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INVESTIGATION AND MODELING OF THE BAGGING PROPERTIES OF KNITTED FABRICS MADE FROM RECYCLED YARNS

Banu ÖZGEN KELEŞ [*]
Elif YILMAZ [*]

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Abstract: The primary objective of this study is to investigate the bagging behavior of knitted fabrics produced from various fiber blends—namely recycled cotton/recycled polyester, recycled cotton/polyester, cotton/polyester, recycled cotton/acrylic, and cotton/acrylic—and to evaluate their suitability for home wear applications. The study further aims to compare these fabrics with those produced from virgin yarns and to model their bagging properties using artificial neural networks (ANNs). A total of 15 knitted fabric samples were produced using both recycled and virgin yarns in three different fabric structures: single jersey, rib, and interlock. The bagging performance of the fabrics was assessed through key parameters, including bagging hysteresis percentage, bagging fatigue percentage, residual bagging hysteresis percentage, and bagging resistance. Statistical analysis of the test results revealed that, depending on the yarn composition and fabric structure, the incorporation of recycled fibers in yarns led to improvements in certain bagging properties. These improvements were observed across all fabric types and knitting structures. Additionally, the ANN-based modeling demonstrated high accuracy in predicting the bagging behavior of recycled knitted fabrics, thereby offering a valuable tool for optimizing fabric design before production.

Keywords: Recycled fiber blended yarn, knitted fabric, fabric bagging property, artificial neural networks, modeling

Geri Dönüşüm İpliklerden Üretilen Örme Kumaşların Torbalanma Özelliğinin İncelenmesi ve Modellenmesi

Öz: Bu çalışmanın temel amacı, geri dönüşümlü pamuk/geri dönüşümlü polyester, geri dönüşümlü pamuk/polyester, pamuk/polyester, geri dönüşümlü pamuk/akrilik ve pamuk/akrilik olmak üzere çeşitli elyaf karışımlarından üretilen örme kumaşların torbalanma davranışını incelenmek ve ev giyim uygulamaları için uygunluğunu değerlendirmektir. Çalışmanın diğer amacı bu kumaşları orijinal ipliklerden üretilen kumaşlarla karşılaştırmak ve yapay sinir ağları (YSA) kullanarak torbalanma özelliklerini modellemektir. Üç farklı kumaş yapısı (süprem, ribana ve interlok) kullanılarak hem geri dönüşümlü hem de orijinal iplikler kullanılarak toplam 15 adet örme kumaş üretilmiştir. Kumaşların torbalanma performansı, torbalanma gecikme yüzdesi, torbalanma yorulma yüzdesi, kalıcı torbalanma gecikme yüzdesi ve torbalanma direnci gibi temel parametreler aracılığıyla değerlendirilmiştir. Test sonuçlarının istatistiksel analizi, iplik içeriğine ve kumaş yapısına bağlı olarak geri dönüşümlü lif içeren ipliklerin kullanımının torbalanma özelliklerinde iyileşmelere yol açtığını ortaya koymuştur. Bu iyileşmeler tüm kumaş tiplerinde ve örgü yapılarında gözlemlenmiştir. Ayrıca, YSA tabanlı modelleme, geri dönüşümlü örme kumaşların torbalanma davranışını tahmin etmede yüksek doğruluk göstermiş ve böylece üretim öncesinde kumaş tasarımının optimize edilmesi için değerli bir araç sunmuştur.

Anahtar Kelimeler: Geri dönüşüm lif karışımlı iplik, örme kumaş, kumaş torbalanma özelliği, yapay sinir ağları, modelleme

[*] Ege University, Emel Akın Vocational Training School, İzmir, 35040, Turkey
Corresponding Author: Elif YILMAZ (elif.yilmaz@ege.edu.tr)

1. INTRODUCTION

Textile products undergo shape changes by being exposed to various dynamic and static forces during their use. Shape changes are not permanent unless the loads applied to the fabric are too high or too long due to the elasticity of the fibers. Fabrics tend to stretch and adapt to the wearer's body movements as much as the fabric allows. However, repetitive body movements and excessive loads on the fabric can turn into permanent deformations, caused by the plastic deformation of the fibers (Başer, 2008).

The recovery amount of woven and knitted fabrics produced from conventional yarns after stretching is limited. When the permanent elongation values of the fabrics are 3% and above, deformations are observed especially in areas such as elbows and knees where joint movements are intense. (Kurban and Babaarslan, 2019). Clothes, especially those made of knitted fabrics, become deformed after being used for a certain period of time, and this situation, which negatively affects the aesthetic appearance of the garment, is called bagging. The fabric is under multi-directional stress during the formation of bagging deformation, which occurs as a result of constant mechanical movements, especially in the knee and elbow areas. This situation reduces the lifespan of the product over time. A garment that has lost its original shape due to bagging in various areas will no longer be preferred by the user due to its poor aesthetic appearance and will eventually be discarded (Zhang et al. 1999a). This, in turn, will lead to an increase in consumption waste and, consequently, environmental pollution. However, as sustainability gains importance and terms like waste recovery and recycling become more common, textile products that become waste solely due to bagging contradict the principles of sustainability. This makes the issue of bagging not only an aesthetic concern but also a critical factor in reducing consumption waste and environmental pollution. Additionally, scientific studies are being conducted on recycled textiles, and mechanical properties of recycled yarns and fabrics are being investigated (Sari et al., 2024; Muthukumara and Thilagavathi, 2024; Gun and Kuyucak, 2022; Uyanık, 2021; Gun and Oner, 2019; Sarioglu, 2019). In our previous studies (Yılmaz and Ozgen, 2023; Yılmaz and Ozgen, 2024), the recycled cotton/polyester fabrics' mechanical performance properties such as circular bending rigidity, dimensional change and weight loss after repetitive laundering, and air permeability and bursting strength properties were examined. In line with this perspective, this study examined the fabric bagging properties of fabrics with different knitting structures produced from recycled yarns with various raw material mixtures, which have not been studied before in the literature, and compared them with those made from original yarns. A limited number of studies on the bagging behavior of knitted fabrics were found in the literature research (Sülar and Seki, 2018; El Messiry and Mohammed, 2016; Karimian et al., 2013; Hasani and Zadeh, 2012; Jaouachi et al., 2010; Bouatay and Ghith, 2014). Wan et. al. (2025) evaluated how different yarn materials—PET, Coolmax®, PBT, and Sorona®—influence the bagging recovery, elasticity, and moisture management of warp-knitted fabrics designed for sportswear. Panahi et. al. analyzed the dynamic elastic recovery of four weft knitted fabrics with different elastic properties. It finds that higher elasticity improves recovery and reduces pressure on the body, enhancing comfort during activities like walking and running. Sular and Seki (2018) provide a comprehensive review of fabric bagging, a permanent three-dimensional deformation that affects garment aesthetics and durability, by exploring its definitions, influencing factors, and various measurement techniques. It emphasizes the need for standardized testing methods to better evaluate and compare fabric performance under stress. In these studies, fabric bagging behavior is described as a complex condition resulting from the interactions between fabric parameters such as fiber, yarn and fabric properties. However, none of the studies have investigated the bagging properties of fabrics made from yarns containing recycled fibers, nor have they compared them with fabrics made from conventional yarns. In this regard, it is believed that there is a need for more research on the bagging behavior of knitted fabrics produced from recycled yarns and the study's findings will fill the gap in literature. Furthermore, this study is pioneering in predicting the bagging properties of recycled knitted fabrics before production using the neural network modeling method.

2. MATERIALS AND METHODS

2.1. Materials

Recycled yarns obtained by mixing cotton, polyester and acrylic fibers in certain proportions were used in the production of knitted fabrics. The yarns were obtained from various companies that produce recycled yarn. The supplied recycled yarns were produced with open-end rotor production technology, and they were selected in the yarn count (Ne 20) that is mostly preferred by major companies operating in the textile and apparel sector in the production of knitted fabrics. Information about the yarns is given in Table 1.

Table 1. Yarn properties used in fabric production

Yarn code	Yarn count (Ne)	Fiber content	Tensile strength (N)	Yarn uniformity U%	Hairiness (H)
Y1	18.57	50% recycled cotton – 50% recycled polyester	2.15	11.23	5.82
Y2	19.65	50% recycled cotton – 50% polyester	3.38	12.53	5.66
Y3*	19.61	50% cotton – 50% polyester	3.47	10.64	5.31
Y4	18.80	50% recycled cotton – 50% acrylic	2.86	11.25	10.40
Y5**	19.65	50% cotton – 50% acrylic	3.44	10.79	9.93
**Reference yarn 1* ** *Reference yarn 2*					

Within the scope of the study, single jersey, rib and interlock knitted fabrics were produced from recycled cotton/polyester, recycled cotton/recycled polyester and recycled cotton/acrylic yarns by keeping the production parameters constant for each fabric structure. The production of single jersey fabrics was carried out on the Mesdan laboratory type circular knitting machine and the production of rib and interlock fabrics was carried out on the Fouquet circular knitting machine (Yılmaz and Ozgen, 2023). The properties of the fabric samples produced are given in Table 2.

Table 2. Fabric properties

Fabric code	Knit structure	Yarn code	Fabric thickness (mm)	Fabric weight (g/m²)	Stitch length (mm)
1S	Single jersey	Y1	0.57	127.50	4.41
2S		Y2	0.57	124.70	4.45
3S*		Y3	0.56	125.40	4.27
4S		Y4	0.62	129.10	4.46
5S*		Y5	0.59	120.00	4.53
1R	Rib	Y1	0.99	205.90	3.87
2R		Y2	1.01	203.00	3.92
3R*		Y3	0.99	201.70	3.91
4R		Y4	1.06	211.80	3.95
5R*		Y5	1.05	219.00	3.84
1I	Interlock	Y1	0.98	287.10	3.86
2I		Y2	0.98	287.10	3.86
3I*		Y3	0.94	287.90	3.86
4I		Y4	1.08	311.30	4.01
5I*		Y5	1.02	301.00	3.91
**Reference fabric samples made of virgin fiber blended yarns*					

As is seen from Table 2, 9 different types of test samples were produced in 3 different knitting structures using 3 different recycled cotton blended yarns (Y1, Y2 and Y4). In addition, 6 reference fabric samples were produced in single jersey, rib and interlock structures with 2 different reference yarns (Y3 and Y5) to compare the properties of the recycled fabrics produced as test samples.

2.2. Methods

2.2.1. Bagging measurement

Fabric bagging properties can be examined using both subjective and objective methods. Subjective methods include measuring bagging height and bagging shape from photographs and subjective evaluation scales. Objective methods include unidirectional tensile tests, ball penetration tests adaptable to a tensile tester, an artificial arm simulating elbow movement, and the application of hydrostatic or pneumatic pressure using a bursting strength tester (Sülar and Seki, 2018).

Since there is no established standard for fabric bagging in the literature, the experimental design employed in this study was developed by adapting previously reported methods of Yokura et al. (1986), Zhang et al. (1999a, 1999b) and Movahed et al., (2017). In this study, a mechanical bagging test was used as an objective method to measure the bagging values of knitted fabrics. In this method, the bagging test was carried out by applying force vertically at a constant speed (200 mm/min) from a steel ball to a fabric sample of a certain diameter (10 cm) in a Zwick/Roell Z010 universal testing machine (Figure 1). Prior to testing, all fabric specimens were conditioned for 24 hours under controlled conditions (20 ±2 °C and 65 ±5% relative humidity) to ensure uniform moisture content and to reduce variability between tests. The process of applying load to the fabric was carried out in 5 consecutive cycles, and the applied load and work done values were determined for each cycle. Bagging parameters (Movahed et al., 2017) were calculated from the bagging test results with the following equations.

$$Bagging\ fatigue\ percentage\ (\%) = \frac{Work\ of\ first\ cycle's\ loading - Work\ of\ last\ cycle'sloading}{Work\ of\ first\ cycle's\ loading} x100 \quad (1)$$

$$Bagging\ hysteresis\ percentage\ (\%) = \frac{Work\ of\ first\ cycle's\ loading\ - Work\ of\ first\ cycle's\ unloading}{Work\ of\ first\ cycle'sloading} x100 \quad (2)$$

$$Bagging\ resistance = \frac{Work\ of\ first\ cycle's\ loading}{Sample's\ weight} \quad (3)$$

$$Residual\ bagging\ hysteresis\ (\%) = \frac{Hysteresis\ of\ first\ cycle - Hysteresis\ of\ last\ cycle}{Hysteresis\ of\ first\ cycle} x100 \quad (4)$$

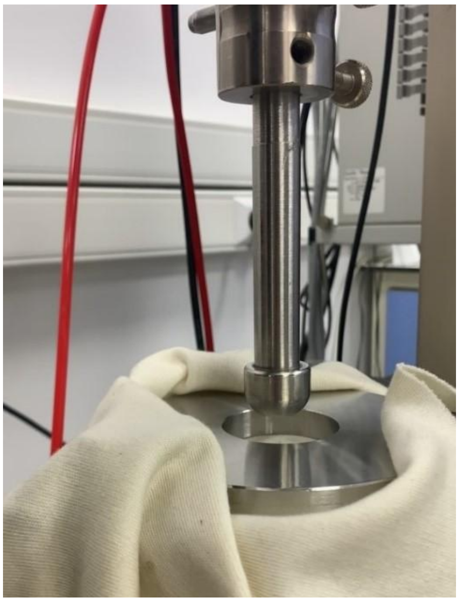

Figure 1:
Bagging test

2.2.2. Modeling of fabric bagging properties

Fabric properties are affected by many different parameters such as fiber type, spinning method used and yarn properties, and structural properties of the fabric. Therefore, examining fabric properties in relation to these parameters is a very complex issue. At this point, modeling methods that are frequently used to predict fabric properties are used (Sarkar et. al., 2021). Within the scope of the study, artificial neural networks technique, one of these methods, was used to predict the bagging properties of fabrics knitted from recycled yarn. Artificial neural networks technique is a data modeling and prediction tool that helps evaluate the relationship between all types of inputs and outputs.

An artificial neural network (ANN) models information processing by mimicking biological neural networks in the brain. It consists of layers of interconnected neurons, including an input layer, one or more hidden layers, and an output layer. Data flows through the network, where each neuron computes a weighted sum of inputs and applies an activation function to introduce non-linearity. Connections between neurons have weights that determine their importance, and biases shift the activation function. During forward propagation, input data is passed through the network, and a prediction is made. The loss function calculates the error between the predicted output and actual target, which is then propagated backward through the network in a process called backpropagation. This adjusts the weights and biases using optimization techniques like gradient descent to minimize error and improve the model. Over multiple training iterations (epochs), the ANN gradually learns to make more accurate predictions, making it effective for tasks such as classification, regression, and pattern recognition.

Applications of the artificial neural networks method in the textile industry date back to the 90s. Although this method has disadvantages such as requiring experience and focusing on the best results during analysis, it is successful in terms of classifying, matching, correlating and predicting data in solving multi-parameter and non-linear problems (Çörekçioğlu et. al., 2021). Figure 2 shows the artificial neural network modeling structure used in this study.

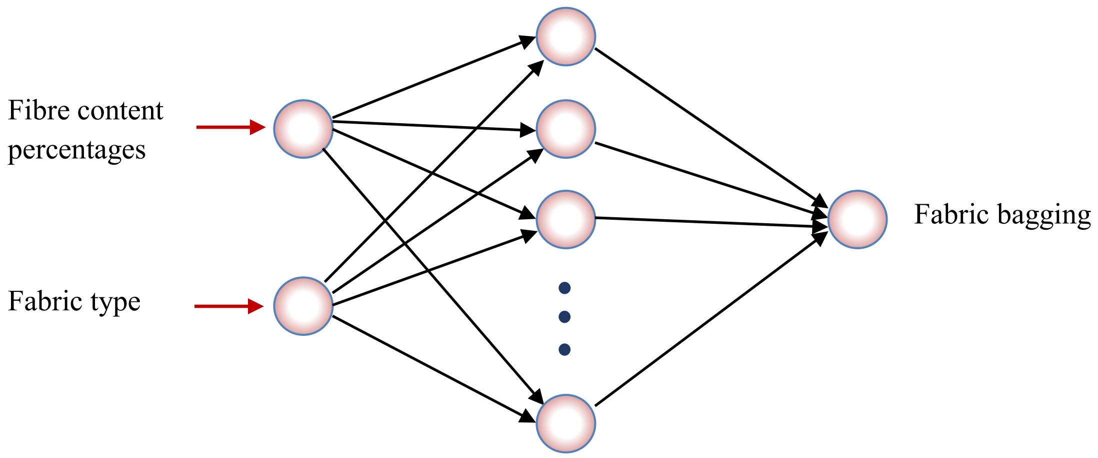

Figure 2:
Artificial neural network model

For modeling, artificial neural network models were designed using the Neural Network interface of the MATLAB R2021b package program. Since studies (Eyupoglu et al., 2021, Sarkar et al., 2021) have shown that the Levenberg-Marquardt (More, 1978) algorithm is one of the most functional neural network training algorithms, this algorithm was used to train the proposed feed-forward back-propagation neural network model. The training subset was first loaded into the neural network in the Levenberg-Marquardt algorithm, and the network was trained by updating the network parameters and using the differences between the output and target values. After this process, another subset of parameters was used to validate the network. These processes were repeated several times until the mean square error (MSE) reached the minimum error value to ensure the required training accuracy. MSE was calculated with the following formula:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(y_i' - y_i)^2 \tag{5}$$

In this equation, y represents the value obtained as a test result and y' represents the predicted value. Gradient Descent with Momentum (GDM) learning algorithm was applied for the learning algorithm in MATLAB software. In this study, TANSIGMOID transfer function was used as the hidden layer transfer function to produce faster output rates. The tansigmoid transfer function was selected in this study primarily due to its non-linear mapping capability, which makes it especially effective in modeling complex, multi-parameter relationships like those observed in textile behavior prediction. In this case, the objective was to model the bagging properties of knitted fabrics based on inputs such as fiber composition and knitting type, both of which exhibit inherently non-linear interactions.

Experimental data obtained from the bagging test were used to train the designed artificial neural network model. By introducing experimental data as input to the model, the bagging properties of recycled yarn knitted fabrics were estimated for different parameter values and the artificial neural network model that gave the least error was determined. Parameters affecting fabric bagging properties are listed as raw material type, knitting structure, knitting density, yarn twist and yarn count. (Uçar et.al., 2002; El Messiry and Mohamed, 2016; Hassani and Zadeh, 2012; Karimian et al., 2013). However, in the study, the effect of raw material type and knitting structure was investigated by keeping density, yarn twist and count parameters constant. For this reason, the cotton, polyester and acrylic type (virgin or recycled) and knitting structure (single jersey, interlock, rib) in the fabric content were determined as input variables in modeling the fabric bagging feature.

2.2.3. Statistical Analysis

The statistical analysis was conducted using SPSS 25.0 Statistics Software. To determine whether the data obtained from the bagging test followed a normal distribution, a normality test was performed. The Shapiro-Wilk test was used for normality testing, and it was found that the data for the bagging hysteresis, bagging fatigue, bagging resistance, and residual bagging hysteresis parameters followed a normal distribution ($p>0.05$). All data were analyzed using one-way analysis of variance (ANOVA). Post-hoc analysis was performed using Bonferroni's test to account for multiple comparisons.

3. RESULTS AND DISCUSSIONS

3.1. Bagging Test Results

Bagging test results of the fabrics are given in Table 3.

Table 3. Bagging test results

Bagging parameters	Bagging fatigue (%)		Bagging resistance (N.mm/g)		Bagging hysteresis (%)		Residual bagging hysteresis (%)	
Fabric code	**Mean**	**St.dev (±)**	**Mean**	**St.dev. (±)**	**Mean**	**St.dev. (±)**	**Mean**	**St.dev. (±)**
1S	87.27	3.56	804.15	194.68	84.42	1.68	24.31	1.70
2S	88.27	0.85	615.68	201.27	85.27	1.04	25.27	0.91
3S	87.93	0.59	613.27	75.81	84.90	1.61	24.23	2.49
4S	83.86	1.99	757.82	313.37	82.89	1.02	20.72	1.85
5S	88.96	1.17	711.15	160.61	87.24	2.41	24.42	1.08
1R	91.42	1.05	640.72	115.97	85.44	1.00	25.30	1.27
2R	89.48	2.46	482.95	152.85	81.32	5.14	26.05	7.63
3R	85.35	4.16	521.65	114.20	79.88	2.33	25.16	10.76
4R	79.52	4.78	392.06	69.00	77.00	4.31	15.59	5.14
5R	86.62	0.81	406.28	40.42	84.85	0.98	22.59	0.70
1I	86.47	3.59	709.72	82.71	83.07	1.23	28.83	1.39
2I	88.01	1.86	1067.67	155.18	85.30	1.52	27.45	1.89
3I	87.42	0.50	946.57	139.96	85.04	1.09	25.25	1.22
4I	86.61	1.24	622.56	64.32	84.04	0.69	24.14	0.84
5I	89.17	2.21	643.78	29.97	84.43	2.43	23.55	2.26

The data obtained from the bagging test were statistically analyzed by grouping them according to the fabric type. The results of the ANOVA test are presented in Table 4.

Table 4. ANOVA test results

Fabric type	Parameters	p-value
Single jersey	Bagging fatigue (%)	0.013*
	Bagging resistance	0.683
	Bagging hysteresis (%)	0.017*
	Residual bagging hysteresis (%)	0.007*
Rib	Bagging fatigue (%)	0.001*
	Bagging resistance	0.051
	Bagging hysteresis (%)	0.024*
	Residual bagging hysteresis (%)	0.197
Interlock	Bagging fatigue (%)	0.550
	Bagging resistance	0.001*
	Bagging hysteresis (%)	0.309
	Residual bagging hysteresis (%)	0.050
*Statistically significant ($p<0.05$)		

As shown in Table 3, the use of recycled cotton fiber in cotton/acrylic blended knitted fabrics reduces the percentage of bagging hysteresis, bagging fatigue, and residual bagging hysteresis, while increasing bagging resistance. In other words, the use of recycled cotton/acrylic blended yarn positively affects the bagging properties of single jersey fabrics more than virgin cotton/acrylic yarn. Recycled cotton fibers are typically shorter and may have more irregular surfaces due to prior use and mechanical processing. These structural changes can make the fibers less extensible and slightly stiffer compared to virgin cotton. Thus, this stiffness may have limited excessive stretching and helped the fabric recover more effectively after deformation (less hysteresis), improving bagging resistance. Moreover, acrylic fibers are synthetic and elastic, offering flexibility and resilience. The contrast between stiffness of recycled cotton and elasticity of acrylic might create a balanced matrix that helps redistribute and absorb mechanical stress and allows the fabric to spring back more efficiently after stretching. The loose fabric construction of single jersey might have amplified these effects by making fabric behavior more sensitive to fiber elasticity and surface roughness. Moreover, due to its thinner and lighter construction compared to rib and interlock, single jersey fabrics allow fiber properties to more directly influence performance. Statistical analysis results support the experimental data. According to Table 4, it is seen that yarn type has a significant effect on the percentages of bagging fatigue (p=0.013), bagging hysteresis (p=0.017), and residual bagging hysteresis (p=0.007) parameters of single jersey fabrics. Post hoc tests revealed a significant difference between the 4S and 5S coded fabrics for the percentages of bagging fatigue ($p_{4S\text{-}5S}$=0,018), bagging hysteresis ($p_{4S\text{-}5S}$=0.010), and residual bagging hysteresis ($p_{4S\text{-}5S}$=0.045). On the other hand, it was determined for single jersey fabrics knitted with cotton/polyester blended yarn, the use of recycled cotton and/or recycled polyester yarn instead of virgin yarn does not result in a significant difference in terms of fabric bagging properties. In cotton/polyester blends, polyester typically plays a stronger role in controlling deformation and recovery because of its high modulus and recovery efficiency. So, whether cotton is virgin or recycled, polyester stabilizes the fabric, minimizing the differences in bagging properties. This could mask the effect of recycled cotton, resulting in no significant change.

When Table 3 is examined, it is observed that the percentage of bagging fatigue and bagging hysteresis in rib fabrics decreases consistently when virgin blend yarns are used instead of recycled cotton/recycled polyester (Y1), recycled cotton/polyester (Y2) and recycled cotton/acrylic (Y4) yarns. Rib fabrics are inherently more elastic due to their looped fabric structure, which is more responsive to compressive forces. In this context, virgin yarns performed better in terms of bagging resistance, possibly due to their smoother surfaces and higher tensile strength. Recycled fibers, with their irregular structure, may disrupt the uniform loop formation in rib fabrics, leading to uneven stress distribution and greater permanent deformation after repeated use. The statistical analysis results also show that yarn type has a significant effect on rib fabrics in terms of the percentages of bagging fatigue (p=0.001) and bagging hysteresis (p=0.024) parameters. Additionally, according to the post hoc tests, a significant difference was found between the 1R and 4R coded rib fabrics for the percentages of bagging fatigue ($p_{1R\text{-}4R}$=0.001) and bagging hysteresis ($p_{1R\text{-}4R}$=0.038).

According to Table 4, it is evident that yarn type also significantly affects the bagging resistance of the interlock fabrics (p=0.001). When this result is compared with the experimental data, it was observed that 2I coded fabric, knitted from recycled cotton/polyester yarn, exhibits the highest bagging resistance, while the 4I coded fabric, knitted from recycled cotton/acrylic yarn, exhibits the lowest bagging resistance among all interlock fabrics. Post hoc test results indicate that significant differences in multiple comparisons of bagging resistance are between the fabrics coded 1I and 2I ($p_{1I\text{-}2I}$=0.009), 2I and 4I ($p_{2I\text{-}4I}$=0.003), 2I and 5I ($p_{2I\text{-}5I}$=0.004), 3I and 4I ($p_{3I\text{-}4I}$=0.019), and 3I and 5I ($p_{3I\text{-}5I}$=0.030). Interlock fabrics showed a distinct response to the type of yarn used. The high density and double-knit structure of interlock fabrics generally provide stability. The improved bagging resistance observed in fabric 2I (made from recycled cotton/polyester) can be attributed to polyester fiber's role in maintaining the fabric's dimensional stability, while recycled cotton added a slight rigidity that helped limit excessive stretching. In contrast, fabrics made from recycled cotton/recycled polyester exhibited lower bagging resistance, likely due to the combined effect of lower mechanical properties of both fiber types, which led to increased fabric deformation. In accordance with the experimental data and statistical analysis results, it can be concluded that the use of recycled cotton fiber in interlock fabrics made from cotton/polyester blended yarn increases bagging resistance compared to the use of virgin cotton fiber. Therefore, it is recommended to use recycled cotton/polyester blended yarns instead of original yarns to improve the fabric's bagging properties. However, when recycled cotton/recycled polyester blended yarn is used, the fabric's bagging resistance significantly decreases. Therefore, if recycled yarn is to be used, recycled cotton/polyester blended yarn should be preferred. On the other hand, although the bagging resistance of interlock fabrics knitted from recycled cotton/acrylic blended yarn is lower than that of virgin cotton/acrylic blended yarn, the fact that this difference is not statistically significant suggests that recycled yarn can be used instead of virgin yarn. Additionally, no significant differences were found between the bagging fatigue, bagging hysteresis and residual bagging hysteresis ($p>0.05$).

3.2. Bagging ANN Results

Modeling with artificial neural networks technique consists of a structure consisting of at least three layers: input layer, hidden layer(s) and output layer. Fiber content percentages and knitting type were determined as variables in the input layer in the modeling study carried out to predict the bagging properties of knitted fabrics produced with different combinations of recycled and original cotton, polyester and acrylic fibers. Models that predict the real measurement data with the least error have been identified by changing the number of hidden layers and the number of neurons in these layers. The condition in which the maximum regression value was obtained in terms of training, testing and validation was accepted as the final model infrastructure.

Among the modeling experiments carried out based on the bagging fatigue percentage (BFP) values, the artificial neural network model with two hidden layers and 10 and 20 neurons in these layers, respectively, was found to be the best predictive model. The number of hidden layers and neurons in the ANN model was determined through a systematic trial-and-error approach, supported by empirical performance evaluation using regression accuracy and mean squared error (MSE) as benchmarks. Table 5 shows the predictions of some models with different numbers of hidden layers and different numbers of neurons in the layers, and the percentage differences between these prediction values and the actual measurement values.

Table 5. Measured and predicted values of bagging fatigue percentage and error percentages with different artificial neural network models

F. Code	Measured BFP values	Values predicted by models				Percent difference between measured and predicted values (%)			
		N=25	N=40	N=10-20	N=25-20	N=25	N=40	N=10-20	N=25-20
1S	87.27	87.27	87.27	87.28	87.17	0.00	0.00	0.01	0.11
2S	88.27	88.27	88.27	88.21	88.21	0.00	0.00	0.07	0.07
3S	87.93	87.93	87.72	88.21	87.95	0.00	0.23	0.32	0.02
4S	83.86	82.90	83.86	83.86	83.78	1.14	0.00	0.00	0.10
5S	88.96	88.96	89.06	88.96	88.96	0.00	0.12	0.00	0.00
1R	91.42	91.42	91.42	91.41	91.33	0.00	0.00	0.01	0.09
2R	89.48	89.72	89.48	89.38	89.42	0.27	0.00	0.11	0.07
3R	85.34	85.60	85.34	85.34	85.27	0.30	0.00	0.00	0.08
4R	79.52	79.52	79.52	79.52	80.55	0.00	0.00	0.00	1.30
5R	86.62	86.79	85.98	86.55	86.24	0.19	0.74	0.09	0.44
1I	86.47	86.47	86.22	86.47	86.38	0.00	0.29	0.00	0.10
2I	88.01	88.01	88.01	88.46	88.28	0.00	0.00	0.52	0.30
3I	87.41	87.41	87.41	87.41	87.46	0.00	0.00	0.00	0.06
4I	86.61	86.61	86.61	86.51	86.56	0.00	0.00	0.11	0.06
5I	89.17	89.17	89.17	89.17	89.16	0.00	0.00	0.00	0.01

*N is number of neurons in hidden layers

Models that make predictions with the least error are given in Table 5. As seen in the table, the measured and predicted values gave very close results to each other. The regression (R) and average error values of the artificial neural network models selected above are shown in Table 6.

Table 6. Regression and mean error results of selected models

Number of hidden layers	Number of neurons in layers	Regression (R)	Mean error
1	25	0.9957	0.11
1	40	0.9979	0.08
2	10-20	0.9986	0.07
2	25-20	0.9957	0.16

The regression values of the 4 different models selected are above 0.99. These results show that the models created can predict bagging fatigue percentages with high accuracy. The graphs of the regression results of the training, validation and testing subsets of the model, which was found to be the most successful with the highest regression value (0.99861) among these models, are given in Figure 3.

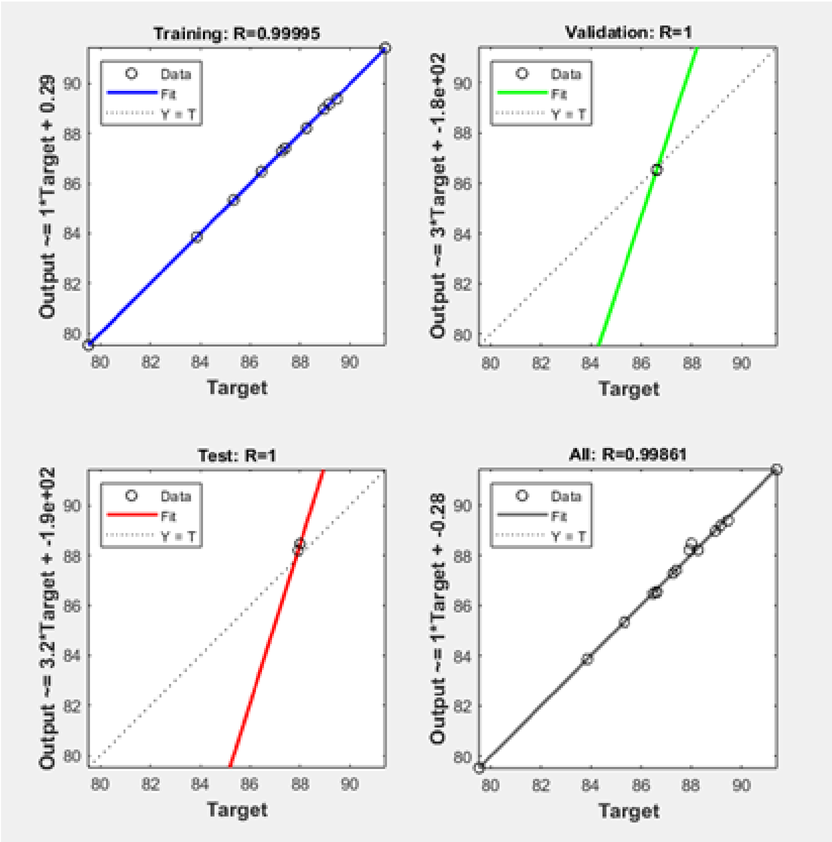

Figure 3:
Regression results of the artificial neural network model for bagging fatigue percentage (2 hidden layers, 10-20 neurons)

All R values are extremely close to 1 which indicates near-perfect correlation between the predicted values and the actual data for bagging fatigue percentage. Especially having R = 1 for Validation and Test sets means the model generalizes exceptionally well to unseen data. The results also showed that the model has learned the training data very well without overfitting, since the test and validation scores are just as high.

3. CONCLUSION

This study aimed to reveal the effects of using recycled yarn with different raw material contents on the bagging properties of knitted fabrics by comparing them with fabrics produced from virgin yarn. For this purpose, knitted fabrics in three different knitting types were produced from yarns with binary blend of recycled cotton/recycled polyester, recycled cotton/polyester, virgin cotton/polyester, recycled cotton/acrylic, and virgin cotton/acrylic fibers, and the performance properties of these fabrics were examined. In addition, the bagging properties of the fabrics were modeled using the artificial neural network technique, allowing the fabric properties to be predicted before fabric production.

As a result of the mechanically performed bagging test within the scope of this study, which investigated the bagging properties of fabrics made of recycled yarns for the first time, it was determined that yarn type has a significant effect on the bagging properties of knitted fabrics, including bagging fatigue, bagging hysteresis, and residual bagging hysteresis. Specifically, the use of recycled cotton/acrylic blended yarn in single jersey fabrics resulted in a significant improvement in bagging resistance while reducing bagging fatigue and hysteresis compared to virgin cotton/acrylic yarn. In contrast, for cotton/polyester blended fabrics, the use of recycled cotton fiber blended yarn instead of virgin cotton blended yarn did not show a statistically significant difference in terms of bagging properties when compared to virgin yarns, suggesting that recycled cotton and/or recycled polyester do not adversely affect fabric performance in this regard. The analysis of rib fabrics also demonstrated significant differences between yarn types, particularly in the bagging fatigue and bagging hysteresis parameters, where virgin yarns consistently performed better than recycled cotton/polyester and recycled cotton/acrylic blends. Similarly, interlock fabrics exhibited a significant variation in bagging resistance, with recycled cotton/polyester yarns yielding higher resistance than recycled cotton/acrylic blends. Overall, the statistical findings reinforce the experimental data and support the conclusion that recycled cotton/polyester blended yarns offer superior bagging resistance without compromising fabric performance. These results highlight the potential of recycled yarns to be utilized in textile production, offering a sustainable alternative without significant loss in quality, particularly in terms of bagging property.

In this study, artificial neural networks were successfully employed to predict the bagging properties of knitted fabrics produced with different combinations of recycled and virgin fibers. The optimal model, consisting of 2 hidden layers and 10 and 20 neurons, was determined as the best predictor for bagging fatigue percentage with a high regression value of 0.99861. These results confirm that ANNs can be a powerful tool in predicting fabric bagging properties, offering a reliable method for fabric performance evaluation.

CONFLICT OF INTERESTS

The authors confirm that there is no conflict of interest or common interest with any person or institution/organization.

AUTHOR CONTRIBUTION

The conceptual framework development, identification and management of the design processes, and data collection were jointly conducted by Banu Özgen Keleş and Elif Yılmaz. Elif Yılmaz was responsible for performing the statistical analyses, whereas Banu Özgen Keleş conducted the artificial neural network (ANN) modeling. Both authors equally contributed to the final approval of the manuscript and share full responsibility for the work.

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