Application of soft computing techniques for the prediction of the air permeability property of fabrics

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The air permeability of a fabric is the measure of the air flow rate through the fabric under a given pressure. It has a great significance on the fabric comfort related properties of clothing. The target of the study is the application of fuzzy logic and artificial neural network simulation for the estimation of the air permeability of the linen woven fabrics. For this aim, eleven different linen woven fabrics were used and their basic physical properties such as; yarn linear density, twist coefficient, fabric unit weight, fabric thickness and air permeability properties were evaluated. The air permeability property of linen fabrics was predicted by using Fuzzy Logic (FL) and Artificial Neural Network (ANN) models using the parameters which are effective on air permeability according to the literature. The predictions of ANN and FL methods compared with experimental results. According to the results, it was seen that ANN and FL models give outputs closer to experimental results, but the estimation success of ANN method was found better than the FL model.
***Key words**: Soft Computing Techniques, Fuzzy Logic (FL), Artificial Neural Network (ANN), Air Permeability, Linen, Woven Fabric*

1. Introduction

Air permeability is very important as it defines the properties of keeping warm, protection against the wind, breathability etc. of the fabrics used as clothing. It is measured as the volume of air in liters which is passed through the specific area of the fabric in one minute at a pressure difference.

There are many studies about the investigation of the relation between the air permeability and structural characteristics of woven fabrics. It is possible to classify the factors influencing the air permeability into three broad groups of the fabric parameters; (1) the physical properties of the fiber, (2) fabric construction and (3) yarn properties. These parameters affect the size and number of porosity which is strongly related with the permeability property [1-5].

The structure of a textile fabric contains pores between the fibers and the yarns. The size of the pores is related to the physical fiber properties such as fiber fineness and fiber shape, and these parameters affect the air permeability of the fabric [3]. The air blocking ability of fabric or enabling the air pass through the fabric easily depends on the construction, geometry, thickness and porosity of fabric. When porosity increases and thickness decreases, air permeability increases [6]. In the same manner, as a fabric structural parameter, density of fabric has an important effect on air permeability. As density increases, air permeability tends to decrease. Yarn properties such as yarn linear density and yarn twist coefficient are the other important parameters determinant for air permeability. When yarn linear density increases, yarn structure becomes more compact and air permeability increases. Likewise, when yarn linear density becomes thinner, air permeability increases too [7].

Tab.1 Measured parameters for evaluating air permeability behavior of linen woven fabrics

Fabric Sample No	Yarn Linear Density (tex)		Yarn Twist Coefficient (turns/m)		Warp Density (picks/cm)	Weft Density (ends/cm)	Thickness (mm)	Weight (gr/cm²)	Air permeability (mm/s)
	Warp	Weft	Warp	Weft					
1	27.60	26.97	625.1	633.2	23.4	18.8	0.29	123.7	1031.2
2	29.83	31.09	503.4	549.1	20.8	18.6	0.35	128.6	927.1
3	55.72	62.18	529.8	490.7	18.4	14.8	0.44	194.1	745.5
4	47.63	48.82	475.2	506.6	18.4	16.8	0.35	159.5	955.7
5	98.44	62.18	479.3	466.1	15.6	12.2	0.60	235.3	451.8
6	21.96	26.49	623.3	619.7	26.4	20.8	0.26	114.1	1125
7	44.75	43.75	469.0	465.6	19.8	18.2	0.37	167.4	847.9
8	56.79	60.89	457.2	443.3	18.0	14.4	0.43	193.9	797.4
9	37.62	36.02	546.5	561.6	19.8	18.0	0.36	158.3	942.3
10	54.19	54.19	457.5	436.0	18.6	14.2	0.44	208.3	643.7
11	66.37	67.89	566.8	582.7	18.2	14.4	0.51	225.7	528.8

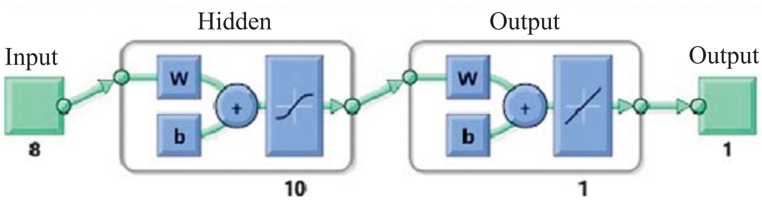

Fig.1 ANN model for prediction of air permeability

Soft computing techniques are powerful data modeling and predicting tool which are able to different domains of applications in various engineering fields [8]. In fabric engineering, various computational tools such as; Finite Element Method (FEM), Artificial Neural Networks (ANNs), Fuzzy Logic (FL) and Genetic Algorithm (GA) have been used in order to represent the fabrics in a computational environment and to predict their final properties [9].

ANN is a powerful data modeling and predicting tool which is able to evaluate any kind of input-output relationships [10]. Matusiak have been used ANNs for the prediction of the air permeability property of 106 variants of cotton woven fabrics of different weave and compactness, test results were confirmed the good quality of air permeability prediction using the artificial neural networks [11]. Çay, investigated 30 different woven fabrics under certain weft and warp densities. The study reported that the neural network prediction error is shown to be five times lower than the corresponding error produced by a multiple linear regression applied on the same data [12]. Militkey et al. introduced the rational basis function neural networks (RBF) and the advantages of RBF in comparison with classical neural networks are discussed. The strategy of optimal RBF numbers selection is described [13]. Nassif, was compared the estimation degree of the regression and ANNs. The findings of this study revealed that ANN is superior to regression model in predicting the woven fabric properties [14]. Tokarska, has been suggested that the first step in assessing the model obtained in the form of an artificial neural network should be to analyze the sensitivity of the input of a neural network. By this way the constructed neural model of fabric flow properties offers a good description of the effect of the structural parameters of the flat textile products [15].

Fuzzy systems are knowledge-based or rule-based systems. The main part of a fuzzy system is a knowledge base consisting of the fuzzy IF-THEN rules. FL method can be applied to all studies conducted in textile area, with this method complex system behaviors can be modeled with simple logic linguistic rules [10]. There are many studies using this method on yarn and fabric quality parameters in textile industry. Dayık and Yılmaz determined the effects of fiber length, fiber fineness and strength on pilling of cotton fabrics were by using fuzzy logic method [16]. Fuzzy logic was also used for predicting the spinnability and strength of a yarn with the help of IF-THEN rules and the methods prediction accuracy was found good [17]. In the study of Park et al. fuzzy logic and neural networks was used for evaluating the total hand values of knitted fabrics and the results were compared with a subjective test. It is stated that fuzzy logic and artificial networks are useful tools for prediction of total hand values of knitted fabrics and correspond better to the subjective test results than the KES-FB system [18]. Kılıç used image analysis and fuzzy logic methods in his study to determine drape coefficient of woven suiting fabrics produced from 100% wool worsted yarns and results of Fuzzy logic were found closer to the conventional Cusick method [19]. Hussain et al. compared the ANN and adaptive neuro-

Tab.2 Comparison between the experimental results, ANN outputs and defuzzificated outputs of air permeability

Fabric Sample No	1	2	3	4	5	6	7	8	9	10	11
Experimental Results	1031.2	927.1	745.5	955.7	451.8	1125	847.9	797.4	942.3	643.7	528.8
ANN Outputs	1067	919	748	956	457	1120	856	793	935	612	535
Difference Between Experimental results & ANN Outputs (%)	3.47	-0.87	0.34	0.03	1.15	-0.44	0.96	-0.55	-0.77	3.47	-0.87
Deffuzificated Outputs	1050	957	710	862	506	1080	855	742	938	736	535
Difference Between Experimental Results & Deffuzificated Outputs (%)	1.82	3.23	-4.76	-9.80	12.00	-4.00	0.84	-6.95	-0.46	14.34	1.17

fuzzy inference system (ANFIS) models with experimental data for predicting the wrinkle recovery of polyester/cotton woven fabrics. According to the study results, predictions of ANN were found better than ANFIS predictions [20].

Various studies are reported in the past which focused on the modeling of the air permeability with artificial neural network (ANN) based models. However, modelling of the air permeability with Fuzzy Logic (FL) model has not been applied yet. In the study, both ANN and FL models will be applied and compared for the estimation of air permeability property of woven fabrics.

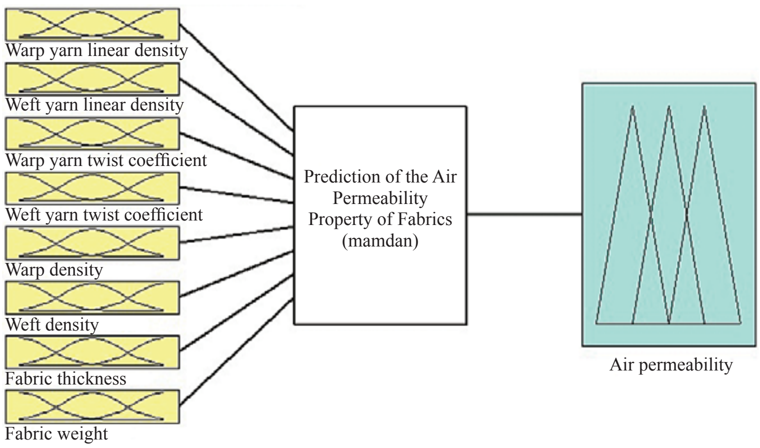

Fig.2 FL model for evaluating air permeability behavior of linen woven fabrics

2. Materials and methods

In the study, 11 types of plain constructed %100 linen fabrics were used as material. Fabrics were supplied from different companies. In order to evaluate the air permeability behavior of woven fabrics made of linen fibers, various yarn and fabric parameters which are effective on air permeability were determined. Yarn linear density (tex), twist coefficient (turns/m), weft (ends/cm) and warp densities (picks/cm), weight (g/cm²), thickness (mm) were measured experimentally.

Warp and weft yarn linear densities for the fabric samples were determined according to ISO 7211-5:1984. Twist coefficients for warp and weft yarns were tested according to ISO 7211-4:1984. Warp and weft densities were measured according to ISO 7211-2 (1984). Thickness of fabric samples was measured with SDL ATLAS Digital Thickness Gauge M034A according to the ISO 5084 standard. Air permeability (mm/s) value of the fabric samples was tested in Textest FX 3300 according to the ISO 9237:1995. All yarn and fabric measurements were conducted at standard atmospheric conditions (20 ± 2 °C, 65 ± 4% Rh).

ANN and FL models were designed for prediction of air permeability. The outputs obtained from ANN and FL models were compared with experimental air permeability results to determine the best prediction method.

For establishing ANN model, Neural Network Toolbox of MATLAB was used and ANN model was constituted for prediction of air permeability. The ANN model was designed with three-layer and feed-forward back propagation algorithm with a sigmoid transfer function in the hidden layer and a linear transfer function in the output layer. Determination of optimum number of the hidden layer neurons is very important in order to predict accurately a parameter using by ANN and this number can be two times more than input or output neurons [21]. Generally, the number of hidden neurons is determined arbitrarily according to the experience [22, 23]. In the study, the number of hidden neurons for ANN model was determined after doing trials to get best results for prediction and 10 hidden neurons were chosen. The data used for calibrating and validating of the network models were obtained from the experimental study. In the study yarn linear density, twist coefficient, warp density, weft density, weight, thickness and air permeability values of 11 different fabrics were measured experimentally and totally 110 measured data were obtained for each one. For the ANN model, air permeability was used as target variable and the rest experimental values were used as input variables. The values of input variables were not scaled from 0 to 1. In the ANN model 70% of these values were used for training,

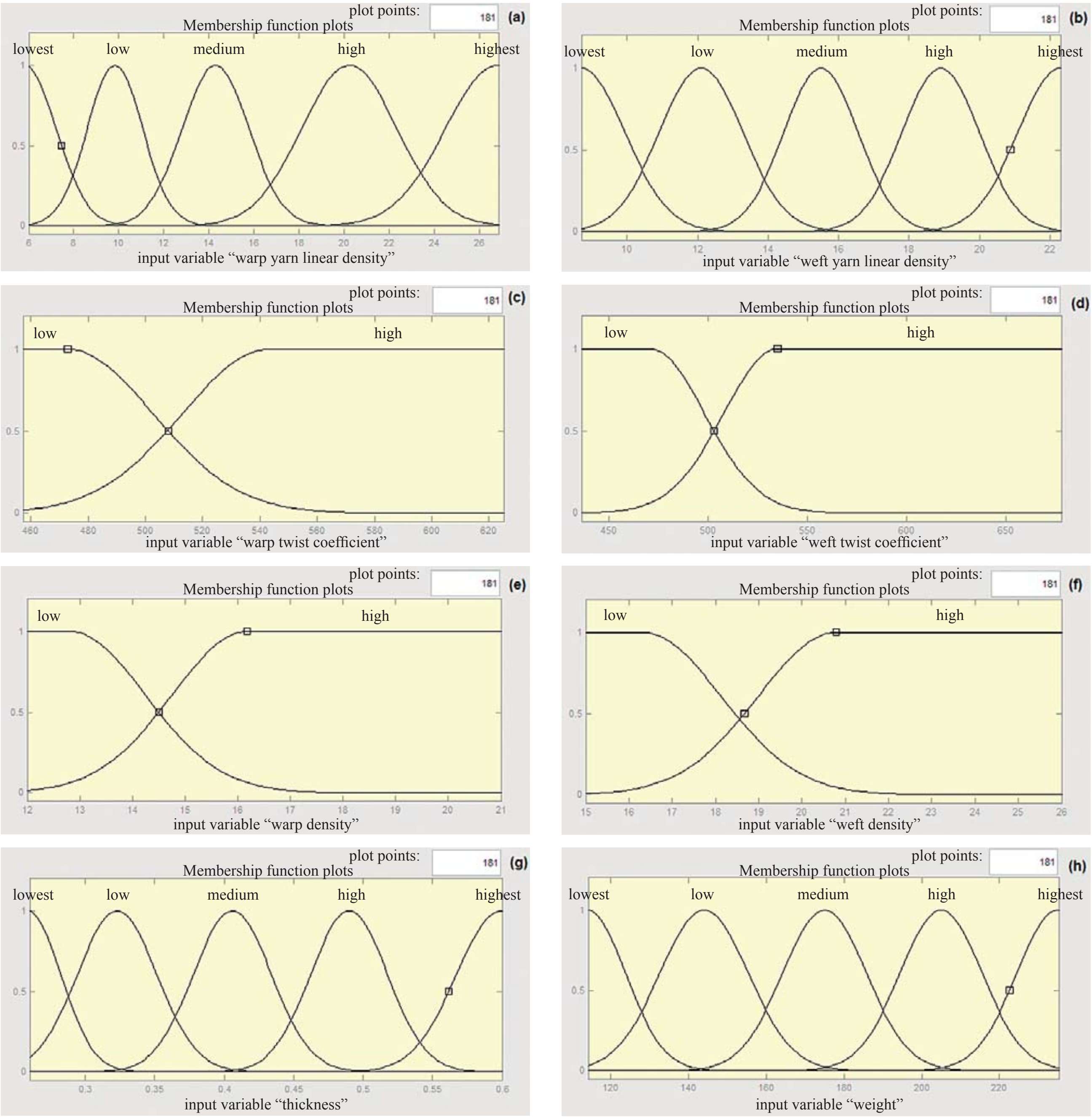

Fig.3 The membership functions of input variables: (a)warp yarn linear density, (b) weft yarn linear density, (c) warp yarn twist coefficient, (d) weft yarn twist coefficient, (e) warp density, (f) weft density, (g) thickness, (h) weight

15% for validation and 15% for testing.

In next stage, for developing FL model and all mathematical calculations, Fuzzy Toolbox of MATLAB was used. In the evaluation with FL technique at first, the relationships between input and output parameters were determined by considering expert opinions. The fuzzification processes for input and output variables were carried out by the light of the literature and the opinions of the experts. Then membership functions and fuzzy "IF-THEN" rules were generated. In the modeling fuzzy inference engine "max-min" inference mechanism was used. Mamdani method was used as an inference method which is commonly used method and the basis of other FL models. After the solution of the implemented FL system obtained by Mamdani method, the solution was inversely operated which is called as defuzzification. Centroid method (Center of Area) was used for defuzzification.

3. Results and discussions

For prediction of the air permeability behavior with the application of ANN and FL methods, yarn and fabric parameters which are effective on air permeability according to the literature such as; yarn linear density, twist coefficient and warp and weft densities, weight and thickness were measured. The measured values and experimental results of fabric air permeability were given in Tab.1.

3.1. Artificial Neural Network (ANN) Model

In the study, three-layer, feed-forward back propagation algorithm with ten hidden neurons and one output neuron ANN model was designed. In addition to this, eight input neurons were used for eight input variables (weft and warp yarn linear density, warp and weft yarn twist coefficient, warp and weft fabric density, fabric weight and fabric thickness). Fig.1 shows the ANN model generated by MATLAB Neural Network Toolbox. The comparison between the experimental results and ANN outputs, and addition to this difference of them in percentages were given in Tab.2. According to results the predictions of ANN are closer to the experimental results.

3.2. Fuzzy Logic (FL) Model

As the other method for prediction of air permeability of fabrics, FL method was used in the study. In the designing of the FL model, yarn linear density, twist coefficient and warp and weft densities, weight and thickness were used as input variables, and air permeability was used as output variable same as the ANN model. The numbers of input and output membership functions were determined by the help of experimental results and using expert knowledge. The created FL model consisted of eight fuzzy inputs, Mamdani inference engine and the output was given in Fig.2. To defining membership values more detailed, five membership functions such as lowest, low, medium, high and highest were used for input parameters; thickness, weight, warp and weft yarn linear densities. For the rest input parameters two

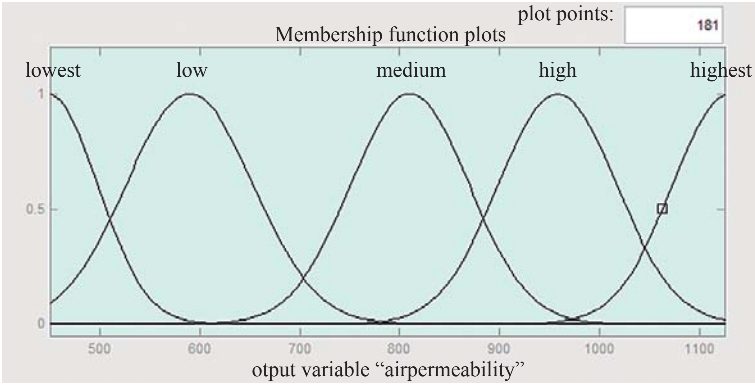

Fig.4 The membership functions of output variable

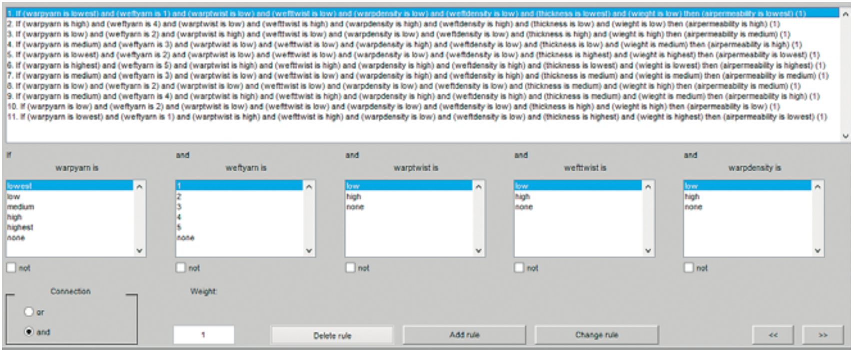

Fig.5 Fuzzy "IF-THEN" rules

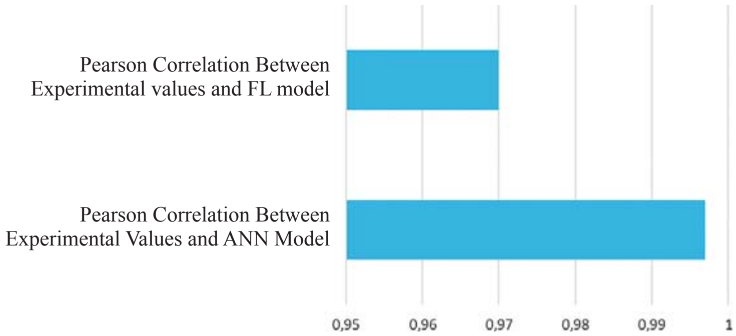

Fig.6 The Pearson correlations of air permeability between the experimental values and the predicted values of ANN and FL models

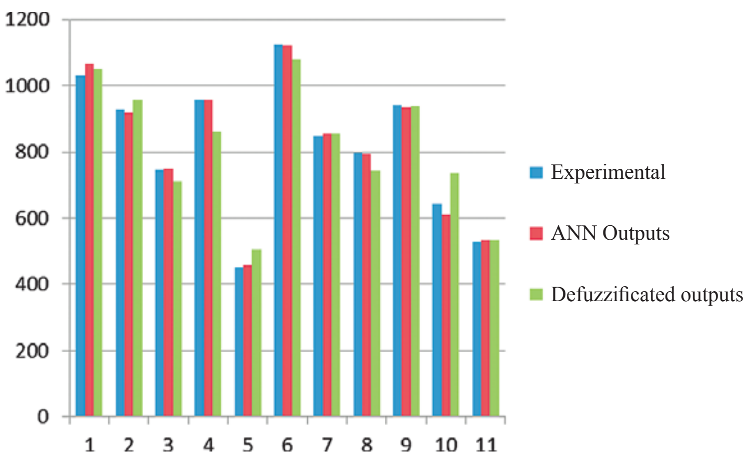

Fig.7 Comparisons between experimental results, ANN outputs and deffuzificated outputs for prediction of air permeability

membership functions such as low and high were used. The membership functions of input variables are given in Fig.3 (a-h). In the study five membership functions were used for output variable. The membership functions of output variable are given in Fig.4.

For the FL model, "IF-THEN" rules were generated according to experimental values and the expert's opinions. For each sample, a rule was established and 11 rules were used for the FL model. "IF-THEN" rules used in the study are given in Figure 5.

The predicted air permeability values obtained by FL, compared with air permeability results obtained from the experimental study. Comparison between experimental results and defuzzificated outputs and their difference in percentages were given in Table 2 for the FL model. In the study, centroid calculation was used for deffuzzification method, which calculates the center of area under the curve [24]. As it can be seen from the table, although the FL predictions are also closer to the experimental values, ANN results were much better than the FL defuzzificated outputs.

3.3. Comparison of ANN and FL methods

In the study the experimental air permeability values were estimated with both ANN and FL methods. The experimental results were compared with the outputs obtained from the designed ANN and FL models by using Pearson correlation. The Pearson correlations of air permeability between the experimental values and the predicted values of ANN and FL models were found to be 0,997 (p-value 0.000) and 0,970 (p-value 0.000) respectively. Fig.6 shows Pearson correlations between the experimental values and the predicted values of ANN and FL models.

As a result, outputs obtained from both ANN and FL predictions were found closer to experimental results; their usability and prediction ability were revealed. But according to the Pearson correlation, it can be conveniently said that the ANN outputs are more reliable than FL outputs to describe real values of fabric air permeability. Comparisons between experimental results, ANN and FL for prediction of air permeability were given in Fig.7. As it is seen from the figure, ANN outputs are more compatible with experimental results.

4. Conclusions

In the study ANN and FL methods were used for prediction of air permeability properties of woven linen fabrics. At first, air permeability values of fabrics, related yarn and fabric parameters were measured and experimental results were obtained. When the experimental results were evaluated, weight was found as the most effective parameter on air permeability. Moreover, yarn linear density and thickness were the other important parameters. In accordance with the literature, because thickness and weight are inversely correlated with the air permeability, the increases in these parameters cause a decrease in air permeability. On the other hand, increase in yarn linear density cause an increase in air permeability.

Yarn linear density, twist coefficient and warp and weft densities, weight and thickness were used as input variables and air permeability was used as the output variable in ANN and FL models.

Later in the study, outputs for prediction of air permeability obtained by ANN and FL models were compared with results obtained from experimental tests. According to the results, it was found that ANN and FL models give closer results to the experimental ones. However, it was verified that ANNs is more reliable and useful tool for prediction air permeability property of linen fabrics. By optimizing these models, it could be possible to predict air permeability behavior of fabrics before producing them, only by specifying the fabric parameters. ANN and FL methods are used frequently in textile industry. As distinct from the other studies mentioned previously, linen fabrics were investigated in this study both with ANN and FL methods. In this context, it is thought that this study is a valuable experimental study which combines soft computing techniques such as artificial neural network and fuzzy logic for evaluating air permeability of linen woven fabrics and determines the best prediction method by comparing them with experimental results.

References:

[1] Oğulata R.T.: Air permeability of woven fabrics, Journal of Textile and Apparel, Technology and Management 5 (2006.) 2, 1-10

[2] Ogulata R.T., S. Mavruz Mezarcioz: Total porosity theoretical analysis, and prediction of the air permeability of woven fabrics, The Journal of the Textile Institute 103 (2012.) 6, 654-661

[3] Fatahi I., A.A. Yazdi: Predicting air permeability from the parameters of weave structure, Fibres & Textiles in Eastern Europe 20 (2012.) 3, 78-81

[4] Havlova M.: Air permeability and constructional parameters of woven fabrics, Fibres & Textiles in Eastern Europe, V.21, (2013.) 2, 84-89

[5] Zupin Z. et al.: Prediction of one-layer woven fabrics air permeability using porosity parameters, Textile Research Journal 82 (2011.) 2, 117-128

[6] Petrulyte S., R. Baltakyte: An investigation into air permeability of terry fabrics regarding the processes of finishing, Tekstil 57 (2008.) 1-2, 15-20

[7] Özdil N.: Physical quality control methods in fabrics, E.U. Textile and Apparel Textile & Apparel Research and Application Center, Izmir, 2003., ISBN 975-483--579-9

[8] Majumdar A. et al.: Soft computing applications in fabrics and clothing: A comprehensive review, Research Journal of Textile and Apparel 14 (2010.) 1, 1-17

[9] Vassiliadis S. et al.: Artificial neural networks and their applications in the engineering of fabrics, Woven Fabric Engineering, InTech, Available from: http://www.intechopen.com/books/woven-fabricengineering/artificial-neural-networks-and-their-applications-in-the-engineering-of-fabrics, 2010., 26 page

[10] Majumdar A.: Soft computing in fibrous materials engineering, Textile Progress 43 (2011.) 1, 1-95

[11] Matusiak M.: Application of artificial neural networks to predict the air permeability of woven fabrics, Fibres & Textiles in Eastern Europe 23 (2015.) 1, 41-48

[12] Çay A. et al.: Prediction of the air permeability of woven fabrics using neural networks, International Journal of Clothing Science and Technology 19, (2007.) 1, 18-35

[13] Militky J. et al.: Influence of fabric construction on the their porosity and air permeability, Available from: http://centrum.tul.cz/centrum/centrum/1Projektovani/1.2_publikace/%5B1.2.30%5D.pdf, access date, 2017., 18 page

[14] Abou-Nassif G.A.: Predicting the tensile and air permeability properties of woven fabrics using artificial neural network and linear regression models, Journal of Textile Science & Engineering 5 (2015.) 5, 1-6

[15] Tokarska M.: Assessing the quality of neural models using a model of flow characteristics of fabrics as an example, Autex Research Journal 6 (2006.) 3, 162-168

[16] Dayık M., F. Yılmaz: Cotton fabric pilling detection with fuzzy logic method, Electronic Journal of Textile Technologies 6 (2012.) 2, 19-27

[17] Sette S. et al.: Building a rule set for the fiber-to-yarn production process by means of soft computing techniques, Textile Research Journal 70 (2000.) 5, 375-386

[18] Park S.W. et al.: Applying fuzzy logic and neural networks to total hand evaluation of knitted fabrics, Textile Research Journal 70 (2000.) 8, 675-681

[19] Kılıç, M.: Determination of fabric drape using image analysis and fuzzy-logic methods, Industria Textila 66 (2015.) 5, 269-277

[20] Hussain T. et al.: Comparison of artificial neural network and adaptive neuro-fuzzy inference system for predicting the wrinkle recovery of woven fabrics, The Journal of the Textile Institute 106 (2015.) 9, 934-938

[21] Özçelik G.: A research on the objectıve evaluation and prediction of fabric pilling property, PhD Thesis, Textile Engineering Department of Ege University, Turkey, 2009., 315 page

[22] Yuan H.C. et al.: Method for estimating the number of hidden neurons in feed-forward neural networks based on information entropy, Computers and Electronics in Agriculture 40 (2003.) 1-3, 57-64

[23] Huang G-B., H.A. Babri: Upper bounds on the number of hidden neurons in feedforward networks with arbitrary bounded nonlinear activation functions, IEEE Transactions on Neural Networks 9 (1998.) 1, 224-229

[24] MATLAB. Fuzzy Logic Toolbox User's Guide, Mathworks R2015b, 2015.