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Study on Strength Properties of Woven Fabrics Including Recycled Cotton Yarns

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Abstract
In this study, yarn was produced by mixing pre-consumer cotton yarn waste and original cotton fibers in certain proportions and plain sheet fabrics were woven using these yarns. Within the scope of the study, yarns with cotton/recycled cotton fiber ratios of 100-0%, 90-10%, 80%-20%, 70-30%, 60-40% were used. All fabrics were subjected to finishing processes respectively under the same conditions. Breaking strength and tear strength tests were carried out to understand the effect of the recycling rate on the strength loss in fabrics. It was determined that there was a decrease of nearly 45% in the tear strength of fabrics obtained by mixing 40% recycled fiber. Additionally, the loss in tensile strength was less than the loss in tear strength.

1. Introduction

Recycling processes have become more important due to the increasingly depleting natural resources and environmental problems in the world. The textile industry is one of the sectors that harms nature the most. Whereas, many products in the textile industry are recyclable. On condition that the textile waste is systematically collected and utilized, textile recycling can be a viable and sustainable industry [1]. The most important solution to prevent environmental damage both in the production phase and end use is recycling [2]. In other words, it is the reuse of the fibers of old textile products [3]. It is very crucial to evaluate the recycling issue in textile products under a single heading, since the machinery, energy types, costs and raw materials used during production, environmental interactions occurring in the processes and the recycling potential of the products are not the same [4].

Textile production processes consume large amounts of natural resources (water, oil, soil), toxic chemicals are used, and this releases carbon dioxide. In addition, millions of tons of textiles are thrown away every year. Many studies are being carried out in the textile sector on minimizing and recycling this waste. A single cotton t-shirt requires 2,700 liters of water. The World Wildlife Fund argues that 20,000 liters of water are required to produce 1 kilogram of cotton, that current production methods are unsustainable, and that by using cotton obtained from discarded clothing, the need for virgin cotton can be reduced and billions of gallons of water can be saved with post-consumer recycled products [37].

It is seen that approximately one million tons of textile waste is generated in Turkey every year. These wastes are recyclable. If this recovery can be fully realized, the amount of recycled cotton to be obtained will meet 17% of the country's seed cotton production. 766,390 hectares of land, corresponding to 17% of Turkey's cultivated area for cotton production, can be used for another agricultural product. 29% of pesticides used in Turkey are used in cotton production. This situation causes significant losses in wildlife in regions where cotton production is intense, such as Çukurova. Recycling of these wastes will also prevent the amount of pesticides that would be used for the same amount of cotton production [8]. Recycled cotton yarn is a valuable alternative to cotton resources, and by using recycled cotton yarn, agricultural land and water will be saved, and CO2 emissions will be reduced.

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To recover fibers from textile wastes and use them in conventional textile processes in the future, the wastes must be opened and separated into fibers [5]. Depending on the end use of the yarn, the fibers may remain combined. Then, through the carding process, the fibers are cleaned and mixed and made ready for spinning for subsequent weaving or knitting processes [6].

Recycling takes place largely in spinning, and recycled fibers are mostly used, especially in the open-end rotor spinning system, where shorter fibers are used compared to the ring spinning system [7].

The wastes that arise during the ready-made garment phase are fabric pieces at the beginning and end of the fabric roll (approximately 15% of the total fabric), scraps and faulty fabric pieces during marker cutting [4]. The amount of waste generated during the carded yarn production phase in a ring mill is approximately 5.5-10.5%, in combed yarn production it is approximately 12%, and in the fabric production and ready-made garment stages, this rate rises up to 23% [8]. When the wastes during garment and yarn production are evaluated, a serious raw material can be gained.

Reusing the residues generated during cotton yarn production is an important recycling step. Cotton recycling is the process of converting cotton fabric into cotton fibers that can be used in textiles over again. Recycled cotton is sometimes also called regenerated cotton, reclaimed cotton, or poor-quality cotton. Recycled content includes parts that are used, refurbished, or rebuilt from scratch. Most recycled cotton products are made from pre-consumer trash, such as cutting residues. Post-consumer trash is more difficult to sort because it comes in many different colors and fabrics and generally requires more work [9].

Wastes are classified as pre-consumer waste and post-consumer waste according to their production stages. Pre-consumer wastes are the industrial wastes generated in fibrous products' manufacturing processes. Post-consumer waste refers to materials and products scrapped after their service life is over [10, 24]. A study was carried out on the production of products that create added value by utilizing textile waste. It has been shown that functional textile materials with high thermophysiological comfort and odor masking properties can be produced by converting waste into biochar and applying it to textile fabrics [11].

There are studies in the literature on the physical, mechanical and structural properties of recycled fabrics. It has been emphasized in many studies that the addition of recycled fibers negatively affects yarn strength and yarn unevenness [26]. It has also been observed that the air permeability values of fabrics obtained from recycled yarns and the effective clothing insulation of garments decrease, but the thermal resistance values increase [28,36]. The effects of waste fiber ratio and number of recycling transitions on yarn properties have been estimated with a mathematical approach [29]. One of the most important difficulties in recycled fabrics is the decrease in the mechanical properties of the produced fabric. For this purpose, optimization studies are being carried out on which fiber blend ratios or which techniques should be used for the production [30]. The effect of waste ratio on the properties of rotor yarns produced from raw cotton has been investigated and it has been stated that the waste ratio can be up to 25% [31]. The effects of production parameters such as rotor diameter, rotor speed, nozzle type, opening roller speed and yarn count on the use of recycled fiber in open-end spinning have been investigated [32, 33]. Dimensional and physical properties of socks produced from recycled yarns have been investigated [34]. The properties of raw and waste cotton blended yarns have been investigated using the parameters of recycling blend ratio, blend technique, drum speed and rotor speed [35]. Again, in the study on the use of waste in rotor yarns, it has been determined that the use of pneumophilic waste between 5-25% has a positive effect on the strength, elongation, irregularity and breakage numbers of yarns [41]. In some studies, only recycling and blends of weft yarns were used to reduce the loss of strength in woven fabrics. Especially if cotton is to be recycled, polyester fiber is used in the warp or as a blend to ensure fabric strength. [12,13]. Studies have also been conducted on the surface properties of recycled fabrics and woven fabric defects and decreases in fabric surface quality were observed [14].

It is possible to use 100% polyester fiber in recycled fabrics. There are studies in the literature on recycled polyester fabrics and yarn quality [15-19]. However, it has not yet been possible to produce durable fabric using 100% recycled cotton fiber. The biggest problem in this regard is that sufficient strength value cannot be provided [20,21].

There are very few studies in the literature on woven fabrics using recycled yarns in both weft and warp yarns. In studies conducted on denim fabrics, the air permeability, bending strength and dimensional change after washing of denim fabrics recycled after consumer use were determined according to standards and according to the results obtained, it was determined that this recycling process could be used effectively in denim production. As a result of the tests, it was evaluated that the recycled fiber added to the blend caused a decrease of approximately 15% in the warp and 10% in the weft in fabric strength, but this was within acceptable limits [38-40].

In this study, bed sheet fabrics were woven using recycled yarns in different ratios in both weft and warp directions and their strength values were examined. As it is known, bed sheet fabric is produced with low fabric weight and thin yarns. Therefore, the strength loss that will occur in thin fabric is more important than fabrics with higher fabric weight and woven with thicker yarns. Therefore, in this study, it was aimed to determine the highest recycling mixture ratio that can be used in bed sheet fabric and to obtain the mixture ratio that remains within the quality standards. For this purpose, the recycling ratio was increased in 10% increments and the changes in the strength properties were examined.

2. Material and Method

The study was conducted in an integrated textile factory producing home textiles, including yarn production, woven fabric production, finishing processes and testing processes. In order to examine the effect of cotton yarn recycling rate on fabric strength loss in fabrics produced with recycled yarns, 5 different yarns were used in both warp and weft directions.

In the mechanical recycling process, no chemicals are used and textile products are converted back into fiber without wet processing. Textile pre-consumer waste was converted into recycled cotton by mechanical method. In this study, 100% cotton waste, namely yarn spinning waste, generated in the winding section of the spinning mill of the factory was evaluated. Table 1 provides the properties of cotton and recycled cotton fibers. The properties of these fibers were measured using Uster AFIS Pro 2 with five specimens. used should be supported by previously published references. Changes that contribute to the method in the study should be described in detail [3], [4].

Table 1. Parameters of cotton and recycled cotton fibers

Parameters	Length (mm)	Short Fiber Content (uniformity) (%)	Fineness (micronare)	Strength (cN/tex)	Fiber Quality Index (FQI)
Cotton	28,78	8,6	3,93	29,5	216
Recycled cotton	20,7	19,5	4,13	27,7	139

FQI have been related fiber strength, mean length and fineness and defined by the following relationship [29, 42]:

$$\text{Fiber Quality Idex (FQI)}=(L\times S) / f \qquad (1)$$

where L = fiber length(mm), S = the fiber strength cN/tex, f = fiber fineness (mic).

The fiber, which is cotton waste in yarn production, was mixed with original cotton in four different mixing ratios. The proportions of recycled cotton and cotton blends are shown in Table 2. In order to determine the highest recycled fiber blend ratio and the best strength value in compliance with the standards, the recycled fiber blend ratio in the yarns was increased by 10 percent. These blends are 100-0%, 90-10%, 80%-20%, 70-30%, 60-40% cotton-recycled cotton. The yarns were produced in the open-end yarn department of the textile factory. For Ne 30 yarns, the twist coefficient is 4.16 in weft yarns and 4.79 in warp yarns.

Table 2. In yarns cotton / recycled cotton blend ratio

Fabric code		Material %
Weft Yarns	F1	100% cotton
	F2	90% cotton -10% recycled cotton
	F3	80% cotton -20% recycled cotton
	F4	70% cotton -30% recycled cotton
	F5	60% cotton -40% recycled cotton
Warp Yarns	F1	100% cotton
	F2	90% cotton -10% recycled cotton
	F3	80% cotton -20% recycled cotton
	F4	70% cotton -30% recycled cotton
	F5	60% cotton -40% recycled cotton

The properties of the produced woven fabrics are given in Table 3. Weft and warp yarns in all fabrics are Ne 30. In woven fabrics, both weft and warp yarns affect the physical and mechanical properties of the fabric. All fabrics are woven in the same density and plain pattern. All fabrics were subjected to finishing processes under the same conditions: burning+cold bleaching / drying / equalize / printing / fixation / finishing / sanforizing. Care has been taken to ensure that yarn production, weaving and finishing processes are carried out under the same conditions for all fabrics.

Table 3. Fabric production details

Parameter	Explanation
Yarn (Warp)	Ne 30, OE-Rotor
Yarn (Weft)	Ne 30, OE-Rotor
Weaving machine	Dornier HTV Jacquard Loom
Width of fabric	280 cm
Fabric structure	Plain 1/1
Weft density	27 ends/cm
Warp density	33 ends/cm
Mass per unit area (g/m2)	~120

After weaving and finishing processes, fabric unit weights (g/m^2) were measured to make comparisons for sheeting fabrics. Fabric unit area weight directly affects fabric properties. For this purpose, all fabrics were produced under the same conditions. In order to make reliable comparisons, it was aimed to ensure that the differences between fabric weights were insignificant. In order to see the mechanical behavior of the fabric against different effects, breaking force (warp/weft) and tearing strength (warp/weft) were measured. Unit fabric weight determination was performed according to TS 251 EN ISO 3801. Tensile strength tests were made according to TS EN ISO 13934-1 with the strip method using the commercial TINIUS OLSEN tensile testing device. The test length is 200 mm, the test speed is 100 mm/min and the width of the fabric samples is 50 mm. Since the fabric weight is less than 200 g/m², the pre-tension is 2 N. Tear strength tests were also carried out with test samples in the same device according to TS EN ISO 13937-2 (single tear test method). Tear strength tests were also applied in both warp and weft directions. Five samples were tested in weft and warp directions for each fabric type in terms of tensile properties of the fabrics.

The results obtained from these measurements were evaluated statistically by ANOVA and correlation analysis. The analysis was performed according to the 95% confidence level. Therefore, if the p value is less than 0.05, it means that the difference is statistically significant. The measurement results obtained from the tests carried out to determine the effects of recycled yarns used in weft and warp on the breaking and tearing strength of bed sheet fabrics were analyzed and evaluated. Additionally, the relationships between the blending ratio of fibers and fabric results were analyzed using correlation analysis.

3. Results and Discussion

3.1. Fabric Weight Results

Mean values of mass of fabrics per unit area are shown in Figure 1. As expected, there are very slight differences in fabric weights in terms of unit area mass of the fabrics.

The fabric weight planned before production is 120 gr/m^2, deviations are insignificant. Since the production and finishing stages are applied to each fabric under the same conditions, the fabric weights are very close to each other.

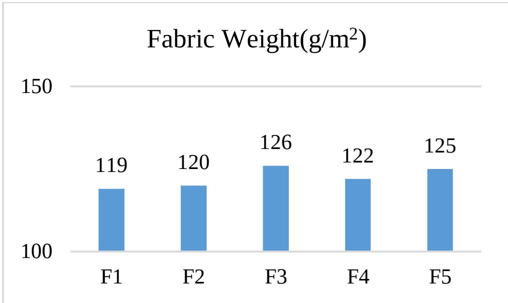

Figure 1. Fabric weight results

3.2. Breaking Strength Results

Mean values of breaking strength (warp/weft) are shown in Table 4. In order to determine the effect of recycled cotton ratio on the strength properties of the fabrics, breaking strength tests were conducted in the warp and weft directions of woven fabrics. It was determined that the breaking strength values of all fabrics, especially in the weft direction, were above 250 N and showed similar behavior. In the warp direction, a decrease in the breaking strength value was observed with a 10% increase in the recycling rate. When the effect of recycled fiber ratio on the breaking strength of the fabrics was evaluated, it was seen that the breaking strength values in both the warp and weft directions in fabrics obtained from recycled cotton fiber decreased compared to 100% cotton yarn. However, this decrease is lower than the values in the warp direction.

The fabric with the highest value for breaking strength is 100% cotton (F1). When F2 fabrics consisting of 90% cotton-10% recycled cotton fiber and F3 fabrics consisting of 80% cotton-20% recycled cotton fiber were evaluated in terms of breaking strength, a decrease in warp direction was observed. For F4 and F5 fabrics, this decrease continued in the warp direction by increasing the recycled cotton fiber ratio to 30% and 40%. While the breaking strength value in the warp direction in 100% cotton yarn was measured as 426 N, with the increase of the 10 percent recycled cotton rate, the warp breaking strength values were 397 N for F2, 367 N for F3, 355 N for F4, and 310.5 for F5.

Table 4. Fabric breaking strength and tear strength results (N) / breaking and tear strength loss results (%)

Fabric Code	Breaking Strength (N)		Tear Strength (N)		Breaking Strength Loss%		Tear Strength Loss %	
	warp	weft	warp	weft	warp	weft	warp	weft
F1	426	312	0	0	0	0	7,8	7,5
F2	397	308	-6,8	-1,3	-18,5	-24,1	6,36	5,69
F3	367	303,5	-13,8	-2,7	-29,5	-32	5,5	5,1
F4	355	286	-16,7	-8,3	-38,7	-42,7	4,78	4,3
F5	310,5	249,5	-27,1	-20	-39	-45,3	4,76	4,1

When the breaking strength values of fabrics in the weft direction were examined, it was seen that the breaking strength values in the weft direction decreased in fabrics obtained from recycled cotton fiber compared to 100% cotton yarn. However, this decrease is lower than the values in the warp direction. When evaluated for breaking strength, a decrease in weft was observed in F2 fabrics consisting of 90% cotton-10% recycled cotton fiber and F3 fabrics consisting of 80% cotton-20% recycled cotton fiber. However, there are no significant differences between the reduction rates. In F4 and F5 fabrics, this decrease continued with small differences in the warp direction in the breaking strength values by increasing the recycled cotton fiber ratio to 30% and 40%. While the breaking strength value in the weft direction in the fabric produced from 100% cotton yarn is measured as 312 N, with the increase of the 10 percent recycled cotton rate, the weft breaking strength values are 308 N for F2, 303.5 N for F3, 286 N for F4, 249 N for F5. While the weft breaking strength of F2, F3 and F4 fabrics was close to the F1 fabric, the lowest weft strength value was observed in 60% cotton-40% recycled cotton (F5), as expected.

The strength of yarns produced from cotton and recycled cotton blends decreases proportionally with the increase in the percentage of recycled fibers in the yarn content. Previously recycled cotton fibers contained a high percentage of short fibers due to the shredding process. While the short fiber content of the fibers used in yarn and fabric production was 8.6% for cotton, the short fiber content in recycled cotton was 19.5%. In addition, the Fiber Quality Index was calculated as 216 and 139 for cotton and recycled cotton fiber according to Formula 1. Globally, the quality of recycled fiber can be determined by the Fiber Quality Index (FQI). The high value of this value means that the fiber quality is also high. The results of the study also show that the quality of recycled fiber decreases compared to the quality of raw cotton [43]. During the draft loading performed while obtaining the yarn, the short fibers in the yarn are more prone to slipping instead of resisting the applied load and as a result, the yarn strength decreases. Therefore, the fabric strength woven with lower strength yarns is also low [24].

The warp and weft strength loss rates in fabrics woven using recycled cotton fiber at 10% increasing rates compared to the F1 fabric in which 100% cotton yarn is used in the warp and weft are given in Table 4. As the recycled fiber ratio increased, the strength values decreased inversely.

When the warp and weft directions were compared, it is seen that the warp breaking strength is higher than the weft breaking strength. Since woven fabrics have more threads in the warp direction, they are stronger in the warp direction, and generally more twist is given to the warp threads to provide the more strength they need during weaving. For this reason, in fabrics produced with the same yarn count and the same texture, warp breaking strength values were higher than weft breaking strength values.

TS 2994 Standard [25] has been produced by weaving or knitting, bed linen, bedsheet, quilt, duvet cover and pillowcase with those products occurs brought bedding for directions, classification and properties, sampling, involves the way supply the market with. The weft and warp breaking strength values of bed sheet fabrics produced according to this standard are expected to be greater than >178 N. Considering this standard value, it can be seen that the warp and weft breaking strengths of all samples are above the lower limit.

The loss in breaking strength values is higher in the warp direction than in the weft direction. As seen in Figure 2, when the graphic lines are examined, the decrease in the strength in the warp direction is greater than the decrease in strength in the weft direction.

The breaking strength loss rates in the warp direction compared to F1 fabric, which is 100% cotton in both warp and weft directions, are shown in Figure 2. Accordingly, the strength loss in the warp direction of F2, obtained by adding 10% recycled cotton compared to F1, was 6.8%. Warp strength loss was 13.8% at 20% recycled cotton, 16.7% at 30% recycled cotton, and 27.1% at 40% recycled cotton.

Compared to F1, the breaking strength loss in the weft direction of F2, obtained with the addition of 10% recycled cotton, was 1.3%. Weft strength loss was 2.7% for 20% recycled cotton, 8.3% for 30% recycled cotton, and 20% for 40% recycled cotton.

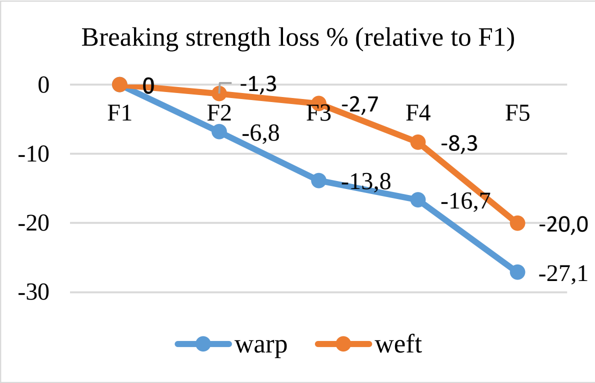

Figure 2. Breaking strength loss (%) of woven fabrics for warp and weft direction

The "p-significance level" results of the breaking strength ANOVA test in warp and weft directions are given in Table 6. The breaking strength values in the warp direction in all fabrics were found to be statistically significant at the 5% level (Table 5). However, although there was a decrease in the breaking strength values in the weft direction, the breaking strength values in the weft direction were found to be statistically insignificant at the 5% level in all fabrics (Table 5). ANOVA statistical analysis results show that the recycled cotton fiber ratio significantly affects the tensile strength value in the warp direction. According to statistical evaluation, the differences between the breaking strength values in the warp direction in fabrics woven with warp yarns with gradually increasing recycled cotton ratio were statistically significant ($p=0.008<0.05$).

Table 5. ANOVA test results of fabric breaking strength values for warp and weft direction

	Warp		**Weft**	
Parameters	**Significant (p)**	**R^2**	**Significant (p)**	**R^2**
Fabric Recycled Rate	0,008*	0,977	0,068	0,822

*: $p < 0.05$ it is significant

However, the recycled cotton fiber ratio does not have a significant effect on the breaking strength in the weft direction. The difference between the breaking strength values in the weft direction in the fabrics woven with weft yarns with a gradually increased recycled cotton ratio was not statistically significant ($p=0.068>0.05$).

3.3. Tear Strength Results

Mean values of tear strength (warp/weft) are shown in Table 4. In order to determine the effect of the recycled cotton ratio on the mechanical properties of the fabrics, the tear strength of woven fabrics was tested in warp and weft directions. A decrease in tear strength values in warp and weft directions was observed with a 10 percent increase in the recycling rate in all fabrics. The warp tear strength values were measured as 7.8 N for 100% cotton yarn (F1), 6.36 N for F2, 5.5 N for F3, 4.76 N for F4 and 4.78 N for F5. The weft tear strength values measured as 7.5 N for 100% cotton yarn (F1), 5.69 N for F2, 5.1 N for F3, 4.3 N for F4 and 4.1 N for F5. Consistent with previous studies [44], the lowest tear strength was observed in F5 fabric with increasing recycled fiber ratio.

The tear strength loss rates of the fabrics having recycled cotton yarns in both warp and weft directions are shown in Figure 3 by comparing to F1 fabric, which is 100% cotton. Accordingly, the tear strength losses in the warp direction were calculated as 18.5% for F2, 29.5% for F3, 38.7% for F4, and 39% for F5 fabrics. The tear strength losses in the weft direction were also calculated as 24.1% for F2, 32% for F3, 42.7% for F4, and 45.3% for F5 fabrics.

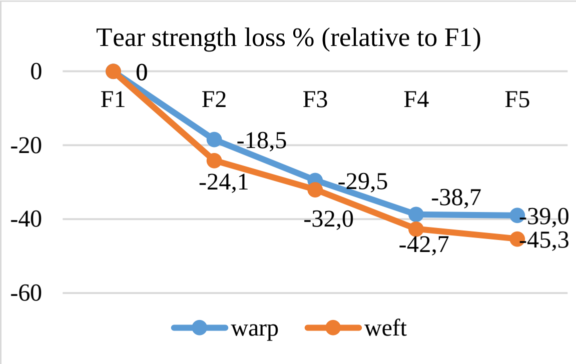

Figure 3. Tear strength loss (%) of woven fabrics for warp and weft direction

When the effect of fabrics produced using different proportions of recycled cotton fibers on the tear strength was examined, different tear strength values were determined for fabrics obtained from original cotton and recycled cotton fibers. The p-significance level results of the tear strength ANOVA test in warp ($p=0.035<0.05$) and weft ($p=0.036>0.05$) directions are given in Table 6 and were found to be statistically significant at the 5% level in all fabrics. The results show that the ratio of recycled cotton fiber significantly affects the tear strength value in both directions.

Table 6. ANOVA test results of fabric tear strength values for warp and weft direction

Parameters	Warp Significant (p)	Warp R^2	Weft Significant (p)	Weft R^2
Fabric recycled rate	0,035*	0,900	0,036*	0,899

*: $p < 0.05$ it is significant

Since tear strength is measured by tearing the yarns one by one, and breaking strength is based on tearing all the yarns within 5 cm together, it is expected that the tear and breaking strength results will be directly proportional to each other.

4. Conclusion and Suggestions

The results of the study can be evaluated as follows:

-Recycled fabric productions in the literature contain research information involving recycled fibers in either the weft or warp direction. However, in this study, the same proportions of recycled fiber were used in both weft and warp directions. In this case, as a result of using recycled fiber in the same blending ratios in both weft and warp directions, strength decreases in both warp and weft directions occurred in the same fabric.

-When blended fabrics containing recycled cotton fibers and fabrics woven from 100% cotton were compared, they showed lower tensile strength and tear strength values with a proportional increase in the percentage of recycled fibers. Especially in 60% cotton-40% cotton recycled fabric, strength losses of up to 45% occurred.

- In terms of fabric strength, blend yarn containing up to 40% pre-consumer recycled fiber was found to be suitable to produce woven fabric. Despite the decrease in strength, recycled fabric containing up to 40% pre-consumer recycled fiber was found to be within tolerances according to the relevant standard in bed linen and home textile production. However, if post-consumer waste is used as recycling, it is thought that the strength values will decrease even more.

-It is necessary to work on the proportions in which strength-increasing fibers can be mixed in linen and home textile fabrics at a level that does not adversely affect the touch and comfort properties, and solutions that can increase the quality of fabric obtained from recycled fibers.

- The lifespan of the bed sheet fabrics produced may be shortened due to the lower yarn strength caused by the addition of recycled fiber. However, today consumers consciously prefer to buy environmentally friendly recycled products and are aware of the problems that may occur.

-In this study, it was investigated to what extent recycled cotton fibers could be included within the quality limits that would not cause problems in the home textile industry. It is recommended to identify the quality differences and problems of the recycled products produced and to complete the missing information of our companies regarding the problems to be encountered.

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Conflict of Interest Statement

There is no conflict of interest between the authors.

References

[1] J.M.Hawley, *‘‘Economic Impact of Textile Recycling’’*, http://krex.kstate.edu/dspace/bitstream/2097/1228/1/EconImpactHawley2008.pdf (Accessed April 14, 2024), 2008.

[2] H. Chen and L.D. Burns, “Environmental analysis of textile products”, *Clothing and Textile Research Journal*, 24, 3, pp 248-26, 2006.

[3] T. Bayraktar, “Tekstil ve konfeksiyon sektöründe ekoloji ve ekolojik etiketler”, *İTKİB AR&GE ve Mevzuat Şubesi*, 2005.

[4] A. Güngör, S. Palamutçu and Y. İkiz,, “Pamuklu tekstiller ve çevre: bir bornozun yaşam döngü değerlendirmesi”, *Tekstil ve Konfeksiyon*, vol 3, pp 197-205, 2009.

[5] J.J. Lu and H. Hamouda, “Current status of fiber waste recycling and its future”, *Advanced Materials Research*, vol. 878, no.28, pp 122-131, 2014.

[6] S.H. Eryuruk, “Greening of the textile and clothing industry”, *Fibres & Textiles in Eastern Europe*, vol.95, no. 6, pp 22-27, 2012.

[7] A.A. Merati and M. Okamura, “Producing medium count yarns from recycled fibers with friction spinning”. *Textile Research Journal.*, vol 74, no.7, pp 640-645, 2004.

[8] Ş. Altun, “Prediction of textile waste profile and recycling opportunities in Turkey”, *Fibres & Textiles in Eastern Europe*, vol. 20, pp.16–20, 2012.

[9] R. Guru, J. Rani, P. Yadav and U. Saini, "Basic application for fibre & fabric recycling to sustainability products." *UGC Approved Journal*, vol. 14, no. 8.1, ISSN : 0976-6650, August 2023.

[10] H. Wang, H. Memon, R. Abro and A. Shah, “Sustainable approach for mélange yarn manufacturers by recycling dyed fibre waste”, *Fibres & Textiles in Eastern Europe*, vol 3, pp 18–22, 2020.

[11] A. Çay, J. Yanık, Ç. Akduman, G. Duman and H. Ertaş, “Application of textile waste derived biochars onto cotton fabric for improved performance and functional properties”, *Journal of Cleaner Production*, vol 251, no. 14, pp 119664, 2020.

[12] T, Vadicherla and D. Saravanan “Effect of blend ratio on the quality characteristics of recycled polyester/cotton blended ring spun yarn”, *Fibres & Textiles in Eastern Europe*, vol 25, no. 2, pp 48-52, 2017.

[13] M. Kalkanci, "Qualitative classification of woven fabrics produced from recycles threads of cotton and blends.", *Industria Textila*, vol 71, no. 2, pp 118-123, 2020.

[14] M. Kalkanci, “Investigation of surface defects and apparel manufacturing efficiency of fabrics woven from recycled cotton and blends”, *Industria Textila*, vol 71 no 3, pp 266-274, 2020.

[15] A. E. Tayyar and S. Ustun,“Usage of recycled pet”, *Pamukkale University Journal of Engineering Sciences*, vol. 16, no. 1, pp 53–62, 2010.

[16] A. Telli, and N. Ozdil, “Properties of the yarns produced from r-pet fibers and their blends”, T*extile & Clothing*, vol. 23, no. 1, pp 3–10, 2013.

[17] A. Telli, and N. Ozdil, “Effect of recycled PET fibers on the performance properties of knitted fabrics”, *Journal of Engineered Fibers and Fabrics*, vol. 10, no. 2, pp 47–60, 2015.

[18] A. Telli, N. Ozdil and O. Babaarslan, “PET bottle wastes in textile industry and contribution to sustainability”, *Journal of Textiles & Engineer*, vol.19, no. 86, pp 49–55, 2012.

[19] S. Uyanık, “The bursting strength properties of knitted fabrics containing recycled polyester fiber”, *The Journal of The Textile Institute*, vol 112, no.2, pp 1998-2003, 2020.

[20] D. Yilmaz, S. Yelkovan, Y. Tirak, ”Comparison of the effects of different cotton fibre wastes on different yarn types”, *Fibres & Textiles in Eastern Europe*, vol. 25, no.124, pp 19-30, 2017.

[21] B. Ütebay, P. Celik and A. Çay, “Effects of cotton textile waste properties on recycled fibre quality”, *Journal of Cleaner Production*, vol 222, pp 29-35, 2019.

[22] TS EN ISO 13934-1:2013. Textiles—tensile properties of fabrics— part 1: Determination of maximum force and elongation at maximum force using the strip method.

[23] TSE EN ISO 13937-2. Textiles - Tear properties of fabrics - Part 2: Determination of tear force of trouser-shaped test specimens (Single tear method).

[24] Y. Arafat and A.J. Uddin, “Recycled fibers from pre-and post-consumer textile waste as blend constituents in manufacturing 100% cotton yarns in ring spinning: A sustainable and eco-friendly approach”, *Heliyon*, vol. 8, no. 11, 2022.

[25] TS 2994 – 2015. Textiles - Woven and knitted - Sheet, quilt case and pillowcase.
[26] J.T. Bolaji, and P.I. Dolez, “Mechanical properties of woven fabrics containing elastane fibers”. *Fibers*, vol. 12, no. 30, pp 3-16, 2024.
[27] A. Aypar and E. Öner , “Quality properties of recycled yarns obtained by recycling fabrics produced from virgin yarns”, *Revista Matéria*, vol.29, no.2, 2024.
[28] Ö. Necef, et al., “Investigating the effect of recycled cotton included fabrics on the thermal behaviour by using a female thermal manikin”, *AUTEX Research Journal*, vol. 23, no 3, 2023.
[29] W. Béchir, A. Béchir and B.H. Mohamed, “Industrial cotton waste: Recycling, Reclaimed fiber behavior and quality prediction of its blend”, *Tekstil ve Konfeksiyon*, vol. 28, no. 1, pp 14-20, 2018.
[30] A. Telli and O. Babaarslan, “Usage of recycled cotton and polyester fibers for sustainable staple yarn technology”, Textile and Apparel, vol 27, no. 3, pp. 224–233, 2017.
[31] M.T. Halimi, M.B. Hassen and B. Azzouz,, “Influence of spinning parameters and recovered fibers from cotton waste on the uniformity and hairiness of rotor spun yarn”, *Journal of Engineered Fibers and Fabrics*, vol 4, no. 3, pp. 36–44, 2009.
[32] H. Hasani, D. Semnani and S. Tabatabaei,, “Determining the optimum spinning conditions to produce the rotor yarns from cotton wastes”, *Industria Textila*, vol 61, no. 6, pp. 59–64, 2010.
[33] H. Hasani and S.A. Tabatabaei, “Optimizing spinning variables to reduce the hairiness of rotor yarns produced from waste fibers collected from the ginning process”, *Fibres & Textiles In Eastern Europe*, vol. 19, no. 86, pp. 21–25, 2011.
[34] A. G. Demiroz , H.N. Akturk, A. M. Sevkan and G. Alan, “Dimensional and physical properties of socks made from reclaimed fibre”, *The Journal of the Textile Institute*, vol 105 no.10, pp 1108-1117, 2014.
[35] R.K., Khan, M.M., Hossain and R.C., Sarker, “Statistical analyses and predicting the properties of cotton/waste blended open-end rotor yarn using taguchi oa design”, *International Journal of Textile Science*, vol. 4, no. 2, pp 27-35, 2015.
[36] J.L. Schmitt and L.F. Folle, “Analysis of the thermophysiological comfort and tensile strength in fabric woven with recycled cotton and filaments obtained from post-consumer waste pet bottle recycling”, *Revista Matéria*, vol. 26, no .1, 2021.
[37] M. M. Mekonnen, and A. Y.Hoekstra, “The green, blue and grey water footprint of crops and derived crop products”, *Hydrol. Earth Syst. Sci*., vol. 15, pp 1577–1600, 2011.
[38] F. Doba Kadem, and Ş. Özdemir, “Denimde Geri Dönüşüm Uygulamaları-Tüketici Sonrası Geri Dönüşüm (Post-Consumer Re-Cycle)”, *Ulusal Çukurova Tekstil KongresiUÇTEK’2019*, 26-27 Eylül 2019, pp 501-508, Adana.
[39] F.Doba Kadem, and Ş. Özdemir, “Tüketici Sonrası Geri Dönüştürülen Denim Kumaşların Seçilmiş Konfor Özellikleri Üzerine Bir Çalışma”. *Çukurova Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi*, vol 35, no. 2, pp. 379-388, 2020.
[40] F.Doba Kadem, “Sürdürülebilir Bir Yaklaşım: Denim Sektöründe Pamuk Atıklarının Geri Dönüşümü Üzerine Bir Çalışma”, *12. Ulusal Kimya Mühendisliği Kongresi (UKMK 2016),* 23-26 Ağustos 2016, İzmir.
[41] R.K., Khan and H. Rahman, “Study of Effect of Rotor Speed, Combing-Roll Speed and Type of Recycled Waste on Rotor Yarn Quality Using Response Surface Methodology”, *IOSR Journal of Polymer and Textile Engineering*, vol 2, no. 1, pp 47-55, 2015.
[42] M.L Regar , C. R Meena, and S. Hada, “In Textile Calculation Fibre to Finished Garment, Fiber Testing”, *Woodhead Publishing*, Sawston, UK; pp. 301–324, 2023.
[43] A, Majundar, P. K, Majundar and B. Sarkar, “Determination of The Technological Value of Cotton Fibre: A Comparative Study of The Traditional and Multiple-Criteria Decision-Making Approaches. *AUTEX Research Journal.;*vol. 5, no. 2, pp.71–80, 2005.
[44] A. Telli and O. Babaarslan, “The effect of Recycled Fibers on the Washing Performance of Denim fabrics”, *The Journal of The Textile Institute*, vol. 108, no. 5, pp 812-820, 2017.