

Thin-layer drying of tea leaves: Mass transfer modeling using semi-empirical and intelligent models

^{1*}Fathi, M., ¹Roshanak, S., ²Rahimmalek, M. and ¹Goli, S. A. H

¹Department of Food Science and Technology, College of Agriculture, Isfahan University of Technology, Isfahan 84156 83111, Iran ²Department of Plant Breeding, College of Agriculture, Isfahan University of Technology, Isfahan 84156 83111, Iran

<u>Article history</u>

<u>Abstract</u>

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Introduction

Due to its sensory properties, stimulating effects and potential health benefits, tea (*Camellia sinensis* L.) is considered as the most popular beverages after water all over the world (Weisburger, 1997; Yang and Landau 2000). The annual global production of tea was reported to be about 4.51 million tons in 2010 (FAOSTAT, 2010). Tea is used in different types, e.g. green, black, and oolong tea. However, the most significant positive effects on human health have been observed by consumption of green tea (Jain *et al.*, 2013).

Possessing critical effects on physical, structural, chemical and nutritional features of the product, makes drying as one of the main operations in tea processing. Different drying methods have been applied for tea; traditionally it is dried using sun or air drying approaches. In spite of widespread usage and low initial operation cost, the quality of tea undergoes significant deterioration (Chan *et al.*, 2009). Oven and microwave were also used for drying of tea (Dong *et al.*, 2011a; Hatibaruah *et al.*, 2012). Oven drying has some disadvantages such as low energy efficiency and long drying time. Compared to oven drying, microwave can significantly reduce drying time of biological materials with minimum quality

Moisture content is a critical factor in quality and shelf-life of foods and agricultural products. This research dealt with prediction of moisture ratio of tea leaves using intelligent genetic algorithm-artificial neural networks (multilayer perceptron, MLP; and radial basis function, RBF) and semi-empirical models during different thin-layer drying processes (i.e. sun, air, hot air, and microwave drying). Effective diffusivities were found in the range of 7.5×10^{-7} to $9457.2 \times 10^{-7} m^2/h$, which the highest D_{eff} value was achieved for microwave drying. Moisture ratio data were modeled using fourteen semi-empirical equations among which Henderson and Pabis, Henderson and Pabis- modified, two-term-modified and Wang and Singh models received highest correlation coefficients. However, the prediction efficiencies of MLP (MSE, NMSE and MAE of 0.0084, 0.0597 and 0.0722, respectively) and RBF (MSE, NMSE and MAE of 0.0043, 0.0973 and 0.0564, respectively) networks were found to be more competent than semi-empirical models and therefore could be applied successfully for predicting moisture ratio of tea leaves during different drying processes.

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degradation. Therefore, microwave drying has now gained popularity as an alternative drying method for a variety of food products (Sellami *et al.*, 2011; Zielinska *et al.*, 2013; Rahimmalek and Goli 2013).

Moisture content significantly influences the quality and shelf life of dried tea. During drying moisture ratio can be estimated applying semiempirical models (Costa and Pereira, 2013). Although these models give a reasonable fitting of the experimental data, their application is limited due to their semi-empirical nature and therefore, they are only capable of estimating data within the processing conditions in which they were developed or they depend on a large number of physical properties of product (Fathi *et al.*, 2011a).

Artificial neural networks (ANN) are intelligent modeling systems based on relationship between dependent and independent variables. This methodology could be used for modeling linear and nonlinear phenomena and does not need the explicit knowledge of the physical meaning of the system or process under investigation (Fathi *et al.*, 2011b). ANN have been recently used for prediction of green tea polyphenols content (Xi *et al.*, 2013), kiwifruit shrinkage (Fathi *et al.*, 2011c) and extraction efficiency of manganese (Khajeh and Barkhordar, 2013). The main drawback of ANN is that their parameters such as number of hidden neurons, learning rate and momentum are chosen by trial and error. Genetic algorithm (GA) as an optimization technique can be used for overcoming this limitation of neural network. GA is inspired by the natural selection principles and Darwin's species evolution theory. GA offers several advantages over the conventional optimization method such as less susceptibility to be stuck at local minima, requiring little knowledge of the process being optimized and capability to find the optimum conditions when the search space is very large (Fathi *et al.*, 2011b).

Dong et al. (2011b) compared chemical features of Eucommia ulmoides flower tea during microwave and hot air drying and reported that microwave drying method could maximally maintain the functional constituents. Effects of different drying methods (i.e. microwave, oven, sun, air, and freeze-drying) on antioxidant properties of tea were investigated. All three thermal drying methods led to decline in total phenolic content, ascorbic acid equivalent antioxidant capacity, and ferric-reducing power with minimal effects on ferrous ion-chelating ability and lipid peroxidation inhibition activity. High amount of losses were observed for air dried leaves. While, freeze-drying did not resulted in significant decrease in total phenolic content, ascorbic acid equivalent antioxidant capacity, and ferric-reducing power. Panchariya et al. (2002) applied different semiempirical models to predict moisture content during drying of black tea at 80-120°C and concluded that Lewis model gave better predictions. Effective diffusivity varied from 1.14×10^{-11} to 2.98×10^{-11} m²/s over the temperature range.

In spite of numerous works conducted on the effect of drying methods on chemical compositions of tea leaves, there was not much attention on modeling of mass transfer during drying. Therefore the objective of this research was to model moisture ratio by semi-empirical and intelligent models during different drying processes (i.e. sun, air, hot air, and microwave drying) of tea leaves.

Materials and Methods

Sample collection and thin-layer drying

Whole tea leaves (Chinese hybrid variety) obtained from a tea farm in Lahijan city in the Northern regions of Iran in the fall growing season. In order to inhibit enzymatic browning, the leaves were immediately blanched using steam at 90°C for one minute. The leaves were then thin-layer dried using following methods: (i) sun drying at about 35°C; (ii) air drying in shade at about 25°C; (iii) hot air drying

at 60°C; (iv) hot air drying at 80°C; (v) hot air drying at 100°C; and (vi) microwave drying at 800 W.

For sun drying leaves were exposed to direct sunlight in trays at about 35°C for 7.5 h in November in Isfahan, Iran. Air drying was carried out under natural air flow in shade for 36 h. Oven drying was conducted in a ventilated oven (Osk, Japan) for 7.5, 5.25 and 4.5 h at 60°C, 80°C and 100°C, respectively. Microwave drying was performed in a domestic digital microwave oven (Nikai, NMO-518N, Japan) with technical features of 230 V, 800 W. The samples were dried for 240 seconds. The thickness of samples for all thin-layer drying methods was kept constant in 5 mm. Moisture contents of samples were determined using moisture meter (Ohaus MB45; Massachusetts, USA) during drying at appropriate time intervals.

Semi-empirical models

The drying curves were represented in moisture ratio (MR) (Eq. 1) versus time (t, in h).

$$MR = \frac{MC_t - MC_e}{MC_0 - MC_e} \tag{1}$$

 MC_0 , MC_t and MC_e are initial moisture content, moisture content at time t and equivalent moisture content.

Moisture ratio values were then fitted using fourteen semi-empirical models listed in Table 1 applying SlideWrite plus software. In these equations a, b, c, k, k_1 , k_2 , k_3 and n model constants.

Artificial neural network

In current research, feedforward network was used for modeling of moisture ratio of tea leaves. Two commonly applied feedforward ANN architectures are multilayer perceptron (MPL) and radial basis function (RBF) networks. MLP consists of (i) an input layer with neurons representing independent variables, (ii) an output layer with neuron(s) representing the dependent variable(s), and (iii) one or more hidden layers containing neuron(s) help to capture the nonlinearity of the system. The processing in hidden layers consists of collecting the data from previous layer, multiplying them by their corresponding weights, summing the values, putting the results in a nonlinear or linear activation function (f) and finally adding a constant value called bias, mathematically:

$$y_j = \sum_{i=1}^{n} f(w_{ij}x_i) + bias_j$$
 (16)

where w, x and y are weight, input and output of i (sending) and j (receiving) neurons. RBF network, which consists single radial hidden layer, uses

Table 1. Semi-empirical mathematical models

Model nam e	Mathematical model	Equation No.
Diffusion approach	$MR = a \exp(-kt) + (1-a) \exp(-kt)$	(2
Henderson and Pabis	$MR = a \exp(-kt)$	(3
Henderson and Pabis-modified	$MR = a \exp(-k_1 t) + b \exp(-k_2 t) + c \exp(-k_3 t)$	(4
Logarithmic	$MR = a \exp(-kt) + c$	(5
Midilli	$MR = a \exp\left(-ka^n\right) + bt$	(6
Newton	$MR = \exp(-kt)$	(7
Page	$M\!R = \exp\left(-k\!a^n\right)$	(8
Page-modified	$MR = \exp\left[-\left(kt\right)^n\right]$	(9
Two-term	$MR = a \exp(-k_1 t) + b \exp(-k_2 t)$	(10
Two-term-exponential	$MR = a \exp(-kt) + (1-a) \exp(-kat)$	(11
Two-term-modified	$MR = a \exp(-k_{1}t) + b \exp(-k_{2}t) + c$	(12
Verma	$MR = a \exp(-k_1 t) + (1-a) \exp(-k_2 t)$	(13
Wang and Singh	$MR = 1 + at + bt^2$	(14
Weibull	$MR = \exp\left[-\left(\frac{t}{b}\right)^{\alpha}\right]$	(15

Gaussian transfer function. The radial basis neurons are special neurons which have a centroid (u) and a spreading vector (σ). The output of the RBF layer is determined based on distance between the input vector and its centroid vector (Eq. 17). Training algorithm for hidden neurons is generally accomplished by an unsupervised fashion. While supervised algorithm is used for output layer. This configuration tends to learn much faster than MLP.

$$y_j = \sum_{i=1}^{n} \left[w_{ij} \exp\left(\frac{-|x_i - u_i|}{2\sigma^2}\right) + bias_j \right]$$
(17)

In this study, drying method and drying time were used as input neurons to predict moisture content of tea leaves as the output of network. A hyperbolic tangent activation function was used in hidden layer, while a linear function was applied for the output layer. The number of hidden neurons varied from 1 to 10. For modeling data were first randomized and then divided into three partitions of training (40%), validation (30%) and testing (30%). To avoid overfitting of the network the training process was carried on for 1000 epochs or until the cross-validation data's mean-squared error (MSE) did not improve for 100 epochs. Testing was carried out with the best weights stored during the training step. Calculation of the performance of the trained network was based on the accuracy of the network in the test partition. Therefore mean-squared error (MSE), normalized mean-squared error (NMSE), mean absolute error (MAE) and correlation coefficient (R) for each

output were calculated based on testing data (Fathi *et al.*, 2011a).

Genetic algorithm

Genetic algorithm, which inspires the principle of a Darwinian-type survival of the fittest in natural evolution, is essentially an iterative, population based, parallel global search algorithm that has a high ability to find optimal value of a complex objective function, without falling into local optima. The best chromosomes mate with other chromosomes of population and survive for the next generation and the most excellent chromosome, which is the most evolved one, is the optimal value. GA optimization technique consists of three principle processes (i.e. selection, crossover and mutation). The initial population of chromosomes is randomly generated. Selection of individuals to produce successive generations plays an important role in a GA. In this step, each chromosome is evaluated by the fitness function. According to the value of the fitness function, the chromosomes associated with the fittest individuals will be selected more often than those associated with unfit ones. In crossover step, two individuals reproduced into a new individual. The mutation operation randomly alters the value of each element of the chromosome according to the mutation probability. It provides the means for introducing new information into the population and therefore avoids sticking in local minima. This cycle is repeated until desired convergence on optimal or near-optimal of

Table 2. Semi-empirical model parameters and their corresponding performance efficiencies

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Dirat Surgeries 11.2296 0.2000 <	Air drying	1.0	0218	1.00023	0.081795	0.988	0.0	025	0.021	12	0.0433	1.02	0.090223	0.991	1 0.0	020	0.0161		0.0410
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Hotair drying (80 °C) 0.9992.1 41.37699 0.1647 0.8580 0.2766 0.321442 2.39034 0.997 0.2329 1.4105 0.3023 Botair drying (100 °C) 0.893327 41.862887 0.814 0.1257 0.6396 0.2359 0.386271 2.25149 0.999 0.000 0.0203 0.0407 Microwave drying 0.01037 1.582-6 0.652 0.7468 3.3227 0.8011 10.345485 1.2614 0.999 0.600 0.0020 0.0107 Are drying 0.538 0.82 0.3852 0.3805 1.1201 0.208 2.511662 0.07663 0.999 0.0000 0.018 Are drying 0.51 0.538 0.3812 0.991 0.0010 0.1017 0.3958 0.5116 0.0319 0.0017 0.393 0.1184 2.3188 0.519171 0.598 0.0016 0.0118 2.525242 0.50171 0.598 0.014 0.5172 0.50277 0.5124 0.5137 0.5141 0.5337 0.5141	Hot air drying (60 °C)	1.91	5299	16.0528	15	0.726	0.280	5	1.5558		0.4086	0.2047	24 2	.62258	0.989	0.3124	1.972	,	0.4686
Indicinity 0.993527 41.802887 0.814 0.1257 0.6396 0.2359 0.386271 2.25149 0.989 0.0030 0.0205 0.0127 Macrowave drying 0.01377 1.582-06 0.682 0.7468 3.3227 0.8011 10.345485 1.2674 0.999 0.6900 3.2458 0.7125 Macrowave drying 0.538 0.382 0.3820 0.929 0.3802 0.816 0.416 0.401 0.999 0.999 0.999 0.999 0.999 0.999 0.999 0.999 0.999 0.999 0.999 0.991 0.9917 Air drying 0.51 0.933 0.3180 0.117 0.1305 0.1184 2.3188 0.59171 0.998 0.0001 0.011 0.9917 0.9983 0.8320 0.9918 0.9918 0.9918 0.9918 0.9918 0.9918 0.9918 0.9918 0.9918 0.9918 0.9918 0.9918 0.9918 0.9918 0.9918 0.9918 0.9918 0.9918 0.991	Hot air drying (80 °C)	0.39	9231	41.3769	99	0.780	0.164	7	0.8580		0.2766	0.3214	42 2	.39034	0.997	0.2329	1.410	i	0.3625
c) Microwave drying 0.010373 1.582-06 0.687 0.697 0.687 0.699 0.690 0.016 0.015 0.018 MAE Sun drying 0.53 0.332 0.3322 0.0389 0.991 0.0020 0.0161 0.9957.28 0.6877.28 0.9999 0.0020 0.0151 Aris drying 0.517 0.437 0.574 0.4378 0.927 0.0177 0.1305 0.1148 2.21582 0.02717 0.972 0.007 0.050 0.0515 0.0535 0.0536 Aris drying 0.541 0.99 0.0105 0.097 0.017 0.1305 0.1148 2.21582 0.01071 0.989 0.0107 0.0149 0.9999	Hot air drying (100	0.89	3527	41.8628	87	0.814	0.125	7	0.6396		0.2359	0.3862	.71 2	25149	0.989	0.0030	0.020		0.0457
	°C)							_											
Note::::::::::::::::::::::::::::::::::::	Microwave drying	0.01	0373	1.58E-0	16	0.682	0.746	8	3.3227		0.8051	103.454	485 1	.26 /94	0.999	0.6900	3.245		0.7752
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		2	ħ	t-s	to.	P R	N	ISE.	NM	ISE	MAE			ĸ	rwo-term-exp	MSF	NMS		MAE
Air dying (b) C 0.51 0.99 0.5116 0.0899 0.991 0.0020 0.0161 0.0410 0.985728 0.08728 0.990 0.0200 0.0171 0.0394 Hot in dying (60 °C) 0.557 0.437 0.5714 0.4379 0.997 0.0167 0.1305 0.1933 0.159833 0.15993 0.8222 0.0200 0.0010 0.0200 0.0010 0.0200 0.0010 0.0000	Sun drving	0.538	0.382	0.53882	0.38026	0.959	0.3	803	1.12	201	0.2068	2.5410	062 0	677693	0.998	0.0006	0.003	i	0.0198
Hotair drying (60 °C) 0.557 0.437 0.974 0.943 0.023 0.1375 0.9833 0.189893 0.832 0.0280 0.0285 0.0350 0.0370 0.0350 0.0370 0.0350 0.0370 0.0350 0.0370 0	Air drying	0.51	0.09	0.51016	0.08999	0.991	0.0	020	0.01	161	0.0410	0.9857	28 0	088728	0.990	0.0020	0.017		0.0394
Hot air dying (80 °C) 0.571 0.363 0.571 0.933 0.927 0.0167 0.1305 0.1148 2.31888 0.591571 0.980 0.0049 0.0355 0.0300 Macrowave drying 0.504 0.993 0.997 0.997 0.917 0.1296 0.1148 2.31888 0.591571 0.900 0.0049 0.0355 0.0300 Macrowave drying 0.504 0.993 0.593 0.993 0.993 0.993 0.993 0.993 0.993 0.9070 0.973 0.973 0.973 0.973 0.973 0.973 0.973 0.973 0.933 0.114 0.1226 0.102 0.303027 0.33017 0.933 0.1147 0.108 0.1042 Air drying (60 °C) 3.759 0.073 0.4490 0.0312 0.2385 0.1310 0.222 0.1 0.10 0.986 0.3948 2.6310 0.5530 Hot air drying (60 °C) 3.18 0.035 3.18011 0.3797 5.272352 8 0.0036 0.	Hot air drying (60 °C)	0.557	0.437	0.5574	0.43789	0.904	0.0	223	0.19	933	0.1375	0.9983	33 0	189893	0.832	0.0280	0.286	i	0.1515
Hot air dying (100 0.557 0.437 0.4378 0.927 0.017 0.1296 0.1184 2.255242 0.702977 0.972 0.070 0.0504 0.0700 Microware drying 0.504 0.993 0.9978 0.9978 0.0042 0.0132 0.999036 0.806906 0.682 0.712 0.070 0.0574 0.0709 Microware drying 0.504 0.993 0.219 0.9930 0.998 0.0012 0.012 0.30607 0.972 0.972 0.070 0.054 0.0709 Microware drying 0.504 0.99 0.0998 0.0017 0.042 0.012 0.30307 0.973 0.0147 0.080 0.0142 Air drying (60 °C) 3.759 0.021 3.7597 0.0259 -6.40024 0.97 0.032 0.0218 0.0458 0.010 0.664 0.0723 0.8169 0.1936 Hot air drying (60 °C) 3.18 0.337 0.4398 -5.196719 0.98 0.0024 0.0519 0.10 0.664	Hot air drying (80 °C)	0.571	0.363	0.57181	0.36337	0.927	0.0	167	0.13	305	0.1148	2.318	88 0	591571	0.980	0.0049	0.035	i	0.0580
Microwave drying 0.504 109.9 0.50405 109.937 0.998 0.004 0.0042 0.0132 0.999036 0.806906 0.682 0.71134 3.2777 0.7879 Two-term-modifiet Verma- Sun drying 0.693 0.219 0.69308 0.21948 -0.333215 0.99 0.0057 0.0346 0.0661 -0.012 0.303027 0.33017 0.9333 0.0147 0.1080 0.1042 Air drying 0.545 0.73 0.54541 0.73637 -0.085068 0.99 0.0057 0.0346 0.0661 -0.012 0.303027 0.3017 0.933 0.0147 0.1080 0.1042 Air drying (60 °C) 3.759 0.025 -6.40024 0.97 0.0060 0.0456 0.6633 5 0.1 0.10 0.664 0.723 0.8169 0.1936 0.2720 0.8169 0.1936 0.211 0.10 0.664 0.723 0.8169 0.1936 0.2720 0.211 0.10 0.639	Hot air drying (100	0.557	0.437	0.5574	0.43789	0.927	0.0	170	0.11	296	0.1184	2.2552	.42 0	702977	0.972	0.0070	0.0504	Ļ	0.0700
Vertex - invariant Vertex - invariant a b c ki kg R MSE NMSE MAE a ki kg R MSE NMSE MAE a ki kg R MSE NMSE MAE Air drying 0.693 0.219 0.6930 0.2196 0.033017 0.0346 0.0061 -0.012 0.30027 0.33017 0.933 0.0147 0.1080 0.1042 Air drying 0.545 0.073 0.54541 0.73657 -0.085068 $\frac{0.97}{8}$ 0.0060 0.0456 0.0693 $\frac{0.222}{5}$ 0.1 0.10 0.664 0.0723 0.8169 0.1936 Hot air drying (80 °C) 3.759 0.025 -6.400024 $\frac{0.97}{8}$ 0.0032 0.0218 0.0458 0.160 0.10 0.664 0.0723 0.8169 0.1720 Hot air drying (80 °C) 3.18 0.0379 -5.272352 $\frac{9}{8}$ 0.0032 0.0218 0.055 0.1	Microwave drying	0.504	109.9	0.50405	109.937	0.998	0.0	004	0.00	042	0.0132	0.9990)36 0	806906	0.682	0.7134	3.277	7	0.7879
Sun drying 0.693 0.219 0.69308 0.21948 -0.333215 0.98 1 0.0057 0.0346 0.0661 -0.012 0.303027 0.33017 0.933 0.0147 0.1080 0.1042 Air drying 0.545 0.073 0.54541 0.73637 -0.085068 4 0.99 0.0312 0.2385 0.1310 0.2222 0.1 0.10 0.986 0.3948 2.6310 0.5530 Hot air drying (60 °C) 3.759 0.021 3.75959 0.02059 -6.400024 8 0.097 0.0060 0.0456 0.0693 0.160 0.10 0.664 0.0723 0.8169 0.1936 Hot air drying (80 °C) 3.18 0.032 3.18011 0.0377 5.272352 8 0.0032 0.0218 0.0458 5 0.1 0.10 0.664 0.0723 0.8169 0.2720 Hot air drying (100 3.127 0.042 3.12797 0.04398 -5.196719 6 0.0054 0.005 0.01 0.10 0.6820 <th></th> <th>a</th> <th>ь</th> <th>c</th> <th>k₁</th> <th>k₂</th> <th>R</th> <th>MSE</th> <th>N</th> <th>MSE</th> <th>MAE</th> <th>a</th> <th>kı</th> <th>k₂</th> <th colspan="2">v erma R</th> <th>NM</th> <th>SE .</th> <th>MAE</th>		a	ь	c	k ₁	k ₂	R	MSE	N	MSE	MAE	a	kı	k ₂	v erma R		NM	SE .	MAE
Air drying 0.545 0.073 0.54541 0.7367 -0.085068 $\frac{1}{4}$ 0.074 0.0812 0.2325 0.1310 0.222 0.10 0.0986 0.3948 2.6310 0.5530 Hot air drying (60 °C) 3.759 0.021 3.75959 0.02059 -6.400024 $\frac{9}{8}$ 0.0060 0.0456 0.0693 $\frac{0.160}{5}$ 0.1 0.10 0.664 0.0723 0.8169 0.1936 Hot air drying (80 °C) 3.18 0.035 3.18011 0.0377 -5.272352 $\frac{8}{8}$ 0.0032 0.0218 0.0693 $\frac{5}{5}$ 0.1 0.10 0.664 0.0723 0.8169 0.1936 Hot air drying (100 3.127 0.042 3.12797 0.04398 -5.196719 $\frac{6}{7}$ 0.098 0.0042 0.016 0.01 0.10 0.640 0.1652 1.5022 0.3159 Microwave drying 0.504 109.2 0.593 0.0017 7 0.0301 0.0476 2.97544 2.130933 1.00 0.640 0.1552 1.5022 0.3159 Macrowave drying -0.052446 <td< th=""><th>Sun drying</th><th>0.693</th><th>0.219</th><th>0.69308</th><th>0.21948</th><th>-0.333215</th><th>0.98</th><th>0.005</th><th>7 0.0</th><th>0346</th><th>0.0661</th><th>-0.012</th><th>0.303027</th><th>0.33017</th><th>0.933</th><th>0.0147</th><th>0.10</th><th>80</th><th>0.1042</th></td<>	Sun drying	0.693	0.219	0.69308	0.21948	-0.333215	0.98	0.005	7 0.0	0346	0.0661	-0.012	0.303027	0.33017	0.933	0.0147	0.10	80	0.1042
Air drying 0.545 0.073 0.54541 0.7367 -0.085068 $\frac{4}{4}$ 0.0312 0.2385 0.110 0.01 0.10 0.986 0.3948 2.6310 0.5330 Hot air drying (60 °C) 3.759 0.021 3.75959 0.02059 -6.400024 $\frac{9.97}{8}$ 0.0060 0.0456 0.0693 $\frac{5}{5}$ 0.160 0.10 0.6644 0.0723 0.8169 0.1936 Hot air drying (80 °C) 3.18 0.035 3.18011 0.0377 5.272352 $\frac{8}{8}$ 0.0032 0.0218 0.0693 0.1400 0.10 0.6644 0.0723 0.8169 0.1936 Hot air drying (100 3.127 0.043 3.12777 0.04398 -5.196719 $\frac{0.98}{7}$ 0.0024 0.0519 0.211 0.10 0.640 0.1652 1.5022 0.3159 Microwave drying 0.504 109.28 0.00171 0.988 0.0024 0.016 0.005 0.01 0.10 0.640 0.1552 1.5022 0.3159 0.0211 <	sur a jing				0.21710		1					0.222			0.000				
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	Air drying	0.545	0.073	0.54541	0.73637	-0.085068	4	0.031	2 0.2	2385	0.1310	6	0.1	0.10	0.986	0.3948	2.63	10	0.5530
S 5 Hot air drying (80 °C) 3.18 0.35 3.18011 0.037 -5.272352 6 0.002 0.016 0.10 0.10 0.10 0.1297 1.2695 0.2720 Hot air drying (100 3.127 0.04398 -5.196719 6 0.0036 0.0214 0.01 0.10 0.10 0.640 0.1297 1.2692 0.3159 Microwave drying 0.504 109.28 -0.001971 7 0.004 0.005 0.01 0.1652 1.5022 0.3159 Ware drying - R MASE NMSE MAE Sun drying -0.05244 0.01927 -0.983 0.0001 0.017	Hot air drying (60 °C)	3.759	0.021	3.75959	0.02059	-6.400024	0.97	0.006	0 0.0	0456	0.0693	0.160	0.1	0.10	0.664	0.0723	0.81	69	0.1936
							8 0.98					5 0.140							
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	Hot air drying (80 °C)	3.18	0.035	3.18011	0.03797	-5.272352	8	0.003	2 0.0	0218	0.0458	5	0.1	0.10	0.639	0.1297	1.26	95	0.2720
TC () 0 <th>Hot air drying (100</th> <th>3.127</th> <th>0.042</th> <th>3.12797</th> <th>0.04398</th> <th>-5.196719</th> <th>0.98</th> <th>0.003</th> <th>6 0.0</th> <th>0244</th> <th>0.0519</th> <th>0.211</th> <th>0.1</th> <th>0.10</th> <th>0.640</th> <th>0.1652</th> <th>1.50</th> <th>22</th> <th>0.3159</th>	Hot air drying (100	3.127	0.042	3.12797	0.04398	-5.196719	0.98	0.003	6 0.0	0244	0.0519	0.211	0.1	0.10	0.640	0.1652	1.50	22	0.3159
Microwave drying 0.504 109.22 0.50491 109.28 -0.00171 0.0004 0.0042 0.0136 0.001 0.010 0.682 0.7593 3.3340 0.8122 Wang and Singh	-0)						6 0.99					o							
Wang and Singhr NMSE MAAE a b R MSE NMSE MAAE a b R MSE NMSE MAE Sun drying -0.05244 0.015927 0.983 0.0047 0.0301 0.0223 0.044 1.1691839 1.191714 0.994 0.0014 0.0101 0.0265 Hot air drying (00°C) -0.063047 -0.01045 0.987 0.0032 0.021 0.0464 4.884371 2.622632 0.986 0.3518 2.1842 0.4967 Hot air drying (00°C) -0.010137 -0.01045 0.987 0.0032 0.0203 0.0171 3.110908 2.390327 0.997 0.2319 1.3983 0.3616 Hot air drying (100° -0.022238 <th< th=""><th>Microwave drying</th><th>0.504</th><th>109.2</th><th>0.50491</th><th>109.288</th><th>-0.001971</th><th>7</th><th>0.000</th><th>4 0.0</th><th>0042</th><th>0.0136</th><th>0.005</th><th>0.01</th><th>0.010</th><th>0.682</th><th>0.7593</th><th>3.33</th><th>40</th><th>0.8122</th></th<>	Microwave drying	0.504	109.2	0.50491	109.288	-0.001971	7	0.000	4 0.0	0042	0.0136	0.005	0.01	0.010	0.682	0.7593	3.33	40	0.8122
a b R MSE NMSE MAE a b R MSE NMSE Sun drying -0.257426 0.015927 0.983 0.0047 0.0301 0.0476 2.97544 2.139093 1.00 0.011 0.0981 0.0874 Air drying -0.062444 0.00928 0.993 0.002 0.021 0.0464 1.1691839 1.19114 0.994 0.0114 0.0905 Hot air drying (60 °C) -0.063047 -0.01101 0.989 0.0029 0.021 0.0464 4.884371 2.622632 0.986 0.3581 2.1842 0.4967 Hot air drying (80 °C) -0.10107 -0.01045 0.987 0.0032 0.021 0.0446 4.884371 2.622632 0.986 0.3581 2.1842 0.4967 Hot air drying (100 -0.01045 0.987 0.0032 0.0224 0.0471 3.110908 2.993327 0.997 0.2319 1.3983 0.3616 "C) -0.002238 -0.008239 0.986 0.					v	Vang and Sir	ngh				1.015				Weibu	41			
Latter sping -0.22/red (m) 0.03/07 0.02/07 0.03/07 0.02/07 0.03/07 0.02/07 0.03/07 0.02/07 0.03/07 0.02/07 0.03/07 0.02/07 0.03/07 0.02/07 0.03/07 0.03/07 0.03/07 0.01/07 0.03/07 0.02/07 0.09/07 0.2/07 0.03/07 0.02/07 0.09/07 0.2/07 0.3/07 0.3/07 0.0/07 0.3/07 0.0/07 0.0/07 0.0/07 0.0/07 0.0/07 0.0/07 0.0/07 0.0/07 0	Sup draing	0.051	11.26	b 0.015027		R	MSE 0.004	,	NMSE 0.0201		MAE 0.0476	a	b	03	R	MSE 0.0171	NMSE 0.0021		MAE
Hotair drying (60 °C) -0.063047 -0.01101 0.989 0.0029 0.0221 0.0446 4.884371 2.622632 0.986 0.3581 2.1842 0.4967 Hotair drying (80 °C) -0.150137 -0.010465 0.987 0.0032 0.0230 0.0471 3.110908 2.390327 0.997 0.2319 1.3983 0.3616 Hotair drying (100 -0.202238 -0.008239 0.986 0.0036 0.0248 0.0425 2.588726 2.251383 0.989 0.1818 1.0951 0.3117 Microwave drying -49.416663 545.86149 0.947 0.0149 0.1228 0.1017 0.009666 1.26777 0.999 0.7632 3.3384 0.8142	Air drying	-0.062	2444	0.000928	0.	993	0.0030)	0.0223	3	0.0449	11.691839	9 1.1917	14	0.994	0.0014	0.0981		0.0265
Hotair drying (80 °C) -0.150137 -0.010465 0.987 0.0032 0.0230 0.0471 3.110908 2.390327 0.997 0.2319 1.3983 0.3616 Hotair drying (100 °C) -0.202238 -0.008239 0.986 0.0036 0.0248 0.0425 2.588726 2.251383 0.989 0.1818 1.0951 0.3117 Microwave drying -49.416663 545.86149 0.947 0.0149 0.1228 0.1017 0.009666 1.26777 0.999 0.7632 3.3384 0.8142	Hot air drying (60 °C)	-0.063	3047	-0.01101	0.	989	0.0029)	0.0221	I I	0.0446	4.884371	2.6226	32	0.986	0.3581	2.1842		0.4967
Hot air drying (100 -0.202238 -0.008239 0.986 0.0036 0.0248 0.0425 2.588726 2.251383 0.989 0.1818 1.0951 0.3117 *C)	Hot air drying (80 °C)	-0.150	0137	-0.010465	0.9	987	0.0032	2	0.0230)	0.0471	3.110908	2.3903	27	0.997	0.2319	1.3983		0.3616
, Microwave drying -49.416663 545.86149 0.947 0.0149 0.1228 0.1017 0.009666 1.26777 0.999 0.7632 3.3384 0.8142	Hot air drying (100 °C)	-0.202	2238	-0.008239	0.	986	0.0036	5	0.0248	3	0.0425	2.588726	2.2513	83	0.989	0.1818	1.0951		0.3117
	Microwave drying	-49.41	6663	545.86149	0.	947	0.0149)	0.1228	3	0.1017	0.009666	1.267	77	0.999	0.7632	3.3384		0.8142

the solutions are achieved (Yang and Landau, 2000). In current work, number of hidden neurons and training parameters (learning rate and momentum) were represented by haploid chromosomes consisting of three genes of binary numbers. The first gene corresponds to the number of neurons in single hidden layer and second and third genes represent the learning rate and momentum of network, respectively. An initial population of 60 chromosomes was randomly generated and the termination criterion of 60 was chosen for generation. The roulette wheel selection based on ranking algorithm was applied for the



Figure 1. Moisture ratio of tea leaves dried using different drying methods versus time (h)

selection operator. Uniform crossover and mutation operators with mixing ratio of 0.5 were used and the probabilities of the crossover and mutation operators were adjusted at 0.9 and 0.01, respectively. In this study, the ANN modeling and GA optimization were performed by Neurosolution release 5.0, produced by NeuroDimension, Inc.

Statistical analysis

The experiments were conducted in two replications. Analysis of variance (ANOVA) of data was performed using a computerized statistical program called 'MSTAT', version C.

Results and Discussion

In this study tea leaves were dried using different methods and moisture ratio was predicted applying semi-empirical and intelligent models.

Semi-empirical models

Initial moisture content of tea leaves was $77.1\pm1.8\%$ which indicated their susceptibility and necessity of drying process. Fig. 2 depicts the drying curves (moisture ratio versus time) for different drying methods. The experimental results indicated the absence of constant drying period and therefore drying took place only in the falling rate period. This illustrates that diffusion was the most likely

physical mechanism governing moisture removal in the tea leaves. Hence, Fick's second low could be used to determine effective diffusivity. General series solution of Fick's second law for slabs is given in Eq. 18. Constant diffusivity, uniform moisture distribution and Thickness (L) of 0.005 m were assumed for tea leaves.

$$MR = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left(-\frac{(2n+1)^2 \pi^2 D_{eff}}{4L^2}t\right) \quad (18)$$

Simplifying above equation by considering the first term of series gives:

$$MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{qq}}{4L^2}t\right)$$
(19)

Values of D_{eff} for sun drying, air drying 25°C, hot air drying at 60°C, 80°C, 100°C and microwave drying were 30.9×10^{-7} , 7.5×10^{-7} , 15.2×10^{-7} , 25.7×10^{-7} , 32.4×10^{-7} and 9457.2×10^{-7} m²/h, respectively. The correlation coefficients for these values were found to be 0.848, 0.935, 0.654, 0.715, 0.744 and 0.964, respectively. It can be seen that D_{eff} values increased with increasing temperature during hot air drying. Microwave drying showed the highest D_{eff} value about three orders of magnitude higher than other drying methods. Effective diffusivities of 3146.04×10^{-7} m²/h for red bell-pepper (Yang and Landau, 2000) and 1443.24×10^{-7} m²/h for onion slices (Weisburger, 1997) were reported during microwave drying. The higher obtained D_{eff} value of microwave drying in

		Optimized	GA-ANN performance					
ANN configuration	Number of hidden neurons	Learning rate of hidden layer	Momentum of hidden layer	Learning rate of output layer	Momentum of output layer	MSE	NMSE	MAE
Multilayer perceptron	7	0.5895	0.0617	0.5443	0.6836	0.0084	0.0597	0.0722
Radial basis function	6	0.8372	0.8396	0.7531	0.1224	0.0110	0.0879	0.0783

Table 3. Model parameter and performance of developed GA-ANN model

this work could be attributed to the thickness of thin layer sample.

Drying data were fitted to the semi-empirical models. Model parameters and performances of prediction were tabulated in Table 2. The ANOVA test on determined coefficients for logarithmic, Midilli, Page, Page- modified, Verma, and Weibull, were not significant at 95% confidence level and therefore could not be used for moisture ratio prediction. Their high values of MSE, NMSE and MAE also confirm incapability of these models. Apart from above mentioned models, other mathematical equations are fairly good, while did not receive acceptable performance against statistical parameters of MSE (min acceptable value of 0.01), NMSE (min acceptable value of 0.05) and MAE (min acceptable value of 0.05) for all drying methods. Panchariya et al. (2002) studied mathematical modeling of MR during thin-layer drying of black tea and reported that Lewis gave better predication ability.

GA-ANN

MLP and RBF neural networks with one hidden layer, 1 to 10 neurons and learning rate and momentum values ranging from 0 to 1 were trained using GA to achieve the optimal network configuration and learning parameters. Optimized MLP and RBF networks had 7 and 6 neurons in hidden layer, respectively. Model parameters and prediction errors of developed GA-ANN are showed in Table 3. Prediction error values indicated much better estimation capability of MLP as well as RBF in comparison to semi-empirical models. The matrices of weights (F matrix of 2×7 between input and hidden layer, G matrix of 1×7 between hidden layer and output layer) and bias values (BHidden matrix of 1×7 for first hidden layer and BOut matrix of 1×1 for output layer) of optimized MLP network are:

F =	-2.48437	-6.4250×10 ⁻¹	5.17409	7.7121×10 ⁻¹	3.5690	1.84446	-2.11832
•	3.72654	4.15236	-2.4767 ×10 ⁻¹	7.6905×10 ⁻¹	1.07524	-1.68915	5.25898





Figure 2. Experimental versus GA-ANN predicted MR values of dried tea leaves for MLP and RBF networks

$G = \left[-2.07564 \right]$	9.66	76×10 ⁻¹	-2.19641	-1.81	18×10 ⁻²	-2.03872	1.09929	-1.9580	57]
$B_{\mu\mu\mu\sigma} = [1.4998 \times 10^{-5}]$	10-4	6.281×10*	-2.3834×	10-4	1.414×10-	-1.3593×	10-4 3.30	6×10*	-2.7040×10-4]
$B_{Out} = [-3.082]$	×10 ⁻⁴	57							

where the values in the first and second rows of matrix of F representing the weights of the connections between hidden neurons and drying method and drying time neurons in input layer, respectively.

Weight (*W*) and bias (*B*) values for RBF network between hidden and output layers presented in the following matrices:

$$W = \begin{bmatrix} 1.15403 & 4.4166 \times 10^{-1} & -7.470 \times 10^{-2} & 1.15679 & -9.4790 \times 10^{-1} & 4.2932 \times 10^{-1} \end{bmatrix}$$
$$B = \begin{bmatrix} -7.6175 \times 10^{-5} \end{bmatrix}$$

The performance of optimized GA-ANN models of MLP and RBF configurations for estimation of moisture ratio of tea leaves based on test data which never were seen by networks during training were studied and the results were plotted in Fig. 2. This figure shows that the GA-ANN estimated values of moisture ratio closely fitted with the experimental data. However, MLP performed better prediction in comparison than RBF (correlation coefficients values 0.991 and 0.982 for MLP and RBF, respectively) and could be suggested for prediction of moisture ratio during drying of tea leaves.

Conclusion

Tea leaves were dried using different methods and their moisture ratio values were predicted by semiempirical and GA-ANN. Effective diffusivity were found to be in the range of 7.5×10^{-7} to 9457.2×10^{-7} m²/h . Semi-empirical models were not fully able to predict moisture ratio of tea leaves. The best model for estimation of MR was found to be MLP genetic algorithm-artificial neural network with 7 hidden neurons and R, MSE, NMSE, and MAE values of 0.991, 0.0084, 0.0597 and 0.0722, respectively. The optimized network could be strongly suggested for prediction of moisture ratio of tea leaves during different drying processes.

References

- Arslan, D. and Özcan, M.M. 2011a. Study the effect of sun, oven and microwave drying on quality of onion slices. LWT - Food Science and Technology 43(7): 1121-1127.
- Arslan, D. and Özcan, M.M. 2011b. Dehydration of red bell-pepper (*Capsicum annuum* L.): Change in drying behavior, colour and antioxidant content. Food and Bioproducts Processing 89(4): 504-513.
- Chan, E.W.C., Lim, Y.Y. Wong, S.K. Lim, K.K. Tan, S.P. Lianto, F.S. and Yong, M.Y. 2009. Effects of different drying methods on the antioxidant properties of leaves and tea of ginger species. Food Chemistry 113(1): 166-172.
- Costa, A. and Pereira, H. 2013. Drying kinetics of cork planks in a cork pile in the field. Food and Bioproducts Processing 91(1): 14-22.
- Dong, J., Fu, Z. Ma, X. Mo, K. and Xia, G. 2011a. Effects of different drying methods on quality of *Eucommia ulmoides* male flower tea. Nongye Jixie Xuebao/ Transactions of the Chinese Society of Agricultural Machinery 42(8): 131-137.
- Dong, J., Ma, X. Fu, Z. and Guo, Y. 2011b. Effects of microwave drying on the contents of functional constituents of *Eucommia ulmoides* flower tea. Industrial Crops and Products 34(1): 1102-1110.
- FAOSTAT. 2010. Food and Agriculture Organization of

the United Nations-Production (FAOSTAT).

- Fathi, M., Mohebbi, M. and Razavi, S. 2011a. Application of image analysis and artificial neural network to predict mass transfer kinetics and color changes of osmotically dehydrated kiwifruit. Food and Bioprocess Technology 4(8): 1357-1366.
- Fathi, M., Mohebbi, M. and Razavi, S.A. 2011b. Effect of osmotic dehydration and air drying on physicochemical properties of dried kiwifruit and modeling of dehydration process using neural network and genetic algorithm. Food and Bioprocess Technology 4(8): 1519-1526.
- Fathi, M., Mohebbi, M. and Razavi, S.M.A. 2011c. Application of fractal theory for prediction of shrinkage of dried kiwifruit using artificial neural network and genetic algorithm. Drying Technology 29(8): 918-925.
- Hatibaruah, D., Baruah, D. and Sanyal, S. 2012. Microwave drying characteristics of assam ctc tea (*Camellia Assamica*). Journal of Food Processing and Preservation 37(4): 366–370.
- Haupt, R.L. and Haupt, S.E. 2004. Practical Genetic Algorithms. Wiley.
- Jain, A. ,Manghani, C. Kohli, S. Nigam, D. and Rani, V. 2013. Tea and human health: The dark shadows. Toxicology Letters 220(1): 82-87.
- Khajeh, M. and Barkhordar, A. 2013. Modelling of solid-phase tea waste extraction for the removal of manganese from food samples by using artificial neural network approach. Food Chemistry 141(2): 712-717.
- Panchariya, P.C., Popovic, D. and Sharma, A.L. 2002. Thin-layer modelling of black tea drying process. Journal of Food Engineering 52(4): 349-357.
- Rahimmalek, M. and Goli, S.A.H. 2013. Evaluation of six drying treatments with respect to essential oil yield, composition and color characteristics of Thymys daenensis subsp. daenensis. Celak leaves. Industrial Crops and Products 42: 613-619.
- Sellami, I.H., Wannes, W.A. Bettaieb, I. Berrima, S. Chahed, T. Marzouk, B. and Limam, F. 2011. Qualitative and quantitative changes in the essential oil of Laurus nobilis L. leaves as affected by different drying methods. Food Chemistry 126(2): 691-697.
- Weisburger, J.H. 1997. Tea and health: a historical perspective. Cancer Letters 114(1-2): 315-317.
- Xi, J., Xue, Y. Xu, Y. and Shen, Y. 2013. Artificial neural network modeling and optimization of ultrahigh pressure extraction of green tea polyphenols. Food Chemistry 141(1): 320-326.
- Yang, C.S. and Landau, J.M. 2000. Effects of tea consumption nutrition health. Journal of Nutrition 130(10): 2409-2412.
- Zielinska, M., Zapotoczny, P. Alves-Filho, O. Eikevik, T.M. and Blaszczak, W. 2013. A multi-stage combined heat pump and microwave vacuum drying of green peas. Journal of Food Engineering 115(3): 347-356.