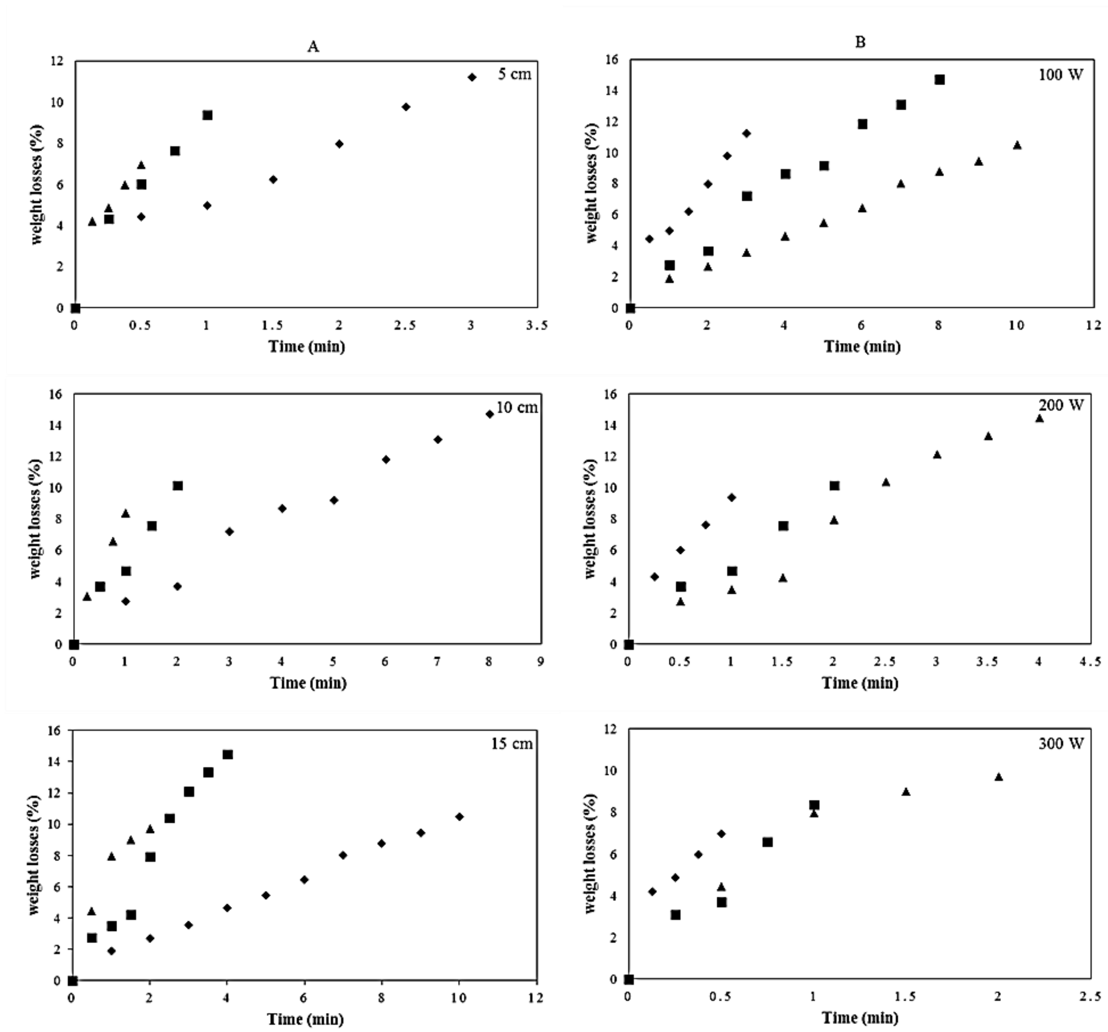

Fig. 3. The effect of different IR powers- 100 W (♦), 200 W (■) and 300 W (▲)- at constant distance from IR lamp (A) and the effect of different distances from IR lamp- 5 cm (♦), 10 cm (■) and 15 cm (▲)- at constant IR power (B) on weight losses in paprika powder.

3.3. *D-value*

D-values were computed utilizing microbial reduction in total holding time. D-values for each treatment were obtained, IR power of 100, 200, and 300 W D-values of 1.30, 0.35, and 0.18 min at a distance of 5 cm, and of 3.59, 1.87, and 0.88 min at a distance of 10 cm, and of 4.56, 1.98, and 0.77 min at a distance of 15 cm, respectively. It was observed that with an increase of IR power and a decrease in the distance, the *B. cereus* reduction has occurred faster, that is to say, the lower the D-value. Increasing the IR power from 100 to 200 W had a more significant impact on D-value than did increasing it from 200 to 300 W. During similar results by Staack et al. (2008), it was reported that with increasing IR temperature (IR power), the D-value was increased. In a study, the effect of IR on *B. cereus* count in cardamom seeds was investigated. The lowest D- value of *B. cereus* in paprika powder at 0.46 min was observed at 300 W, and 5 cm (Shavandi et al., 2020b).

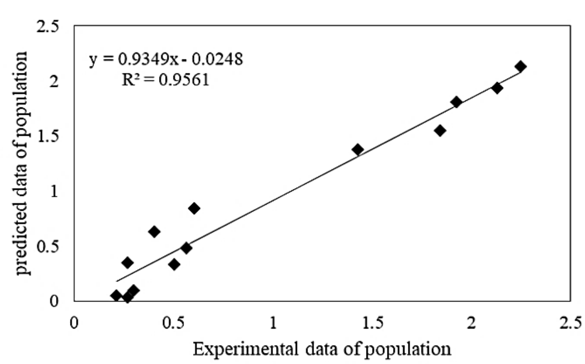

Fig. 4. Experimental versus predicted values of log N of *B. cereus* using GA-ANN model for the test data set (r = 0.978).

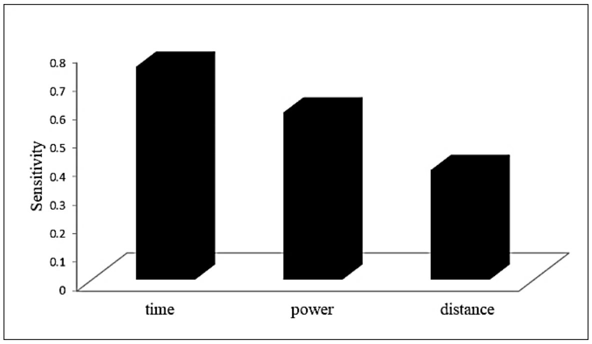

Fig. 5. Sensitivity analysis of optimized GA-ANN (3/20/1) for prediction of *B. cereus* population.

3.4. Weight loss

Fig. 3.(A and B) are shown the weight losses of the treated samples at different IR power and constant distance, as well as the various distance from the IR source at fixed IR power during the time, respectively. The results showed that by decreasing sample distance from the IR source and increasing IR power in all treatments, weight losses were significantly increased ($p < 0.05$). It was found that the highest weight losses in the treated paprika powder at 200 W, 15 cm, and 4 min were equal to 14.48%.

Compression and hardness are sorely necessary for grinding processes. Physical attributes are widely correlated with the moisture content of the seeds. Therefore, the change in moisture content of samples during the decontamination process is another important parameter (Murthy & Bhattacharya, 1998). The moisture content reduction should be limited due to the economic importance related to the weight losses. On the other hand, lower moisture content values cause harder and crispy surfaces with more energy requirements during grinding (Erdoğdu & Ekiz, 2013). In a study, the effect of IR on weight loss in cardamom seeds was investigated. The highest weight loss (16.72%) in treated cardamom seeds was observed at 300 W, 15 cm, and 8 min (Shavandi et al., 2020b).

3.5. GA-ANN

The GA-ANN model was performed for evaluation of the *B. cereus* population in paprika powder and ANN with 2-25 neurons were trained using GA to find the optimal network configuration. It was observed that GA-ANN with 20 neurons in 1 hidden layer could predict the *B. cereus* population in paprika powder with a high correlation coefficient (r = 0.978). The prediction performance of the GA-ANN model for the experimental and predicted value of the reduction of the *B. cereus* population in paprika powder is shown in Fig. 4. The bias and weight values of the optimized network were presented in Table 1 that could be applied in a computer program for the prediction of the *B. cereus* population in paprika powder. Based on the results the GA-ANN model had a good efficiency in the prediction of the inactivation of *B. cereus* in the paprika powder by IR.

Table 1. The weights and bias values of optimized GA-ANN model.

Hidden neurons	Bias	Input neurons			Output neurons
		Time	Power	Distance	log N of *B. cereus*
1	-0.350	0.137	-0.104	0.089	-0.098
2	-2.799	1.391	3.146	-6.438	-5.238
3	-1.521	-15.336	2.891	-3.234	13.903
4	0.020	0.894	0.190	-0.388	-1.034
5	0.068	-0.245	-0.166	0.454	0.199
6	-0.542	-0.136	0.124	-0.131	-0.019
7	0.294	-0.142	-0.100	-0.070	-0.120
8	-0.407	0.100	0.333	-0.062	-0.435
9	3.053	1.269	-5.782	1.578	3.311
10	0.412	-0.751	0.293	1.723	1.432
11	2.386	-1.007	-4.839	9.318	5.932
12	1.183	9.306	-1.749	0.625	-8.748
13	-0.014	0.275	-0.076	0.294	-0.201
14	-0.823	0.241	1.262	-0.475	-1.246
15	-0.071	-0.394	-0.134	0.471	-0.177
16	0.356	-0.513	-0.225	0.499	0.644
17	-0.215	0.048	0.457	-0.177	-0.340
18	0.015	-6.482	1.176	-1.264	5.567
19	0.022	-0.034	-0.134	0.078	0.013
20	-0.169	0.180	0.377	-0.241	-0.233
Bias					-0.242

Fig. 5 demonstrates the sensitivity analysis of neural network models to different inputs. Among the input variables, IR treatment time was the most sensitive factor, followed by IR power and eventually sample distance from IR source for predicting the reduction of *B. cereus* population in paprika powder by the selected GA-ANN. In a study, the effect of IR on the modeling of *B. cereus* inactivation through the genetic algorithm-artificial neural network in cardamom seeds was investigated. The developed GA-ANN, which included 12 hidden neurons, could predict the *B. cereus* population with $R^2 = 0.908$. The results indicated that the GA-ANN model could give a good prediction for the population of *B. cereus* in cardamom seeds (Shavandi et al., 2020b).

4. Conclusion

The decontamination of *B. cereus* in paprika powder by IR radiation was modeled by the GA-ANN and the effect on weight loss percentage, D-value, and color change as a function of sample distance from IR source and IR power was investigated. The highest rate of paprika powder decontamination 2.3 log CFU/g was obtained at 200 W IR power, 5 cm distance, and 1 min time. The highest color changes of paprika powder were observed at 100 W, 10 cm, and 8 min and changed a* (redness decrease) from 42.537 ± 0.201 to 38.645 ± 0.429. The lowest D-value of *B. cereus* in paprika powder at 0.18 min was observed at 300 W, and 5 cm. The highest weight loss in the treated paprika powder at 200 W, 15 cm, and 4 min was equal to 14.48%. The IR treatments decreased the *B. cereus* numbers in paprika powder to acceptable levels. The study results indicated that the GA-ANN with one hidden layer comprising 20 neurons with an acceptable correlation coefficient (0.978) could successfully be used for the prediction of the bacteria counts in paprika powder.

Acknowledgment

Not applicable.

Conflict of interest

All authors have no conflict of interest to report.

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