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Closed-Loop Recycled Yarn Production from Yarn Wastes and Investigation of Their Physical Properties within the Scope of Sustainability

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Abstract

Recycling in textile is very popular in terms of sustainability, and a lot of studies were made by many researchers in this area and are still being made. In this study, yarns containing 10-50% waste using cotton as the main fiber were obtained in 3 different yarn counts, Ne 10, Ne 20, and Ne 30, and it was aimed to reveal the effects of waste on yarn properties. As a result of the graphical and statistical evaluations of the obtained data, it was determined that the waste did not affect the yarn properties as negatively as expected. Ne 10 is the most suitable yarn count in the production of waste yarn, considering that the waste content and ratio in the blended yarns affect the yarn properties less and even do not make a significant difference. The optimum blend ratio of waste, in terms of yarn unevenness and yarn imperfections, is 30%. While a 30% waste rate is the most suitable in terms of all properties of Ne 20 yarns, it seems reasonable to obtain yarn with lower waste rates in Ne 30 yarns in terms of hairiness and breaking strength.

Keywords: Yarn waste, Sustainability, Recycling, Blend yarn properties, Waste ratio

İplik Atıklarından Kapalı Döngü Geri Dönüşüm İplik Üretimi ve Fiziksel Özelliklerinin Sürdürülebilirlik Kapsamında Araştırılması

Öz

Tekstilde geri dönüşüm sürdürülebilirlik açısından oldukça popülerdir ve bu alanda birçok araştırmacı tarafından birçok çalışma yapılmış ve yapılmaya devam etmektedir. Bu çalışmada, Ne 10, Ne 20 ve Ne 30 olmak üzere 3 farklı iplik numarasında, ana lif olarak pamuk kullanılarak %10-50 telef içeren iplikler elde edilmiş ve telefin iplik özelliklerine etkilerinin ortaya çıkarılması amaçlanmıştır. Elde edilen verilerin grafiksel ve istatistiksel değerlendirmeleri sonucunda telefin iplik özelliklerini beklendiği kadar olumsuz

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etkilemediği belirlenmiştir. Harmanlanmış ipliklerdeki telef içeriği ve oranının iplik özelliklerini daha az etkilediği ve hatta önemli bir fark yaratmadığı düşünüldüğünde, telef iplik üretiminde Ne 10 en uygun iplik numarasıdır. İplik düzgünsüzlüğü ve iplik hataları açısından teleflerin optimum karışım oranı %30'dur. Ne 20 ipliklerin tüm özellikleri açısından %30 fire oranı en uygunu iken, Ne 30 ipliklerde tüylülük ve kopma mukavemeti açısından daha düşük fire oranlarına sahip iplik elde etmek makul gözükmektedir.

Anahtar Kelimeler: Üstüpü, Sürdürülebilirlik, Geri dönüşüm, Karışım iplik özellikleri, Telef oranı

1. INTRODUCTION

Sustainability is an important approach used in the solution of production, environment, and economy-related problems in different industries in recent years. In today's competitive environment, producing with limited resources, reducing the environmental effects resulting from production, reducing costs, and ensuring customer satisfaction are only possible with sustainability [1]. Sustainability is examined in three different dimensions economic, environmental, and social indicators.

The textile and ready-made clothing industry has a significant sustainability impact due to intense mass consumption, fast fashion trends, short-term use of products, and increasing textile waste [2]. When the global fiber consumption data for 2021 is analyzed, it is stated that the total fiber consumption is 113 million tons. While synthetic fibers take the first place in total fiber consumption with a share of 64%, cotton fiber follows the second place with a share of 22% [3].

In an evaluation made by Made-By, 28 different textile fibers were classified in different sustainability categories in terms of their environmental impacts. Fibers were evaluated according to criteria for greenhouse gas emissions, human toxicity, ecotoxicity, energy, water, and land use. Based on the criteria, each fiber was scored and placed in 5 categories from Classes A-E as shown in Table 1. Fibers with insufficient data could not be classified. In this classification, recycled and organic fibers have high sustainability, while conventional fibers have lower sustainability [4].

Table 1. Classification of textile fibers in terms of sustainability

Made-By Environmental Benchmark Fibres					
Class A	**Class B**	**Class C**	**Class D**	**Class E**	**Unclassified**
Mechanically Recycled Nylon	Chemically Recycled Nylon	Conventional Flax (Linen)	MODAL® (Lenzing Viscose Product)	Bamboo Viscose	Acetate
Mechanically Recycled Polyester	Mechanically Recycled Polyester	Conventional Hemp	Poly-acrylic	Conventional Cotton	Alpaca Wool
Organic Flax (Linen)	CRAILAR® Flax	PLA	Virgin Polyester	Generic Viscose	Cashmere Wool
Organic Hemp	In Conversion Cotton	Ramie		Rayon	Leather
Recycled Cotton	Monocel® (Bamboo Lyocell Product)			Spandex (Elastane)	Mohair Wool
Recycled Wool	Organic Cotton			Virgin Nylon	Natural Bamboo
	TENCEL® (Lenzing Lyocell Product)			Wool	Organic Wool
					Silk
More Sustainable				**Less Sustainable**	

It is stated that the CO_2 emission of the textile industry, which has a high production and consumption volume, is about 2% of the total industrial CO_2 emissions in the world, which is about 1.2 billion tons/year; 21 times more than those of all international flights and maritime shipping combined. [5]. Therefore, the sustainable textile industry needs to identify and develop solutions to eliminate these environmental effects. If certain environmental impacts in the textile sector are to be considered; these can be listed as fibers, yarn fabric production, finishing dyeing processes, garment quality control, packaging, transportation, use, and disposal.

While fiber-based products are increasing day by day to meet the needs of the industry due to changing living standards, they also create negative effects on the environment and human health. For example, the cultivation processes of cotton, which is a sensitive plant, cause 1-6% of the world's freshwater area to be consumed. Synthetic fertilizers produced using a significant amount of energy resources (1.5% of the world's annual energy consumption) release large amounts of carbon dioxide and increase global warming [6]. In addition, synthetic-based products do not degrade in nature for many years, increasing the consumption of limited petroleum-derived natural resources and the amount of waste.

It is stated that 41% of the electrical energy consumed between textile processes belongs to the spinning processes. Weaving and wet processes follow this order [7]. Specific water consumption for dyeing varies between 30-50 liters per kg of fabric, depending on the type of dye used [8]. It is estimated that an average of 1.000-3.000 m^3 of wastewater is generated because of the production of approximately 12-20 tons of textile per day [9].

From the point of view of transport, use and disposal, while there is energy consumption during the delivery of the products to the consumer, energy, water, and detergents are used during the use of textile products. What happens to the product at the end of its useful life is also important within the scope of this evaluation. According to a study report called 'Carbon Footprint Study' made in 2009, the carbon footprint (CO_2e) of a 100% cotton shirt with a size of 40-42 and a weight of 220 g was calculated as 10.75 kg throughout its life cycle. The CO_2 emission emitted into the atmosphere is approximately 50 times higher than the net weight of the shirt [10].

Textile wastes can also be classified as solid, liquid, or gaseous wastes according to the phase they are in. Solid wastes include basic textile wastes in the form of fiber, yarn, fabric, cardboard, plastic, etc. other auxiliary materials. Liquid wastes are wastewater containing dyes and chemicals, especially after finishing processes. Gas-phase wastes are many different substances that are released after textile processes and cause emissions.

Wastes can be evaluated in different ways according to waste management strategies. The waste hierarchy is given in Figure 1. The 3R principle (Reduce, reuse, recycle) is generally adopted as a textile waste treatment strategy. [11].

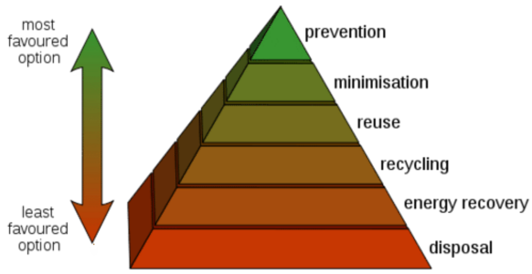

Figure 1. Waste hierarchy

Recycling is seen as the best solution for both natural and regenerated and synthetic-based textile wastes, for reasons such as reducing environmental impacts in production processes, preventing problems that may arise due to wastes, and being able to benefit from depleted oil for a longer period. Recycling is classified as closed and open-loop recycling. In closed-loop recycling, the material of a product is recycled and used in the production of the same product, while in open-loop recycling, the material of a product is recycled and used in the production of another product [12,13].

The recycling process of cotton starts with proper classification. At this stage, pre-consumption wastes within the enterprise and post-consumption wastes from outside the enterprise can be used. Pre-consumption wastes arise in yarn production, weaving, knitting, finishing, sewing, or quality-control stages. A classification is made according to the quality and color of the incoming wastes. In this classification, different criteria such as the structure of the waste (yarn number, production method, fabric weight, etc.), raw material, size, and color are used. The quality of the fibers obtained as a result of the recycling process is closely related to the characteristics of the waste material.

Recycling in textile is very popular because of the reasons mentioned above, and a lot of studies were made by many researchers in this area and are still being made.

Koo et al investigated the effects of mechanical and chemical recycling processes on yarn properties (breaking strength, elongation at break, melting temperature, degradation behavior). Conventional yarns and chemically recycled yarns showed similar processability, physical and mechanical properties, and long-term degradation behavior [14].

Duru and Babaarslan investigated the influence of opening roller speed on quality properties of the open-end spun yarn made from 40/60 blend of spinning cotton waste and virgin polyester fibre. From the results, a high opening roller speed was recommended. while spinning waste content does not provide the expected results [15].

Gun et al. investigated the conventional open-end yarn produced using 50/50% polyester/recycled cotton blended open-end yarn and 100% conventional cotton fiber with the addition of polyester fibers by removing cotton waste. Knitted socks with 3 different loop lengths, with and without elastane, were produced from these yarns and their performance properties were examined. Socks produced from recycled fibers showed higher loop density, weight, thickness, pilling tendency, and lower air permeability than conventional cotton socks. It was found that socks produced from recycled fibers show less mass loss, higher color strength, and lower color variation after wear [16].

Khan et al. researched the effect of blending ratio (17/83% and 33/67%), blending techniques (blow room and draw frame blend), roller speed (800 and 850 rpm), and rotor speed. (80000 and 85000 rpm) on the properties of cotton/recycled waste, fiber blended yarns. It was found that the most effective parameters on yarn properties are waste rate and rotor speed. Reducing the rotor speed had a positive effect in terms of yarn evenness, faults, and strength. A high roller speed is recommended in the draw mix and mixes with high waste [17].

Wanassi et al. in their study of different rotor speeds (65000, 70000, and 80000 rpm), opening roller speed (7700, 8200, and 8700 rpm), and twist factor (137, 165, and 183) 100% recycled cotton open-end yarn quality investigated the effect on the parameters. As a result, it was seen that rotor speed increased the hairiness, thin place, thick place, and unevenness values. The twist factor does not have a significant effect on the quality of 100% recycled cotton yarns [18].

Yelkovan investigated the properties of yarns spun from cotton and recycled cotton fibers in her graduate study. Ring, Rocos compact, and Rieter 46 compact yarns were produced by mixing 3 different wastes (blend, hat, and pneumafil) with cotton at rates of 5-40%. When yarn hairiness and nep values were examined, room waste gave the best results, and when other yarn properties were examined, hat waste gave the best results. Compact yarns gave better results in terms of hairiness, strength, and elongation compared to conventional ring yarns. Since the yarns produced from pneumafil wastes are very clean, it was suggested that they can be used at high ratios such as 40%, while dirty waste such as hat and room waste should be used at lower ratios [19].

Gun et al. investigated the thermal properties of socks in the continuation of their study According to the results of the study, the addition of elastane caused an increase in thermal conductivity, thermal resistance, and thermal absorption values, and a decrease in water vapor permeability values.

Socks produced from recycled fibers showed lower thermal conductivity and thermal absorption and higher thermal resistance than cotton socks. While the water vapor permeability results of socks produced from recycled fibers without elastane were found to be higher than cotton socks without elastane, there was no statistical difference between the samples containing elastane [20].

In the Ph.D. thesis study of Telli, open-end yarns with the number Ne 12 were produced by using conventional cotton (CO), recycled cotton (r-CO), and r-PET fibers at certain mixing ratios. Denim fabrics were produced by using these recycled yarns in the weft direction and Ne 20/2 100% cotton ring carded yarns in the warp direction, and enzyme and stone washing processes were applied to the denim fabrics. The results of the mixtures of CO/r-CO and CO/r-PET were found to be compatible. In r-CO/r-PET mixtures, as the r-PET ratio increased, yarn breaking strength and elongation increased, while unevenness, yarn defects, and hairiness values decreased. r-CO fiber negatively affected the breaking and tear strength, while r-PET fiber increased the breaking strength, elongation at break and tear strength, and decreased the softness [21].

In the study of Yuksekkaya et al. (open-end yarns and single jersey knitted fabrics were produced from these yarns by using conventional and recycled cotton and polyester fibers at certain mixing ratios (100% and 50/50%). According to the results of the study, it was found that the yarns produced from recycled fibers showed better properties in terms of unevenness and yarn defects. Yarn breaking strength and fabric bursting strength are higher in conventional yarns and fabrics than in recycled samples. The coefficients of kinetic friction and pilling values of all fabrics were found to be close to each other [22].

Vadicherla and Saravanan investigated the quality parameters of recycled polyester/conventional cotton blended ring yarns, which have three different yarn counts (23.6; 29.5, and 39.4 tex), and different blends ratios (0/100%, 33/67%, 50/50%, 67/33%, and 100/0%). As the recycled polyester content increased, the strength, elongation, hairiness values of the yarns increased, and the values of unevenness, thin-thick places, and neps decreased. As yarn counts decrease, strength, elongation, unevenness, thin-thick place, neps, and hairiness values increase [23].

Sarioğlu and Kaynak investigated the quality characteristics of ring and compact yarns produced from PET/CO and r-PET/CO fibers at 100%, 70/30%, 50/50%, and 30/70% blend ratios. With the study, it was found that spinning technology, raw material, and blend ratio have a significant effect on yarn properties. It was concluded that yarns containing r-PET had lower strength values than yarns containing PET. The lowest evenness values for both spinning technologies were obtained from conventional PET yarn. Higher yarn evenness values in r-PET yarns caused more yarn defects and lower strength [24].

Béchir et al. investigated the effect of blending ratios of cotton fibers recycled from waste with conventional cotton fibers on yarn quality parameters and estimated the quality of recycled cotton fiber blends utilizing a mathematical model. When the recycled cotton ratio in the blends increases from 40% to 75%, 20%, 13%, 32%, 50%, and 20% increases are seen in the yarn unevenness, thin places, thick places, neps, hairiness values, respectively, strength decrease was observed as 16%. Increasing the number of passages decreased many fiber quality parameter values [25].

Demiroz Gun and Oner investigated the effects of different yarn counts (Ne 30, Ne 20, Ne 12), fiber blend ratios (60/40%, 70/30%, 85/15%), different waste sources, yarn twist coefficients and rotor diameters on yarn quality. According to the results of the study, the effects of blend ratio, yarn count and twist coefficient on yarn quality parameters were found to be statistically significant. The addition of conventional polyester to the structure caused an increase in quality parameters. Considering the maximum use of recycled fibers and the minimum use of conventional polyester fiber, yarns with 60/40% blending ratio in Ne 30 count, yarns with 70/30% blending ratio in Ne 20 count, and 85/15% blending rate in Ne 12 count could be produced [26].

Uyanık aimed to determine the optimum yarn count and fiber blend ratio in yarns using recycled polyester fibers. For this, recycled polyester, conventional polyester, and viscose fiber in different blend ratios (100% PET, 100% r-PET, 100% CV, 65/35% r-PET/CV, 50/50% r-PET/CV, and 35-65% r-PET/CV), were produced in different yarn counts (Ne 10, Ne 20, Ne 30, Ne 40). The study showed that rPET fibers had usually negative effects on the yarn properties, especially in fine yarns, due to the physical and chemical deteriorations caused by the contaminants that pollute rPET fibers during their re-processing. The findings revealed that rPET fibers are found suitable for thick yarns as either pure or in all different blend ratios, especially for Ne 10 and Ne 20, and are also found suitable if they are used in lower ratios than 65% for Ne 30 yarns, whereas they are suitable if they are used in lower ratios than 35% for Ne 40 yarns [27].

Ute et al. produced single jersey knitted fabrics with Ne 20/1 O.E. yarns in different blend ratios (10/90%, 30/70%, 50/50%) from conventional cotton and different cotton waste types (blowroom, carding, drawframe, and fabric) and examined the quality characteristics. Blowroom and comb wastes contain a large amount of short fibers and foreign matter as they are formed during the cleaning of the fibers. While the strength of yarns containing 50% carding waste was found to be lower than the others, the use of blowroom waste up to 30% did not change the yarn properties except for thick places and neps. Fibers recycled from fabric waste showed similar behavior as recycled fibers from blowroom waste. As the proportion of waste fibers increased, the air permeability of the fabrics decreased depending on the yarn hairiness. For pilling values, the highest results were obtained for fabrics with card waste with the highest short fiber content [28].

Utebay et al. investigated the effects of different types of waste (interlock/single jersey, dyed/raw, large/small size, 2/3/4/5 different number of passages in the opening machine, and different mixing ratios) on the recycled fiber properties. It has been observed that recycled fibers obtained from loose-structured raw fabrics give better results. Feeding small-sized fabrics to the opener increased the rate of short fiber. As the number of passages increased, the short fiber content in the recycled fibers increased, but no change in yarn properties was observed. When the number of passages exceeded 3, the yarn properties started to decrease [29].

In the study by Kilic et al. the performance properties of open-end yarn and knitted fabrics produced with conventional and recycled cotton fibers and their blends (100%, 75/25%, 50/50%, and 25/75%) were investigated. Yarn and fabrics produced from 100% cotton gave the best results among all samples. The results of the study revealed that the use of recycled cotton in up to 75% of the mixture did not make a significant difference in the results [30].

Sarıoğlu produced ring and compact yarns obtained from PET/CO and r-PET/CO fibers at 100%, 70/30%, 50/50%, and 30/70% blend ratios, and worked on the optimization of its features. It was found that the blend type (raw material type), blend ratio, and yarn production technology have a significant effect on burst strength and air permeability of fabrics. The mixture type did not show a significant effect on the weft-warp directional capillary absorbency ratio. As a result of the optimization, it was observed that the knitted fabrics produced from compact yarns with a PET/CO ratio of 58.62/41.38% gave the most optimum value with a value of 0.72 [31].

In the second part of her study, Uyanık investigated the bursting strength properties of knitted fabrics, having blend yarns with recycled polyester fiber (100% PET, 100% r-PET, 100% viscose, 65/35% r-PET/viscose, 50/50% r-PET/viscose and 35-65% r-PET/viscose) at different yarn counts (Ne 10, Ne 20, Ne 30, and Ne 40). The study results revealed that the rPET fibers provided the bursting strength values which are close to that of virgin PET fibers for the knitted fabrics having coarse yarns, whereas they do not contribute positively to the knitted fabrics having fine yarns. As become in the first study, it is once more proved that the use of rPET fiber is more suitable for the knitted fabrics containing coarse yarns, and it is not definitely proper for the ones having Ne 40 yarns. [32].

In our study, determining the properties of the yarns containing mechanical recycled fiber from waste yarns was aimed at different yarn counts. The study will contribute to the literature by revealing the effect of the blend ratio of waste fiber on the yarn properties in different yarn count and determine which count and blend ratio are more suitable for waste fiber usage.

2. EXPERIMENTAL

8 different cotton yarns containing waste of cotton ring spun yarn were produced in different yarn counts and different blend ratios in rotor spinning to determine the optimum blend ratio of waste for yarn quality. Wastes were obtained by converting back into fiber form with rapid rotation and pulling of the needle drums in the rag puller machine.

HVI test results of cotton fiber are SCI: 113; Mic: 4.3; UHML: 27.3 mm; Ul: 80%; SF: 2.3%; Str: 27.9 g/tex; Elg: 6.9%; Rd 77.9; +b: 10.3; CGrd (upland): 12-2; TrCnt: 25; Tr Ar: 0.25%; Tr Grd 2.

Blend ratios of waste were applied between 10-50% for rotor spun yarns. Yarn types containing the blend ratios of fiber recycled from waste yarn, yarn counts in the obtained cotton yarns, process parameters, and rotor machine parameters for spinning were given in Tables 2-4 respectively.

Table 2. Yarn types

Yarn count	Twist factor	Yarn type	Abbreviation
Ne 10	αe 3.4	100% cotton	100% CO
		90% cotton – 10% waste	90-10% CO-WST
		80% cotton – 20% waste	80-20% CO-WST
		70% cotton – 30% waste	70-30% CO-WST
		60% cotton – 40% waste	60-40% CO-WST
		50% cotton – 50% waste	50-50% CO-WST
Ne 20	αe 3.6	100% cotton	100% CO
		90% cotton – 10% waste	90-10% CO-WST
		80% cotton – 20% waste	80-20% CO-WST
		70% cotton – 30% waste	70-30% CO-WST
		60% cotton – 40% waste	60-40% CO-WST
		50% cotton – 50% waste	50-50% CO-WST
Ne 30	αe 3.8	100% cotton	100% CO
		90% cotton – 10% waste	90-10% CO-WST
		80% cotton – 20% waste	80-20% CO-WST
		70% cotton – 30% waste	70-30% CO-WST
		60% cotton – 40% waste	60-40% CO-WST
		50% cotton – 50% waste	50-50% CO-WST

Table 3. Process parameters

Blow Room	Rieter Unifloc A11		
	Trützschler Axi-Flow Cleaner		
	Trützschler MPM Mixer		
	Trützschler CVT4 Cleanomat		
	Trützschler Dustex		
Card	Rieter C70	55 kg/h	Ne 0.100
Draw Frame-1	Rieter SB-D 45	750 rpm	Ne 0.100
Draw Frame-2	Rieter RSB-D 45	750 rpm	Ne 0.100
O.E. Rotor	Model	Rieter R20	
	Openning roller type	B174-DN-64	
	Rotor type (Ne 20-30)	34-XT-BD-AE1	
	Rotor type (Ne 10)	40-XT-BD-AE1	
	Navel type	Spiral	

Table 4. Rotor machine parameters

Yarn count	Openning roller speed	Rotor speed	Rotor diameter
Ne 10	8.500 rpm	65.000 rpm	40 mm
Ne 20	8.500 rpm	75.000 rpm	34 mm
Ne 30	8.700 rpm	105.000 rpm	34 mm

The obtained yarns were tested repeating five times to determine yarn characteristics according to relevant standards. Before the tests, all samples were conditioned according to TS EN ISO 139 standard performed in a standard atmosphere of 20±2 ºC and 65±2% humidity. By using Uster Tester 6 at 400 m/min test speed unevenness, imperfections, hairiness values of the produced yarns were measured Tenacity and breaking elongation values of yarns were measured with Uster Tensorapid 5 at 500 mm/min test speed and 500 mm gauge length.

For the statistical analysis including analysis of variance (ANOVA) and Pearson correlation tests, SPSS 25 software package was used to interpret the experimental data. All test results were assessed at a 95% confidence interval. ANOVA and correlation tests were carried out by considering waste ratios as the main factor in the cotton blended yarns, and the results obtained were interpreted as the effect of waste (WST) ratios on yarn properties.

3. RESULTS AND DISCUSSION

The yarn properties and statistical results were given in Tables 5-7 respectively. The results were interpreted considering experimental-statistical test results with subtitles showing yarn properties.

Table 5. ANOVA results

Factor waste	Ne 10		Ne 20		Ne 30	
Variables	**F**	**Sig.**	**F**	**Sig.**	**F**	**Sig.**
CVm	5.595	**.001**	3.107	**.027**	3.268	**.022**
Thin	1.952	.123	3.465	**.017**	.830	.541
Thick	2.623	**.050**	2.604	**.050**	26.823	**.000**
Neps	.593	.706	5.096	**.003**	50.953	**.000**
Hairiness	.668	.651	52.785	**.000**	25.090	**.000**
Elongation	16.311	**.000**	14.687	**.000**	.787	.570
Tenacity	14.561	**.000**	5.980	**.001**	8.742	**.000**

Table 6. Pearson correlation results

Factor waste	CVm	Thin	Thick	Neps	Hairiness	Elongation	Tenacity
Ne 10	-.150	.072	-.117	-.036	-.009	**-.520****	**-.737****
Ne 20	-.255	**-.469****	**-.373***	**.448***	**-.530****	.273	**.403***
Ne 30	-.287	.104	-.072	-.194	-.064	-.112	-.057

Table 7. Yarn properties

Yarn		CVm %	Thin -50%	Thick +50%	Neps +200%	H	Tenacity cN/tex	Elongation %
Ne 10	100% CO	13.94	1.60	62.20	4.80	8.69	15.19	8.09
	90-10% CO-WST	13.12	0.60	21.40	3.40	8.36	13.21	7.46
	80-20% CO-WST	13.81	0.60	34.40	4.20	8.52	13.86	8.15
	70-30% CO-WST	13.02	3.60	28.60	3.60	7.92	12.76	7.52
	60-40% CO-WST	12.94	1.20	29.20	2.20	8.53	13.12	7.34
	50-50% CO-WST	13.85	1.20	47.60	5.20	8.68	12.05	7.52
Ne 20	100% CO	15.83	158.60	280.20	26.20	6.00	9.26	4.94
	90-10% CO-WST	18.34	305.20	372.20	70.40	7.71	9.25	5.23
	80-20% CO-WST	15.95	47.80	195.80	87.20	7.24	11.84	7.73
	70-30% CO-WST	14.86	4.60	86.80	47.20	4.97	11.93	7.42
	60-40% CO-WST	14.70	10.20	103.80	74.20	5.47	11.54	7.16
	50-50% CO-WST	16.24	20.80	209.60	89.40	5.56	10.39	5.33
Ne 30	100% CO	17.37	35.80	113.80	83.20	5.43	8.13	5.63
	90-10% CO-WST	15.63	28.20	150.80	152.80	4.51	10.16	5.61
	80-20% CO-WST	16.57	30.60	207.40	269.20	4.77	9.46	5.50
	70-30% CO-WST	15.21	22.80	40.20	42.40	5.48	8.30	5.68
	60-40% CO-WST	16.35	40.20	96.60	65.80	5.36	8.14	5.70
	50-50% CO-WST	15.93	36.60	162.80	118.60	4.67	9.35	5.41

3.1. Unevenness

As seen in Figure 2, the unevenness values increase from Ne 10 yarns to Ne 30 yarns, that is, from coarse yarns to fine yarns, as expected. On the other hand, comparing based on each yarn count, there are no big differences between the unevenness values, except for 90-10% CO-WST yarn of Ne 20 group. For this yarn, it is thought that this result is due to a momentary error during yarn production. Also, when each yarn count group is evaluated separately, an increasing trend in unevenness was not observed in parallel with the increase in the waste rate in the yarn.

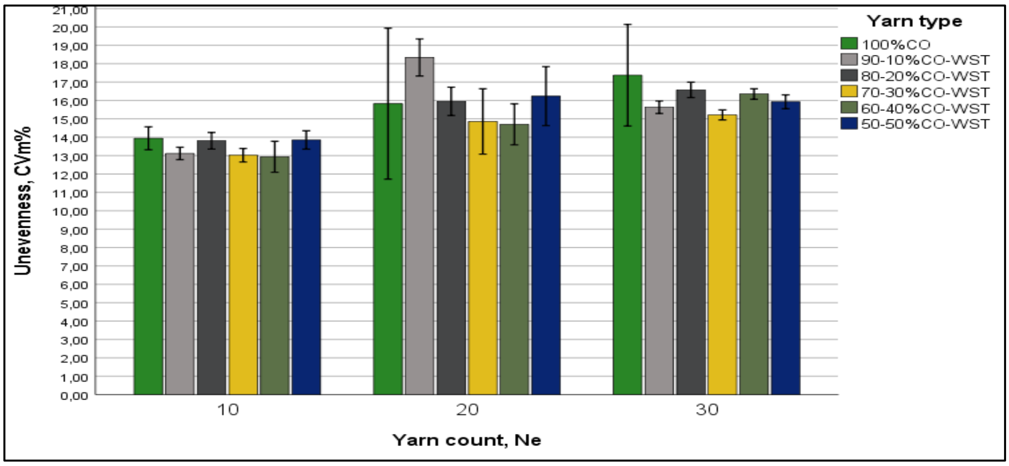

Figure 2. Unevenness

According to the ANOVA test results given in Table 5, all p, which is significance, values ≤ 0.05 in all yarn counts, and waste content in the blended yarn have a significant effect on yarn unevenness. On the contrary, when correlation results are examined in Table 6, it is seen that the relationship between waste content and unevenness is much weak and negative

3.2. Thin Places

According to Table 5 and Figure 3 showing the thin places of samples, when the thin places are evaluated excluding Ne 20 yarns, while it is the highest for Ne 30 yarns, it is the lowest for Ne 10 yarns. It is possible to say that the thin places for Ne 10 yarns are quite close to each other, even almost the same. Ne 30 yarns have a similar situation, and the thin places are close to each other, but the thin places are slightly higher in yarns containing 40% and 50% waste, which is higher than the others.

In Ne 20 yarn group, 100% CO and 90-10% CO-WST yarns have considerably higher thin places than expected, which is thought to be due to any problems experienced during low sample-based production. Except for these yarns, it is seen that the thin places increase, albeit slightly, with the increase in the waste ratio. Excluding the aforementioned Ne 20 yarns, which have more thin places than expected, we can say that the thin places generally increase from coarse yarns to fine yarns, and the increase in waste ratio partially increases the thin places in the yarn.

According to ANOVA test results given in Table 5, p values for Ne 10 and Ne 30 yarns are greater than 0.05, which was chosen as the significance level, with the values of 0.123 and 0.541 respectively. This result indicates that the changes in the waste ratio do not have a statistically significant effect on the thin places in the yarn. In Ne 20 yarns, waste has a significant effect on thin places with a p-value of 0.017. From Table 6, it is also seen that for Ne 20 yarns, the relationship between waste and thin places is moderately strong and negative, whereas these relationships are not strongly and positive for the other yarn counts. This means that waste content partially decreases thin places in Ne 20 yarns.

3.3. Thick Places

As can be seen from Figure 4 and Table 5, the thick places for Ne 10 yarns are close to each other and 100% CO has the highest value. In Ne 20 yarns, 90-10% CO-WST yarn has the highest thick places, while 70-30% CO-WST yarn has the lowest value, and a tendency to increase in the thick places is observed with the increase in the waste ratio in the yarn, excluding yarns containing 10, 20 and 30% waste in general. In Ne 30 yarns, 80-20% CO-WST yarn has the highest thick places and 70-30% CO-WST yarn has the lowest value as in 20 number yarns. Although there is a zigzag trend with the increase in the waste ratio, there is an increase in the thick places, as in Ne 20 yarns. When all yarn counts are considered together, it should be stated that thick places are seen at least in Ne 10 yarns, most in Ne 20 yarns, and closer to Ne 20 yarns in Ne 30 yarns, but at lower values.

ANOVA results given in Table 5 show that waste content has significant effect on the thick values for all yarn counts, based on p values of ≤ 0.05. However, when correlation results in Table 6 are investigated there is only close to moderately and negative relationship between waste and thick places for Ne 20 yarns. This indicates that increasing waste content partially decreases thick places for Ne 20 yarns.

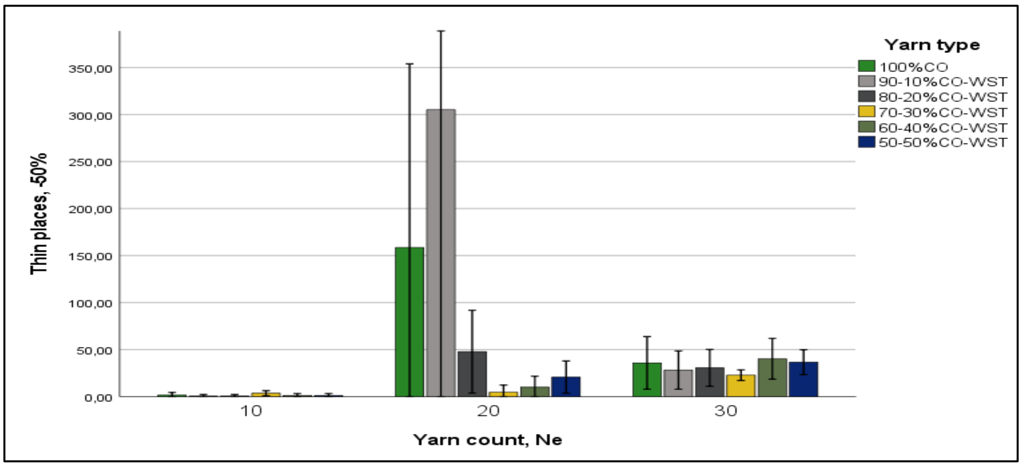

Figure 3. Thin places

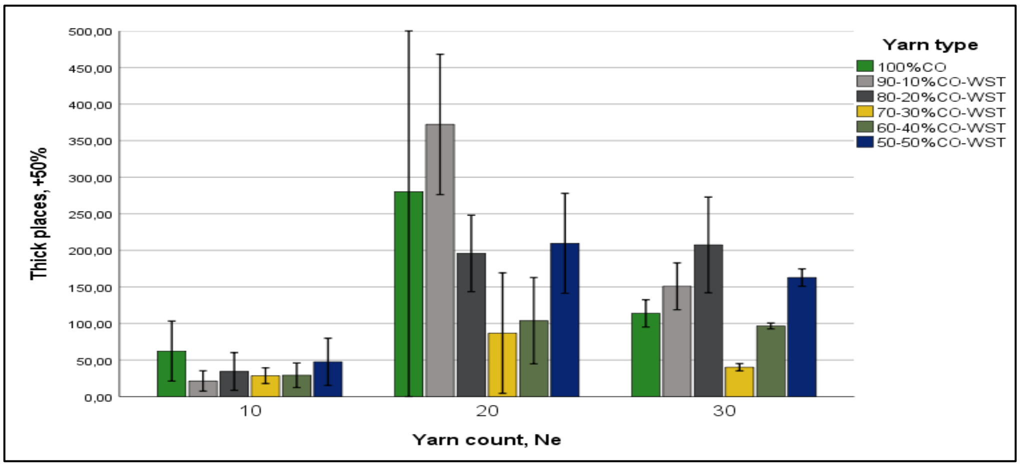

Figure 4. Thick places

3.4. Neps

From Figure 5 and Table 5, it is seen that the neps values of all blended yarns in Ne 10 yarns are almost the same and almost non-existent. Zigzag trends are observed for both Ne 20 and Ne 30 yarns, and it is seen that neps values increase from 100%CO yarn to 80-20% CO-WST yarns, decrease when it comes to 70-30% CO-WST yarns, but increase again from 70-30% CO-WST yarns to 50-50% CO-WST yarns. On the other hand, 100%CO yarn has the lowest neps value in Ne 20 yarns, while 30-70% CO-WST yarn has the lowest neps value in Ne 30 yarns. According to the highest neps values, it is seen that the max values are close to each other in yarns with different waste ratios in Ne 20 yarns, and 80-20% CO-WST yarn in Ne 30 yarns has the highest neps value with a much higher value than expected. In general, when evaluated in terms of all blended yarns, it can be said that Ne 30 yarns have higher neps values than Ne 20 yarns, except for 30-70% CO-WST and 40-60% CO-WST yarns, and the neps values of these yarns are slightly higher in Ne 20 yarns than that of Ne 30 yarns.

Based on ANOVA results, p value for Ne 10 is greater than 0.05, whereas p values for Ne 20 and Ne 30 yarns are lower than 0.05. These results show that waste content does not have a statistically significant effect on neps of Ne 10 yarn, but it has significant effect on neps in Ne 20 and Ne 30 yarns. Correlation results in Table 6 display that the relationship between waste and neps is moderately strong and positive for Ne 20 yarns, whereas these relationships are not strongly for the other yarn counts. This means waste content in Ne 20 yarns partially increases neps.

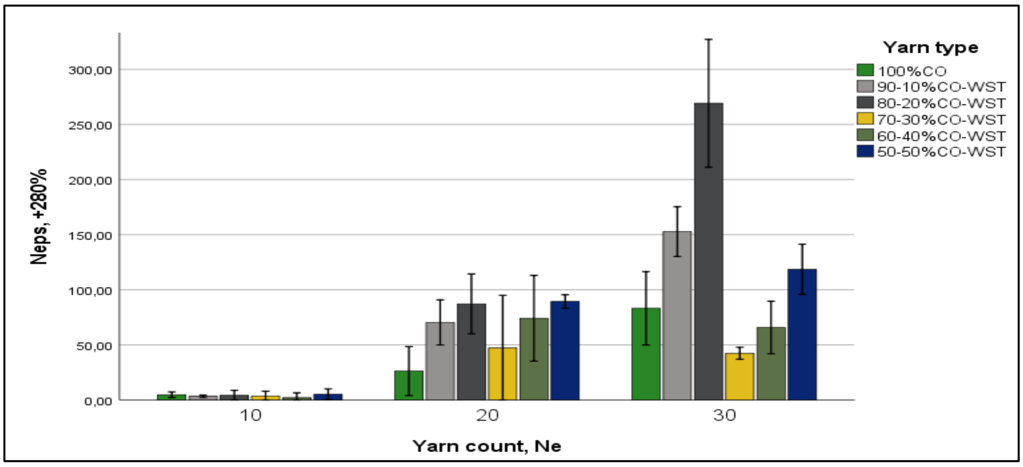

Figure 5. Neps

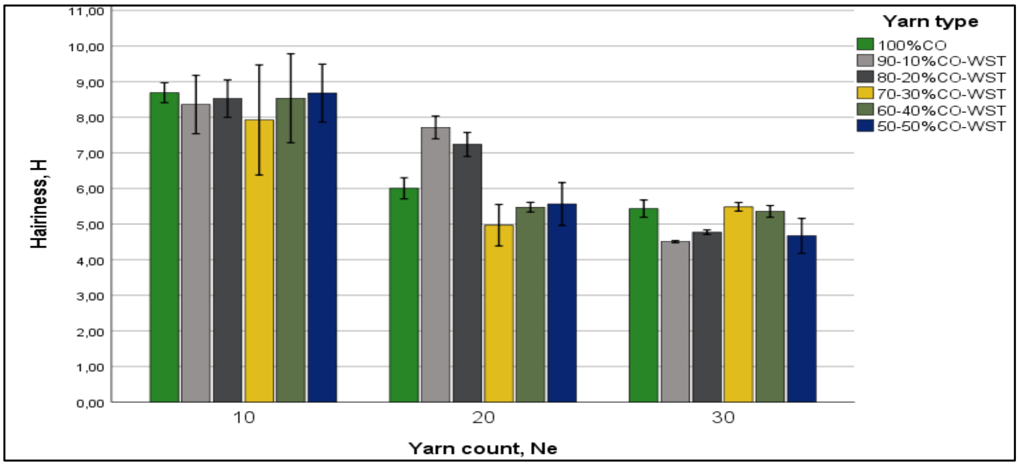

Figure 6. Hairiness

3.5. Hairiness

According to Figure 6 and Table 5, the hairiness values decrease significantly from Ne 10 yarns to Ne 30 yarns, that is, from coarse yarns to fine yarns. While 70-30% CO-WST yarn haS the lowest hairiness value for Ne 10 yarns, the hairiness values of other yarns are very close to each other. In Ne 20 yarns, 90-10% CO-WST and 80-20% CO-WST yarns showed the highest hairiness with close values, 70-30% CO-WST yarn showed the lowest hairiness, while the other yarns showed very close hairiness with slightly higher hairiness values than that of this yarn. In Ne 30 yarns, contrary to the trends seen in Ne 20 yarns, 90-10% CO-WST, 80-20% CO-WST and 50-50% CO-WST yarns have the lowest hairiness with almost the same values, while 100% CO, 70-30% CO-WST and 60-40% CO-WST yarns have higher hairiness with the same values. However, when the 90-10% CO-WST and 80-20% CO-WST yarns in Ne 20 yarns are ignored in general, it is possible to state that the hairiness values of yarns with different waste ratios in all yarn counts do not differ much.

ANOVA results in Table 5 show p value is higher than 0.05 for Ne 10, while p values are lower than 0.05 for Ne 20 and Ne 30 yarns. These results express that waste content does not have a statistically significant effect on hairiness in Ne 10 yarn, whereas it has significant effect on hairiness of Ne 20 and Ne 30 yarns. From Table 6, it is seen that there is moderately strong and negative relationship between waste and hairiness for Ne 20 yarns, and this means waste content partially decreases hairiness in Ne 20 yarns.

3.6. Breaking Strength (Tenacity)

From Figure 7 and Table 5, where the strength test results are shown, it is observed that the strength values decrease from coarse yarns to fine yarns, that is, from Ne 10 yarns to Ne 30 yarns. For Ne 10 yarns, it is seen that with the increase of the waste ratio, the strength decreases in general and the yarn with the highest waste ratio, 50-50% CO-WST yarn, has the lowest strength value. In Ne 20 yarns, 100% CO and 90-10% CO-WST yarns with the highest cotton content have the lowest and the same strength values, while the yarns containing 20%, 30%, and 40% waste have the highest and almost the same strength values. In Ne 30 yarns, when 100% CO yarn and 50-50% CO-WST yarn are excluded, it is seen that the strength values decrease with the increase in the waste ratio, while 100% CO, 70-30% CO-WST and 60-40% CO-WST yarns have the lowest and almost the same strength values, while 90-10% CO-WST yarn has the highest value, 80-20% CO-WST and 50-50% CO-WST yarns are slightly lower than that of this yarn and have the same strength values as each other. When the yarns that disrupt the general trend are ignored, it can be said that the increase in the waste ratio in all yarn counts reduces tenacity values in terms of strength.

According to p values ≤ 0.05 in Table 5, waste has significant effect on tenacity for all yarn counts. Correlation results display that the relationship between waste and tenacity is strong and negative for Ne 10 yarns whereas it is moderately strong and positive for Ne 20 yarns. These gives meaning of waste content decreases tenacity in Ne 10 yarns, while it increases tenacity in Ne 20 yarns.

3.7. Breaking Elongation

The elongation results seen in Figure 8 and Table 5 showed parallelism with the strength results, and accordingly, it is observed that the elongation at break values decreases from coarse yarns to fine yarns, that is, from Ne 10 yarns to Ne 30 yarns, except for yarns that do not comply with the general trend. In the evaluation based on yarn counts, it is seen that the elongation values of yarns with different waste ratios are close to each other for Ne 10 and Ne 30 yarns. For Ne 20 yarns, the elongation values are gathered under two groups, that is, the elongation values of 100% CO, 90-10% CO-WST and 50-50% CO-WST yarns are low and close to each other, on the contrary, the elongation values of 80-20% CO-WST, 70-30% CO-WST and 60-40% CO-WST yarns are close to each other and much higher than that of other yarns.

From Table 5, it is seen that p values are lower than 0.05 for Ne 10 and Ne 20 yarns, while p value is higher than 0.05 for Ne 30 yarns. These results show that waste content has a significant effect on elongation in Ne 10 and Ne 20 yarns, as it has not significant effect on elongation in Ne 30 yarns. According to Table 6, there is moderately strong and negative relationship between waste and elongation for Ne 10 yarns, and this express increase in waste content partially decreases elongation in Ne 10 yarns.

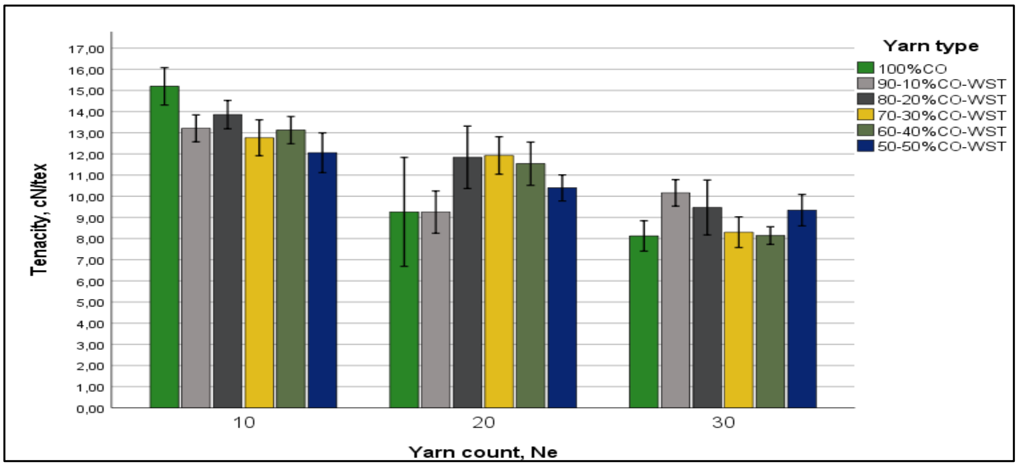

Figure 7. Breaking strength (Tenacity)

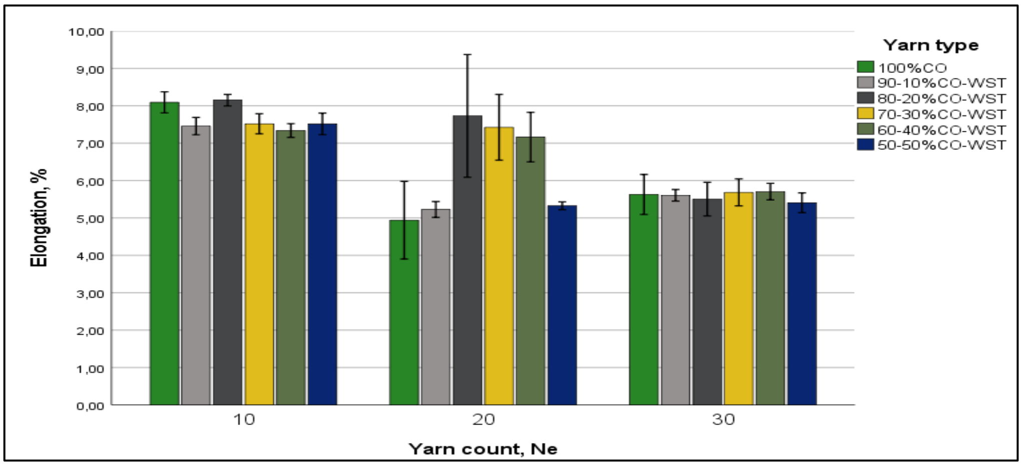

Figure 8. Breaking elongation

4. CONCLUSION

In this study, yarns containing 10-50% waste using cotton as the main fiber were obtained in 3 different yarn counts, Ne 10, Ne 20, and Ne 30, and it was aimed to reveal the effects of waste on yarn properties.

As a result of the graphical and statistical evaluations of the obtained data, it was determined that the waste did not affect the yarn properties as negatively as expected.

Excluding the breaking strength and elongation, the yarn count that was least affected by the waste content was Ne 10, the coarsest yarn. While the breaking strength and elongation of Ne 10 yarns decreased with the increase in the waste ratio, yarn evenness, yarn imperfection, and hairiness values were close to each other in all blend ratios, and the increase in the waste rate did not adversely affect these properties.

In Ne 20 yarns, on the other hand, it was determined that the effect of waste on yarn properties showed a zigzag trend, increasing from low waste ratio too high, generally, 70-30% CO-WST yarn breakage occurred and then again with the increase of waste, it partially negatively affected yarn properties. Except unevenness and elongation, all yarn properties were moderately affected by waste content.

As in Ne 20 yarns, for Ne 30 yarns, the effect of waste shows a partially zigzag tendency, but the properties of yarns with different blend ratios are closer to each other and the increase in waste ratio has fewer negative effects on yarn properties as seen in unevenness, thin places, and breaking elongation. Also, as in Ne 20 yarns, while the waste ratio changed in terms of yarn properties, the breaking point was mostly 70-30% CO-WST yarns. The yarn properties that were most affected by the increase in waste content and ratio in Ne 30 yarns were thick places, neps and tenacity although the effects are limited.

Considering all the yarn counts, it was concluded that Ne 10 is the most suitable yarn count in the production of waste yarn, considering that the waste content and ratio in the blended yarns affect the yarn properties less and even do not make a significant difference as expected.

In addition, for Ne 20 and Ne 30 yarns, when hairiness and breaking strength-elongation are not taken into account, it has been observed that the optimum blend ratio in terms of yarn unevenness and yarn imperfections is in the 70-30% CO-WST yarn, that is, the yarn containing 30% waste. While 30% waste rate is the most suitable in terms of all properties of Ne 20 yarns, it seems reasonable to obtain yarn with lower waste rates in Ne 30 yarns in terms of hairiness and breaking strength.

In future studies, it is recommended to obtain yarns with higher waste ratios, especially in Ne 10 yarns, to reveal the effects of waste on yarn properties and fabric properties, and to identify yarns and fabrics where more waste can be used in terms of sustainability.

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