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Analysis and Prediction of Air Permeability of 100% Cotton Single Jersey Fabric Using Machine Learning Approaches

Sharmin Akter,
Daffodil International University,
Bangladesh

Md. Sohel Ahammed,
University of Business and Technology,
Bangladesh

Dr. Mashiur Rahman Khan,
University of Textiles,
Bangladesh

ABSTRACT

The air permeability property has great significance on the fabric comfort related property. In this study Artificial Neural Network (ANN), Random Forest and Additive Regression Classification Models have been applied for the prediction of the air permeability of single jersey knitted fabrics made of 100% cotton fiber. For this aim, 100 different single jersey knitted fabrics were used and there basic properties such as yarn linear density, tightness factor, fabric loop length, fabric thickness, stitch density, fabric unit weight, and air permeability properties were evaluated. ANN, Random Forest, and Additive Regression Classification Models were developed to predict air permeability properties of single jersey fabrics. It was found that all the models give outputs closer to the experimental results. However, ANN estimation success was found higher than other models.

Keywords: Artificial Neural Network, Random Forest, Additive Regression Classification Model, Single Jersey, Air permeability, Cotton

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Introduction

Textile fabrics are mainly used for clothing and domestic purposes other than technical uses. However, the use of textiles fabric diversified to medical, construction, agriculture etc. in the last decades. Because of the increased interest of the technical uses, fabric design and fabric engineering procedure have improved. As the nonlinear behavior of textile fabrics increase the difficulty in fabric design and engineering, a different computational model has been developed to predict its final properties. This model is helpful for the researchers and textile experts also. The intelligent systems such as artificial neural network, fuzzy logic system, finite element methods show great capacity because it easily accommodates to nonlinear relations.

Chattopadhyay and Guha [1] stated that ANN is mostly used in the textile field in the classification as well as in the prediction of properties. In the case of cotton, ANNs have been used for the grading of the color of the raw fibers [2-4], evenness [5-6] or hairiness [7-8]. Mwasiagi et al [9] used ANN and K-means for classification of cotton lint. Basu et al [10] said that a lot of computational technique has been developed for the prediction of the behavior of the fabric. In case of fabric, ANN has been used for fault detection [11-18], drape [19], fabric hand [20-23], tensile strength [24], stiffness [25], bursting [26], pilling [27] or permeability[28]. There are a few numbers of works based on the evaluation of knitted fabric air permeability property on the evaluation of knitted fabric geometrical parameters. Ogata and Martz [29] proposed a theoretical model for the prediction of plainly knitted fabrics produced from the ring and compact yarn of different yarn number linear density and tightness based on D'Arcy's law. They found near positive linear relationship between porosity and air permeability. Nazir [30] investigated the effect of knitting parameters on the air permeability and moisture management of interlock fabric. It was found that the increase in knitting stitch length and decrease in knitting machine gauge result in decrease in the fabric unit weight and the fabric density accompanied with increase in fabric thickness and porosity. And the increase in porosity results in an increase in fabric air permeability. Ju and Ryu [31] investigate and predict the effects of the structural properties of plainly knitted fabrics on the subjective perception of textures, sensibilities, and preference among consumers by using statistical analysis tools, such as factor and regression analysis and ANFIS. They also indicated the necessity of a new method for the prediction of non-linear relations. Fayala et al. [32] analyzed the nonlinear relationship between fabric parameters and thermal conductivity of single jersey knitted fabric by using fabric properties such as porosity, air permeability and weight and fiber conductivity as input elements in neural network approach. Unal et al [33] measured bursting strength and air permeability properties of the fabrics associated with fiber and yarn properties separately by using regression and artificial neural networks.

In this study artificial neural network has been applied for the prediction of the air permeability of single jersey knitted fabrics from fabric geometrical parameters. Random Forest and Additive Regression Classification Model have been also developed to compare with ANN.

Materials and methods

The air permeability property of a fabric is related to fabric parameters. According to literature, it is obvious that the quality and quantity of data is very important to predict fabric parameters. Therefore, in order to predict air permeability value of knitted fabric different values of air permeability of single jersey knitted fabric were collected from different textile industries in Bangladesh. It is generally known that yarn linear density, loop length, stitch density, fabric tightness factors, fabric thickness have an important effect on air permeability of the knitted fabric. Thus 100 different fabrics were used with different yarn linear density (11.81 Tex to 29.94 Tex) and different tightness (slack, medium and tight). The knitting process of single jersey fabrics were performed on a 24 gauge, 28 gauge and 32 gauge circular knitting machine.

According to ASTM D-3776 test standard, each fabric GSM (fabric unit weight) was tested. Wales per cm (WPcm) and course per cm (CPcm) of fabric were measured with counting glass. Fabric stitch density and tightness factor were measures according to the equation (i) & (ii) respectively [34].

$$tightness\ factors = \frac{\sqrt{Tex}}{l} \ldots\ldots\ldots\ldots\ldots \text{(i)}$$

$$Stitch\ density = WPcm\ X\ CPcm \ldots\ \ . \text{(ii)}$$

Fabric thickness and air permeability were measured with Shirley carpet thickness tester and Textest AG FX 3300 air permeability tester according to the ASTM D1777 and TS 391 EN ISO 9237, respectively. Furthermore loop length was measured according to TS EN 14970 [35]. A relative air humidity of 65±2% and temperature 20 ± 2^0C was maintained during all those testing.

For the analysis and prediction of air permeability of knitted fabric artificial neural network, Random Forest classification algorithm and Additive Regression classification model were applied and the performances of the model were compared.

In our model, 100 sample instances from our dataset were used. We have defined 75 clusters. Of the 100 single jersey fabric samples, 75 (75 %) samples were chosen as the training set at random, while the rest (25 %) was chosen for the testing set.

Table 1. Fabric properties and experimental value of air permeability

Sample Number	Yarn Count (tex)	Loop length (mm)	Stitch density (loops/cm2)	Thickness (mm)	Fabric unit weight (gm/m^2)	Tightness factor	Air permeability (mm/s)
1	24.6	1.84	251.55	0.41	170	2.69	861.54
2	22.71	2.18	260.07	0.4	160	2.19	889.76
3	22.71	2.78	260.41	0.4	165	1.71	876.48
4	22.71	2.77	344.41	0.39	168	1.72	1019.24
5	21.09	2.84	314.6	0.4	150	1.61	1047.46
6	21.09	2.84	277.7	0.39	155	1.61	1069.04
7	21.09	2.18	292.96	0.39	153	2.1	1178.6
8	19.68	2.25	273.89	0.38	140	1.97	1185.24
9	19.68	2.83	327.34	0.39	142	1.56	1552.1
10	19.68	2.85	337.04	0.38	140	1.55	1512.26
11	19.68	3.12	347.52	0.37	140	1.42	1522.22
12	19.05	2.84	557.28	0.37	135	1.53	1525.54
13	18.45	3.21	322.43	0.34	130	1.34	1533.84
14	18.45	3.22	341.74	0.34	138	1.33	1620.16
15	18.45	3.12	277.83	0.31	134	1.37	1842.6
16	17.37	3.28	331.82	0.3	10	1.27	1693.2
17	17.37	3.24	624.04	o.29	122	1.29	1673.28
18	17.37	3.32	594.46	0.27	126	1.25	1899.04
19	17.37	2.89	602.26	0.23	121	1.44	1711.46
20	14.76	3.41	303.85	0.28	100	1.12	2008.6
21	14.76	3.11	711.06	0.19	105	1.23	2065.04
22	14.76	3.26	326.61	0.26	110	1.17	3041.12
23	14.76	3.18	317.39	0.2	110	1.21	3685.2

24	14.76	3.12	297.8	o.19	105	1.2	2948.16
25	14.76	2.92	633.38	0.21	108	1.31	2065.04
26	19.72	2.5	278.53	0.069	161.38	1.78	1193
27	19.72	2.85	219.48	0.057	136.78	1.56	1562
28	19.72	3.2	193.2	0.068	136.9	1.39	1562
29	19.72	2.6	290.16	0.06	159.48	1.71	1532
30	19.72	2.86	246.81	0.06	143.72	1.55	1647
31	19.72	3.3	194.85	0.058	134.22	1.34	1948
32	14.79	2.56	292.8	0.063	120.88	1.5	2020
33	14.79	2.84	229.56	0.059	105.72	1.34	2077
34	14.79	3.2	180	0.052	87.22	1.2	3059
35	14.79	2.61	312	0.059	126.1	1.47	2459
36	14.79	2.8	234	0.06	118.24	1.37	2966
37	14.79	2.5	194.48	0.065	107.16	1.54	3708
38	11.83	2.5	299	0.053	86.98	1.37	2938
39	11.83	2.8	252	0.053	75.86	1.23	3502
40	11.83	3.2	192	0.061	76.62	1.07	3680
41	11.83	2.51	312	0.052	98.3	1.37	3128
42	11.83	2.9	234	0.056	89.58	1.18	3306
43	11.83	3.3	180	0.06	76.82	1.04	4616
44	29.7	0.735	132.5	0.518	133.65	7.41	4997.5
45	29.7	0.817	155.33	0.63	174.23	6.67	4866.7
46	29.7	0.762	153	0.592	160.12	7.15	3830
47	29.7	0.757	155.75	0.552	161.88	7.12	3336.7
48	29.7	0.777	151.67	0.584	161.88	7.01	3883.3
49	29.7	0.727	153.33	0.586	153.06	7.49	3493.3
50	29.7	0.796	145.17	0.564	158.79	6.84	3680
51	29.7	0.786	151.67	0.564	163.65	6.93	4043.3
52	29.7	0.73	162	0.57	162.32	7.46	3725
53	29.7	0.783	149.25	0.566	160.56	6.96	4070
54	29.7	0.783	153	0.542	164.53	6.96	4076.7
55	29.7	0.758	157.17	0.6	163.65	7.19	3980
56	29.7	0.747	159.08	0.574	163.21	7.29	3453.3
57	29.7	0.78	155.67	0.582	166.73	6.98	3786.7
58	29.7	0.751	157.33	0.558	162.32	7.25	3463.3
59	29.7	0.763	151.42	0.544	158.79	7.14	3950
60	29.7	0.76	153.33	0.538	160.12	7.17	4360
61	29.7	0.774	149.25	0.522	158.79	7.04	3800

62	29.7	0.769	150.75	0.568	159.24	7.08	4120
63	29.7	0.757	153.58	0.552	159.68	7.2	3513.3
64	29.7	0.731	155.5	0.55	156.15	7.45	3906.7
65	29.94	0.786	134.58	0.584	146.44	6.96	4753.2
66	29.94	0.877	171.08	0.73	207.76	6.24	4360
67	29.94	0.754	185	0.66	193.2	7.25	4473.3
68	29.94	0.832	171.17	0.654	197.17	6.57	3596.7
69	29.94	0.792	177.33	0.69	194.52	6.91	5420
70	29.94	0.808	171.08	0.638	191.44	6.77	3910
71	29.94	0.829	173.58	0.666	199.38	6.6	3615
72	29.94	0.85	165.58	0.648	194.96	6.44	4506.7
73	29.94	0.782	175.58	0.626	190.11	6.99	4380
74	29.94	0.833	164.83	0.61	190.11	6.57	4163.3
75	29.94	0.807	168.67	0.716	188.35	6.78	4063.3
76	29.94	0.799	177.42	0.72	196.29	6.85	3860
77	29.94	0.813	172.5	0.66	194.08	6.7	4203.3
78	29.94	0.831	164.83	0.588	189.67	6.58	3556.7
79	29.94	0.81	171.08	0.672	191.88	6.75	3840
80	29.94	0.818	169.92	0.65	192.32	6.69	4816.7
81	29.94	0.878	164.75	0.638	200.26	6.23	4186.7
82	29.94	0.808	168.08	0.644	187.91	6.77	4496.7
83	29.94	0.842	166.92	0.644	194.52	6.49	3933.3
84	29.94	0.795	175.5	0.668	193.2	6.88	4216.7
85	29.94	0.782	172	0.654	186.14	6.99	4903.3
86	24.6	0.265	280	0.63	144	18.74	741
87	24.6	0.276	257.4	0.62	155	17.99	709
89	24.6	0.279	281.71	0.64	175	17.76	406
91	19.68	0.28	245.49	0.58	129	15.85	802
92	19.68	0.253	280	0.6	140	17.51	556
93	19.68	0.263	289.5	0.61	152	16.86	433
94	19.68	0.279	242.2	0.59	163	15.9	305
95	19.45	3	234	0.57	117	1.47	1620
96	19.67	2.9	273	0.58	124	1.53	1400
97	19.54	2.6	312	0.53	135	1.7	1380
98	19.66	2.45	299	0.53	140	1.81	1290
99	11.81	2.8	252	0.53	75.86	6.48	3502
100	19.68	2.5	278.53	0.69	161.38	6.43	1193

Results and Discussion

Prediction of Air permeability with model-01 (ANN)

In model 01, a multilayer feedforward network with one hidden layer trained by back propagation algorithm was used to predict the air permeability properties of the 100% cotton single jersey knitted fabrics with using fiber properties. In all models developed in the study, the linear transfer function was used in the input and output layers, whilst hyperbolic transfer function was used in the hidden layers for the fabric property estimations. For all estimations, the training of the network was performed in two phases. In the first stage, the back propagation algorithm was applied for 100 epochs. Learning rate and momentum coefficient used in the back propagation algorithm was set to 0.01 and 0.25 respectively. In the second stage of the training, the conjugate gradient descent algorithm was applied for 50 epochs. The basic concept of Backpropagation artificial neural network (BPANN) was shown in the following figure 1.

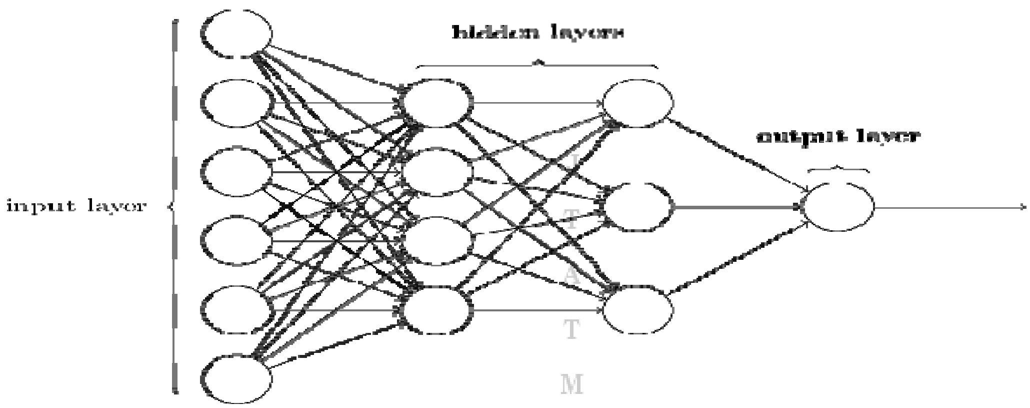

Figure 1. Backpropagation Artificial Neural Network

In our ANN model, seven input layers were used which were Yarn Count, Loop length (mm), Stitch density (loops/ cm2), Thickness (mm), GSM, Tightness Factor and Yarn diameter (mm) as input. Output layer was the prediction of Air permeability in (mm/s).

In the hiddenlayer, there are four nodes and the single output node. Output node gives the prediction of air permeability in millimeters per second (mm/s).

Table 2. Necessary attributes for the model-01 (ANN)

Learning rate	0.30
Momentum	0.20
Epoch	500

In the backpropagation neural network algorithm, each input attribute is connected to each node of the hidden layer and nodes of the hidden layer are connected to the output node which gives the prediction of air permeability.

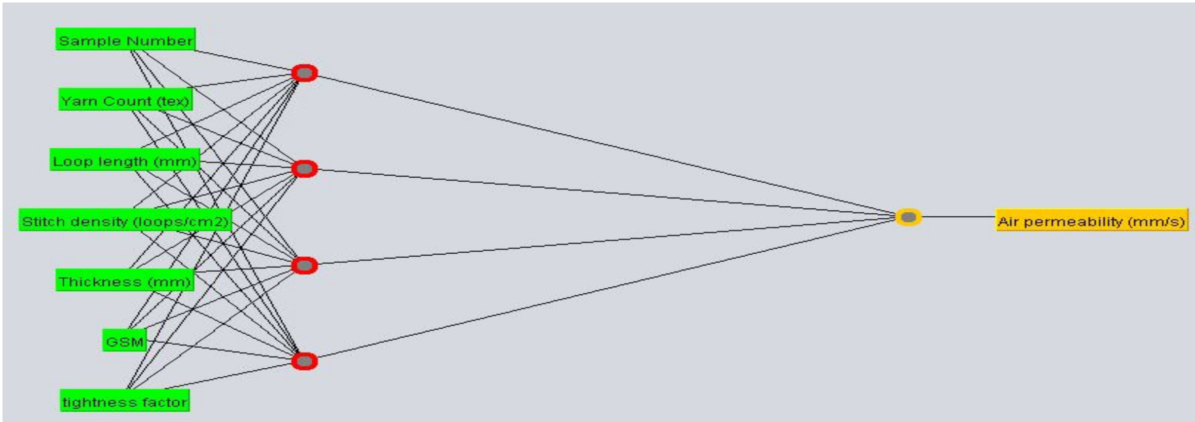

Figure 2. Backpropagation neural network of our proposed model

According to the Backpropagation artificial neural network (figure 2), the following results were observed for the model-01 as shown in the table 3.

Table 3. Experimental result for model-01(ANN)

Experimental result of Model-01 (ANN)	
Correlation coefficient	**0.9623**
Mean absolute error	250.218
Root mean squared error	300.89
Relative absolute error	25.6384
Root relative squared error	32.198

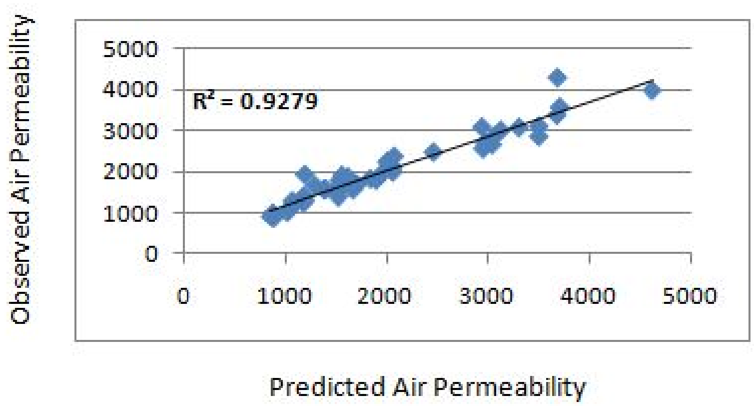

Figure 3. Regression coefficient of an artificial neural network for air permeability property

The weights which are developed for the prediction of air permeability properties of single jersey fabrics with fabric parameters as independent variables are yarn linear density, loop length, stitch density, fabric thickness, GSM, tightness factor. The most important parameter that has an effect on fabric air permeability is yarn diameter which is followed by yarn count. As the yarn diameter increases which means that yarn gets thicker, the air permeability of the fabrics decrease due to the decrease of fabric porosity. In addition to yarn diameter, the increase in loop length also causes an increment in the air permeability values of the fabrics which are followed by the fabric

GSM. Increasing stitch density (i.e. the number of wales and course yarns per unit area) causes a decrease in porous volume and an increase in the thickness of a sample, which results in a decrease in the air permeability value. Increasing tightness factor causes a decrease in porosity, which results in a decrease in fabric air permeability. In Figure 3, the regression coefficient of the neural network is given.

Prediction of Air permeability with model-02 (Random Forest Classification algorithm)

Our model-02 was developed using Random forest classification algorithm (RFA) to predict the air permeability of 100% cotton single jersey fabric. Random forests or random decision forests are an ensemble learning method for classification, regression and other tasks that operates by constructing a multitude of decision trees at training time and outputting the class that is the mode of the classes or mean prediction of the individual trees.

A random forest is a meta estimator that fits a number of decision tree classifiers on various sub-samples of the dataset and uses averaging to improve the predictive accuracy and control over-fitting. The sub-sample size is always the same as the original input sample size but the samples are drawn with replacement if *bootstrap=True* (default).

We observed the following finding from our model-02 as shown in table 4.

Table 4. Experimental result for model-02(Random Forest Algorithm)

Experimental result of Model-02 (Random Forest Algorithm)	
Correlation coefficient	**0.9462**
Mean absolute error	323.6335
Root mean squared error	445.1247
Relative absolute error	30.0678
Root relative squared error	33.1966

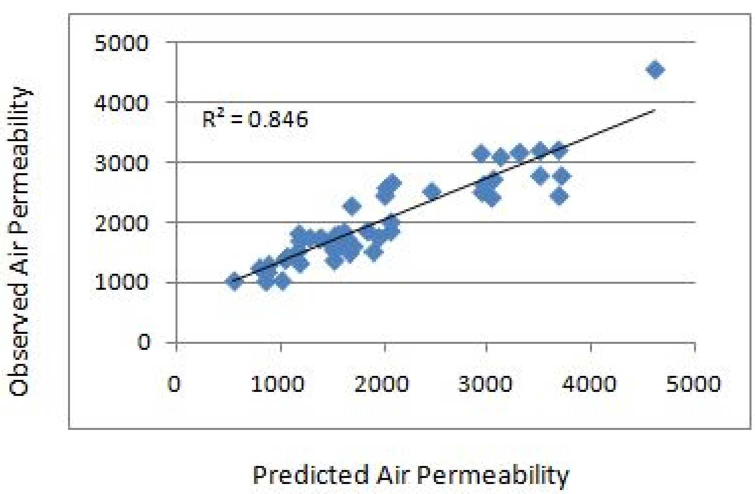

Figure 4. Regression coefficient of Random Forest Classification Algorithm

From the Random Forest Classification algorithm, the weights of the network were calculated and the air permeability of the 100% cotton single jersey was predicted.

From the Random Forest Classification algorithm, it is shown that loop length and yarn linear density has a greater effect on air permeability of fabric than other parameters.

In Figure 4, the regression coefficient of the Random Forest Algorithm is given.

Prediction of Air permeability with model-03 (Additive Regression algorithm)
An additive Regression model (ARM) is a nonparametric regression method. It was suggested by Jerome H. Friedman and Werner Stuetzle (1981) and is an essential part of the ACE algorithm. The ARM uses a one-dimensional smoother to build a restricted class of nonparametric regression models. Because of this, it is less affected by the curse of dimensionality than e.g. a *p*-dimensional smoother. Furthermore, the ARM more flexible than a standard linear model, while being more interpretable than a general regression surface at the cost of approximation errors. In our model, we observed that the accuracy is about to 89.32% and additional experimental findings were shown in table 5.

Table 5. Experimental result for model-02(Additive Regression)

Experimental result of Model-03(Additive Regression Algorithm)	
Correlation coefficient	0.8932
Mean absolute error	435.6671
Root mean squared error	622.2425
Relative absolute error	34.5138
Root relative squared error	45.0098

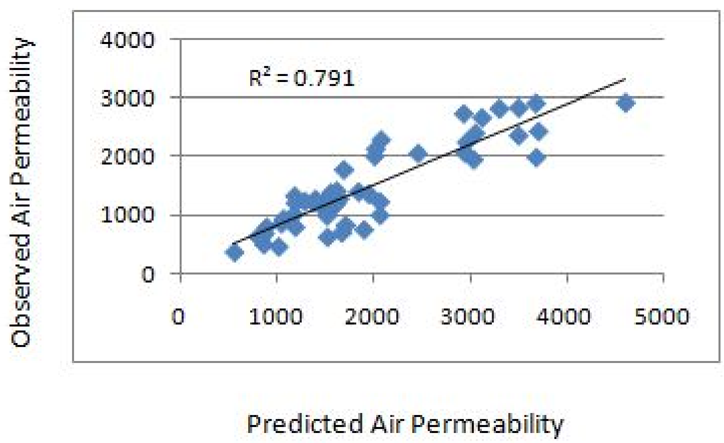

Figure 5. Regression coefficient of Additive Regression Algorithm for air permeability property

From additive regression algorithm, it is seen that the most important parameter which has a great effect on air permeability property of fabric is yarn diameter which is followed by yarn count. In addition to yarn diameter, the increase in loop length also causes an increment in the air permeability values of the fabrics which are followed by the fabric GSM. In Figure 5, the regression coefficient of the Additive Regression Algorithm is given.

The descriptive statistics of all models for the estimation of the air permeability of the 100% cotton single jersey fabrics are shown in Table 6.

Table 6. Descriptive statistics of all models to predict air permeability

Parameters	**Model-01 (ANN)**	**Model-02 RFA**	**Model-03 (ARM)**
Correlation coefficient	**0.9623**	**0.9462**	**0.8932**
Mean absolute error	250.218	323.6335	435.6671
Root mean squared error	300.89	445.1247	622.2425
Relative absolute error	25.6384	30.0678	34.5138
Root relative squared error	32.198	33.1966	45.0098

According to the result of root mean square value, the error of ANN is less than RFA and ARM. The correlations of air permeability between the experimental values and the predicted values of ANN, RFA, and ARM models were found to be 0.9623, 0.9462 and 0.892 respectively. Outputs obtained from both ANN and RFA predictions were found closer to experimental results. But according to the correlation, it can be conveniently said that the ANN outputs are more reliable than RFA and ARM outputs to describe real values of fabric air permeability. By comparing all the results from the table 5 that ANN outputs are more compatible with experimental results than RFA and ARM.

Conclusion

In this study ANN, RFA and ARM methods were used for prediction of air permeability properties of 100% cotton single jersey fabrics. At first, air permeability values of fabrics, related fabric parameters were measured and experimental results were obtained. When the experimental results were evaluated, loop length and yarn linear density were found as the most effective parameter on air permeability. Moreover, the tightness factor 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 a decrease in air permeability. When the performance of these three different modeling methods are examined, it was found that ANN and RFA models give closer results to the experimental ones than ARM. As a conclusion, in all analysis, descriptive statistics such as root mean square error, absolute error means and coefficients of correlation are better in neural network architectures than those in Random Forest Algorithm and Additive Regression Algorithm. By optimizing these models, it could be possible to predict air permeability behavior of fabrics before producing them, only by specifying the fabric parameters, which will be helpful for the researcher as well as factory people.

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