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TECHNOLOGICAL INFORMATION

Investigation of the use of hemp fibers in recycling spinning

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ABSTRACT. In recycle yarn spinning, the original fibers are added to the blend as a carrier because of the recycled fibers obtained by opening from fabric scraps are very short and coarse. In the textile recycling industry, mostly petroleum-based synthetic fibers are used as carrier fibers. In an environmentally important activity such as recycling spinning, it is necessary to reduce the use of synthetics used as carrier fibers. When considered from this point of view, hemp fibers come to the fore with their important performance and environmental features. Based on this fact, in this study, in addition to the standard production conditions in the recycling yarn production facility, hemp fibers in different proportions were added to the blends to reduce the ratio of polyester as carrier fiber and the effects of this situation on yarn quality were examined. According to the results, it was observed that adding hemp fiber to the recycle yarn blend increased yarn tenacity, yarn unevenness and yarn hairiness while decreased yarn elongation properties.

Keywords: Cannabis sativa; hemp fiber; mechanical recycling; performance properties; recycled yarn.

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Introduction

The production of textile materials has undergone dramatic changes in the last century. Sustainability in textile production has become the most important issue due to factors such as increasing environmental pollution, consumed resources, carbon footprint and dependence on petroleum. There is a need to be careful and cautious about the use of resources. Due to their advantages such as are eco-friendly nature, biodegradability, less pollution and minimal health hazards, natural fibers have started to attract attention again with the approaching environmental problems and the global energy crisis in recent years (Vigneshwaran et al., 2020). The fact that natural fibers have limited resources requires careful design of textile products to be produced from these fibers, careful planning of production and proper optimization of the conditions. Taking into account this fact, the textile products and production systems should be designed sustainable by choosing the more efficient resource and ecological responsive fibers, and producing less waste and pollution (Fletcher, 2008). As in other sectors, experts in the textile industry need to start evaluating alternative sources for petroleum-dependent raw materials used as fiber (Pollio, 2016). Therefore, it is imperative that professionals in the textile industry start evaluating alternative sources for the raw material used. While evaluating alternative sources; sustainable, renewable and less polluting natural fibers should be reconsidered for uses that have so far been dominated by synthetic fibers (Mahajan, Binaz, Singh, & Arora, 2022). In this regard, among natural fibers, hemp is a potential raw material due to its excellent fiber properties (Blackburn, 2005; Cerino et al., 2021; Hazekamp et al., 2016). In addition to desirable textile properties, hemp is often lauded as an excellent rotational crop that requires the use of small amounts of pesticides (Gedik & Avinc, 2020). The fiber transfers heat well, is resistant to mildew, blocks ultraviolet light and has natural antibacterial properties (Kashyap, 2015).

The fibers used in the production of sustainable fashion products in the textile industry play an important role. The fibers are used in all production steps until the final product in the textile industry, such as labor, energy, water, chemicals, etc. they are the main determinant for resources (Oner & Ozdas, 2021). Textile recycling, most often refers to the reprocessing of pre- or post-consumer textile waste for use in new textile or non-textile products. Textile recycling methods are typically classified as mechanical, chemical and thermal (Sandin & Peters, 2018). Textile wastes can be recycled into fiber form by mechanical or chemical methods. Mechanical recycling method is the cheapest and the simplest way for recycling of textile wastes (Demiroz Gun & Kuyucak, 2022). In the mechanical recycling method, textile wastes are sorted, cut with a guillotine, and turned into fibers by shredding or garnet machines, which have rotating drums covered with sharp steel pins or wires (Gulich, 2006). In order to obtain yarn from recycled fibers, there are the open-end rotor spinning process, the woollen spinning process and the open-end friction spinning process (Dref), which allows economical production (Payne, 2015; Gulich, 2006). Textile wastes cannot be used alone in recycling spinning. Carrier fibers are blended into the yarns in order to ensure that the textile wastes in the form of fibers can be spun into yarn and to increase the quality and strength of the yarns obtained from these fibers. For this reason, it is important that the carrier fibers to be used are sustainable while providing performance properties.

There are various studies in the literature on the use of hemp fibers in the textile industry. Most of the studies are about the use of hemp fibers in composite structure due to their important strength properties (Huda et al., 2005; Sanadi et al., 1994; Ramamoorthy et al., 2014; Zou et al., 2011; Baghaei & Skrifvars, 2016; Corbin et al., 2019; Liu et al., 2021; Yang et al., 2022). Some researchers have examined the change in yarn properties with the use of hemp fibers in yarn production (Mustata & Mustata, 2013; Turunen & Van Der Werf, 2007; Zhang et al., 2014; Kozłowski et al., 2013). In addition, the use of hemp fibers in fabric production and the effects of the applied finishing processes have been examined (Yang et al., 2013; Stankovic, 2008; Hwang & Ji, 2012; Jin Lee & Sun Ji, 2016; Stankovic & Bizjak, 2014; Hyun & Seung, 2018; Paulitz et al., 2017; Ali, Rahman, & Chen, 2015; Zhang & Zhang, 2010; Wang et al., 2003).

As seen in literature research, there is no study on the use of hemp fibers, which is an important sustainable fiber for the environment, in recycling applications. In this study, the use of hemp as a carrier fiber required in the production of recycled yarn was investigated, and the effect of hemp use on yarn performance properties in recycled yarn was compared with reference recycled yarns.

Material and methods

In order to investigate the effects of the use of hemp fibers in recycling spinning, a total of 20 different recycling yarns were produced in four different yarn counts, five different blend schemes in which the hemp ratio was gradually increased. The study was carried out in a factory that produces recycled yarn. For this reason, the recycled yarns produced by the factory were included in the experimental group as a reference. In addition, the samples of the study were produced according to the production conditions of the factory. Reference yarn samples of the study have the most common blending ratios used by recycling yarn mills for those yarn counts. As the yarn count gets finer in recycle spinning, the ratio of carrier fiber (virgin polyester) used in the blend increases (Demiroz Gun & Oner, 2019). The yarn samples of the study were all made from blending of recycled cotton fibers, virgin polyester fibers in 1.3 dtex fiber fineness and 38 mm fiber length, and hemp fibers with cottonization and cutting processes were used.

In order to make the provided pool-retted hemp fibers usable in short staple spinning (cottonization), alkaline scouring, bleaching, softening and cutting processes were applied to the fibers, respectively. Alkali scouring was performed in order to improve the hydrophilicity of the hemp fibers, and the process was designed according to the literature (Gedik and Avinc, 2018). Alkali scouring was applied using 5 g L^{-1} sodium hydroxide and 1 g L^{-1} wetting agent at 80°C for 60 minutes. Bleaching was carried out with 30 mL L^{-1} hydrogen peroxide at 130°C for 60 minutes. Then the fibers went through softening process at 40°C for 30 minutes by weak nonionic softeners. After the fibers were dried freely, they were cut in a Balkan DTA62 Guillotine Cutting Machine with an average fiber length of 38 mm. Infrared spectroscopy (FT-IR) analysis method was applied to examine the change of chemical characteristics of the fibers as a result of chemical processes applied to hemp fibers. Infrared spectroscopy was performed on a Perkin-Elmer Spectrum Two FT-IR spectrophotometer equipped with ATR apparatus. The spectrum recorded as the average of 5 scans was taken for each sample.

Recycled cotton fibers used in the yarn samples obtained from fabric scraps coming from apparel manufacturing industry. Fabric scraps that came as pre-consumer garment waste were separated into cotton according to raw material analysis. The fabric scraps selected by the discrimination process were cut in a Balkan DTA62 Guillotine Cutting Machine. Then they were subjected to the opening process in Balkan DT30 Mega Pulling Machine.

The recycled yarns were manufactured according to the standard procedures of the company. Recycled cotton waste materials, virgin polyester fibers and cottonized hemp fibers were fed with Balkan B10 Bale Opener and blended using Balkan Dt80 Box Room. The blended fibers were carded on Trützschler TC 11 at

150 m min.$^{-1}$ and 54 kg h^{-1} machine settings. After the carding process, one passage drawing was carried out using Rieter RSB-D 50 Draw Frame. Six doublings and six drafts were applied during drawing passages at 600 m/min, and 5.5 ktex slivers were produced. Recycled yarns were spun on a Rieter R36 open-end spinning machine with rotor diameter 36 mm to produce Ne 30 (19.7 tex) counts, rotor diameter 44 mm to produce Ne 20 (29.5 tex) counts, and 54mm to produce Ne 12 (49.2 tex) and Ne 6 (98.4 tex) counts. Material and the spinning parameters describing yarn types are shown in Table 1.

The yarn samples were produced simultaneously on the machine at reference yarn settings according to the yarn count for each yarn type (Figure 1). Only 30-4 coded Ne 30 yarn was produced in a separate lot at a higher twist level because it could not provide sufficient strength in the machine.

Table 1. The basic properties of the yarns produced in the study.

Sample Code	Yarn Count (Ne)	Recycled Cotton Ratio (%)	Virgin Polyester Ratio (%)	Hemp Ratio (%)	Twist (T/m)	Twist Coefficient (αe)	Rotor Diameter (mm)	Rotor Speed (rpm)
6-R	6	85	15	-	360	3.7	54	50000
6-1		25	50	25				
6-2		50	35	15				
6-3		50	25	25				
6-4		50	15	35				
12-R	12	75	25	-	520	3.8	54	53000
12-1		25	50	25				
12-2		50	35	15				
12-3		50	25	25				
12-4		50	15	35				
20-R	20	35	65	-	620	3.6	44	68000
20-1		25	50	25				
20-2		50	35	15				
20-3		50	25	25				
20-4		50	15	35				
30-R	30	50	50	-	780	3.7	36	84000
30-1		25	50	25				
30-2		50	35	15				
30-3		50	25	25				
30-4		50	15	35	860	4.0	36	76000

Figure 1. Example of yarn samples running on the same machine.

In order to conditioning the yarn samples produced in this study, the samples were kept in the laboratory for 24 hours at standard atmospheric conditions (20±2°C, 65±2% RH) before the tests according to ASTM D1776/D1776M-15. As yarn quality properties, unevenness, imperfections (thin places, thick places and neps), hairiness, yarn tenacity and elongation values of the yarn samples were measured. Unevenness, imperfections and hairiness properties of the yarn samples were measured on Uster Evenness Tester 3 at testing speed 400 m/min according to ASTM 1425 and yarn tensile properties were tested on Uster Tensorapid 3 Tester in accordance with EN ISO 2062. The obtained results were evaluated with a variance analysis, followed by a post hoc test (Student Newman, Kuel – SNK), by using SPSS 22.0 statistical software. For all statistical analyses, $p < 0.05$ (confidence level of 95%) was considered to be significant.

Results and discussion

The most important threshold for the use of hemp fibers in yarn production is the cottonization process. Because, hemp fibers in their raw state are quite hard, rigid and unsuitable for spinning. In order to change this natural structure of hemp fibers, lignin and pectin structures must be removed by the cottonization process. In this study, the optimum cottonization application was determined as a result of many trials. In order to see the effect of the applied cottonization process, FTIR analyzes were performed before and after the treatment.

Afterwards, the yarns of different fineness were produced by blending hemp fibers, which was made into spinnable by chemical treatment, with recycled cotton and virgin polyester fibers in different proportions. The quality tests were carried out to make comparative analyzes according to the performance characteristics of the yarns produced.

FTIR spectroscopy

In studies in the literature, some characterization studies have been carried out in order to examine the change of chemical content of fibers as a result of chemical processes applied to hemp fibers (Chung et al., 2004; Yao et al., 2008; Karthik & Murugan, 2013; Corami et al., 2020). Among these characterization studies, infrared spectroscopy (FTIR) analysis method has been observed as the most frequently used method (Meleiro & García-Ruiz, 2016). This is because the chemical bonds distinguishing the compounds in the fibers can be easily determined by FTIR spectroscopy. According to these studies, infrared wavelengths that characterize the compounds (cellulose, hemicellulose, lignin and pectin) frequently found in the structure of hemp fibers were determined (Dai and Fan, 2010; Terpakova et al., 2012; Kabir et al., 2013). The results of FTIR applied to the hemp fibers before and after the treatment by taking these determined wavelengths into consideration are shown in Figure 2.

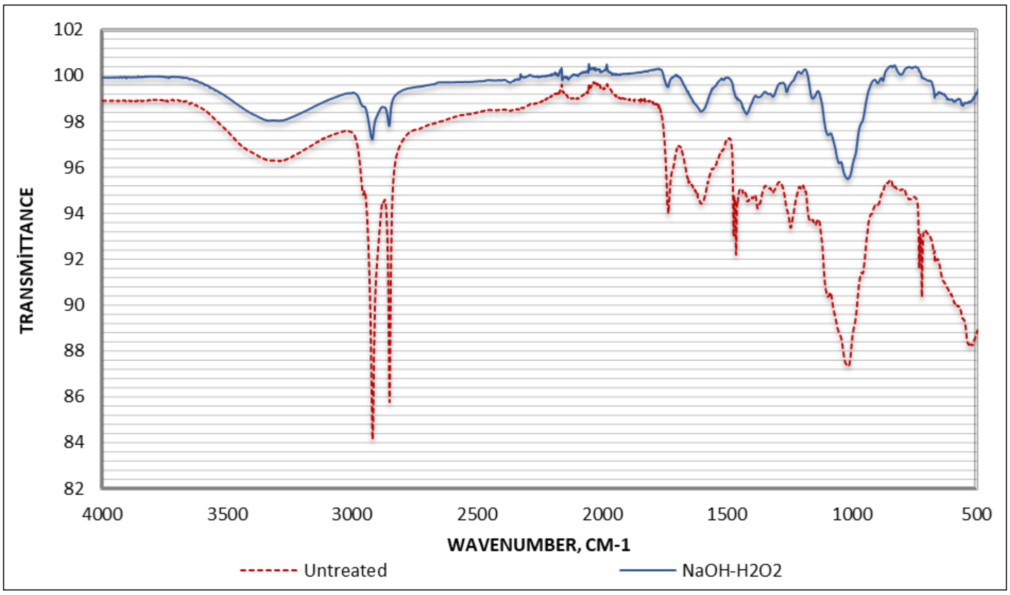

Figure 2. FTIR spectra of the untreated and cottonized hemp fibers.

When the FTIR spectra of hemp fibers before and after chemical treatment are examined, a significant decrease is observed in the wave number of 2900-2800 cm^{-1}, 1750 cm^{-1}, 1450 cm^{-1}, 1260 cm^{-1}, 1020 cm^{-1} and 750 cm^{-1}. As a result of the chemical treatment, the decrease seen in the 2900-2800 cm^{-1}, 1020 cm^{-1} and 750 cm^{-1} signals, it is seen that the amount of cellulose/hemicellulose in the hemp fiber decreased. Similarly, the decrease in the signals at 1454 cm^{-1} and 1260 cm^{-1} wave numbers after chemical treatment indicates that the lignin substance and the decrease in the 1750 cm^{-1} signal indicate that the pectin substance are largely removed from the structure of the hemp fiber.

Tenacity

A basic and classic problem in textile materials science is the link between the strength of fibers and yarns. Therefore, establishing this relationship is important both in theory and in practice (Ramey et al., 1977). The tenacity results of the yarns produced in this study are given in Figure 3.

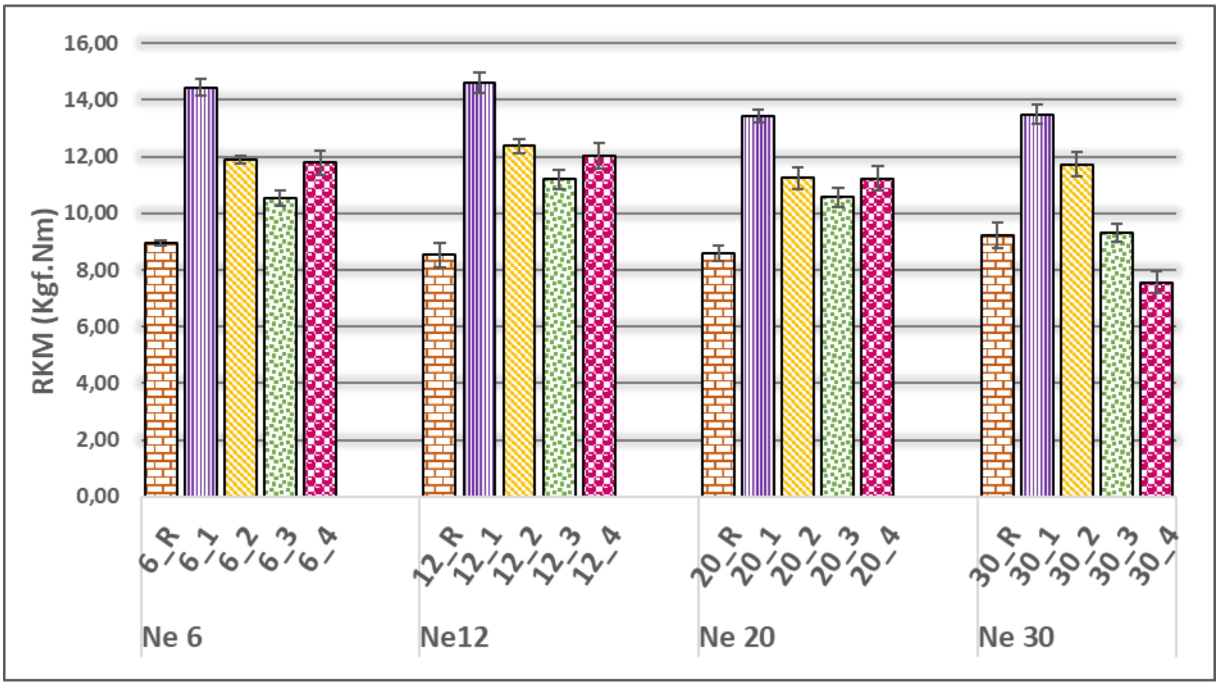

Figure 3. Tenacity results of the yarns.

When the tenacity measurement results are examined, it is seen that the highest value is in 25% recycled cotton, 25% hemp and 50% polyester blended yarns. It has been determined that, hemp and polyester with high fiber strength properties increase the tenacity of the yarns which have the highest polyester-hemp ratio in their blends. It is seen that as the polyester ratio in the blend increases, the tenacity of the yarn increases. Despite the decrease in the rate of polyester in the blend, the increase in the hemp ratio has a positive reflection on the tenacity values of the yarns. Considering the yarn counts, the remarkable result is the lowest tenacity value of the Ne 30, 50% recycled cotton, 35% hemp and 15% polyester blend yarn. The number of fibers in the cross section of the yarn, which is an effective parameter in strength, can also affect the data. As these yarns are thin yarns, the low number of fibers in the cross-section and the decrease in the polyester ratio in the structure may have caused this situation.

In general, it is understood that hemp fiber added to the recycled yarn structure has a positive effect on yarn tenacity (Zhang et al., 2014). Hemp fiber has a longer main length and greater fiber stiffness and initial modulus than polyester and cotton fiber. Therefore, its distribution in the yarn structure contributes to the strength of the recycled yarn. For each yarn fineness, it has been found that blends prepared by adding hemp to the blends currently used as reference in the production of the factory give better tenacity results.

According to the variance analysis it is seen that tenacity values of the yarns are significantly different between each other statistically ($p<0.05$). SNK post hoc test results according to the tenacity are given in Table 2 and Table 3, respectively.

Considering the blend ratio, as seen in the SNK post hoc results for the tenacity values, the lowest value is the reference yarn, while the yarn with the blend ratio of 25% recycled cotton / 25% hemp / 50% polyester shows the highest value. The tenacity values of each blend showed differences from each other in the Table 3. It is estimated that the hemp fiber plays the decisive role here.

Considering the yarn count, as seen in SNK post hoc results, the lowest value is Ne 30 and the highest value is Ne 12, as seen in the SNK post hoc results. It can be thought that the tenacity of the yarn tends to increase as the number of fibers in the cross section increases as the yarn gets thicker.

Table 2. Results of SNK post hoc tests of the tenacity values according to blending.

Blending	N	Subset for α=0.05				
		1	2	3	4	5
Reference	40	8.8163				
50rec/25hemp/25pet	40		10.3958			
50rec/35hemp/15pet	40			10.6455		
50rec/15hemp/35pet	40				11.811	
25rec/25hemp/50pet	40					13.995
Sigma		1.000	1.000	1.000	1.000	1.000

Table 3. Results of SNK post hoc tests of the tenacity values according to yarn count.

Yarn count	N	Subset for α=0.05			
		1	2	3	4
Ne 30	50	10.2608			
Ne 20	50		11.0114		
Ne 6	50			11.5166	
Ne 12	50				11.7420
Sigma		1.000	1.000	1.000	1.000

Elongation

When the blended yarn is subjected to a force, the fibers of both components elongate as the force increases, until the smaller-elongation fibers break and thus transfer all the load to the other fibers. If there are enough fibers with higher elongation in the yarn cross-section, the blended yarn will not break. Fiber shear plays a particularly important role when the constituent fibers in a blended yarn have different fiber breaking elongation values (Baykal et al., 2006). The elongation results of the yarns produced in this study are presented in Figure 4.

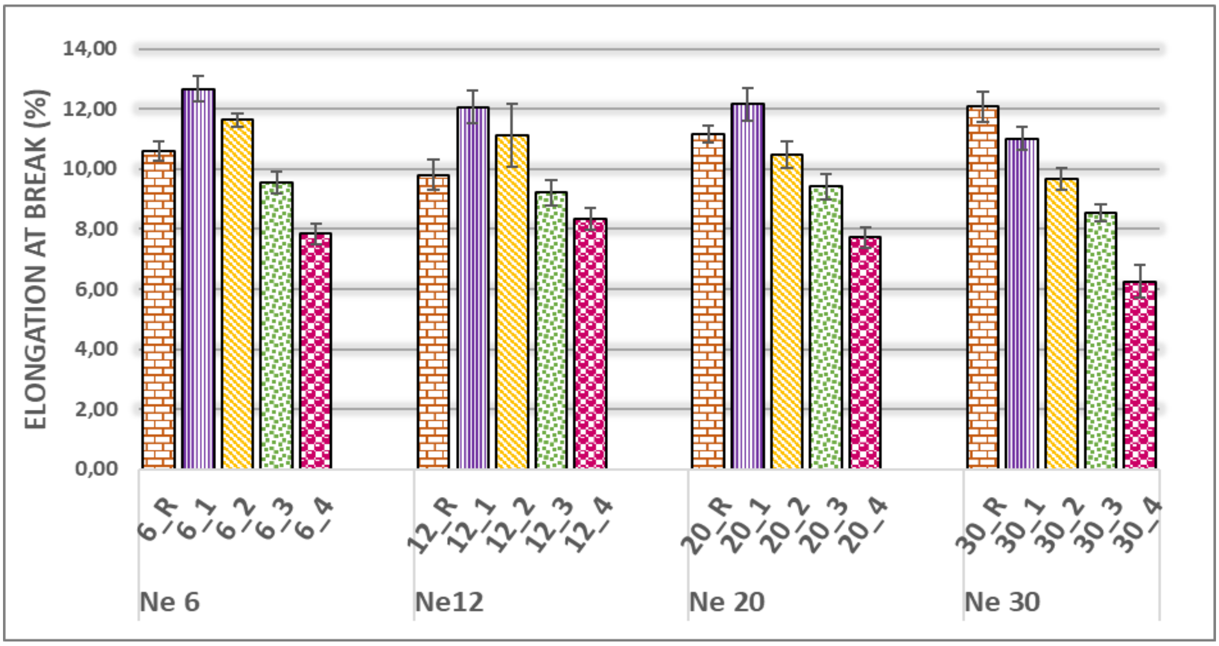

Figure 4. Elongation results of the yarns.

For all yarn types, the highest elongation value is observed in 25% recycled cotton, 25% hemp and 50% polyester blend, and it is determined that the elongation values decreased as the polyester ratio in the blend decreased. It can be interpreted that recycled cotton has no serious effect on the elongation values of the blended yarns. The effect of the hemp rate in the blend on the elongation can be thought as minimum. Here, polyester plays the biggest role in determining the elongation value, and hemp fiber does not have a positive effect on elongation of the recycled yarns. In the literature, similar to the findings obtained in this study, it was observed that the yarn elongation gradually increased with the decrease of hemp fiber content and the increase of polyester fiber content in blended yarns (Zhang et al., 2014).

According to the variance analysis it is seen that elongation values of the yarns are significantly different between each other statistically ($p<0.05$). SNK post hoc test results according to the elongation are given in Table 4 and Table 5, respectively.

Table 4. Results of SNK post hoc tests of the elongation values according to blending.

Blending	N	Subset for α=0.05				
		1	2	3	4	5
50rec/35hemp/15pet	40	7.5450				
50rec/25hemp/25pet	40		9.1828			
50rec/15hemp/35pet	40			10.7300		
Reference	40				10.9155	
25rec/25hemp/50pet	40					11.9815
Sigma		1.000	1.000	1.000	1.000	1.000

Table 5. Results of SNK post hoc tests of the elongation values according to yarn count.

Yarn count	N	Subset for α=0.05		
		1	2	3
Ne 30	50	9.5162		
Ne 12	50		10.1148	
Ne 20	50		10.1892	
Ne 6	50			10.4636
Sigma		1.000	0.360	1.000

When SNK post hoc results are examined for the effect of blending ratios, it is seen that each blend is in a different group and creates significant differences. It can be said that the polyester ratio in the blend is decisive in determining the elongation properties of the yarns. The positive contribution of the polyester fiber in the yarn blend to the elongation ability was also demonstrated by Vadicherla and Saravanan (2017).

Considering the yarn count, as seen in SNK post hoc results for elongation values, Ne 30 gives the lowest value, while the highest value is Ne 6 yarn. There appears to be no statistically difference in elongation between Ne 12 and Ne 20 count yarns.

Unevenness

The unevenness, usually measured as the change in mass per unit length along the yarn, is fundamental and important as it can affect many other properties of the yarn and fabric made from it (Balcı Kılıc & Okur, 2019). The unevenness results of the yarns produced in this study are illustrated in Figure 5.

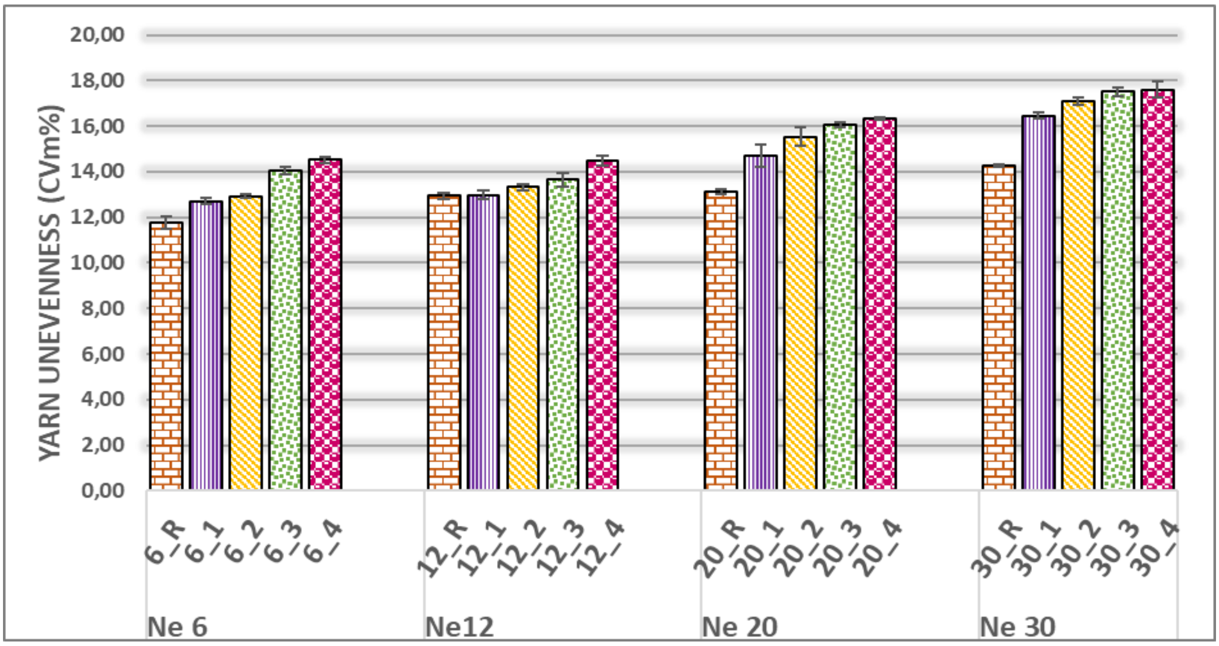

Figure 5. Unevenness results of the yarns.

Considering the findings, it is seen that the inclusion of hemp fiber in the yarn structure increases the unevenness. It is thought that, this is caused by the hard, thick and rough structure of hemp fiber. In terms of yarn unevenness, it has been determined that reference blends currently used in production give more successful results. As stated by Zhang et al. (2013), hemp fibers have a morphologically rough surface due to their beam structure. And this condition can cause an uneven surface on the yarn. This finding is consistent with the studies of other researchers (Donmez Kretzschmar et al., 2007; Wanassi et al., 2016; Zou et al., 2014). When the unevenness results are examined, it is seen that the irregularity values increase as the yarn count increases. The finer yarn, the lower the fiber mass in the cross section and the easier occurrence of defects in the thin structure may be the reasons for this situation. The reasons for this finding may be the less fiber amount in the cross-section of the finer yarn, and the easier the defects of mistakes in the finer yarn structure.

The effect of blending rate on the unevenness was found statistically significant ($p<0.05$). Among the measured yarns, the results of SNK post hoc test applied according to blending are illustrated in Table 6. Besides, the results of SNK post hoc test for yarn count are seen in Table 7.

As can be seen from the SNK post hoc results, each blend group was placed separately and differentiated from each other. In addition, it is clearly seen that yarn irregularity increases with the increase the ratio of hemp fiber in the yarn structure.

Table 6. Results of SNK post hoc tests of the unevenness values according to blending.

Blending	N	Subset for α=0.05				
		1	2	3	4	5
Reference	40	13.0280				
25rec/25hemp/50pet	40		14.2060			
50rec/15hemp/35pet	40			14.7155		
50rec/25hemp/25pet	40				15.3175	
50rec/35hemp/15pet	40					15.7400
Sigma		1.000	1.000	1.000	1.000	1.000

Table 7. Results of SNK post hoc tests of the unevenness values according to yarn count.

Yarn count	N	Subset for α=0.05			
		1	2	3	4
Ne 6	50	13.1920			
Ne 12	50		13.4772		
Ne 20	50			15.1540	
Ne 30	50				16.5824
Sigma		1.000	1.000	1.000	1.000

When the groups that cause a statistically significant difference in terms of yarn fineness are examined, it is seen that each yarn count is in a separate group. As can be understanded from this situation, each change in yarn counts causes a statistically significant variance in yarn unevenness.

Imperfections

The imperfections as thin, thick places and neps are important determinants that affect the outer appearance of the yarns and the quality of the products, especially in rotor spinning (Repon et al., 2016). The imperfection results of the yarns produced in this study are given in Table 8.

Table 8. The imperfections of the yarns.

Sample Code	Thin Places (-50%)	Thick Places (+50%)	Neps (+280%)
6-R	0.00	9.40	5.40
6-1	0.00	13.60	4.80
6-2	0.40	57.20	25.00
6-3	1.40	33.20	14.60
6-4	1.00	19.00	7.40
12-R	0.00	4.60	0.80
12-1	0.00	26.20	17.60
12-2	0.40	70.80	48.60
12-3	0.40	35.40	25.20

12-4	0.20	49.60	35.00
20-R	0.20	25.00	24.60
20-1	2.80	59.00	58.20
20-2	5.80	77.00	80.20
20-3	3.40	93.60	93.60
20-4	4.40	204.80	201.20
30-R	1.60	58.40	106.80
30-1	8.20	107.40	90.00
30-2	19.80	148.80	299.60
30-3	23.80	173.60	334.40
30-4	19.00	251.60	420.20

In terms of the imperfection findings in Table 8, trends are similar to the unevenness results. These findings are compatible with the effect of yarn count on unevenness and imperfections which is known as thicker yarns have good unevenness values than thinner yarns due to including higher number of fibers in the cross section of yarn. These results are consistent with the recycled yarn study in the literature (Demiroz Gun & Oner, 2019). In addition to this, it is once again seen that the coarse nature of the hemp fiber causes an increase in the thick places mistake in the yarn.

Hairiness

Apart from special usage purposes, yarn hairiness becomes a very undesirable parameter because machine speeds increase as a result of technological developments and high efficiency is required, and it should be measured and controlled (Barella & Manich, 1988). The hairiness results of the yarns produced in this study are shown in Figure 6.

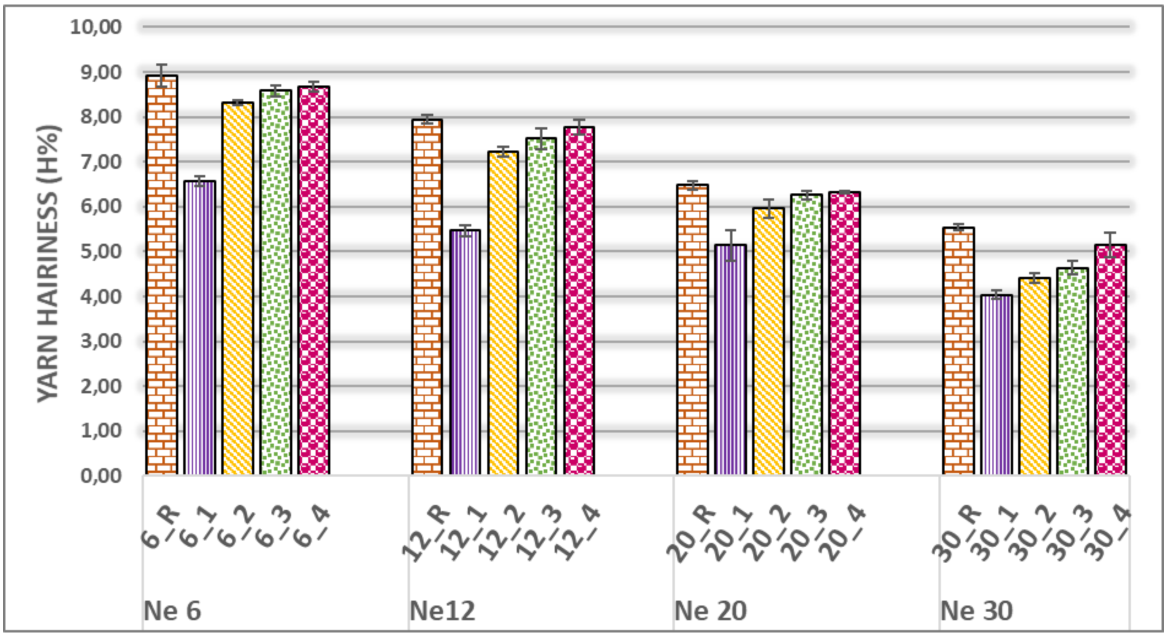

Figure 6. Hairiness results of the yarns.

As the yarn becomes thinner, yarn hairiness decreases for all yarn types with the effect of the twist and the number of fibers in the cross section. This finding is in agreement with the studies in the literature (Demiroz Gun & Oner, 2019; Halimi et al., 2009). The hairiness values of the yarns increase in coarse yarns because of the having more fibers in the yarn cross-section increases the fibers protruding from the yarn surface. Besides, it is observed that the hairiness of the recycled yarns increased as the polyester ratio in the blends decreased and the hemp ratio increased. Compared to other yarn types, it is determined that Ne 30 count, 25% recycled cotton, 25% hemp and 50% polyester blend yarn has the lowest hairiness value.

According to the variance analysis it is seen that the hairiness values of the yarns are significantly different between each other statistically ($p<0.05$). SNK post hoc test results according to the hairiness are given in Table 9 and Table 10, respectively.

Table 9. Results of SNK post hoc tests of the hairiness values according to blending.

Blending	N	Subset for α=0.05			
		1	2	3	4
25rec/25hemp/50pet	40	5.3000			
50rec/15hemp/35pet	40		6.5500		
50rec/25hemp/25pet	40			6.8500	
50rec/35hemp/15pet	40			6.9000	
Reference	40				7.3000
Sigma		1.000	1.000	0.657	1.000

Table 10. Results of SNK post hoc tests of the hairiness values according to yarn count.

Yarn count	N	Subset for α=0.05			
		1	2	3	4
Ne 30	50	4.8400			
Ne 20	50		6.0400		
Ne 12	50			7.2000	
Ne 6	50				8.2400
Sigma		1.000	1.000	1.000	1.000

As seen in the results of the SNK post hoc analysis, the increase in polyester ratio caused a decrease in hairiness. In addition, yarns containing 15% and 25% polyester are in the same group without any statistical difference.

When SNK post hoc results are examined according to the yarn count, it is seen that each yarn count is in statistically significant different groups.

When the findings are evaluated in general, it seems possible to use natural hemp fibers instead of petroleum-based polyester fibers, which are carrier fibers in recycling spinning. For Ne 6, Ne 12 and Ne 20 yarns, it has been observed that the polyester ratio can be reduced up to 15% with the use of hemp, when the recycled cotton fibers are 50% in the blend. For Ne 30 yarns, the polyester ratio in the blend should not be reduced below 25%.

Conclusion

In this study, the performance and quality properties of recycled yarns containing hemp fibers in different yarn counts and blend ratios were measured, their applicability in production processes was comprehensively examined with generally accepted test methods in the literature and industry, and researches were made for their usability in later processing stages.

In the light of the findings obtained in this study, it was seen that hemp fibers may be used in the production of recycled yarns, may support short recycled fibers as a carrier, and raise them above the standard in terms of performance. According to the experimental set used in this study, it was understood that the inclusion of hemp fiber in the current recycling blend increased the yarn strength, decreased the elongation ability, and increased the yarn unevenness and hairiness, generally.

With this study, the usage conditions of hemp fibers in the production of recycled yarn were investigated and applied in real time in the factory production line. The results of the study are expected to be beneficial to science and industry representatives who conduct research on hemp fibers and place emphasis on recycling and sustainability. Future studies are planned to prepare hemp fibers with different chemical processes, to incorporate them into the yarn structure with different blending methods, and to improve the properties of the recycled yarn with different finishing processes.

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References

Ali, A., Rahman, M., & Chen, Y. (2015). Cotton spinning properties of chemically modified hemp fibres. *International Journal of Science and Research (IJSR), 4*(8), 1482-1490.

Baghaei, B., & Skrifvars, M. (2016). Characterisation of polylactic acid biocomposites made from prepregs composed of woven polylactic acid/hemp–lyocell hybrid yarn fabrics. *Composites Part A: Applied Science and Manufacturing, 81*, 139–144. DOI: https://doi.org/10.1016/j.compositesa.2015.10.042.

Balcı Kılıc, G., & Okur, A. (2019). Effect of yarn characteristics on surface properties of knitted fabrics. *Textile Research Journal*, *89*(12), 2476-2489. DOI: https://doi.org/10.1177/0040517518797337.

Barella, A., & Manich, A. M. (1988). The influence of the spinning process, yarn linear density, and fibre properties on the hairiness of ring-spun and rotor-spun cotton yarns. *The Journal of The Textile Institute, 79*(2), 189-197. DOI: https://doi.org/10.1080/00405008808659135.

Baykal, P. D., Babaarslan, O., & Erol, R. (2006). Prediction of strength and elongation properties of cotton polyester-blended OE rotor yarns. *Fibres and Textiles in Eastern Europe*, 14(1), 18-21.

Blackburn, R. (2005). *Biodegradable And Sustainable Fibres.* Cambridge, EN:Woodhead Publishing.

Cerino, P., Buonerba, C., Cannazza, G., D'Auria, J., Ottoni, E., Fulgione, A., & Gallo, A. (2021). A review of hemp as food and nutritional supplement. *Cannabis and Cannabinoid Research, 6*(1) 19-27. DOI: https://doi.org/10.1089/can.2020.0001

Chung, C., Lee, M., & Choe, E. K. (2004). Characterization of cotton fabric scouring by FT-IR ATR spectroscopy. *Carbohydrate Polymers*, *58*(4), 417-420. DOI: https://doi.org/10.1016/j.carbpol.2004.08.005.

Corbin, A. C., Soulat, D., Ferreira, M., Labanieh, A. R., Gabrion, X., Malécot, P., & Placet, V. (2019). Towards hemp fabrics for high-performance composites: Influence of weave pattern and features. *Composites Part B: Engineering, 181*, 107582. DOI: https://doi.org/10.1016/j.compositesb.2019.107582.

Corami, F., Rosso, B., Bravo, B., Gambaro, A., & Barbante, C. (2020). A novel method for purification, quantitative analysis and characterization of microplastic fibers using Micro-FTIR. *Chemosphere*, *238*, 124564, DOI: https://doi.org/10.1016/j.chemosphere.2019.124564.

Dai, D., & Fan, M. (2010). Characteristic and performance of elementary hemp fibre. *Materials Science and Application, 1*(6), 336-342. DOI: http://dx.doi.org/10.4236/msa.2010.16049.

Mahajan, A., Binaz, V., Singh, I., & Arora, N. (2022). Selection of natural fiber for sustainable composites using hybrid multi criteria decision making techniques. *Composites Part C: Open Access, 7*. DOI: https://doi.org/10.1016/j.jcomc.2021.100224.

Demiroz Gun, A. D., & Kuyucak, C. N. (2022). Performance properties of plain knitted fabrics made from open end recycled acrylic yarn with the effects of covered and PBT elastic yarns. *Fibers and Polymers*, *23*(1), 282-294. DOI: https://doi.org/10.1007/s12221-021-0329-y.

Demiroz Gun, A., & Oner, E. (2019). Investigation of the quality properties of open-end spun recycled yarns made from blends of recycled fabric scrap wastes and virgin polyester fibre. *The Journal of the Textile Institute, 110*(11), 1569-1579. DOI: https://doi.org/10.1080/00405000.2019.1608620.

Donmez Kretzschmar, S., Ozguney, A. T., Ozcelik, G., & Ozerdem, A. (2007). The comparison of cotton knitted fabric properties made of compact and conventional ring yarns before and after the dyeing process. *Textile Research Journal,* 77(4), 233-241. DOI: https://doi.org/10.1177/0040517507076745.

Fletcher, K. (2008). Sustainable Fashion and Textiles: Design Journeys (1st ed.). Londron, Routledge. DOI: https://doi.org/10.4324/9781849772778.

Gedik, G., & Avinc, O. (2018). Bleaching of hemp (cannabis sativa l.) fibers with peracetic acid for textiles industry purposes. *Fibers and Polymers*, *19*(1), 82-93. DOI: https://doi.org/10.1007/s12221-018-7165-0.

Gedik, G., & Avinc, O. (2020). Hemp fiber as a sustainable raw material source for textile industry: can we use its potential for more eco-friendly production?. In S. Muthu & M. Gardetti (Eds.), *Sustainability in the textile and apparel industries. Sustainable Textiles: Production, Processing, Manufacturing & Chemistry* (p. 87-109). Springer, Cham. DOI: https://doi.org/10.1007/978-3-030-38541-5_4

Gulich, B. (2006). *Development of products made of reclaimed fibres*. Y. Wang (Ed.), *In recycling in textiles,* (p. 117-113). London, EN: Woodhead Publishing. DOI: http://dx.doi.org/10.1533/9781845691424.3.117

Halimi, M. T., Azzouz, B., Hassen, M. B., & Sakli, F. (2009). 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*, *4*(3), 1558-9250. DOI: https://doi.org/10.1177/155892500900400304.

Hazekamp, A., Tejkalová, K., & Papadimitriou, S. (2016). Cannabis: from cultivar to chemovar II—A metabolomics approach to cannabis classification. *Cannabis Cannabinoid Research, 1*(1), 202-215. DOI: https://doi.org/10.1089/can.2016.0017.

Huda, M. S., Drzal, L., Misra, M., Mohanty, A. K., Williams, K., & Mielewski, D. F. (2005). A study on biocomposites from recycled newspaper fiber and poly (lactic acid). *Industrial & Engineering Chemistry Research*, *44*(15), 5593-5601. DOI: https://doi.org/10.1021/ie0488849.

Hwang, M. S., & Ji, D.S. (2012). The effects of yarn number and liquid ammonia treatment on the physical properties of hemp woven fabrics. *Fibers and Polymers*, *13*(10), 1335-1340. DOI: https://doi.org/10.1007/s12221-012-1335-x.

Hyun, A.K., & Seung, J.K. (2018). Hand and wear comfort of knitted fabrics made of hemp/tencel yarns applicable to garment. *Fibers and Polymers*, *19*(7), 1539–1547. DOI: https://doi.org/10.1007/s12221-018-8275-z.

Jin Lee, J., & Sun Ji, D. (2016). Evaluation of liquid moisture management properties on hemp woven fabrics treated with liquid ammonia. *Textile Research Journal, 87*(14), 1752–1764. DOI: https://doi.org/10.1177/0040517516659374.

Kabir, M. M., Wang, H., Lau, K.T., & Cardona, F. (2013). Effects of chemical treatments on hemp fibre structure. *Applied Surface Science*, *276*, 13-23. DOI: https://doi.org/10.1016/j.apsusc.2013.02.086.

Kashyap, R. (2015). Sustainable fibers and fabrics used in home textiles. *International Journal for Scientific Research and Development*, *3*, 901-903.

Karthik, T., & Murugan, R. (2013). Characterization and analysis of ligno-cellulosic seed fiber from Pergularia daemia plant for textile applications. *Fibers and Polymers*, *14*(3), 465-472. DOI: https://doi.org/10.1007/s12221-013-0465-0.

Kozłowski, R., Czaplicki, Z., Zaręba, S., & Mańkowski, J. (2013). Rotor cotton yarns with the content of enzymatically modified hemp fibers. *Journal of Natural Fibers*, *10*(1), 1-13. DOI: http://dx.doi.org/10.1080/15440478.2012.738062.

Liu, Z., Chen, K., Fernando, A., Gao, Y., Li, G., Jin, L., & Zheng, Z. (2021). Permeable graphited hemp fabrics-based, wearing-comfortable pressure sensors for monitoring human activities. *Chemical Engineering Journal*, *403*, 126191. DOI: https://doi.org/10.1016/j.cej.2020.126191.

Meleiro, P. P., & García-Ruiz, C. (2016). Spectroscopic techniques for the forensic analysis of textile fibers. *Applied Spectroscopy Reviews*, *51*(4), 278-301. DOI: https://doi.org/10.1080/05704928.2015.1132720.

Mustata, A., & Mustata, F.S.C. (2013). Moisture absorption and desorption in flax and hemp fibres and yarns. *Fibres and Textiles in Eastern Europe, 99*(3), 26–30.

Oner, J., & Ozdas, F. (2021). Investigation of textile waste usage in stone mastic asphalt (SMA) mixtures. *Gradevinar*, *73*(5), 555–567. DOI: https://doi.org/10.14256/JCE.3135.2020.

Paulitz, J., Sigmund, I., Kosan, B., & Meister, F. (2017), Lyocell fibers for textile processing derived from organically grown hemp. *Procedia Engineering, 200*, 260–268. DOI: https://doi.org/10.1016/j.proeng.2017.07.037.

Payne, A. (2015). Open and closed-loop recycling of textile and apparel products.In S. S. Muthu (Ed.), *In Woodhead Publishing Series in Textiles, Handbook of Life Cycle Assessment (LCA) of Textiles and Clothing* (p.103-123). Cambridge, EN: Woodhead Publishing.

Pollio, A. (2016). The name of cannabis: a short guide for nonbotanists. *Cannabis Cannabnoid Research*, *1*, 234-238. Doi:10.1089/can.2016.0027.

Ramamoorthy, S. K., Persson, A., & Skrifvars, M. (2014), Reusing textile waste as reinforcements in composites. *Journal of Applied Polymer Science, 131*(17), 1-16. DOI: https://doi.org/10.1002/app.40687.

Ramey, H. H., Lawson, R., & Worley, S. (1977). Relationship of cotton fiber properties to yarn tenacity. *Textile Research Journal*, *47*(10), 685-691. DOI: https://doi.org/10.1177/004051757704701008.

Repon, M., Mamun, R., Reza, S., Kumer Das, M., & Islam, T. (2016). Effect of spinning parameters on thick, thin places and neps of rotor spun yarn. *Journal of Textile Science and Technology, 17*(3), 47-55. DOI: https://doi.org/10.4236/jtst.2016.23007.

Sanadi, A. R., Young, R. A., Clemons, C., & Rowell, R. M. (1994). Recycled newspaper fibers as reinforcing fillers in thermoplastics: part I: analysis of tensile and ımpact properties in polypropylene. *Journal of Reinforced Plastics and Composites*, *13*(1), 54-67. DOI: https://doi.org/10.1177/073168449401300104.

Sandin, G., & Peters, G.M. (2018). Environmental impact of textile reuse and recycling – a review. *Journal of Cleaner Production*, *184*, 353-365. DOI: https://doi.org/10.1016/j.jclepro.2018.02.266.

Stankovic, S. (2008). Static lateral compression of hemp/filament hybrid yarn knitted fabrics. *Fibers and Polymers*, *9*, 187-193. DOI: https://doi.org/10.1007/s12221-008-0030-4.

Stankovic, S. B., & Bizjak, M. (2014). Effect of yarn folding on comfort properties of hemp knitted fabrics. *Clothing and Textiles Research Journal, 32*(3), 202–214. DOI: https://doi.org/10.1177/0887302X14537114.

Terpakova, E., Kidalova, L., Estokova, A., Cigasova, J., & Stevulova, N. (2012). Chemical modification of hemp shives and their characterization. *Procedia Engineering*, *42*, 931-941. DOI: https://doi.org/10.1016/j.proeng.2012.07.486.

Turunen, L., & Van Der Werf, H. M. G. (2007). The production chain of hemp and flax textile yarn and its environmental impacts. *Journal of Industrial Hemp, 12*(2), 43–66. DOI: https://doi.org/10.1300/J237v12n02_04.

Vadicherla, T., & Saravanan, D. (2017). Effect of blend ratio on the quality characteristics of recycled polyester/cotton blended ring spun yarn. *Fibres and Textiles in Eastern Europe*, *25*, 48-52. DOI: https://doi.org/10.5604/12303666.1227875.

Vigneshwaran, S., Sundarakannan, R., John, K. M., Johnson, R. D. J., Prasath, K. A., Ajith, S., ... Uthayakumar, M. (2020). Recent advancement in the natural fiber polymer composites: A comprehensive review. *Journal of Cleaner Production*, *277*, 124109. DOI: https://doi.org/10.1016/j.jclepro.2020.124109.

Wanassi, B., Azzouz, B., & Hassen, M. B. (2016), Value-added waste cotton yarn: optimization of recycling process and spinning of reclaimed fibers. *Industrial Crops and Products, 87*, 27-32. DOI: https://doi.org/10.1016/j.indcrop.2016.04.020.

Wang, H. M., Postle, R., Kessler, R. W., & Kessler, W. (2003). Removing pectin and lignin during chemical processing of hemp for textile applications. *Textile Research Journal*, *73*(8), 664–669. DOI: http://dx.doi.org/10.1177/004051750307300802.

Yang, X., Fan, W., Wang, H., Shi, Y., Wang, S., Liew, R. K., & Ge, S. (2022). Recycling of bast textile wastes into high value-added products: a review. *Environmental Chemistry Letters*, *20*(18), 1-17. DOI: http://dx.doi.org/10.1007/s10311-022-01484-z.

Yang, Y. Y., Hao, X. M., Hao, X., Li, H. W., & Feng, X. X. (2013). Investigate on moisture absorption/desorption of shoe material containing hemp fiber. *Advanced Materials Research, 627*, 49-52. DOI: https://doi.org/10.4028/www.scientific.net/AMR.627.49.

Yao, J., Liu, Y., Yang, S., & Liu, J. (2008). Characterization of secondary structure transformation of stretched and slenderized wool fibers with FTIR spectra. *Journal of Engineered Fibers and Fabrics*, *3*(2), 1558-9250. DOI: https://doi.org/10.1177/155892500800300205.

Zhang, H., Zhang, J., & Gao, Y. (2014). Study on the Relationship Between Blending Ratio and Performance of Hemp/Polyester Yarn. *Journal of Natural Fibers*, *11*(2), 136–143. DOI: https://doi.org/10.1080/15440478.2013.861780.

Zhang, J., Zhang, H., & Zhang, J. (2013). Evaluation of liquid ammonia treatment on surface characteristics of hemp fiber. *Cellulose, 21*(1), 569–579. DOI: https://doi.org/10.1007/s10570-013-0097-y.

Zhang, J. Q., & Zhang, J. C. (2010). Effect of finishing treatment with softening agent on spinnability of hemp fibre. *Indian Journal of Fibre and Textile Research*, *35*(2), 115-120.

Zou, Y., Reddy, N., & Yang, Y. (2011). Reusing polyester/cotton blend fabrics for composites. *Composites Part B: Engineering*, *42*(4), 763-770. DOI: https://doi.org/10.1016/j.compositesb.2011.01.022.

Zou, Z., Zheng, S., Cheng, L., Xi, B., & Yao, J. (2014). Effect of some variables on the fibre packing pattern in a yarn cross-section for vortex spun yarn. *Fibres and Textiles in Eastern Europe*, *104(*2), 40-46.