

Experimental and Theoretical Investigation of Rough Rice Drying in Infrared-assisted Hot Air Dryer using Artificial Neural Network

D. Zare, H. Naderi, A. A. Jafari

Abstract—Drying characteristics of rough rice (variety of lenjan) with an initial moisture content of 25% dry basis (db) was studied in a hot air dryer assisted by infrared heating. Three arrival air temperatures (30, 40 and 50°C) and four infrared radiation intensities (0, 0.2, 0.4 and 0.6 W/cm²) and three arrival air speeds (0.1, 0.15 and 0.2 m.s⁻¹) were studied. Bending strength of brown rice kernel, percentage of cracked kernels and time of drying were measured and evaluated. The results showed that increasing the drying arrival air temperature and radiation intensity of infrared resulted decrease in drying time. High bending strength and low percentage of cracked kernel was obtained when paddy was dried by hot air assisted infrared dryer. Between this factors and their interactive effect were a significant difference ($p < 0.01$). An intensity level of 0.2 W/cm² was found to be optimum for radiation drying. Furthermore, in the present study, the application of Artificial Neural Network (ANN) for predicting the moisture content during drying (output parameter for ANN modeling) was investigated. Infrared Radiation intensity, drying air temperature, arrival air speed and drying time were considered as input parameters for the model. An ANN model with two hidden layers with 8 and 14 neurons were selected for studying the influence of transfer functions and training algorithms. The results revealed that a network with the Tansig (hyperbolic tangent sigmoid) transfer function and trainlm (Levenberg-Marquardt) back propagation algorithm made the most accurate predictions for the paddy drying system. Mean square error (MSE) was calculated and found that the random errors were within and acceptable range of $\pm 5\%$ with coefficient of determination (R^2) of 99%.

Keywords—Rough rice, Infrared-hot air, Artificial Neural Network

I. INTRODUCTION

RICE is one of the leading food crops of the world and is second only to wheat in terms of annual production for food stuff. It is the staple food of over half of the world's population. About 90% of the world's rice is produced and consumed in Asia. The rice quality and energy used in drying were significantly dependent on the method of drying [1].

A generalized deep-bed model has been developed for paddy drying to optimize the drying process in terms of energy consumption and grain quality [2].

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Infrared radiation (IR) heating involves the exposure of a material to electromagnetic radiation in the wave lengthrange of 0.8–1000 μ m. IR drying is fundamentally different from convection drying where the material is dried directly by absorption of IR energy rather than transfer of heat from the air [4]. IR radiation drying has significant advantages over conventional drying. The advantages are versatility, simplicity of the equipment, easy accommodation of IR heating with convective, conductive and microwave heating, fast transient response and significant energy saving [5]. Many researchers reported that, though IR heating provides a rapid means of heating and drying, it is attractive for only surface heating application. As the IR energy is absorbed on the surface, it allows only a shallow layer to be [6]. The optimum radiation intensity and grain bed depth was found to lie between 3100 and 4290 W.cm⁻² and 12 and 16 mm, respectively [7]. The research has been done in modeling the drying.

Cakmak and Yildiz have conducted a research on modeling the nonlinear behavior of drying grapes using neural networks feed forward (FNN). They first manufactured a dryer for experimental and mathematical evaluation for drying grapes. Then they estimated drying rate using an exponential model using nonlinear regression. They also estimated drying rate using a neural network model. Finally, these two models were compared with each other. Their results showed that the neural network method has greater accuracy and uniformity in estimating the drying rate [7].

Momenzadeh et al. has worked on corn drying using a microwave-assisted fluidized bed dryer. They used four levels of air temperatures (30, 40, 50 and 60°C), and five power levels (180, 360, 540, 720 and 900W) for corn drying. The survey results showed that the increase in air temperature and power can be reduced drying time until 50%. They used an artificial neural network (ANN) to model and estimate the drying time. In this network, the input parameters were selected air temperature and moisture content. The results showed that network training algorithm (trainrp) and transfer function (tansig) have the most accurate forecast for estimating drying time of corn [5].

The objectives of this research were to (1) study the effects of operating parameters of the infrared dryer, including radiation intensity, air temperature and velocity, on the rate of drying, the force of fail in rough rice kernels and percentage of cracked kernels, (2) develop and evaluate ANN model for the apparatus designed for paddy drying.

II. MATERIAL AND METHODS

A. Experimental procedure

In this study, a pilot-scale infrared-hot air dryer was designed and implemented for drying of 200g samples of paddy. A schematic of this apparatus is presented in Fig.1. The bed was equipped with a perforated teflon distributor bed to provide a uniform air flow. In addition, the system consisted of a variable-speed centrifugal fan controlled by an inverter (N50-007SF, Korea), two 1-kW and three 0.5-kW electric preheaters, and a temperature controller (SU-105IP, Samwon Engineering, Korea) used to keep the inlet air temperature at a constant value. The air velocity approaching the bed was measured using a Testo 425 (Germany) hotwire anemometer with an accuracy of 0.03 m/s. The different infrared radiations were produced by three 250W infrared lights (OSRAM Company, Slovakia). Drying characteristics of rough rice (lenjan variety) in thin layer form having initial moisture content of $25 \pm 0.5\%$ (d.b.) was studied in a hot air dryer assisted by infrared heating when moisture content decreased to $12 \pm 0.5\%$ (d.b.). Experimental factors included drying air temperatures (30, 40 and 50°C), infrared power intensity (0, 0.2, 0.4 and 0.6 W/cm^2) and drying air flow rate (0.1, 0.15 and 0.2 m/s). The experiments were conducted in three replications for combinations of different levels of factors.

During each drying experiment, about 200g sample of paddy was placed in the drying bed and the moisture loss was periodically measured by taking out the bed and weighing it on a digital balance (GF-600, A&D Company, Japan; accuracy, 0.001 g) in less than 10 s. In addition, the temperature and relative humidity of inlet and outlet air were measured using a Testo625 with an accuracy of 0.5°C and 2.5% RH.

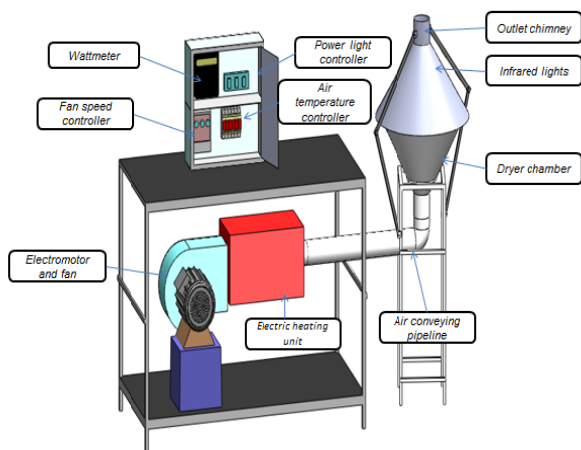


Fig. 1 Schematic of experimental apparatus

Surface temperature of the samples in a series of experiments under infrared lamps was measured with digital laser thermometer (TESTO-830-T2, Germany). To avoid exceeding of grain temperature beyond the standard level (70°C) a certain height (45cm) for installation of the lamp was considered.

Bending strength of brown rice kernel was measured using the standard device (SANTAM, STM-20) equipped with a load cell (Fig.2) with capacity of 50kg force (BONGSHIN-50, Taiwan). Based on previous researches compressive strength is not a good criterion for predicting rice strength. Meanwhile the tensile strength and flexural strength of cortical function in healthy rice are better predicted [8]. Also due to the difficulty of the tests for tensile strength of rice seed, the best choice for testing is the bending test [9]. Thus, for the bending test, triaxial tests were used and the brown rice kernel was placed between fixed jaws and loading jaw imposed a force in middle of each kernel. The speed of loading jaw was chosen 0.5 mm.s^{-1} [10]. The location of brown rice kernel on the jaw is shown in fig 3.

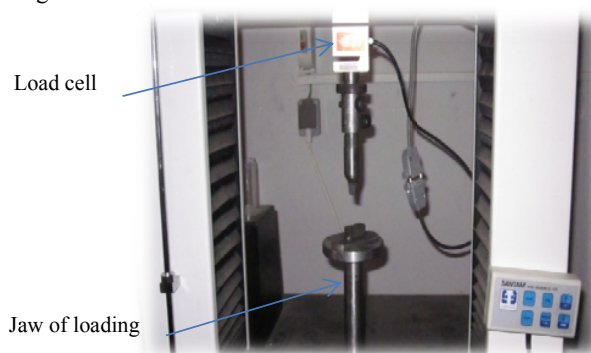


Fig. 2 Load cell and jaw of loading

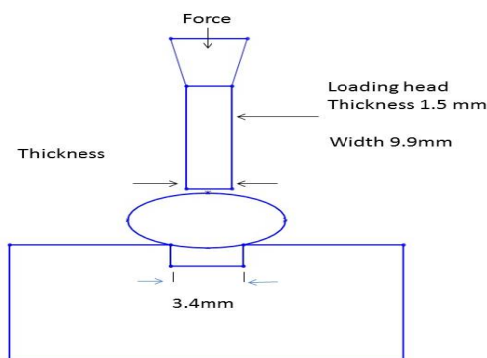


Fig. 3 The location of brown rice kernel

B. Artificial Neural Network (ANN) modeling

Artificial Neural Networks have been applied successfully for prediction and optimization problems in process Engineering. ANN is a massive parallel-distributed information processing system that has certain performance characteristics resembling biological neural networks of the human brain. ANN has been designed as a generalization of mathematical models of human cognition and neural biology [11]. The available dataset was divided into three parts; one used to train the network and the other used to validate the model and the other for testing the model. The network consists of an input layer, an output layer and a number of hidden layers. At each node in a layer the information is received, stored, processed and communicated further to nodes in the next layer.

All the weights are initialized to small random numeric values at the beginning of training. These weights are updated or modified iteratively using the generalized delta rule or the steepest-gradient descent principle. The training process converges when no considerable change is observed in the values associated with the connection links or when a termination criterion is satisfied [12].

The ANN model was trained using 70% randomly selected data points and the 15% data points were utilized for validation and the 15% remaining data were utilized to testing network performance. MATLAB 7.0 was used for training, validation and testing of neural network.

The methodology used for the evaluation of network performance involves obtaining the minimum statistical measures of error between experimental and predicted data obtained by the model. In this study, statistical parameters namely, mean square error (MSE), and correlation coefficient (R^2) represented by “(1)”, “(2)” were computed to check the performance of the developed model [13].

$$MSE = \frac{\sum_{p=1}^M \sum_{i=1}^N (S_{ip} - T_{ip})^2}{n_p \times n_o} \quad (1)$$

$$R^2 = 1 - \frac{\sum_{ip=1}^N [S_{ip} - T_{ip}]^2}{\sum_{ip=1}^N [S_{ip} - T_{ip}]^2} \left(T_{ip} = \frac{\sum_{ip=1}^n S_{ip}}{n} \right) \quad (2)$$

In these equations S_{ip} Network output of neuron i in pattern p , T_{ip} is Target of neuron i in pattern p , n_p is The number of patterns, n_o is The number of output layer neurons, N is the number of output neurons, M is the number of training patterns.

In order to obtain the optimum number of neurons in the hidden layers for each of sample geometry, the ANN model was trained with varying numbers of neurons and randomly chosen tansig, tansig transfer functions and trainlm algorithm. The maximum neurons studied were 20, starting with a minimum of 1 neuron and then increasing the network size in steps by adding a neuron each time. Errors increased rapidly when the number of neurons was less than 8. The predictions were highly sensitive to the number of neurons. In addition, based on error analysis results, it was found that the ANN model was the lowest error obtained with 8, 14 in hidden neurons.

Radiation intensity (4 levels), drying air temperature (3 levels), velocity of air (3 levels) and time during drying chosen as input layers and the moisture content was set as the output layer. Fig. 4 depicts the schematic structure of the applied neural network, with its four inputs and single output. There is no feedback from the output to the inputs. The Classical back propagation algorithm was used to train the network. Furthermore, a logarithmic Tansig activation function was applied and mathematical definition of the

transfer function was trainlm. This function (hyperbolic tangent sigmoid (Tansig) Takes the input (which may have any value between plus and minus infinity) and the output value in the range -1 to 1 [6].

$$a = \frac{(e^n - e^{-n})}{(e^n + e^{-n})}, \quad a = \text{Tansig}(n) \quad (3)$$

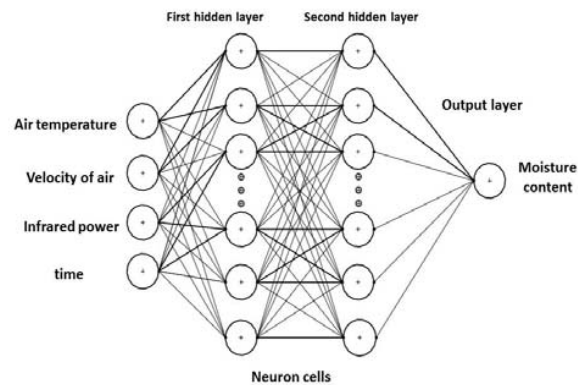


Fig. 4 Selected neural network structure

One of the most difficult tasks in ANN model development is finding the optimal network architecture. This network architecture can be selected out of several network configurations containing the combination of various model parameters namely, the number of neurons in the hidden layers, different transfer functions and the training algorithms [5].

Among the topology tested with regards to values of the lowest MSE and highest correlation coefficient of determination as can be seen in table (1) Network with structure of 4-8-14-1 with 19 cycles and Transfer function of tansig and training algorithms lm (Levenberg-Marquardt) were compared to other topologies and chosen.

TABLE I
THE RESULTS OF THE NEURAL NETWORK TO ESTIMATE THE MOISTURE CONTENT IN DIFFERENT FUNCTIONS

Number of training cycles	Mean Square Error (MSE)	Transfer function	topology
32	0.00332	tansig	4-8-12-1
24	0.00781	tansig	4-8-10-1
19	0.0012	tansig	4-8-14-1
15	0.0162	logsig	4-10-14-1
51	0.00731	logsig	4-8-14-1
112	0.00891	logsig	4-10-14-1

III. RESULTS AND DISCUSSION

A. Investigation on the drying time

To determine which differences between treatments are significant, the Tukey test (HSD) was used to compare averages. This test shows that the only significant difference that they are relatively high. Drying time was influenced by the radiation intensity (0, 0.2, 0.4 and 0.6 W.cm⁻²), inlet air

temperature (30, 40 and 50 °C) air speed (0.1, 0.15 and 0.2 m/s) at the 1% level. The minimum drying duration belongs to treatment having highest radiation and drying temperature. It is clear from Fig.5 the drying time was significantly reduced when higher infrared intensity was chosen. This is due to the fact water molecules in paddy absorbed infrared radiation and caused the molecules vibrated rapidly and therefore the effective diffusion was increased significantly.

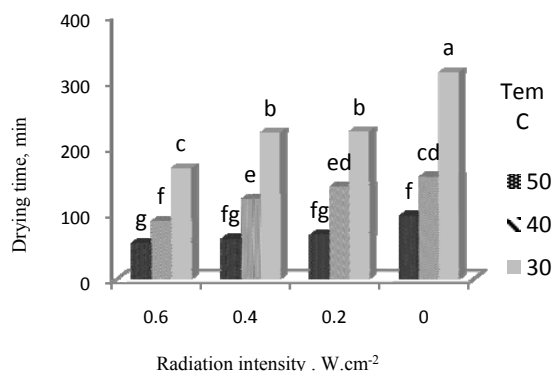


Fig. 5 Comparison of drying time at different radiation intensities and drying air temperatures (similar letters indicate no significant difference in the graph)

Similar results were reported by other researchers on drying of barley and blueberries in combined hot air-infrared drying method [8, 14-15]. Based on information illustrated in Fig. 6 it seems that the drying duration decreased when air flow rate increased from 0.1 to 0.2 m/s. This is due to the cooling effect of higher air flow rates. However based on statistical analysis these differences were not significant.

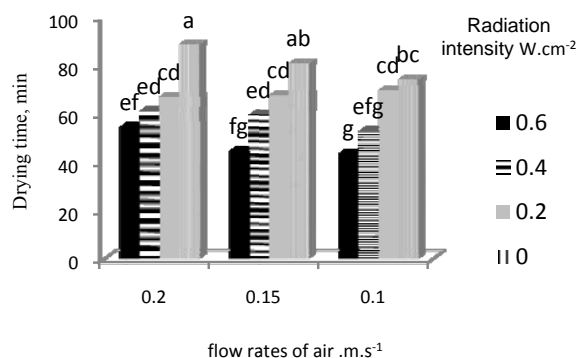


Fig. 6 Comparison of drying time at different radiation intensities and drying air flow rates (similar letters indicate no significant difference in the graph)

B. Math investigation of the force to failure and cracks in brown rice kernel

A standard florescent crack detector was used to investigate the effect of drying treatment on crack kernels. Cracks in kernels were measured for 50 kernels for each drying treatments in three replications. The review of trials revealed that the maximum percentage of cracked kernels and consequently the minimum breaking force (N) were obtained

in infrared intensity of 0.6 W/cm² due to stress caused by higher temperature resulted in higher radiation. Mean while the minimum cracked kernels were seen in the radiation intensity of 0.2 W/cm² (Fig. 7 and Fig 8).

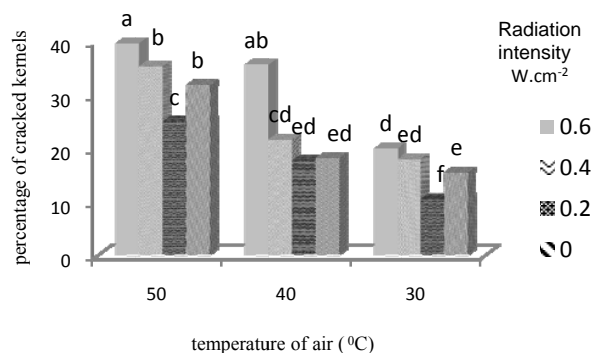


Fig. 7 Comparison of percentage of crack, in various (similar letters indicate no significant difference in the graph)

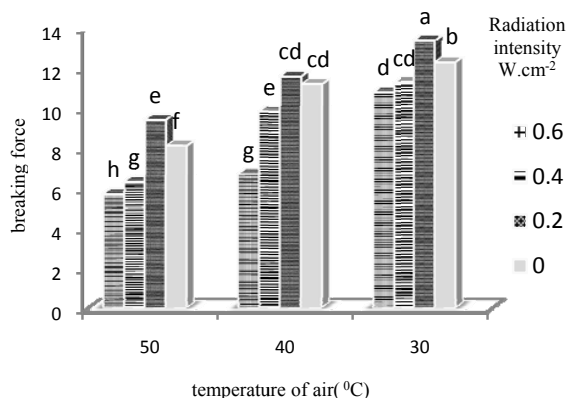


Fig. 8 Comparison of breaking force, in various (similar letters indicate no significant difference in the graph)

C. Units sensitive analysis in ANN prediction

The data were first normalized and divide into three parts one used for training the network, one for validation and the other for testing. Training was continued until reaching to an optimal architecture. Network performance was evaluated by plotting the ANN model output against the testing data and analyzing the percentage error between the predicted and desired values (experimental data). For an example a comparison between the experimental data versus predicted moisture content by ANN (validation) is shown in Fig. 9 for infrared radiation of 0.6 W.cm⁻², air flow rate of 0.15 m/s and drying temperature of 40°C. Similar trends were obtained for other drying treatments.

The effect of uncertainty in output experimental and ANN prediction values on mean square error (MSE) was studied by introducing small random errors within range of $\pm 5\%$ [13]. The ANN prediction results have a very strong dependence on input parameters. The present work was consistent with the works of reference [11,13].

As it can see in Fig.10 and 11 the value of MSE and coefficient of determination (R^2) in total of network are in sequence 0.00127 and 0.998.

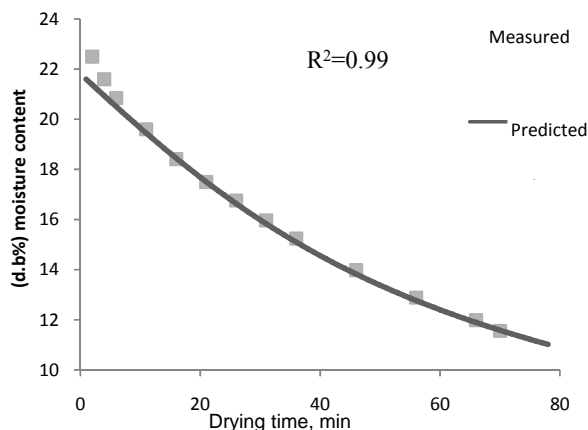


Fig. 9 Comparison of experimental vs. predicted moisture content for infrared radiation of 0.6 W/cm^2 , air flow rate of 0.15 m/s and drying temperature of 40°C

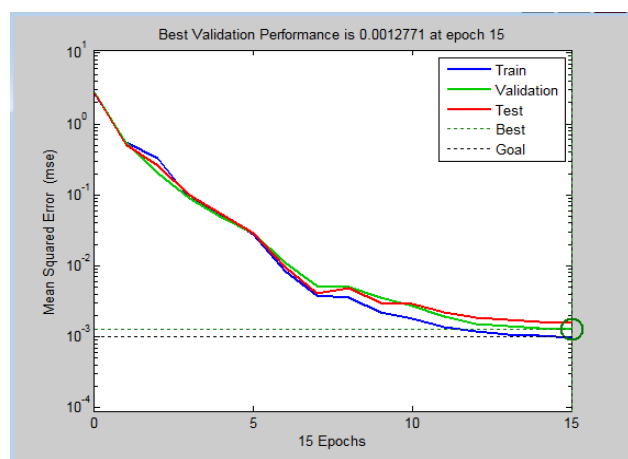


Fig. 10 Diagram of prediction of moisture and get to the minimum error

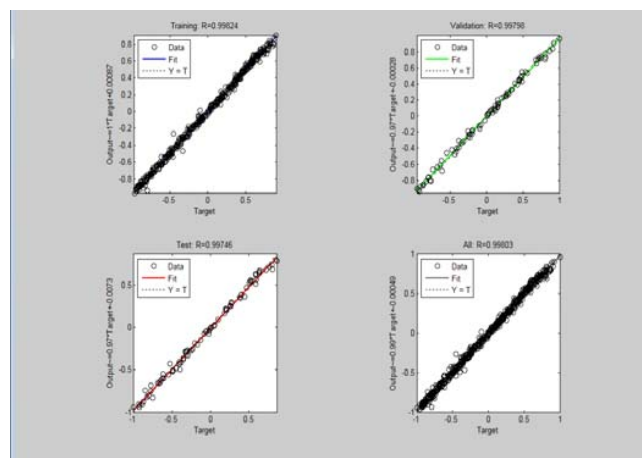


Fig. 11 Comparison of experimental vs. predicted moisture content in training, validation, testing and total of network

IV. CONCLUSION

Increasing infrared radiation intensity, drying air

temperature and flow rates resulted decrease in drying time. High bending strength and low percentage of cracked kernel was obtained when paddy was dried by infrared - hot air dryer. An intensity level of 0.2 W/cm^2 was found to be optimum for radiation drying to obtain high quality. Based on the error analysis results, it was found that the neural network with 8 neurons in first hidden layer and 14 neurons in second and Tansig transfer function with trainlm back propagation algorithm was the most appropriate ANN configuration for prediction of paddy moisture variation in thin layer form in infrared-hot-air dryer.

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