DEVELOPMENT AND CHARACTERIZATION OF HEMP-CONTAINING HYBRID YARNS FOR CLOTHING

GAMZE OKYAY,[*] OĞUZ DEMIRYUREK,[**]
MÜNEVVER ERTEK AVCI[***] and HILAL BILGIC[***]

[*]*Department of Fashion Design, Yeşilyurt Vocational School, Malatya Turgut Ozal University, Malatya, Turkey*
[**]*Department of Textile Engineering, Faculty of Engineering, Erciyes University, Kayseri, Turkey*
[***]*Department of Textile, Clothing, Footwear, and Leather, Yeşilyurt Vocational School, Malatya Turgut Ozal University, Malatya, Turkey*
✉ *Corresponding author: G. Okyay, gamze.okyay@ozal.edu.tr*

Received December 22, 2022

Known for its sustainable properties, the usability of hemp instead of conventional cotton hybrid yarns for clothing was investigated by spinning hybrid ring yarns using conventional cotton, viscose-hemp, and organic cotton-viscose-hemp blends for the sheath and elastane and polyester (Lycra and T400) for the core in the yarn structure. Unevenness, yarn imperfections, hairiness, tenacity, and breaking elongation properties of the spun hybrid yarns were examined comparatively by statistical analysis methods. The findings revealed that sheath fiber type, number of components in the yarn structure, and blend ratio were influential factors on yarn quality. Using hemp fiber in the yarn structure slightly decreased the yarn properties, except for tenacity, in general. This situation was more visible in hybrid yarns, which have three different fibers in the sheath. Blending viscose and hemp fibers in the yarn sheath structure provided a synergetic effect, improving the weak properties of both fibers. These yarns had nearly the same tenacity values (from 12.98 to 15.47) as conventional cotton yarns (from 15.24 to 16.8), which could be explained by the fact that hemp fiber has a higher tenacity value (45 cN/tex) than other fibers. Moreover, these yarns had the highest elongation values (from 15.88 to 10.79) due to the good elongation properties of the viscose fibers (20%), compared to other sheath fibers. As a result, when the produced yarns were evaluated in terms of sustainability and performance, viscose-hemp-blended yarns had the optimum yarn properties.

Keywords: hemp, viscose, organic cotton, hybrid yarn, greener production, clothing

INTRODUCTION

The clothing industry satisfies one of people's basic needs and becomes an inevitable part of human life.[1] However, with the steady increase in the world population, the massive use of natural resources and detrimental chemicals in the clothing industry creates significant environmental effects.[2] Because of this, environmental sustainability has become a key concern for clothing manufacturers' businesses, consumers' lifestyles, and product purchasing preferences.[3,4] Accordingly, clothing companies should develop initiatives to motivate their stakeholders to participate in eco-friendly fashion business practices.[4,5] Three major forms of initiatives of textile companies for environmental sustainability are corporate social responsibility, green supply chain management, and eco-design.[6] The term 'eco-design' refers to the process of developing products in which the design and development processes prioritize environmental concerns and obligations.[7,8] Material selection, manufacturing procedures, and design rethinking are three important components of eco-design approaches.[1]

At present, conventional cotton fibers are used to manufacture 40% of all clothing, making it one of the most chemically reliant crops, using 10% of all chemicals and 25% of pesticides used in global agriculture.[4,9] Conventional cotton cultivation also demands more natural resources (such as land, water, and electricity) than other textile fiber crops; conventional cotton fields currently account for 2.5% of all agricultural acreage on the planet. Conventional cotton crops necessitate a huge amount of water for irrigation, which reduces soil fertility owing to salinization. Also, conventional cotton cultivation contributes 1.5 percent of world energy use annually for the manufacturing of industrial fertilizers, while producing excessive levels of greenhouse gases and carbon dioxide. Thus, it also contributes to climate change and the depletion of natural resources.[4,10] As a result of the growing awareness of environmental pollution and human health in the clothing manufacturing industry, as well as the growing demand for clothes, environmental protection demands, raw material resource requirements, and ecological consequences, there has been a desire for sustainable clothing manufacturing that uses less natural resources and reduces exposure to hazardous chemicals.

Fibers like bamboo,[11-13] Tencel,[14,15] and flax,[16,17] which are more sustainable and environmentally friendly than conventional cotton, have started to be employed in apparel production in the last few years.[18] Industrial hemp fiber, which stands out and shines with its strong sustainable yield potential for the apparel sector, is highlighted as a substitution fiber in this study. Hemp is one of the greenest textile plants on the planet, as well as one of the oldest textile plants in human history.[19] Hemp, unlike cotton grown by traditional methods, is a natural fiber that does not pollute the environment for two reasons: first, its higher yield, ease of farming, and pest tolerance, needing little or no agrochemical application, such as fertilizers and pesticides, and second, its deep roots bind and improve soil fertility. It needs less space, water, and energy for the same amount of yield compared to conventional cotton.[4,20] In addition, hemp fibers have antibacterial and anti-static properties, as well as good moisture absorption, breathability, and UV protection.[18,21-25] However, it is recommended that the hemp ratio in the yarn structure should not exceed 30%, since high crystallinity, high rigidity, high impurity, and low cohesion of hemp fibers cause difficulties in spinning.[26,27] Therefore, the hemp blend ratio in the hybrid yarns produced was determined as 30% and below, and viscose-hemp and organic cotton-viscose-hemp blends were selected in this study. This is because the organic cotton and viscose fibers are soft, the length, and fineness are even, and the spinning property is good, which can make up for the performance and production insufficiency of hemp.[27]

There are some studies in the literature on hemp concerning its harvesting,[28-31] extraction process,[32-34] and its use in composites.[35-43] Despite a thorough review of the literature, a specific study analyzing or producing viscose-hemp and organic cotton-viscose-hemp blended hybrid yarns was not found.

To address the aforementioned issues, this research intends to develop hemp-containing hybrid yarns as an alternative to the conventional cotton hybrid yarns used in the garment industry. In order to achieve this goal, hybrid yarns of various compositions were produced, and the structural and mechanical properties of the produced yarns were compared for the first time using statistical analysis methods.

EXPERIMENTAL

Materials

In this study, conventional cotton (CT, Şanlıurfa province, Turkey), organic cotton (OC, Akkucak Tekstil San. Tic. Ltd. Şti., Turkey), viscose (V, Viscose EcoVero, Lenzing, Austria), and hemp (H, cottonized hemp, La Chanvrière, France) were used as sheath fibers, and elastane (L, Lycra®, Lycra, UK) and polyester (T, T400®, Lycra, UK) were used as core component.

Cross-section images of the fibers were taken at 1000X magnification using a ZEISS EVO scanning electron microscope, in VP mode, operating with an accelerating voltage of 25 keV. The USTER HVI 1000 instrument was used to determine the characteristics of CT and OC fibers. Other fibers' characteristics were listed in accordance with the product information provided by the supplier.

Methods

Spinning hybrid yarns

In this study, conventional ring-spun (RS), core-spun (CS), and dual-core spun (DCS) yarns were produced with a yarn linear density of Ne 10/1 (59 tex), using a conventional ring spinning machine (Marzoli MDS1, Italy). The notations and blend percentages of the produced hybrid yarns are displayed in Table 1. A conventional ring-spinning frame was used to spin the RS yarns. The CS and DCS yarns were produced on the same modified ring-spinning apparatus. Similar to the CS yarn production, L and T core filaments were supplied separately under the control of a positive feed roller system, during the DCS yarn production. The filaments were routed to the V-grooved guide roller, and both core materials were wrapped in CT, VH, and OCVH sheath fiber blends. The ring-spun, core-spun and dual-core spun yarn production frame is shown in our previous paper.[44] The fabrication parameters of all yarns are given in Table 2.

Yarn analysis

RS, CS, and DCS yarn specimens were initially conditioned in the laboratory under standard atmospheric conditions (20 ± 1 °C and 65 ± 2% RH) for 24 h, according to TS EN ISO 139. The final value of the yarn produced from one cop was determined by taking the mean of ten samples from each cop. Five produced cops were tested and considered as replications. Error bars were calculated from the standard error of the mean of the test results. All analyses were carried out according to the TS EN ISO 2062 standard. Yarn count was determined using a Uster Zweigle yarn reel. At a 400 m/min test speed, the Uster Tester 5 was used to measure yarn unevenness, imperfections, and hairiness. On the Uster Tensorapid 4 test apparatus, measurements of yarn tenacity and elongation were run at 5000 mm/min test speed and 0.5 m jaw distance.

Statistical analysis

The experimental study data were introduced into the IBM® SPSS 26 statistical package software and subjected to two-way analysis of variance (ANOVA). The significance of the sheath fiber type and core component type was analyzed in a 95% confidence interval (CI). The mean differences of subgroups were also compared by a post-hoc Duncan test at 95% CI. In the ANOVA table, df, F, and p stand for the degree of freedom, variation between the sample means, and whether there is a significant difference between the sample means, respectively. The difference between the groups is significant if the p-value is less than 0.05.

Table 1
Blend percentages of the produced hybrid yarns

Yarn notation	Sheath and core blend percentages					
	Conventional cotton	Organic cotton	Viscose	Hemp	Lycra	T400
CT	100.00					
CTL	96.30				3.70	
CTLT	87.80				3.70	8.50
VH			70.00	30.00		
VHL			67.40	28.90	3.70	
VHLT			61.50	26.30	3.70	8.50
OCVH		35.00	35.00	30.00		
OCVHL		33.70	33.70	28.90	3.70	
OCVHLT		30.75	30.75	26.30	3.70	8.50

CT: conventional cotton, OC: organic cotton, V: viscose, H: hemp, L: Lycra, and T: T400

Table 2
Spinning parameters of fabricated hybrid yarns

Yarn linear density (Ne)	T/m	ae	Lycra drawing	T400 drawing
10/1	550.0	4.4	3.6	1.1

T/m: Number of twists per meter, ae: Twist coefficient

Table 3
Characteristics of the fibers used in hybrid yarn fabrication

Properties	Conventional cotton	Organic cotton	Viscose	Hemp	Lycra	T400
Length (mm)	29.28	29.74	38.00	33.00		
Linear density (tex)	0.18	0.18	0.13	0.39	7.80	5.50
Tenacity (cN/tex)	31.00	31.90	25.00	45.00	9.23	35.35
Elongation (%)	5.30	5.10	20.00	2.60	520.00	24.00
Maturity (%)	88.00	88.00				
Short fiber (%)	11.50	10.00				
Trash count	123.00	148.00				

RESULTS AND DISCUSSION

The properties and scanning electron microscope images of the fibers used in hybrid yarn fabrication are given in Table 3 and Figure 1, respectively. According to the images in Figure 1, the cross-sections of conventional cotton and organic cotton are bean-like, whereas those of viscose and hemp are serrated and polygonal, respectively.

Further in this part, the structural properties, such as unevenness, imperfections, hairiness, and mechanical properties, such as tenacity and breaking elongation of RS, CS, and DCS yarns, were evaluated comparatively.

Yarn unevenness (U%)

The unevenness values (U%) and statistical test (ANOVA and DUNCAN) results of the hybrid yarns produced in this study are given in Figure 2 and Tables 4-5, respectively. As shown in Figure 2, hybrid yarns with OCVH sheath fibers provided the highest unevenness values (from 19.41 to 19.60), while hybrid yarns with CT sheath fibers provided the lowest (from 10.07 to 10.78), regardless of the core component. Fiber length and length variations are the main causes of yarn unevenness, as they cause low fiber-to-fiber friction in the yarn structure.[45,46] It is known that hemp fibers cause low fiber-to-fiber friction in the yarn structure due to their inherent characteristics, such as shortness, poor uniformity, and high length variations.[27] Furthermore, using V fibers in the yarn structure reduces yarn unevenness values because the crimped cross-section of the V fibers generates a higher surface area, *i.e.*, more fiber-to-fiber friction.[45,47] Therefore, the observation of the highest U% values in hybrid yarns containing OCVH sheath fibers could be explained, firstly, by the use of hemp fiber in the yarn structure and secondly, by reducing the viscose fiber ratio. The incorporation of core and dual core components in the yarn structure reduced unevenness slightly in hybrid yarns with CT sheath fiber, but had no effect on VH and OCVH sheath fiber hybrid yarns. The fact that the core components are filaments might be the cause of this. ANOVA results indicated that sheath fiber type ($p = 0.000$) and sheath fiber type and core component type ($p = 0.004$) were statistically significant at a level of 5%, while core component type ($p = 0.437$) was not statistically significant on the yarn unevenness values. The unevenness values of yarns were compared using the DUNCAN test, as seen in Table 5. According to the results, CT, VH, and OCVH hybrid yarn types were significantly different from each other. However, core component types (R, L, and LT) were not significantly different from each other, statistically.

As a result, hybrid yarns containing different sheath fiber blends resulted in different yarn unevenness values. On the contrary, yarns formed from the identical sheath fiber blend, with or without a core component, gave similar unevenness values.

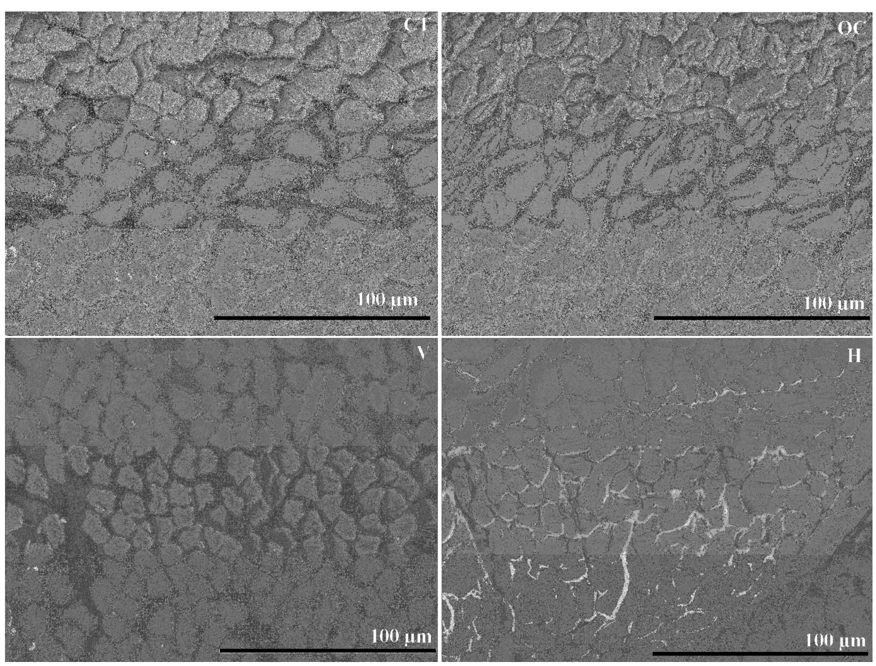

Figure 1: SEM images of fibers used in hybrid yarn fabrication (CT: conventional cotton, OC: organic cotton, V: viscose, and H: hemp)

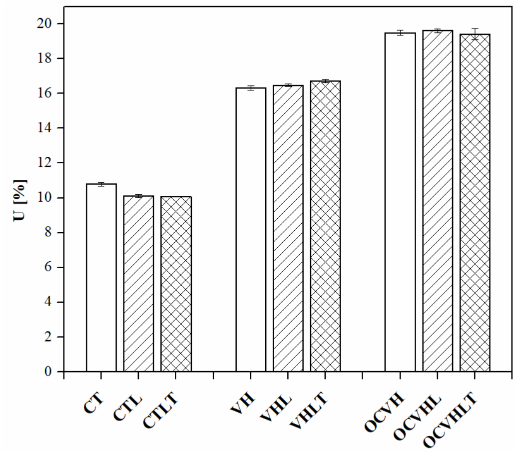

Figure 2: Unevenness values of spun hybrid yarns

Table 4
ANOVA findings for yarn unevenness values

Source	Type III sum of squares	df	Mean square	F value	p-value
Corrected model	659.667[a]	8	82.458	818.472	0.000
Intercept	10729.870	1	10729.874	106503.511	0.000
Sheath fiber type	657.580	2	328.791	3263.543	0.000
Core component type	0.171	2	0.085	0.847	0.437
Sheath fiber type * Core component type	1.914	4	0.479	4.750	0.004
Error	3.627	36	0.101		
Total	11393.168	45			
Corrected total	663.294	44			

[a] R squared = 0.995 (Adjusted R squared = 0.993)

Table 5
DUNCAN findings for yarn unevenness values

Yarn unevenness	Group			
	N	1	2	3
Sheath fiber type				
CT	15	10.322		
VH	15		16.497	
OCVH	15			19.505
Sig.		1.000	1.000	1.000
Core component type				
R	15	15.397		
L	15	15.398		
LT	15	15.528		
Sig.		0.293		

CT: conventional cotton, OC: organic cotton, V: viscose, H: hemp, R: rigid, L: Lycra, and T: T400

Yarn imperfections

Yarn imperfection values and statistical analysis outcomes (ANOVA and DUNCAN) are displayed in Figures 3-5 and Tables 6-11, respectively. There were no thin places (-50%) detected in the hybrid yarns with CT sheath fiber. While there were some thin places in VH sheath fiber hybrid yarns, they grew significantly in the OCVH sheath fiber hybrid yarns (Fig. 3). Yarn imperfection is highly influenced by fiber characteristics.[48] A larger rate of thin places could be noticed in the hybrid yarns containing OCVH sheath fibers due to the non-uniform fineness and length of H fibers, as well as the increase in fiber variety in the blend. Using core components boosted yarn thin place values in hybrid yarns containing VH and OCVH sheath fibers. Moreover, this increase was much more significant in DCS yarns. That might be the result of the core components being unable to be wrapped uniformly due to lower fiber-to-fiber cohesion brought on by the presence of multiple different fibers in the sheath of these yarns, as well as due to the reduced sheath fiber ratio brought about by the use of the dual-core component. The sheath fiber type ($p = 0.000$) and core component type ($p = 0.035$), as well as the interacting effect of these two factors ($p = 0.042$) on thin places, were statistically significant at the 5% level, according to ANOVA results (Table 6). According to the DUNCAN test results for thin places (Table 9), where the difference between VH and OCVH sheath fiber types was statistically significant, the difference between CT and VH sheath fiber types was insignificant. When the core components were investigated, the difference between R and L core components was statistically insignificant, however, the difference between R and LT core component types was statistically significant.

According to Figure 4, OCVH and VH sheath fiber hybrid yarns had much higher thick places (+50%) than hybrid yarns spun entirely of CT sheath fibers, regardless of the core component. This could be due to the non-uniform structure between sheath fibers in these yarns. When the effect of the core component was evaluated, there was no obvious tendency in yarn thick place values. According to the ANOVA results (Table 7), sheath fiber type ($p = 0.000$) had a statistically significant effect on the yarn thick places, although core component type ($p = 0.435$) and the interactive effect of these two components ($p = 0.526$) did not.

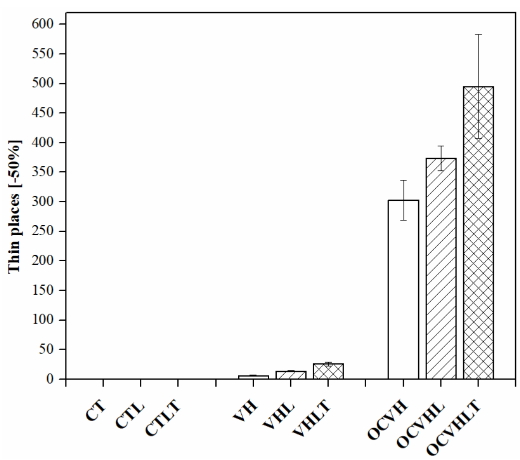

Figure 3: Thin places values of spun hybrid yarns

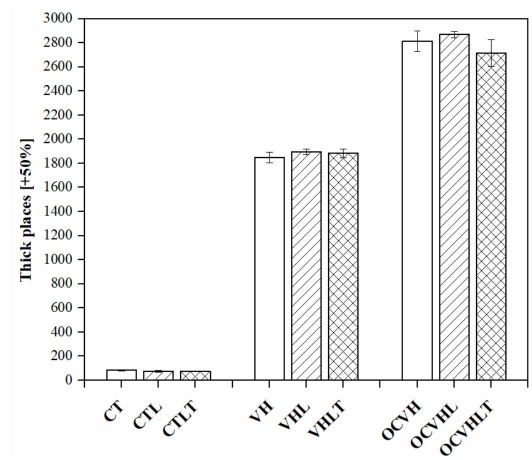

Figure 4: Thick places values of spun hybrid yarns

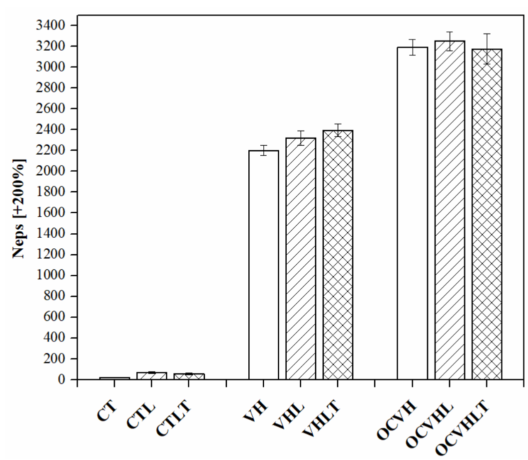

Figure 5: Neps values of spun hybrid yarns

Table 6
ANOVA findings for yarn thin places values

Source	Type III sum of squares	df	Mean square	F value	p-value
Corrected model	1562360.000[a]	8	195295.000	37.603	0.000
Intercept	822151.250	1	822151.250	158.301	0.000
Sheath fiber type	1466625.833	2	733312.917	141.195	0.000
Core component type	38132.500	2	19066.250	3.671	0.035
Sheath fiber type * Core component type	57601.667	4	14400.417	2.773	0.042
Error	186970.000	36	5193.611		
Total	2571481.250	45			
Corrected total	1749330.000	44			

[a] R squared = 0.893 (Adjusted R squared = 0.869)

Table 7
ANOVA findings for yarn thick places values

Source	Type III sum of squares	df	Mean square	F value	p-value
Corrected model	57595635.078[a]	8	7199454.385	537.813	0.000
Intercept	112875842.222	1	112875842.222	8432.044	0.000
Sheath fiber type	57529295.244	2	28764647.622	2148.775	0.000
Core component type	22838.544	2	11419.272	0.853	0.435
Sheath fiber type * Core component type	43501.289	4	10875.322	0.812	0.526
Error	481915.200	36	13386.533		
Total	170953392.500	45			
Corrected total	58077550.278	44			

[a] R squared = 0.992 (Adjusted R squared = 0.990)

Table 8
ANOVA findings for yarn neps values

Source	Type III sum of squares	df	Mean square	F value	p-value
Corrected model	79460008.244[a]	8	9932501.031	391.828	0.000
Intercept	154610629.606	1	154610629.606	6099.246	0.000
Sheath fiber type	79341753.678	2	39670876.839	1564.979	0.000
Core component type	55189.211	2	27594.606	1.089	0.348
Sheath fiber type * Core component type	63065.356	4	15766.339	0.622	0.650
Error	912568.900	36	25349.136		
Total	234983206.750	45			
Corrected total	80372577.144	44			

[a] R squared = 0.989 (Adjusted R squared = 0.986)

In this study, neps were measured at +200% levels. It was observed that the neps content per kilometer was increased with the usage of H fibers and the increase of fiber variety in the blend, regardless of the core component (Fig. 5). This could be due to the physical properties of H fibers and the usage of various fibers in the blend, resulting in a less uniform distribution in the yarn cross-section. The use of core component in all yarns, except for the OCVHLT sample, slightly increased the yarn neps values. ANOVA results revealed that sheath fiber type had a statistically significant effect on the yarn neps values ($p = 0.000$). However, core component type ($p = 0.348$) and the interaction of these factors ($p = 0.650$) had no statistically significant effect on yarn neps values (Table 8 and Table 11). Comparing thick place and neps values of the hybrid yarns formed from CT, VH, and OCVH sheath fibers, the difference between thick place and neps values for all fiber types was statistically significant, whereas, for yarns containing R, L, and LT core components, the difference of all core types for thick places and neps values were statistically insignificant according to the DUNCAN test results given in Table 10 and Table 11.

Table 9
DUNCAN findings for yarn thin places values

Yarn thin places	Group		
	N	1	2
Sheath fiber type			
CT	15	0.167	
VH	15	15.000	
OCVH	15		390.333
Sig.		0.576	1.000
Core component type			
R	15	103.000	
L	15	129.000	129.000
LT	15		173.500
Sig.		0.330	0.099

CT: conventional cotton, OC: organic cotton, V: viscose, H: hemp, R: rigid, L: Lycra, and T: T400

Table 10
DUNCAN findings for yarn thick places values

Yarn thick places	Group			
	N	1	2	3
Sheath fiber type				
CT	15	76.333		
VH	15		1875.800	
OCVH	15			2799.400
Sig.		1.000	1.000	1.000
Core component type				
R	15	1557.100		
L	15	1582.033		
LT	15	1612.200		
Sig.		0.227		

CT: conventional cotton, OC: organic cotton, V: viscose, H: hemp, R: rigid, L: Lycra, and T: T400

Table 11
DUNCAN findings for yarn neps values

Yarn neps	Group			
	N	1	2	3
Sheath fiber type				
CT	15	49.100		
VH	15		2305.733	
OCVH	15			3205.933
Sig.		1.000	1.000	1.000
Core component type				
R	15	1804.100		
L	15	1876.667		
LT	15	1880.000		
Sig.		0.226		

CT: conventional cotton, OC: organic cotton, V: viscose, H: hemp, R: rigid, L: Lycra, and T: T400

When the yarn imperfection results are evaluated together, it can be said that thin places, thick places, and neps were increased with the H fibers' presence in the blend, and this increase was more noticeable when H and OC fibers were used together in the blend, as reported for yarn unevenness. The effect of core component usage and core component type on yarn imperfection varied depending on the sheath fiber blends.

Yarn hairiness

The Uster hairiness values (H) of spun yarns are shown in Figure 6 and the statistical test results (ANOVA and DUNCAN) are given in Tables 12 and 13. The hybrid yarns produced from VH blended fibers had the lowest hairiness values (from 6.94 to 7.28). The hairiness values increased when OC and H fibers were combined in the blend. The type of fiber and blending ratio are the main factors affecting yarn hairiness. Owing to their non-uniform fineness and length, OC and H fibers did not bind properly in the yarn body,[47] which resulted in an increase in hairiness. Therefore, the presence of V fibers in the blend reduced hairiness. In contrast to CT sheath fiber hybrid yarns, where the addition of core components reduced hairiness, VH, and OCVH sheath fiber yarns either did not change or slightly increased the hairiness, similarly to other yarn properties. This might be due to the characteristics of hemp fibers used in the sheath of VH and OCVH hybrid yarns. ANOVA test results display that sheath fiber type ($p = 0.000$), core component type ($p = 0.000$), and sheath fiber type*core component type ($p = 0.000$) had a statistically significant effect on the yarn hairiness values. The hairiness values of yarns were compared using the DUNCAN test, as shown in Table 13. According to the findings, CT, VH, and OCVH hybrid yarn types were significantly different from each other. The core component types of R and L were not significantly different from each other, whereas the L and LT core types of yarn were significantly different from each other.

Yarn tenacity

The tenacity values and statistical test results (ANOVA and DUNCAN) of the spun yarns are presented in Figure 7, Tables 14 and 15, respectively. While the hybrid yarns formed with CT sheath fiber had the highest tenacity (from 15.24 to 16.80), OCVH hybrid yarns containing three different sheath fibers had the lowest tenacity value (from 10.64 to 11.31), regardless of the core component, as shown in Figure 7. Moreover, VH yarns had nearly the same tenacity values as CT yarns, which could be explained by the fact that hemp fiber has a higher tenacity value (45 cN/tex) than other fibers (OC: 32 cN/tex and V: 25 cN/tex) in the blend, and the VH sheath fiber blends had a synergistic effect in the yarn structure. Considering all yarn properties, the lowest tenacity value of OCVH hybrid yarns might be due to the incompatibility of three different sheath fibers in the yarn structure and the inability to achieve uniform distribution in the yarn structure due to low fiber-to-fiber friction. Since this sheath part of the yarn carries more of the load than the core component, sheath fibers contribute more to the tensile properties of the yarn in CS yarns.[45,49-51] As a result, the CS yarns' tenacity characteristics varied depending on the sheath fiber types.

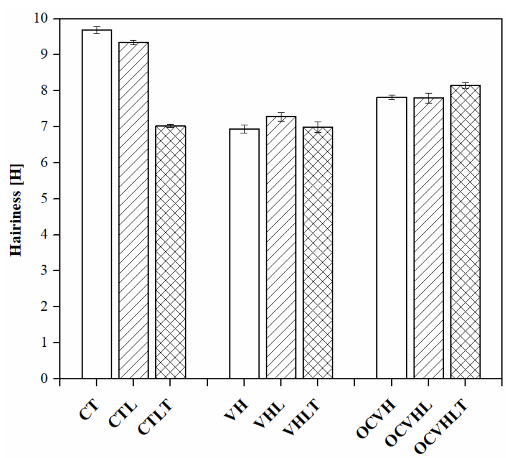

Figure 6: Hairiness values of spun hybrid yarns

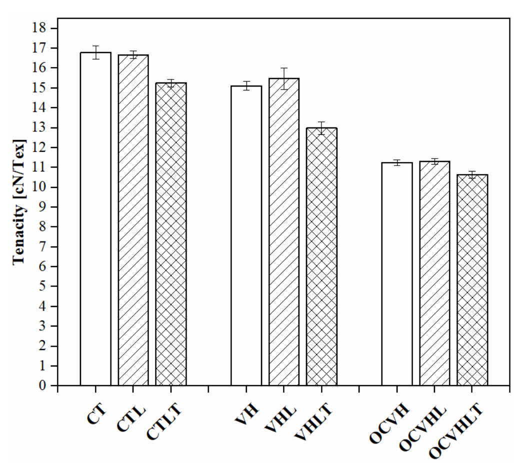

Figure 7: Tenacity values of spun hybrid yarns

Table 12
ANOVA findings for yarn hairiness values

Source	Type III sum of squares	df	Mean square	F value	p-value
Corrected model	41.372[a]	8	5.172	99.901	0.000
Intercept	2804.028	1	2804.028	54166.666	0.000
Sheath fiber type	19.542	2	9.771	188.750	0.000
Core component type	5.787	2	2.894	55.900	0.000
Sheath fiber type * Core component type	16.043	4	4.011	77.478	0.000
Error	1.864	36	.052		
Total	2847.264	45			
Corrected total	43.236	44			

[a] R squared = 0.957 (Adjusted R squared = 0.947)

Table 13
DUNCAN findings for yarn hairiness values

Yarn hairiness	Group			
	N	1	2	3
Sheath fiber type				
CT	15			8.685
VH	15	7.072		
OCVH	15		7.924	
Sig.		1.000	1.000	1.000
Core component type				
R	15		8.154	
L	15		8.141	
LT	15	7.387		
Sig.		1.000	0.873	

CT: conventional cotton, OC: organic cotton, V: viscose, H: hemp, R: rigid, L: Lycra, and T: T400

Table 14
ANOVA findings for yarn tenacity values

Source	Type III sum of squares	df	Mean square	F value	p-value
Corrected model	234.849a	8	29.356	77.403	0.000
Intercept	8752.091	1	8752.091	23076.690	0.000
Sheath fiber type	208.018	2	104.009	274.242	0.000
Core component type	21.889	2	10.945	28.858	0.000
Sheath fiber type * Core component type	4.941	4	1.235	3.257	0.022
Error	13.653	36	0.379		
Total	9000.593	45			
Corrected total	248.502	44			

[a] R squared = 0.946 (Adjusted R squared = 0.934)

When the role of the core component on yarn tenacity was examined, it was discovered that the L core component increased or did not change the tenacity. On the other hand, using LT core components together negatively affected the tenacity values of all yarns. This could be due to the reduced proportion of sheath fibers, which has a major effect on tenacity, as a result of using two core components and thus being unable to cover the core components uniformly. When the tenacity values of the spun yarns were evaluated statistically, the ANOVA findings revealed that sheath fiber type ($p = 0.000$), core component type ($p = 0.000$), and the interaction of these factors ($p = 0.022$) all had a statistically significant effect on the yarn tenacity values. The tenacity values of yarns were compared using the DUNCAN test, as seen in Table 15. According to the findings, the CT, VH, and OCVH hybrid yarn types were significantly different from each other. The core component types of R and L were not significantly different from each other, even though the L and LT core types of yarns were significantly different from each other.

Table 15
DUNCAN findings for yarn tenacity values

Yarn tenacity	Group			
	N	1	2	3
Sheath fiber type				
CT	15			16.241
VH	15		14.525	
OCVH	15	11.071		
Sig.		1.000	1.000	1.000
Core component type				
R	15		14.388	
L	15		14.488	
LT	15	12.961		
Sig.		1.000	0.666	

CT: conventional cotton, OC: organic cotton, V: viscose, H: hemp, R: rigid, L: Lycra, and T: T400

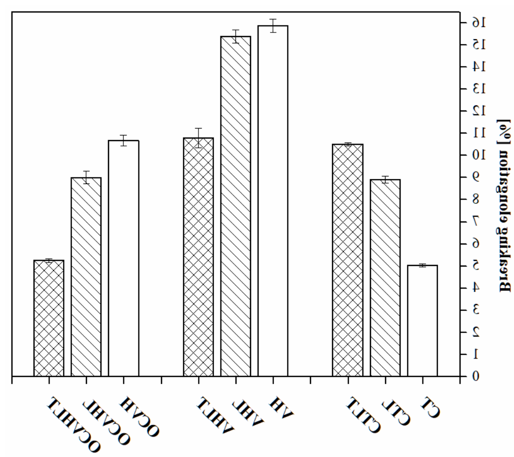

Figure 8: Breaking elongation values of spun hybrid yarns

Table 16
ANOVA findings for yarn breaking elongation values

Source	Type III sum of squares	df	Mean square	F value	p-value
Corrected model	571.233[a]	8	71.404	231.694	0.000
Intercept	4647.387	1	4647.387	15079.944	0.000
Sheath fiber type	335.362	2	167.681	544.095	0.000
Core component type	40.885	2	20.442	66.332	0.000
Sheath fiber type * Core component type	194.986	4	48.746	158.174	0.000
Error	11.095	36	0.308		
Total	5229.715	45			
Corrected total	582.327	44			

[a] R squared = 0.981 (Adjusted R squared = 0.977)

Yarn breaking elongation

The breaking elongation values and statistical test results (ANOVA and DUNCAN) of spun yarns are shown in Figure 8 and Tables 16 and 17, respectively. Due to having good elongation properties of the V fibers (20%) compared to other sheath fibers, hybrid yarns containing V fibers had the highest elongation values, as expected, while hybrid yarns including CT sheath fiber had the lowest elongation values, regardless of the core component. Decreasing the V fiber ratio and usage of the H and OC fibers in OCVH hybrid yarns decreased the breaking elongation (Fig. 8). The reason why the lowest elongation was seen in CT hybrid yarns could be the characteristic elongation feature of the CT fibers (5.3%).

Table 17
DUNCAN findings for yarn breaking elongation values

Yarn elongation	Group			
	N	1	2	3
Sheath fiber type				
CT	15	8.151		
VH	15		14.022	
OCVH	15	8.314		
Sig.		0.428	1.000	
Core component type				
R	15		10.531	
L	15			11.101
LT	15	8.855		
Sig.		1.000	1.000	1.000

CT: conventional cotton, OC: organic cotton, V: viscose, H: hemp, R: rigid, L: Lycra, and T: T400

When the effect of the core component on the elongation values was evaluated, it was seen that the core component negatively affected the elongation values in hybrid yarns formed from VH and OCVH sheath fibers, regardless of core component type. Moreover, in hybrid yarns with CT sheath fiber, the L core component had less elongation at break than the LT core component, whereas in hybrid yarns with VH and OCVH sheath fibers, the converse was true. These contradictory situations might result from the fact that the core components could not be wrapped uniformly due to causing lower fiber-to-fiber cohesion in the presence of multiple different fibers in the sheath of these yarns and also due to the reduced sheath fiber ratio with the use of dual-core components. Sheath fiber type ($p = 0.000$), core component type ($p = 0.000$), and the intersection of these parameters ($p = 0.000$) all exhibited statistically significant effects on yarn breaking elongation values, according to the ANOVA results. The DUNCAN test was conducted to compare the breaking elongation values of hybrid yarns, as illustrated in Table 17. The VH and OCVH yarn types were observed to be significantly different from one another, while the CT and OCVH fiber types were not. The three core component types (R, L, and LT) differed significantly from each other.

CONCLUSION

In this study, for the first time, yarn properties, such as unevenness, yarn imperfections, hairiness, tenacity and breaking elongation of hybrid yarns containing viscose-hemp and organic cotton-viscose-hemp, and those of reference yarns were comparatively examined by statistical analysis methods. The findings were summarized below.

- The type, blend ratio, and the number of fibers used in the sheath all had a huge impact on the yarn's structural and mechanical properties.
- Except for tenacity, the use of hemp fiber in the yarn structure slightly decreased the yarn properties, as expected.
- The use of more than two fiber types in the yarn sheath structure caused the yarn properties to deteriorate.
- The combination of viscose and hemp fibers in the yarn sheath structure provided a synergetic effect, enhancing the weak properties of both fibers.
- The use of core components in the yarn structure either did not change the yarn properties or affected them depending on the sheath fiber blend.

As a result, when the produced yarns were evaluated in terms of sustainability and performance, viscose-hemp-blended yarns had the optimum yarn properties.

ACKNOWLEDGMENTS: The authors appreciate the contributions of Çalık Denim, Malatya, Turkey, who carried out yarn production and analysis.

REFERENCES

[1] S. S. Muthu, "Sustainability in Denim", United Kingdom, Elsevier, 2017

[2] Y. J. Dhir, in: "Waste Management in the Fashion and Textile Industries", edited by R. Nayak and A. Patnaik, Woodhead Publishing, 2021, pp. 31-58

[3] M. R. Khan and M. Islam, *Text. Cloth. Sustain.*, **1**, 1 (2015), https://doi.org/10.1186/s40689-015-0008-8

[4] S. S. Muthu, "Sustainability in the Textile Industry", Hong Kong, Springer, 2017

[5] M. C. S. D. Abreu, in: "Roadmap to Sustainable Textiles and Clothing", edited by S. Muthu, Springer, 2015, pp. 1-21

[6] B. Resta, P. Gaiardelli, R. Pinto and S. Dotti, *J. Clean Prod.*, **135**, 620 (2016), https://doi.org/10.1016/j.jclepro.2016.06.135

[7] H. Lewis, J. Gertsakis, T. Grant, N. Morelli and A. Sweatman, "Design Environment: A Global Guide to Designing Greener Goods", Routledge, 2017

[8] US Environmental Protection Agency, https://www3.epa.gov/ttnchie1/ap42/ch04/final/c4s11.pdf (accessed 17 February 2016)

[9] G. Sweeny, http://www.alternet.org/environment/its-second-dirtiest-thing-world-and-you're-wearing-it (accessed 2 March 2016)

[10] Organic cotton, http://www.organiccotton.org/oc/Cottongeneral/Impact-of-cotton/Risk-of-cotton-farming.php (Accessed 2 March 2016)

[11] A. Basit, W. Latif, S. A. Baig and A. Afzal, *Cloth. Text. Res. J.*, **36**, 267 (2018), https://doi.org/10.1177/0887302X18782778

[12] Z. A. Abro, N. Chen, Z. Yifan, H. Cheng-Yu, A. M. R. Abassi *et al.*, *Autex Res. J.*, **18**, 323 (2018), https://doi.org/10.1515/aut-2018-0017

[13] A. M. Adnan and S. M. Imran, Master's Thesis, University of Boras, Boras, 2010

[14] D. Eichinger and J. Leitner, "Cotton Blends with Tencel® and Lenzing Modal", Lenzing AG, Austria, 2000, p. 1-7

[15] F. Afroz and M. M. Islam, *Heliyon*, **7**, e08243 (2021), https://doi.org/10.1016/j.heliyon.2021.e08243

[16] N. Okur, *J. Nat. Fibers*, 1 (2021), https://doi.org/10.1080/15440478.2021.1993488

[17] M. J. Ebskamp, *Trends Biotechnol.*, **20**, 229 (2002), https://doi.org/10.1016/S0167-7799(02)01953-4

[18] A. G. D. Schumacher, S. Pequito and J. Pazour, *J. Clean Prod.*, **268**, 122180 (2020), https://doi.org/10.1016/j.jclepro.2020.122180

[19] A. Curteza, *Radar*, **2**, 19 (2011)

[20] Green choices, http://www.greenchoices.org/green-living/clothes/more-sustainable-fabrics (Accessed 2 March 2016)

[21] L. Mwaikambo, *Afr. J. Sci. Technol.*, **7**, 120 (2006)

[22] M. Ahirwar and B. K. Behera, *J. Text. Inst.*, **113**, 1 (2021), https://doi.org/10.1080/00405000.2021.1909799

[23] S. Rana, S. Pichandi, S. Parveen and R. Fangueiro, in "Roadmap to Sustainable Textiles and Clothing", edited by S. Muthu, Springer, 2014, pp. 1-35

[24] M. Kostic, B. Pejic and P. Skundric, *BioResour. Technol.*, **99**, 94 (2008), https://doi.org/10.1016/j.biortech.2006.11.050

[25] B. A. Khan, P. Warner and H. Wang, *BioResources*, **9**, 3642 (2014)

[26] D. E. Akin, L. L. Rigsby, N. Patel and K. L. Eriksson, *TRJ*, **67**, 829 (1997), https://doi.org/10.1177/004051759706701107

[27] Y. Liu, R. C. Xu and Y. P. Zhang, *Adv. Mater. Res.*, **332**, 667 (2011), https://doi.org/10.4028/www.scientific.net/AMR.332-334.667

[28] M. Liu, D. Fernando, G. Daniel, B. Madsen A. S. Meyer *et al.*, *Ind. Crop. Prod.*, **69**, 29 (2015), https://doi.org/10.1016/j.indcrop.2015.02.010

[29] M. Nykter, H. R. Kymäläinen, A. B. Thomsen, H. Lilholt, H. Koponen *et al.*, *Biomass Bioenerg.*, **32**, 392 (2008), https://doi.org/10.1016/j.biombioe.2007.10.015

[30] J. Kamat, Ph.D. Thesis, University of Toronto, Canada, 2000

[31] B. Mazian, A. Bergeret, J. C. Benezet and L. Malhautier, *Ind. Crop. Prod.*, **116**, 170 (2018), https://doi.org/10.1016/j.indcrop.2018.02.062

[32] M. Gregoire, L. E. De, M. Bar, S. Musio, S. Amaducci *et al.*, *SN Appl. Sci.*, **1**, 1 (2019), https://doi.org/10.1007/s42452-019-1332-4

[33] P. Lyu, L. Xia, X. Jiang, X. Liu, W. Xu *et al.*, *Ind. Crop. Prod.*, **178**, 114620 (2022), https://doi.org/10.1016/j.indcrop.2022.114620

[34] S. Amaducci and H. J. Gusovius, in "Industrial Applications of Natural Fibres: Structure, Properties and Technical Applications", edited by J. Müssig, Wiley, 2010, pp. 109-134

[35] P. Anand, D. Rajesh, M. Shunmuga Sundaram and V. Anbumalar, *J. Nat. Fibers*, 1 (2021), https://doi.org/10.1080/15440478.2021.1982809

[36] P. Anand and V. Anbumalar, *Cellulose Chem. Technol.*, **51**, 91 (2017), https://www.cellulosechemtechnol.ro/pdf/CCT1-2(2017)/p.91-101.pdf

[37] F. J. Alonso-Montemayor, Q. Tarrés, H. Oliver-Ortega, F. X. Espinach, R. I. Narro-Céspedes *et al.*, *Polymers*, **12**, 1 (2020), https://doi.org/10.3390/polym12051041

[38] M. M. Kabir, M. Y. Al-Haik, S. H. Aldajah, K. T. Lau and H. Wang, *Fibers Polym.*, **21**, 2098 (2020), https://doi.org/10.1007/s12221-020-9630-4

[39] S. Dalle Vacche, V. Karunakaran, S. M. Ronchetti, A. Vitale and R. Bongiovanni, *J. Compos. Sci.*, **5**, 1 (2021), https://doi.org/10.3390/jcs5010011
[40] A. K. Bledzki, H. P. Fink and K. Specht, *J. Appl. Polym. Sci.*, **93**, 2150 (2004), https://doi.org/10.1002/app.20712
[41] R. Joffe and J. Andersons, in "Natural Filler and Fibre Composites: Development and Characterisation", edited by S. Syngellakis, WIT, 2015, pp. 13-26
[42] E. Twite□Kabamba, A. Mechraoui and D. Rodrigue, *Polym. Compos.*, **30**, 1401 (2009), https://doi.org/10.1002/pc.20704
[43] H. C. Han and X. L. Gong, *Polym. Compos.*, **37**, 385 (2016), https://doi.org/10.1002/pc.23191
[44] M. Ertek Avci and O. Demiryurek, *Cellulose Chem. Technol.*, **56**, 1089 (2022), https://doi.org/10.35812/CelluloseChemTechnol.2022.56.97
[45] S. H. Ç. Aydoğdu and D. Yilmaz, *Cellulose Chem. Technol.*, **54**, 381 (2020), https://doi.org/10.35812/CelluloseChemTechnol.2020.54.39
[46] O. Demiryürek and A. Kılıç, *Ind. Text.*, **69**, 1 (2018)
[47] O. Demiryürek and D. Uysaltürk, *Fibers Text. East. Eur.*, **1**, 22 (2014)
[48] S. A. Malik, A. Tanwari, U. Syed, R. F. Qureshi and N. Mengal, *J. Nat. Fibers*, **9**, 197 (2012), https://doi.org/10.1080/15440478.2012.706446
[49] A. Das and R. Chakraborty, *Ind. J. Fib. Text. Res.*, **38**, 237 (2013).
[50] M. B. Qadir, T. Hussain, M. Malik, F. Ahmad and S. H. Jeong, *J. Text. Inst.*, **105**, 753 (2014), https://doi.org/10.1080/00405000.2013.848045
[51] O. Babaarslan, *TRJ*, **71**, 367 (2001), https://doi.org/10.1177/004051750107100415