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# Optimization of air drying process for lavender leaves

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A b s t r a c t. The back-propagation artificial neural network and response surface methodology were used to investigate the estimation capabilities of these two methodologies and optimize the acceptability of desirability functions methodology in an air drying process. The independent factors were the air temperature, air velocity and drying time in the drying process for lavender leaves, while the moisture content, drying rate, energy efficiency and exergy efficiency were selected as the dependent variables or responses. In addition to this isoresponse contour plots were helpful to predict the results. The artificial neural network models determined an optimum point set at the air temperature equal 46.8°C, the air velocity equal 0.726 m $s^{-1}$ and the drying time equal 9.72 h to minimize the moisture content and to maximize the drying rate, the energy and exergy efficiencies. At the optimum point the moisture content, drying rate, energy and exergy efficiencies were found to be 0.32 g $g^{-1}$, 0.29 g $g^{-1}h^{-1}$, 0.67 and 0.80, respectively.

K e y w o r d s: artificial neural networks, optimization, response surface methodology, drying, lavender

## INTRODUCTION

*Lavandula officinalis* is commonly called lavender and is locally known as 'Ostokhodous' in Iran. Lavender is frequently used as an aid to sleep and relaxation. Lavender oil (or extract of lavender) is claimed to heal acne when used diluted 1:10 with water, rosewater, or witch hazel. It is also used in the treatment of skin burns and inflammatory conditions (it is a traditional treatment for these in Iran and nearby regions).

Energy is found as a fundamental concept of thermodynamics and one of the most significant aspects of the engineering analysis (Bayrak *et al*., 2003). However exergy is equal to the maximum amount of work that can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment. In the drying industry, the goal is a maximum moisture removal using a minimum amount of energy to obtain the desired final conditions of the product (Aghbashlo *et al*., 2009b; Hassan-Beygi, 2009; Karimi, 2010).

Response surface methodology has important applications in industry, from design to development and improvementof existing product. It also can be useful for formulation of new products. In addition to analyzing the effects of the controlling or independent variables, this experimental methodology develops a mathematical model, which describes the food and industrial process (Chakraborty *et al*., 2007; Rodrigues and Fernandez, 2007; Sharma and Prasad, 2006; Yao *et al*., 2007).

Artificial neural networks are mathematical models of biological neural systems. In addition, the artificial neural networks are being used in the field of agricultural product processing due to their ability for solving non-linear problems (Ganjyal and Hanna, 2002).

The present study focused on modeling the influence of the air temperature, air velocity and drying time (as independent variables) on changes in moisture content, drying rate, energy efficiency and exergy efficiency (as dependent variables) in an air drying process for lavender leaves.

The modeling was based on two techniques of the response surface methodology and the artificial neural network. Different factorial designs are available in response surface methodology techniques (Mason *et al*., 1989). Here a model with three factors and four responses as a full factorial central composite design was used. Based on the desirability functions and the artificial neural network designed, an optimum point was found to obtain a minimum value for moisture content and maximum values for drying rate, energy and exergy efficiencies.

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## MATERIALS AND METHODS

Fresh lavender leaves were daily harvested in the educational farm of the Horticulture Engineering Department, Universityof Tehran, Karaj, Iran. The dryer was adjusted to a preset temperature for about half an hour to achieve a steady state. Then, sample was uniformly spread in a square basket in a single layer. The sample mass was kept constant at 65 g (±0.5 g) for all runs. During the course of the drying process, lavender leaves were weighed using a digital balance connected to a computer. The relative humidity and temperature in the dryer were measured and recorded every 5 s. The drying process was continued until the drying rate reached zero. The samples were then placed in an oven of 65°C for 24 h in order to find the moisture content.

Drying experiments were performed in a cabinet type laboratory dryer, installed in the Agricultural Machinery Engineering Department, University of Tehran (Yadollahinia, 2006). The dryer used for the experimental work consists of a fan, heaters, a drying chamber and instruments for various measurements which consist of a digital balance (model GF3000, A&D, Japan) with accuracy 0.02 g, a temperature sensor (model LM35, NSC, USA) with accuracy 1°C, a relative humidity sensor (model Capacitive, Philips, UK) with a rated accuracy 3% and an anemometer (model 405-V1, TESTO, UK) with a rated accuracy equal to 3%.

Moisture content (*MC*, dry basis) of lavender leave samples was calculated using the following equation:

$$MC = \frac{W_i M_{Ci} - (W_t - W_{t+\Delta t})}{W_i (1 - M_{Ci})}, \tag{1}$$

where: $W_i$ is the initial mass, $M_{Ci}$ is the initial moisture content, $W_t$ and $W_{t+\Delta t}$ are the masses at drying time *t* and $t + \Delta t$, respectively.

Within a period of time ($\Delta t$) the mean drying rate (*DR*) (dry basis) could be calculated by dividing the difference in product mass ($\Delta W$) within this period of time by $\Delta t$ and dry solid mass ($W_d$) (Corzo *et al*., 2008):

$$DR = \frac{\Delta W}{W_d \Delta t} = \frac{W_t - W_{t+\Delta t}}{W_i (1 - M_{Ci})(t_{t+\Delta t - tt})}. \tag{2}$$

Instantaneous energy efficiency ($\eta_{energy}$) was determined using the following equation (Corzo *et al*., 2008):

$$\eta_{energy} = \frac{Energy\ required\ \ for\ evaporation\ at\ time\ t}{Input\ energy\ at\ in\ \ flow\ at\ time\ t}$$

$$= \frac{(W_i - W_t) h_{fg})}{m_{da} (h_{dai} - h_{dat})}, \tag{3}$$

where: $h_{fg}$ is the latent heat of vaporization of water at the average temperature of the moist food, $m_{da}$ is the mass flow rate of dry air, $h_{dai}$ and $h_{dat}$ are the specific enthalpy of dry air at initial and time, *t*, respectively.

The enthalpy of the air used in the drying process was obtained using the following equation (Akpinar *et al*., 2006):

$$h_{da} = c_{pda} (T - T_{ref}) + h_{fg} w, \tag{4}$$

where: $c_{pda}$ is the specific heat, *T* is the air temperature, $T_{ref}$ is the reference temperature, $h_{fg}$ is the latent heat of vaporization of water at the reference temperature, and *w* is the humidity ratio of air.

The exergy efficiency ($\eta_{exergy}$) was determined by dividing the exergy use (investment) in the drying of the product to exergy of the drying air supplied to the system (Akpinar *et al*., 2006; Midilli and Kucuk, 2003):

$$\eta_{exergy} = \frac{Energy\ inflow - Exergy\ loss}{Exergy\ inflow} =$$

$$1 - \frac{Exergy\ loss}{Exergy\ inflow}. \tag{5}$$

The general form of applicable exergy equation was used for steady flow systems (Midilli and Kucuk, 2003):

$$Exergy = m_{da} c_{pda} \left[ \left( T - T_{ref} \right) - T_{ref} \ln \frac{T}{T_{ref}} \right], \tag{6}$$

where: $m_{da}$ is the mass flow rate, *T* is temperature of inlet or outlet air, and $T_{ref}$ is the reference temperature. The exergy loss can be determined as follow (Akpinar *et al*., 2006):

$$Exergy\ loss = Exergy\ inflow - Exergy\ outflow. \tag{7}$$

In this study the ambient temperature was considered as the reference temperature: $T_{ref}$ = 28°C

The principle of response surface methodology was described by Castillo (2007). An empirical second-order polynomial model for three factors is presented in the following form:

$$y_k = a_0 + \sum_{i=1}^{3} a_i x_i + \sum_{i=1}^{3} \sum_{j=1}^{3} a_{ij} x_i x_j \tag{8}$$

where: $y_k$ (*k* = 1, 2, 3 and 4) are the predicted responses (moisture content, drying rate, energy and exergy efficiencies) used as dependent variables: $x_i$ (*i* = 1, 2 and 3) are the input predictors or controlling variables or independent variables; and $a_0, a_i\ (i = 1, 2, 3)$ and $a_{ij}\ (i = 1, 2, 3;\ j = i, \ldots, 3)$ were the model coefficient parameters.

Each factor in the central composite design was studied at three different levels (-1, 0, +1), two star points and three repetitions at the centre point (Table 1). The analysis of results was performed with statistical and graphical analysis software (SAS 9.1).

A program of multiple input and multiple output (MIMO) network was written in MATLAB 7.2 software. The network inputs consisted of air temperature, air velocity and drying time while the moisture content, drying rate, energy efficiency and exergy efficiency were selected as the network outputs or responses. Standard Bayesian regularization back-propagation training algorithm was used for training the network. It is one of the best ways to improve generalization performance of network for function approximation problems (Anderson, 1995).

The network architecture consisted of an input layer with three neurons, an output layer with four neurons, and a hidden layer (Fig. 1).

The desirability method was used as one of the most popular methods of optimization. For each response $y_k$, a desirability function $d_k(y_k)$ assigned numbers between 0 and 1 to the possible values of $y_k$; with $d_k(y_k) = 0$ representing a completely undesirable value of $y_k$ and $d_k(y_k) = 1$ representing a completely desirable or ideal response value. The individual desirabilities were then combined using the geometric mean, which gives the overall desirability ($D$):

$$D = (d_1(y_1)d_2(y_2)\dots d_m(y_m))^{1/m}, \qquad (9)$$

where: $m$ – denotes the number of responses.

## RESULTS AND DISCUSSION

The experimental values as well as the obtained values from fitted models based on response surface methodology in the designed points are shown in Table 2.

The regression models were highly significant, as is evident from the calculated Fisher $F$ values (103.42, 281.63, 98.12 and 142.96 for responses of moisture content, drying rate, energy efficiency and exergy efficiency, respectively) and a probability ($P$) value of 0.000 for all responses. The large value of $F$ means that the most of the variation in the response can be predicted by the regression equation. The $P$ value also estimates whether $F$ is large enough to indicate statistical significance. If $P$ value is lower than 0.05, the model is statistically significant.

The regression results obtained from central composite design models are given in Table 3, where $P$ values are represented along with the coefficients.

The $P$ value is defined as the smallest level of significance leading to rejection of null hypothesis. In general, a smaller value of $P$ indicates more significant for the corresponding coefficient term (Ravikumar *et al.*, 2007).

The values of constants, which are independent of any factor and interaction of the factors, were found to be 0.221, 0.234, 0.598 and 0.835 for coded responses of the moisture content, drying rate, energy and exergy efficiencies, respectively.

The effect of the linear factors the air temperature, air velocity and drying time was found to be highly significant ($P$ = 0.000, 0.003 and 0.001, respectively) on the moisture content of lavender. The square terms of the air temperature and the drying time were also found to be significant ($P$ = 0.001 and 0.025, respectively) which means there was a curved line relationship between the moisture content and this square factors. The interaction term of the air temperature ∗ drying time was significant in the model ($P$ = 0.031). Whereas the interaction terms of the air tempe- rature ∗ air velocity and the air velocity ∗ drying time ($P$ = 0.124 and 0.887, respectively) and the squared term the air velocity ($P$ = 0.745) were not found to be significant.

A positive sign of the coefficient means a synergistic effect, while a negative sign represents an antagonistic effect. All the linear variables had a negative relationship with the moisture content, so that the moisture content of lavender decreased with increasing these factors. Whereas the square and interaction terms significant in the model had a positive effect on the moisture content which indicates that with an increase in these factors, the moisture content increased. Furthermore, the high values of $R^2$ (93.35%) and $R^2$ (adjusted) (92.53%) indicate a high dependence and correlation between the observed and predicted values of moisture content. This also shows that 93.35% of the total moisture content variation can be explained by this model.

The moisture content model as fitted in terms of the experimental factors corresponded to:

$$MC = 5.1952 - 0.1359T - 0.1620V - 0.1518t + 0.0010T^2 + 0.0036t^2 + 0.0013Tt, \qquad (10)$$

where $V$ is an air velocity.

**T a b l e 1.** Independent variables and their levels for central composite design

| Independent variables | Variable levels | | |
|---|---|---|---|
| | -1 | 0 | +1 |
| Air temperature ($T$, °C) | 40 | 50 | 60 |
| Air velocity ($V$, m s$^{-1}$) | 0.60 | 0.90 | 1.20 |
| Drying time ($t$, h) | 6.00 | 9.00 | 12.00 |

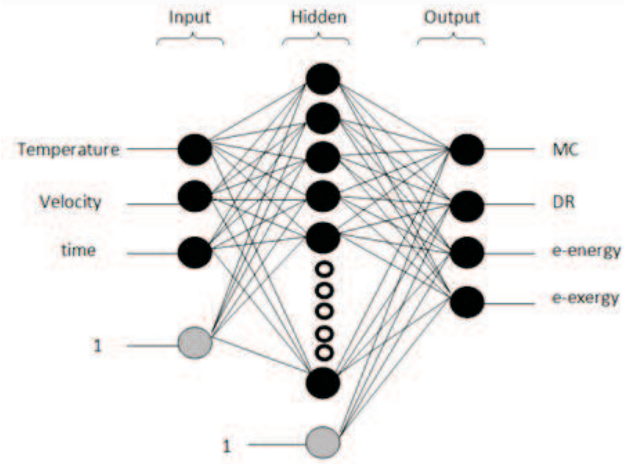


**Fig. 1.** Schematic representation of multilayer artificial neural network used in the present study.

**Table 2.** Observed values of moisture content ($MC$, $g_{water}\ g_{db}^{-1}$), drying rate ($DR$, $g_{water}\ g_{db}^{-1}\ h^{-1}$), energy efficiency ($\eta_{energy}$) and exergy efficiency ($\eta_{exergy}$) for drying lavender based on central rotatable composite design and values of response surface methodology in design points

| Air temperature (°C) | Air velocity (m s$^{-1}$) | Drying time (h) | Experiment data | | | | RS models | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $MC$ | $DR$ | $\eta_{energy}$ | $\eta_{exergy}$ | $MC$ | $DR$ | $\eta_{energy}$ | $\eta_{exergy}$ |
| -1 | -1 | -1 | 0.74 | 0.268 | 0.99 | 0.851 | 0.765 | 0.279 | 0.971 | 0.849 |
| -1 | -1 | 1 | 0.582 | 0.146 | 0.721 | 0.759 | 0.552 | 0.143 | 0.721 | 0.753 |
| -1 | 1 | -1 | 0.616 | 0.288 | 0.716 | 0.927 | 0.668 | 0.290 | 0.708 | 0.917 |
| -1 | 1 | 1 | 0.422 | 0.159 | 0.575 | 0.799 | 0.455 | 0.154 | 0.551 | 0.785 |
| 1 | -1 | -1 | 0.125 | 0.369 | 0.647 | 0.893 | 0.175 | 0.372 | 0.663 | 0.891 |
| 1 | -1 | 1 | 0.092 | 0.187 | 0.525 | 0.797 | 0.113 | 0.176 | 0.525 | 0.795 |
| 1 | 1 | -1 | 0.079 | 0.377 | 0.526 | 0.953 | 0.078 | 0.384 | 0.518 | 0.959 |
| 1 | 1 | 1 | 0.063 | 0.189 | 0.463 | 0.823 | 0.016 | 0.187 | 0.474 | 0.827 |
| -2 | 0 | 0 | 0.968 | 0.15 | 0.749 | 0.749 | 0.933 | 0.181 | 0.760 | 0.765 |
| 2 | 0 | 0 | 0.07 | 0.251 | 0.468 | 0.842 | 0.068 | 0.287 | 0.436 | 0.835 |
| 0 | -1.682 | 0 | 0.338 | 0.22 | 0.804 | 0.797 | 0.303 | 0.224 | 0.802 | 0.793 |
| 0 | 1.682 | 0 | 0.157 | 0.241 | 0.523 | 0.88 | 0.139 | 0.243 | 0.537 | 0.877 |
| 0 | 0 | -1.682 | 0.492 | 0.461 | 0.766 | 0.998 | 0.430 | 0.414 | 0.774 | 1.000 |
| 0 | 0 | 1.682 | 0.172 | 0.154 | 0.523 | 0.801 | 0.198 | 0.134 | 0.526 | 0.808 |
| 0 | 0 | 0 | 0.222 | 0.235 | 0.586 | 0.83 | 0.221 | 0.234 | 0.598 | 0.835 |
| 0 | 0 | 0 | 0.213 | 0.236 | 0.587 | 0.826 | 0.221 | 0.234 | 0.598 | 0.835 |
| 0 | 0 | 0 | 0.206 | 0.237 | 0.588 | 0.827 | 0.221 | 0.234 | 0.598 | 0.835 |

In the drying rate model, the significant effective terms (like the moisture content model) consisted all the linear factors, the square terms of the air temperature and the drying time as well as the interaction term of the air temperature ∗ drying time. Whereas the interaction terms of the air temperature ∗ air velocity and air velocity ∗ drying time ($P$ = 0.407 and 0.672, respectively) as well as the squared term the air velocity ($P$ = 0.581) were not found to be significant.

The linear variable the drying time, the square term the air temperature and the interaction term the air temperature ∗ drying time also had a negative relationship with the drying rate. Whereas the linear terms the air temperature and the velocity as well as the square term the drying time had a positive effect on the drying rate. In other word the drying rate increased with an increase of the positive effective terms and/or with a decrease of the negative effective terms.

Multiregression analysis, also, was performed to obtain a quadratic response surface model for the drying rate:

$$DR = 0.0252 + 0.0193T + 0.0189V - 0.0547t - 0.0001T^2 + 0.0029t^2 - 0.0005Tt\ , \tag{11}$$

A side from the squared term air temperature ($P$ = 0.179) other factors and terms were significantly affected on exergy efficiency.

The factors that had a negative relationship with energy efficiency involved all the linear factors the air temperature, air velocity and drying time. While two the square terms, air velocity and drying time as well as all the interaction terms had a positive effect on energy efficiency.

Quadratic response surface model of energy efficiency which found usingmultiregression analysis is presented as:

$$\eta_{energy} = 3.0070 - 0.0269T - 1.4948V - 0.1319t + 0.2809V^2 + 0.0021t^2 + 0.0098TV + 0.0009Tt + 0.0260Vt\ . \tag{12}$$

For the exergy efficiency model, it was found that the effect of all the linear factors and the square terms the air temperature and the drying time as well as the interaction term the air velocity ∗ drying time were significant on the exergy efficiency. Because $p$-value for the air temperature ∗ air velocity, the air temperature ∗ drying time and the square air velocity was found to be 0.257, 0.831 and 0.166, respectively, these terms had not a significance effect on the exergy efficiency.

The model of exergy efficiency as fitted in terms of the experimental factors corresponded to:

**Table 3.** Estimated regression coefficients for air temperature (°C), air velocity (m $s^{-1}$) and time (h) in coded units based on predictive model

| Term | Moisture content | | | | Drying rate | | | | Energy efficiency | | | | Exergy efficiency | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Estimate | SE | SS | P-value | Estimate | SE | SS | P-value | Estimate | SE | SS | P-value | Estimate | SE | SS | P-value |
| $T$ | -0.257 | 0.0116 | 0.9035 | 0.0001 | 0.0315 | 0.0023 | 0.0135 | 0.0001 | -0.0963 | 0.0054 | 0.1267 | 0.0001 | 0.0209 | 0.0025 | 0.0059 | 0.0001 |
| $V$ | -0.049 | 0.0116 | 0.0323 | 0.0028 | 0.0056 | 0.0023 | 0.0004 | 0.0335 | -0.0786 | 0.0054 | 0.0845 | 0.0001 | 0.0250 | 0.0025 | 0.0085 | 0.0001 |
| $t$ | -0.069 | 0.0116 | 0.0646 | 0.0007 | -0.0833 | 0.0023 | 0.0947 | 0.0001 | -0.0736 | 0.0054 | 0.0740 | 0.0001 | -0.0569 | 0.0025 | 0.0443 | 0.0001 |
| $T^2$ | 0.099 | 0.0122 | 0.1207 | 0.0011 | -0.0117 | 0.0024 | 0.0017 | 0.0007 | | | | | -0.0125 | 0.0026 | 0.0019 | 0.0007 |
| $TV$ | | | | | | | | | 0.0296 | 0.0071 | 0.0069 | 0.0030 | | | | |
| $Tt$ | 0.0379 | 0.0151 | 0.0115 | 0.0310 | -0.0150 | 0.0030 | 0.0018 | 0.0005 | 0.0282 | 0.0071 | 0.0064 | 0.0039 | | | | |
| $V^2$ | | | | | | | | | 0.0253 | 0.0057 | 0.0079 | 0.0021 | | | | |
| $Vt$ | | | | | | | | | 0.0234 | 0.0071 | 0.0045 | 0.0106 | -0.0088 | 0.0032 | 0.0006 | 0.0210 |
| $t^2$ | 0.0328 | 0.0122 | 0.0133 | 0.0254 | 0.0260 | 0.0024 | 0.0084 | 0.0001 | 0.0185 | 0.0057 | 0.0042 | 0.0116 | 0.0244 | 0.0026 | 0.0074 | 0.0001 |
| | | | | | | | | Fit statistic | | | | | | | | |
| Mean | | 0.3268 | | | | 0.2453 | | | | 0.6329 | | | | 0.8447 | | |
| $R^2$ (%) | | 93.35 | | | | 91.41 | | | | 92.99 | | | | 90.85 | | |
| Adj. $R^2$ (%) | | 92.53 | | | | 90.06 | | | | 91.38 | | | | 88.16 | | |
| RMSE | | 0.0427 | | | | 0.0085 | | | | 0.0199 | | | | 0.0091 | | |
| CV | | 13.0809 | | | | 3.4783 | | | | 3.1548 | | | | 1.0778 | | |

$$\eta_{exergy} = 0.6549 + 0.0146\,T + 0.1714\,V - 0.0590\,t - 0.0001\,T^2 + 0.0027\,t^2 - 0.0098\,Vt\,. \quad (13)$$

The results related to the obtained models (the models of the moisture content, drying rate, energy and exergy efficiencies) were consistent with the study of Corzo *et al*. (2008) for coroba slices.

A contour plot is a graphical technique to represent a 3D surface by plotting constant z-slices, called contours, on a 2 dimensional format, which can be employed to determine the individual and cumulative effect of the variable and the mutual interaction between the variable and the dependent variable (Ravikumar *et al*., 2007).

Whereas the air velocity had the least effect on responses in comparison with other factors, therefore, the combined effects of the two factors the air temperature and the drying time on the responses (the air velocity held as a constant) is described in the following then the other contour plots will be intelligible.

Figure 2 shows the isoresponse contour plots, where moisture content of lavender is represented by varying simultaneous two factors from -1.68 to +1.68 in coded units while the third factor is held as a constant at a coded value equal zero. The lines of contour plots in the Fig. 2b reveal the values of the moisture content into the range of the studied temperature and time. These values are more or less the same as the experimental values. From this contour plot it is clear that moisture content decreased with an increase in the temperature and/or the drying time. The least value of the moisture content (0.1 g $g^{-1}$) occurred at maximum values of the temperature and time as well as the highest value of the moisture content (1.1 g $g^{-1}$) was also obtained at a minimum value temperature and time, simultaneously. Similar results were reported by Corzo *et al*. (2008).

The contour plot of drying rate, in velocity held as a constant at a coded value equal zero, is shown in Fig. 3. It is found from the contour that the maximum value of the drying rate occurred at a maximum value for the air temperature and a minimum value forthe drying time, simultaneously, so that the drying rate decreased step by step with increasing time. This decreasing process of drying rate was more severe in the higher temperatures, as reported in earlier research by Corzo *et al*. (2008).

The contour plots of the energy efficiency are shown in Fig. 4. The air temperature and the drying time in Fig. 4b varied from coded values -1.68 to 1.68 and the air velocity was held at the coded value equal zero. As is found in the contour plot the maximum value of the energy efficiency occurred in one area of the least value of temperature and time but the least value of this efficiency occurred at the a maximum value of temperature and time, simultaneously. This result was consistent with the study of Aghbashlo *et al*. (2008). It is found also that the temperature factor had more of an effect on the energy efficiency in comparison with the time factor.

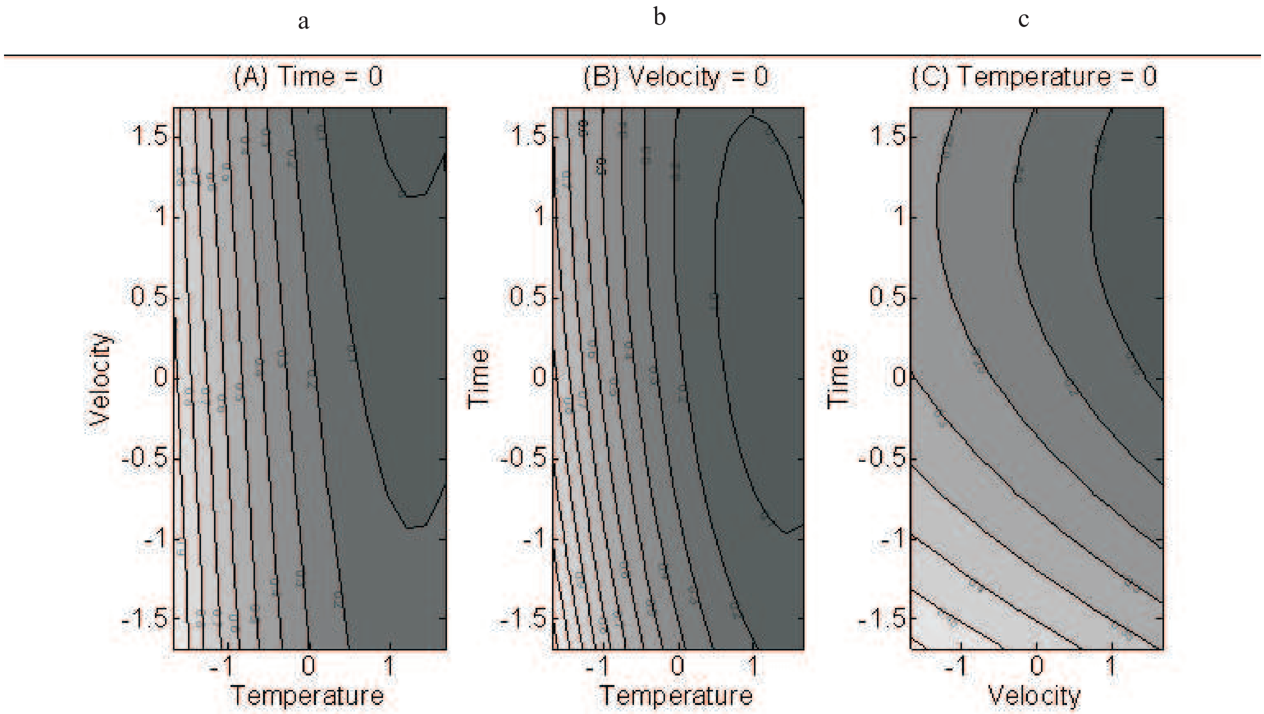


**Fig. 2.** Contour plots for predicted response surface of moisture content (*MC*): a – $t = 0$, b – $V = 0$, c – $T = 0$.

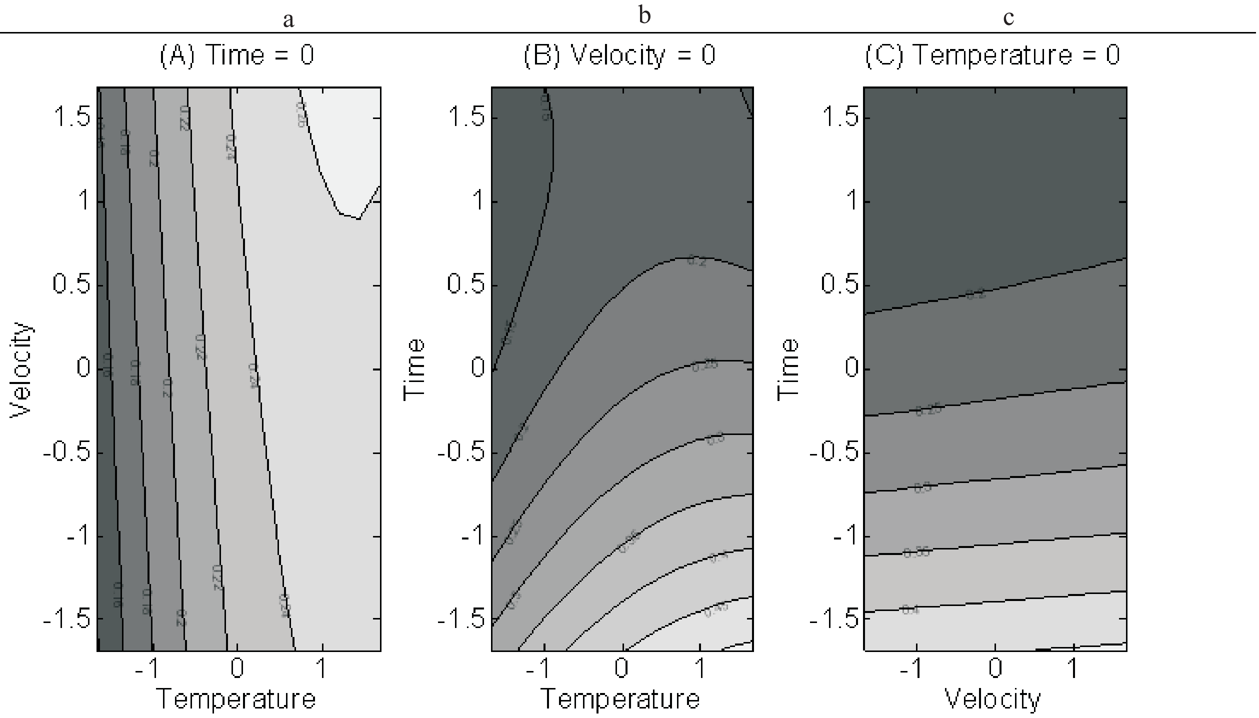


**Fig. 3.** Contour plots for predicted response surface of drying rate (*DR*): a – $t$ = 0, b – $V$ = 0, c – $T$ = 0.

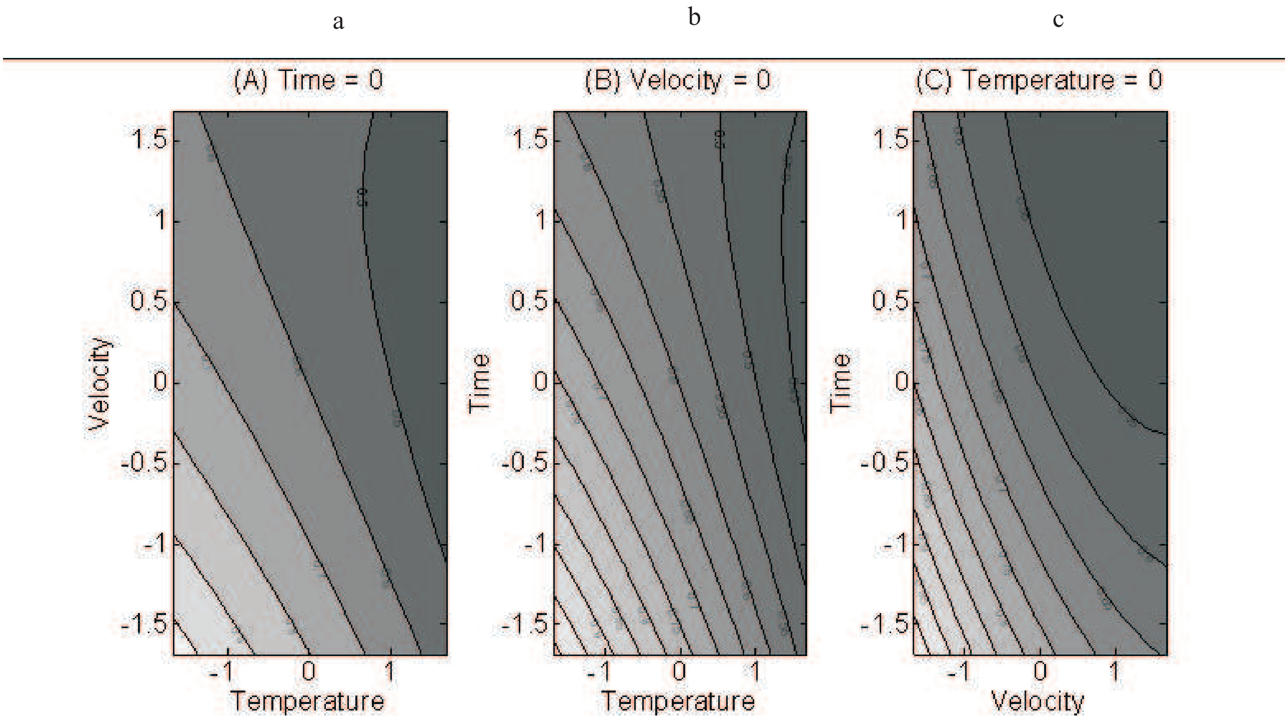


**Fig. 4.** Contour plots for predicted response surface of energy efficiency ($\eta_{energy}$): a – $t$ = 0, b – $V$ = 0, c – $T$ = 0.

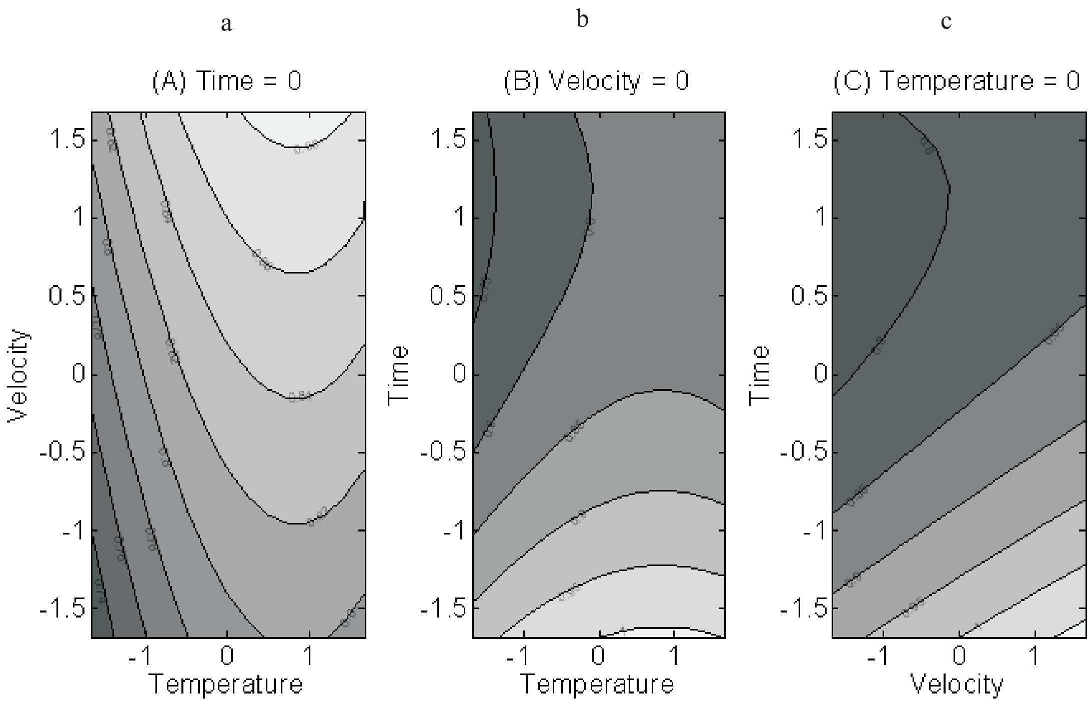


**Fig. 5.** Contour plots for predicted response surface ofexergy efficiency ($\eta_{exergy}$): a – $t$ = 0, b – $V$ = 0, c – $T$ = 0.

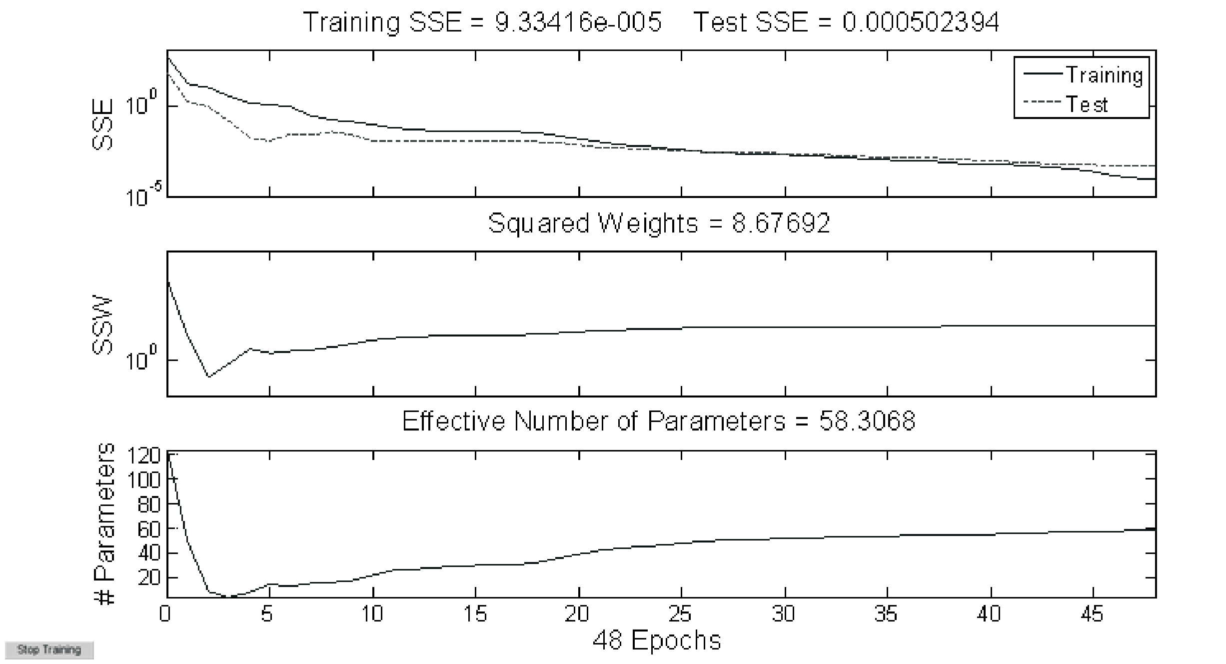


**Fig. 6.** Curve of SSE to training subset and test subset.

**T a b l e 4.** Obtained values of moisture content (*MC*, $g_{water}\ g_{db}^{-1}$), drying rate (*DR,* $g_{water}\ g_{db}^{-1}h^{-1}$), energy efficiency ($\eta_{energy}$) and exergy efficiency ($\eta_{exergy}$) for drying lavender using artificial neural networks in design points

| Air temperature (°C) | Air velocity (m s$^{-1}$) | Drying time (h) | ANN model | | | | ANN error (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | *MC* | *DR* | $\eta_{energy}$ | $\eta_{exergy}$ | *MC* | *DR* | $\eta_{energy}$ | $\eta_{exergy}$ |
| -1 | -1 | -1 | 0.741 | 0.268 | 0.987 | 0.852 | 0.134 | 0.027 | 0.268 | 0.132 |
| -1 | -1 | 1 | 0.582 | 0.147 | 0.720 | 0.759 | 0.063 | 0.505 | 0.098 | 0.033 |
| -1 | 1 | -1 | 0.617 | 0.289 | 0.716 | 0.925 | 0.152 | 0.238 | 0.014 | 0.208 |
| -1 | 1 | 1 | 0.423 | 0.159 | 0.574 | 0.799 | 0.252 | 0.271 | 0.165 | 0.053 |
| 1 | -1 | -1 | 0.126 | 0.369 | 0.647 | 0.894 | 0.773 | 0.024 | 0.038 | 0.108 |
| 1 | -1 | 1 | 0.092 | 0.187 | 0.524 | 0.799 | 0.063 | 0.151 | 0.160 | 0.270 |
| 1 | 1 | -1 | 0.079 | 0.377 | 0.527 | 0.955 | 0.531 | 0.008 | 0.100 | 0.175 |
| 1 | 1 | 1 | 0.064 | 0.189 | 0.463 | 0.825 | 1.957 | 0.112 | 0.002 | 0.195 |
| -2 | 0 | 0 | 0.966 | 0.150 | 0.751 | 0.750 | 0.162 | 0.188 | 0.228 | 0.103 |
| 2 | 0 | 0 | 0.069 | 0.253 | 0.469 | 0.840 | 1.518 | 0.637 | 0.306 | 0.206 |
| 0 | -1.682 | 0 | 0.337 | 0.220 | 0.806 | 0.795 | 0.236 | 0.114 | 0.301 | 0.291 |
| 0 | 1.682 | 0 | 0.155 | 0.241 | 0.524 | 0.880 | 1.141 | 0.175 | 0.176 | 0.000 |
| 0 | 0 | -1.682 | 0.491 | 0.459 | 0.766 | 0.996 | 0.304 | 0.419 | 0.014 | 0.155 |
| 0 | 0 | 1.682 | 0.171 | 0.155 | 0.526 | 0.799 | 0.519 | 0.824 | 0.506 | 0.201 |
| 0 | 0 | 0 | 0.224 | 0.235 | 0.587 | 0.832 | 0.787 | 0.038 | 0.181 | 0.271 |
| 0 | 0 | 0 | 0.224 | 0.235 | 0.587 | 0.832 | 5.045 | 0.386 | 0.011 | 0.757 |
| 0 | 0 | 0 | 0.224 | 0.235 | 0.587 | 0.832 | 8.615 | 0.807 | 0.159 | 0.635 |

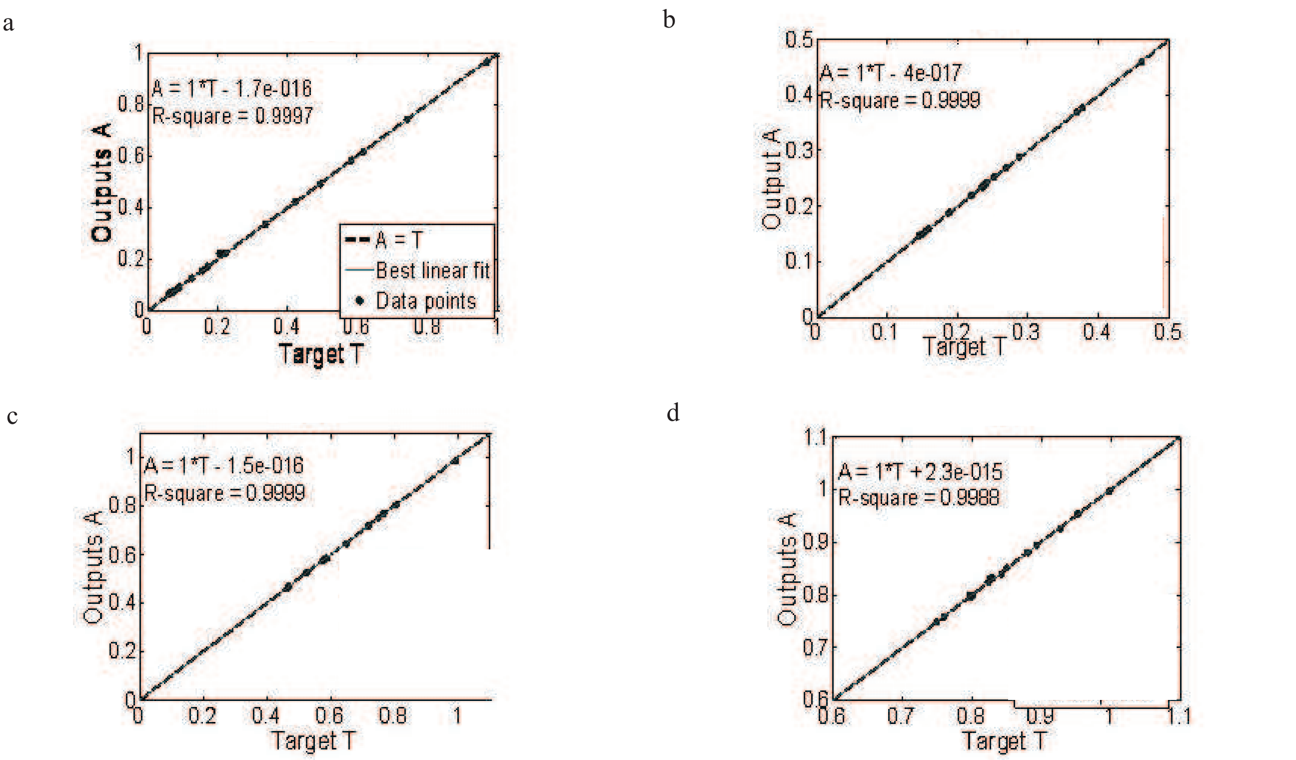


**Fig. 7.** Linear regression between the network outputs and the corresponding targets: a – the data is related to moisture content, b – the data is related to drying rate, c – the data is related to energy efficiency and d – the data is related to exergy efficiency.

In contour plot (b) presented in Fig. 5, it is found that by increasing the time, the exergy efficiency was faced with a decreasing trend. However the exergy efficiency had an increasing trend when the temperature increased. It also is observed in the contour that the highest value for this efficiency occurred when the temperature changed into a range of -1.3 to 1.6 at the least value of the time.

A self-organizing feature map network based on back-propagation training algorithm was used to predict the processes of the air drying for lavender. Three factors, the air temperature, air velocity and drying time, were used as each unit of input layer. The output layer was composed of four response variables, the moisture content, drying rate, energy and exergy efficiencies. A set of factors was used for training the network into the computer. Several iterations were conducted with different numbers of neurons of hidden layer in order to determine the optimal artificial neural network structure. It was started with two neurons and increased the number of neurons up to twelve. The least MSE value and a good prediction of the outputs of both training and test sets were obtained with twelve neurons in the hidden layer (Fig. 6). Obtained values for the moisture content, drying rate, energy and exergy efficiencies using trained artificial neural networks in design points are presented in Table 4. The low values of error (%) for the network outputs corresponding design points indicated that there was a good agreement between the network outputs and corresponding data related to the experimental samples. It was also found that high values for $R^2$ as well as an adequate accordance between the linear regressions which were related to the network outputs in the design points, and the lines $T$=$A$ revealed other reasons for nicety of this artificial neural network (Fig. 7).

Optimization is one of the most important steps in the design and analysis of experiment. Often the object of experimentation is to find the levels of factors which optimize the response. Because of working with more than one response in the present work such as the moisture content, drying rate, energy efficiency and exergy efficiency, a simultaneous multiple response optimization was performed.

In the present experiment which involved multiple responses, the acceptability of the process depended on more than one response. In order to optimize the process, it was taken as a constraint that moisture content must be as low as possible and drying rate, energy and exergy efficiencies must be as high as possible. In such situations the desirability of the process depends on the simultaneous optimization of all responses. Optimization was implemented by using the desirability profile and its function. In the application, all the parameters (the air temperature, air velocity and drying time) were put into the network input layer, but two parameters were fixed and only the other parameter was adaptable. Before optimization, an experiment data as initial data (0, 0, and 0 in coded units for the air temperature, air velocity and drying time, respectively) was

**T a b l e 5.** Optimum process of parameters

| Run | $T$ | $V$ | $t$ | Desirability |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0.450 |
| 1 | -0.32 | 0 | 0 | 0.490 |
| 2 | -0.32 | -0.58 | 0 | 0.499 |
| 3 | -0.32 | -0.58 | 0.24 | 0.515 |

a

b

c

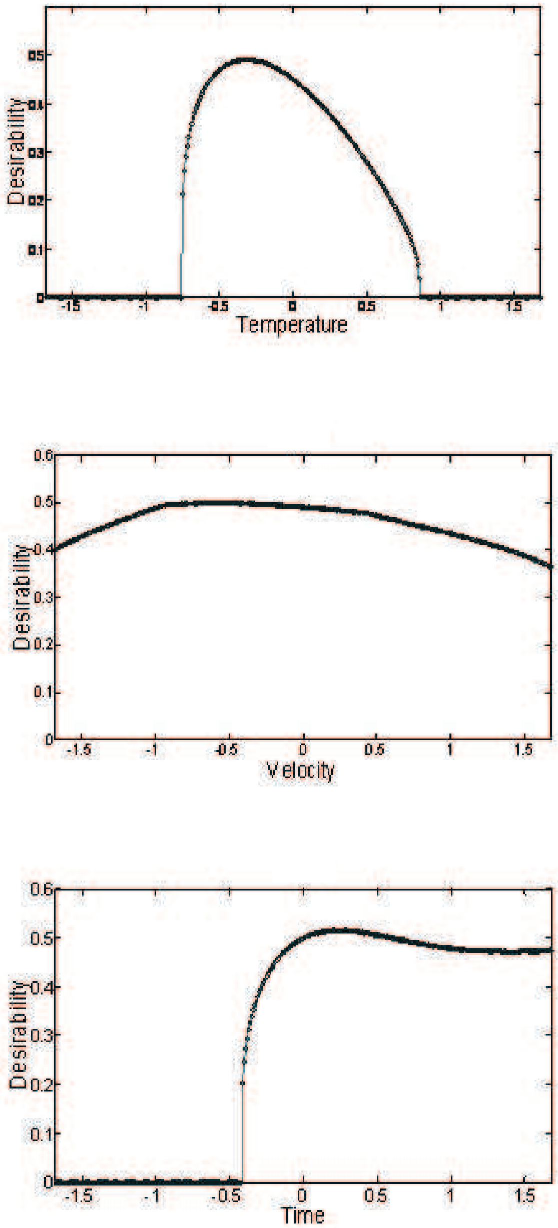


**Fig. 8.** Prediction profile of trend of desirability in conditions: a – fix $V$ = 0, $t$ = 0 and adapt $T$; b – fix $T$ = -0.32, $t$ = 0 and adapt $V$; c – fix $T$ = -0.32, $V$ = -0.58 and adapt $t$.

chosen. The simulation showed when the air temperature, air velocity and drying time values were equal to -0.32 (46.8°C), -0.58 (0.726 m $s^{-1}$) and 0.24 (9.72 h) in the coded units, respectively, the desirability had a maximum value equal to 0.52, which obtained the moisture content equal to 0.32 g $g^{-1}$, drying rate equal to 0.29 g $g^{-1}$ $h^{-1}$, energy efficiency equal to 0.67 and exergy efficiency equal to 0.80. The optimization process is shown in Table 5 and Fig. 8.

## CONCLUSIONS

1. Moisture content obtained a minimum value in high temperature and time; maximum value of drying rate was occurred in maximum air temperature; minimum drying time and maximum value of the energy efficiency was occurred in one area of the minimum temperature and time and maximum value for the exergy efficiency was obtained in minimum and maximum of the time and temperature.

2. The trained artificial neural network found the maximum desirability point as -0.32 (46.8°C), -0.58 (0.726 m $s^{-1}$) and 0.24 (9.72 h) for the air temperature, air velocity and drying rate, respectively, to obtain moisture content – 0.32 g $g^{-1}$, drying rate – 0.29 g water $g^{-1}$ $h^{-1}$, energy efficiency – 0.67 and exergy efficiency – 0.80.

## REFERENCES

**Aghbashlo M., Kianmehr M.H., and Arabhosseini A., 2009a.** Energy and exergy analyses of thin-layer drying of potato slices in a semi-industrial continuous band dryer. Drying Technol., 26(12), 1501-1508.

**Aghbashlo M., Kianmehr M.H., Khani S., and Ghasemi M., 2009b.** Mathematical modelling of thin-layer drying of carrot. Int. Agrophysics, 23, 313-317.

**Akpinar E.K., Midilli A., and Bicer Y., 2006.** The first and second law analyses of thermodynamic of pumpkin drying process. J. Food Eng., 72(4), 320-331.

**Amer B.M.A., Morcos M.A., and Sabbah M.A., 2003.** New method for the determination of drying rates of fig fruits depending on empirical data under conditions suiting solar drying. Proc. Conf. New Methods Means and Technologies for Applications of Agricultural Products, September 18-19, Raudondvaris, Lithuania.

**Anderson J.A., 1995.** An Introduction to Neural Networks. Prentice-Hall Press, New Delhi, India.

**Bayrak M., Midilli A., and Nurveren K., 2003.** Energy and exergy analyses of sugar production stages. Int. J. Energy Res., 27(11), 989-1001.

**Castillo E.D., 2007.** Process Optimization: A Statistical Approach. Springer Press, New York, USA.

**Chakraborty S.K., Kumbhar B.K., and Sarkar B.C., 2007.** Process parameter optimization for instant pigeon pea dhal using response surface methodology. J. Food Eng., 81(1), 171-178.

**Corzo O., Bracho N., Vasquez A., and Pereira A., 2008**. Optimization of a thin layer drying process for coroba slices. J. Food Eng., 85, 372-380.

**Ganjyal G.M. and Hanna M.A., 2002.** Review on residence time distribution (RTD) in food extrudates and study on the potential of neural networks. J. Food Sci., 68(4), 1996-2002.

**Hassan-Beygi S.R., Aghbashlo M., Kianmehr M.H., and Massah J., 2009.** Drying characteristics of walnut (*Juglans regia* L.) during convection drying. Int. Agrophysics, 23, 129-135.

**Karimi F., 2010.** Applications of superheated steam for the drying of food products. Int. Agrophys., 24, 195-204.

**Mason R.I., Funst R.F., and Hess J.L., 1989.** Statistical Design and Analysis of Experiments. Wiley Press, New York, USA.

**Midilli A. and Kucuk H., 2003.** Energy and exergy analyses of solar drying process of pistachio. Energy, 28, 539-556.

**Ravikumar K., Krishnan S., Ramalingam S., and Balu K., 2007**. Optimization of process variables by the application of response surface methodology for dye removal using a novel adsorbent. Dyes Pigments, 72, 66-74.

**Rodrigues S. and Fernandez F.A.N., 2007.** Dehydration of melons in a ternary system followed by air-drying. J. Food Eng., 80(2), 678-687.

**Sharma G.P. and Prasad S., 2006.** Optimization of process parameters for microwave drying of garlic. J. Food Eng., 441-446.

**Yadollahinia A., 2006.** A thin tayer drying model for paddy dryer. MSc. Thesis, Faculty of Biosys. Eng., Univ. Tehran, Iran.

**Yao N., Floros J.D., and Seetharamant K., 2007.** Optimisation of hard pretzel production. Int. J. Food Sci. Technol., 42(3), 269-280.