(REFEREED RESEARCH)

A RESEARCH FOR SPINNING SILK/COTTON BLEND ON OPEN-END ROTOR SPINNING SYSTEM

İPEK/PAMUK KARIŞIMININ OPEN-END ROTOR İPLİK EĞİRME SİSTEMİNDE EĞRİLMESİ ÜZERİNE BİR ARAŞTIRMA

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ABSTRACT

Silk is a special and expensive natural fiber. It enhances added value of products that its used in. Open-end rotor spinning system is the second most favorite spinning system in short staple fiber spinning systems after ring spinning. This spinning system has cost advantages because of its less process needs and high production rate in comparison with ring spinning system. In this study, spinnability of silk fiber in open-end rotor spinning system was investigated. The effects of silk fiber ratio in blends, twist coefficient, rotor speed, rotor type, opening roller type and speed to yarn properties were investigated. Furthermore, single jersey fabrics were produced by Mesdan-lab 294E with medium stitch density and the effect of silk fiber ratio on air permeability, abrasion resistance (through weight loss), surface friction coefficient, thickness and weight of fabrics were investigated. Yarn hairiness and breaking elongation were increased with increasing silk ratio on yarns. Also, air permeability and abrasion resistance of the fabrics were decreased with increasing silk ratio on them.

Keywords: Silk Waste, Open-end Rotor Spinning, Yarn Properties, Air-permeability, Abrasion Resistance.

ÖZET

İpek özel ve pahalı bir liftir. Bulunduğu ürünün özelliklerini ve katma değerini artırır. Open-end rotor iplikçiliği, kısa lif iplikçiliğinde ring iplik eğirme yönteminden sonra en çok tercih edilen eğirme yöntemidir. Üretim prosesi ring iplikçiliğine göre daha kısa ve üretim hızı daha yüksek olduğu için maliyet açısından daha avantajlıdır. Bu çalışmada, open-end rotor iplikçiliğinde ipek lifinin eğrilebilirliğinin incelenmesi amaçlanmıştır. Karışımda ipek oranının, büküm katsayısının, rotor hızının, rotor tipinin, açıcı silindir hızının ve açıcı silindir tipinin iplik özelliklerine etkisi incelenmiştir. Ayrıca Mesdan-lab 294E numune örme makinesinde orta sıklıkta süprem kumaşlar örülerek, karışımda ipek oranının hava geçirgenliği, aşınma dayanımı (ağırlık kaybı), patlama mukavemeti, yüzey sürtünme katsayısı, kumaş kalınlığı ve gramajı değerlerine etkisi incelenmiştir. Karışımda ipek oranı arttıkça iplik kopma uzaması (%) artmış, iplik tüylülüğü değerleri yükselmiştir. Kumaşlarda da ipek oranının artışına bağlı olarak hava geçirgenliği değeri ve aşınma dayanımı azalmıştır.

Anahtar Kelimeler: İpek Artığı, Open-end Rotor İplikçiliği, İplik Özellikleri, Hava Geçirgenliği, Aşınma Dayanımı

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1. INTRODUCTION

Silk is a protein fiber which is produced by silkworms. It is the only natural filament fiber. China is the biggest silk fiber producer in the world. Silk can be used for filament yarn production and in addition to this, silk wastes can also be used to produce yarns. Silk wastes are the fibers which cannot be reeled continuously. These fibers are utilized in staple fiber spinning. Silk wastes are classified with regard to process steps they are obtained in as; cocoon wastes, reeling wastes, twist and weaving wastes (1, 22).

The diameter of silk filaments which are extracted from the cocoon, varies between 12-30 microns. The average fineness of raw silk filaments ranges between 1.8 to 3 denier. The fiber fineness of silk becomes about 1.3 denier after sericin removal. Its fiber tenacity is about 38 cN/tex and its breaking elongation (%) ranges between 15 to 25 %. (1, 22)

Numerous researchers investigated spinnability of silk fibers in ring spinning system and properties of silk blended yarns (2, 4, 5, 9, 10, 11, 12). Chollakup et al. (2004) investigated handle properties of fabrics produced with silk/cotton blend yarns. Chollakup et al. (2008) spun six types of 30 tex silk and cotton blended yarns at 50/50 blending ratio in the cotton spinning system in order to study the effects of blending factors on the fiber distribution in the yarn cross-section. In order to analyze the fiber migration, they proposed a new method of zoning the yarn cross section. They investigated three migration parameters, the Index of Blend Irregularity, the Migration Intensity and the Migration Index in their work. According to their results, the intimate blending gave a more homogeneous fiber distribution; with no radial migration tendency. They reported that the shorter and coarser fibers, like cotton, tended to migrate towards the external yarn layer, whereas the longer and finer fibers, like silk, tended to move towards the yarn core. Rameshkumar et al. (2009) produced 100% PET, 100% silk waste yarns and PET/silk waste core-spun yarns with different core/sheath ratios. They knitted fabrics from these yarns. Thermal comfort properties of these fabrics were investigated in terms of fabric thickness, yarn structure and fiber properties. There are also studies about spinning silk fibers in open-end rotor spinning system (8, 13). Loghavi et al. (2008) produced silk waste/cotton open-end rotor yarns at three different blend ratios (65/35, 50/50 and 35/65) in their study. In addition to this, 100% cotton and silk rotor spun yarns were produced using same parameters. The physical and mechanical properties of the produced yarns; including tensile strength, evenness, imperfection, hairiness, friction and abrasion resistance were investigated. Nibikora and Wanga (2010) produced nine different yarn samples from spun silk/cashmere (blend ratio is 85/15) using three different opening rollers and navels. The sliver size was 3.6 ktex, the fiber length 15 - 20 mm, and the yarn count was 36.4 tex. Optimum selection was achieved using the multi-objective fuzzy optimal model according to the Uster test results of yarn quality properties. A pin type roller and spiral grooved ceramic were found the best choice for spinning stability and yarn quality properties.

Aksakal et al. (2009) investigated tensile properties of silk filament yarns. Das and Ghosh (2008) investigated the yarn imperfections of four different Indian tasar silk yarns. Four varieties of tasar silk yarns, thigh reeled, machine reeled, single twisted (tram), and double twisted (organzine) were considered in their study. They found that the contribution of neps and thick places in total imperfection values of silk yarns were 60% and 30%, respectively. They also reported that the mechanism of generation of thick places and neps were similar and thin places were normally due to lesser number of baves in the resultant reeled yarn.

Chollakup et al. (2009) studied dyeing properties of eri silk/cotton blend yarns. Chollakup et al. (2009) investigated the effect of bleaching conditions on the mechanical properties of Eri silk ⁄ cotton blends in their study. They dyed the blended yarn with warm-dyeing reactive dyes after bleaching. They investigated the effect of the blending ratio on dyeing and mechanical properties. They explained that dyeing Eri silk ⁄cotton blend yarns with the warm-dyeing Remazol RR dyes could not provide a uniform shade onto the yarns due to the different physical characteristics of the two fibers. Cotton fiber has better dye absorption as compared with Eri silk. Özgüney et al. (2015) studied applicability of root dyestuff printing technique on silk fabrics. Quaynor et al. (1999) investigated dimensional changes in knitted silk and cotton fabrics with laundering. The fabrics were subjected to relaxation processes and an extended series of wash and tumble dry cycles. They found that cotton shrank more than silk and silk rib knits stretch excessively in width. They reported that silk attained full relaxation after one laundering cycle. Mengüç et al. (2015) investigated handle and prick properties of silk fabrics. They used five different specialty animal fibers and wool as raw materials in their work. Yarns were spun using two different spinning systems. In the first method, animal fibers were spun blended with viscose fibers in a short staple spinning system. In the second method, core spun yarns were produced by using PVA yarn as core and animal fibers as sheath. Later, the yarns were knitted in a single jersey structure. After the production of all fabrics, handle properties such as surface friction, stiffness, and prickliness were tested by using both subjective and objective measurement techniques.

The purpose of this study is to investigate spinnability of silk waste fibers in open-end rotor spinning system; therefore we want to achieve optimum spinning conditions that are led to spin a yarn with optimum quality. For this purpose, a systematic and comprehensive research was carried out. Silk waste/cotton blend yarns were produced with 3 different twist coefficients. Then, effects of blending ratio and twist coefficient on yarn properties were investigated by statistical analysis. Full factorial design was chosen for variance analyses. Apart from the other studies, the effects of rotor type, rotor speed, openning roller type and speed on yarn quality were also investigated. Moreover, knitted fabrics were produced using a selected group of yarns. Then, effect of blending ratio on air permeability, abrasion resistance, bursting strength, thickness and weight of fabrics were evaluated statistically.

2. MATERIAL AND METHODS

The aim of this study is to investigate spinnability of silk – cotton blended yarns in open-end rotor spinning system, which is the second most used spinning system after ring spinning in short staple fiber spinning. In addition mechanical properties of their fabrics were investigated. For this purpose, China originate 100% mulberry silk fibers (waste silk) were supplied in sliver form (Figure 1). The properties of silk fibers were measured with Favigraph (Table 1). Although waste silk fibers were used, silk is an expensive fiber type, so to make the price of the product more affordable, silk was blended with cotton fiber with different proportions (Table 1). The effects of silk fiber ratio in blends, twist coefficient, rotor speed, rotor type, opening roller type and speed on the properties of yarns which were produced in open-end rotor spinning system were investigated.

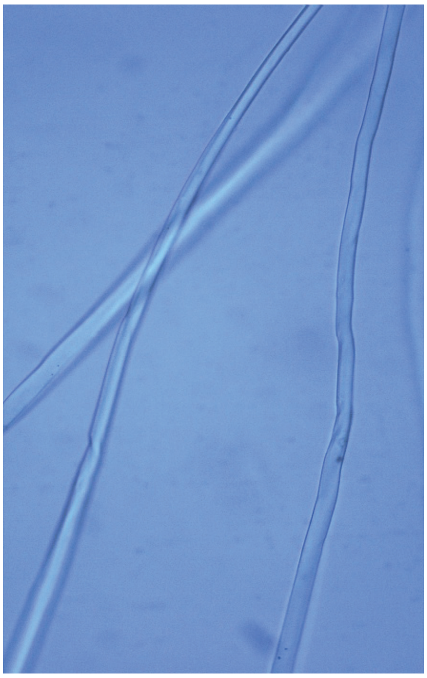

Figure 1. The microscopic view of silk fibers.

Table 1. The specifications of cotton fiber (HVI test results) and silk fiber (Favigraph test results).

Fiber specification	**Cotton fiber (HVI test results)**	**Fiber specification**	**Silk fiber (Favigraph test results)**
Fiber fineness (mic)	4.26	Fiber fineness (dtex)	0.97
Upper half mean length (UHML) (mm)	30.30	CV (%) of fiber fineness CV%	22.7
Mean length (mm)	25.78	Fiber length (mm)	38.1
Uniformity index (UI) (%)	85.1	CV (%) of Fiber length	16.2
Short fiber index (SFI)	<3.5	Fiber tenacity (cN/tex)	47.1
Area of foreign matter (Amt)	1763	CV(%) of tenacity	19.9
Strength (cN/tex)	27.30	Fiber elongation (%)	14.23
Elongation (%)	7	CV (%) of elongation	27.89

Silk and cotton fibers were blended in drawframe with three different blending ratios. Yarn samples were spun in RIETER R40 open-end spinning machine with the linear density of Ne 30 and with different twist coefficients (αe= 3.6 -3.9 - 4.2) which are available for knitting process. Unfortunately, efficient spinning stability could not be achieved under the 3.6 twist factor in this study because of low silk fiber cohesion. Within the context of this study, 100% cotton yarn was also spun. Spinning 100% silk yarn was tried but because of silk's low fiber to fiber friction, we failed. It was intended to produce silk-cotton blend yarns by not increasing the cost. For this reason, the highest silk ratio on the yarns was set on 45% level. K4K navel type (universal applications, high spin-stability) was used for all spun yarn types. 100,000 rpm rotor speed and 7,500 rpm opening roller speed were fixed for all yarn types for us being able to investigate the effects twist coefficient and silk ratio. We used 33 XT-BD rotor and B174 in all of our spinning processes. Experimental plan is given on Table 2. Yarn linear density and twist coefficient were also fixed to investigate the effects of machine parameters. In this case yarns were spun with three different rotor speeds and three different blending ratios. In order to investigate the effects of rotor type, opening roller type and speed, twist coefficient and blend ratio were fixed and yarns were produced according to the experimental plan as given on Table 3.

For the purpose of investigation is the effect of blend ratio on fabric properties, 4 types of yarns with linear density of Ne 30/1 and twist coefficient of αe= 3.9 were selected and then they were knitted in Mesdan-lab 294E sample knitting machine.

Yarns which were produced for this study were conditioned for 24 hours at 20°C±2 and %65±5 RH. Then, tests for determining yarn count, yarn evenness, yarn imperfection (IPI values), yarn hairiness, (Uster Tester 5), yarn tenacity and elongation at break (%) (Llyod Tester) were carried out. Air permeability (FX 3300), fabric thickness (SDL Atlas), fabric weight, fabric bursting strength (EC37 hydraulic tester), surface friction coefficient (FrictorQ) and abrasion resistance (weight loss) (Martindale) tests were done to the produced fabrics. The details of quality tests for yarn and fabric samples are given in Table 4.

Table 2. Experimental plan (Rotor speed 100,000 rpm (33 XT BD), opening roller speed 7,500 rpm (B174))

Blend ratio (%)	**Yarn count (Ne)**	**Twist coefficient (αe)**
100% Cotton	30	3.6 / 3.9 / 4.2
15/85% Silk/Cotton		
30/70% Silk/Cotton		
45/55% Silk/Cotton		

Statistical analyses were performed by implementing SPSS 15.0 statistical software. To determine the statistical importance of the variations, multivariate variance analysis was applied. To deduce whether the parameters were significant or not, p values were examined. Ergün (20) emphasized that if p value of a parameter is greater than 0.05 ($p>0.05$), the parameter will not be important and should be ignored. Selection of post-hoc type is too crucial. Selection of post-hoc statistics must rely on scientific basis, after analyzing multivariate analyses. Whether variance and sample size are equal or not between groups may effect on post-hoc statistics selection. Duncan post-hoc multiple range test is similar to SNK test, but that uses a special table unique. Compared to SNK test, Duncan test is

Table 3. The experimental plan for machine parameters (Ne30/1, αe=3.9)

Machine parameters		Blend ratio (%)
Rotor speed	85,000 rpm/ 100,000 rpm/ 115,000 rpm	15 /85% Silk/Cotton
		30 /70% Silk/Cotton
		45/ 55% Silk/Cotton
Rotor type	**33 XT-BD**(for all types of material, good yarn quality, for smooth yarns) **33 XT5-B** (primarly used for viscose, good yarn quality)	30/70% Silk/Cotton
Opening roller speed	7,500 rpm / 8,000 rpm / 8,500 rpm	30 /70% Silk/Cotton
Opening roller type	**B174**(prefarable used for cotton, highly suitable for viscose)/ **S43** (for man-made fibers at high production speeds, reduced fiber damages by 50-60%)/ **S21** (particularly suitable for man-made yarns)	30/70% Silk/Cotton

Table 4. The quality tests for yarn samples and fabric samples.

Test	Test repetition for each samples	Standard
Yarn count (Ne)	5 yarn samples/ 5 tests for each bobbins	TS 244 EN ISO 2060
Yarn tenacity (cN/Tex) and elongation (%)	5 yarn samples/ 10 tests for each bobbins	TS EN ISO 2062
Yarn evenness and yarn imperfections	5 yarn samples/ 1 tests for each bobbins (The measurement length was 400 m/bobbin)	ISO 16549
Fabric weight	5 tests for each fabric samples	TS EN 12127
Fabric thickness	(200 gf, 20 cm^2) 10 tests for each fabric samples	TS 7128 EN ISO 5084
Fabric bursting strength	5 tests for each fabric samples	TS 393 EN ISO 13938-1
Abrasion (Martindale)	3 tests for each fabric samples	TS EN ISO 12974-2
Air permeability	(100 Pa, 20 cm^2) 10 tests for each fabric samples	TS 391 EN ISO 9237
Surface friction coefficient	5 tests for each fabric samples	

considered to produce more consistent results (21). In order to see the differences of raw materials clearly, Duncan tests were applied on test results because of equality of the variances. Effect of rotor type was evaluated with paired sample t test. F values and their significance according to 95% confidence interval (α= 0.05) were evaluated.

3. RESULTS AND DISCUSSION

The test results of yarn samples were given in Table 5, Table 6 and Table 7. The variance analyses (multivariate) of test results were given in Table 8. The effect of blend ratio on yarn properties were found statistically significant (for α=0.05) except yarn tenacity. On the other hand, the effect of twist coefficient on yarn tenacity, yarn elongation and yarn hairiness values were found statistically significant. When the ratio of silk increased in yarn, yarn tenacity, yarn elongation and yarn hairiness increased.

In order to see the differences of blend ratio clearly, Duncan tests were applied on test results (Table 9). The elongation (%) values of silk fibers range 15 to 20 percent (1). In our study, the elongation of cotton fiber was found 7 percent and the elongation of silk fiber was found 14.23 percent. Thereby, when the ratio of silk increased in yarn, yarn elongation increased.

Table 5. The physical properties of yarns (Ne 30/1, αe=3.6)

Yarn properties	Ne 30			
	Twist coefficient (αe) 3.6			
	100% Cotton	15 / 85% Silk/Cotton	30 / 70% Silk/Cotton	45 / 55% Silk/Cotton
Yarn count (Ne)	30.02	30.01	29.43	30.7
CV(%) of yarn count	0.86	2.81	3.91	3.17
Tenacity (cN/tex)	9.35	9	9.3	9.33
CV(%) of tenacity	3.35	4.15	8.23	5.51
Yarn elongation at break (%)	6.3	7.71	7.62	8.03
CV (%) of yarn elongation	4.16	4.5	3.79	2.95
Uster CV%	14.54	15.23	14.76	14.5
Thin places/1000m	29.5	34	19	16
Thick places/1000m	59.5	74	62	58
Nep/1000m	16.5	48.5	43	50
Yarn diameter (2Dθ, mm)	0,249	0,249	0,248	0,248
Yarn hairiness H	4.24	4.3	4.38	4.65
sH	1.08	1.09	1.09	1.19

Table 6. The physical properties of yarns (Ne30/1, αe=3.9)

Yarn properties	Ne 30			
	Twist coefficient (αe) 3.9			
	100% Cotton	15 / 85% Silk/Cotton	30 / 70% Silk/Cotton	45 / 55% Silk/Cotton
Yarn count (Ne)	30.23	29.9	29.39	31.03
CV(%) of yarn count	1.33	2.94	1.21	1.53
Tenacity (cN/tex)	10.15	9.69	10.16	10.28
CV(%) of tenacity	4.51	3.78	5.33	4.32
Yarn elongation at break (%)	6.65	8.22	8.27	8.65
CV (%) of yarn elongation	2.98	4.00	4.07	2.66
Uster CV%	14.67	15.09	15.24	14.5
Thin places/1000m	23	35	20	17
Thick places/1000m	66	90.5	60.5	53.5
Nep/1000m	17.5	56	49.5	47
Yarn diameter (2Dθ, mm)	0,244	0,247	0,244	0,245
Yarn hairiness H	4.06	4.21	4.34	4.62
sH	1.05	1.07	1.08	1.18

Table 7. The physical properties of yarns (Ne30/1, αe=4.2)

Yarn properties	Ne 30			
	Twist coefficient (αe) 4.2			
	100% Cotton	15 / 85% Silk/Cotton	30 / 70% Silk/Cotton	45 / 55% Silk/Cotton
Yarn count (Ne)	29.83	30.2	30.39	30.89
CV(%) of yarn count	2.01	2.91	4.41	4.02
Tenacity (cN/tex)	10.92	10.31	10.58	10.3
CV(%) of tenacity	3.91	6.98	7.2	8.61
Yarn elongation at break (%)	7.41	8.55	8.23	8.58
CV (%) of yarn elongation	2.58	3.63	3.6	3.87
Uster CV%	14.48	15.19	14.39	14.63
Thin places/1000m	24	28.5	18	17.5
Thick places/1000m	58.5	95.5	50	61.5
Nep/1000m	21	57.5	43	47.5
Yarn diameter (2Dθ, mm)	0,242	0,242	0,239	0,240
Yarn hairiness H	3.99	4.11	4.15	4.52
sH	1.02	1.05	1.01	1.16

Table 8. The results of statistical analyses (multivariate).

Factor	Yarn properties	F value	Significance (p value)
Blend ratio	Tenacity (cN/tex)	1.804	0.159
	Elongation (%)	97.753	0.000*
	Uster CV%	4.252	0.010*
	Thin places	9.049	0.000*
	Thick places	11.320	0.000*
	Nep values	29.661	0.000*
	Uster yarn hairiness - H	13.681	0.000*
Twist coefficient	Tenacity (cN/tex)	25.300	0.000*
	Elongation (%)	38.713	0.000*
	Uster CV%	0.681	0.511
	Thin places	0.432	0.652
	Thick places	0.366	0.695
	Nep values	0.438	0.648
	Uster yarn hairiness - H	4.060	0.023*

*significant for α= 0.05 level.

The effect of blending ratio on the yarn evenness, thin places, thick places and nep values were found statistically significant, but generalization could not be made. The worst values were found for 15% silk/85%cotton yarns and the differences of other yarn types were not found statistically significant. According to "Duncan" tests results, when the silk ratio increased in yarn, the yarn hairiness values also increased (Table 9). Owing to their different characteristics, the fibers take up different positions in the body of yarn. The fiber migration is dependent upon degree of length, elasticity, stiffness, fineness, crimp, etc. Short, coarse, stiff fibers move out of the core towards the sheath, while long, fine, flexible fibers move towards the core (24). Also the study for fiber migration on silk/cotton blend yarns of Chollakup et al. (2004) supported this situation and they found that the shorter and coarser fibers, like cotton, tended to migrate towards the external yarn layer, whereas the longer and finer fibers, like silk, tended to move towards the yarn core. The silk fiber has 38 mm mean fiber length value and the upper half mean length value of cotton fiber was measured 30.3 mm in our study. Thus, silk fibers tend to move towards the core of the yarn, while cotton fibers want to migrate towards the sheath. Hairiness values of blended yarns can be explained by fiber migration (25). Therefore the yarn hairiness of 45/55% Silk/Cotton yarns were found higher than yarn hairiness values than the others.

The effect of rotor speed (rpm) on yarn properties were evaluated for each blending ratio. The variance analyses were given in Table 10. The multivariate test was applied on yarn test results for each blend ratio individually due to see the effect of rotor speed. The effect of rotor speed on yarn elongation and thick places were found statistically significant for 15/85 and 30/70% blend ratios. On the other hand, the effect of rotor speed on Uster CV%, thick places, nep value and yarn hairiness value were found statistically significant for only 45/55% silk/cotton blend ratio.

Table 9. Duncan test comparison results for spinning system.

Blend Ratio	**Yarn elongation (%)**			**Blend Ratio**	**Yarn hairiness H**		
	1	**2**	**3**		**1**	**2**	**3**
100% Cotton	6.788			**100% Cotton**	4.095		
30/70% Silk/Cotton		8.041		**15/85% Silk/Cotton**	4.207	4.207	
15/85% Silk/Cotton		8.159		**30/70% Silk/Cotton**		4.289	
45/55% Silk/Cotton			8.421	**45/55% Silk/Cotton**			4.596
Significance	1.0	0.263	1.0	**Significance**	0.179	0.323	1.0

Table 10. The effect of rotor speed on yarn properties.

Parametre	İplik özellikleri	15/ 85% Silk/Cotton		30/ 70% Silk/Cotton		45/ 55% Silk/Cotton	
		F	Significance (p value)	F	Significance (p value)	F	Significance (p value)
Rotor speed rpm	Tenacity	0.846	0.453	0.841	0.455	0.337	0.720
	Elongation	9.790	0.003 *	5.958	0.016 *	3.788	0.053
	Uster Cv%	14.428	0.001 *	1.008	0.394	4.659	0.032*
	Thin places	20.260	0.000 *	0.692	0.520	2.331	0.140
	Thick places	6.185	0.014 *	6.862	0.010 *	17.591	0.000*
	Nep values	3.630	0.059	1.316	0.304	5.683	0.018*
	Yarn hairiness H	1.788	0.209	0.653	0.538	4.683	0.031*

*significant for α= 0.05 level.

Table 11. Comparison of yarn elongation of 15/85% Silk/Cotton yarn (Duncan test)

Rotor speed (rpm)	N	**Yarn elongation %**	
		1	**2**
115,000	5	6.941	
85,000	5		8.095
100,000	5		8.215
Significance		1.0	0.713

Table 12. Comparison of thick places of 30/70% Silk/Cotton yarn (Duncan test)

Rotor speed (rpm)	N	**Thick places**	
		1	**2**
85,000	5	44.500	
100,000	5	60.500	60.500
115,000	5		78.500
Significance		0.107	0.074

In order to see the differences of rotor speed clearly, Duncan tests were applied on test results. When the rotor speed (rpm) increased, yarn elongation (%) value decreased for 15/85 % and 30/70 % Silk/Cotton yarns (Table 11). As the rotor speed increased, the yarn evenness (Table 13), the thick places (Table 12), the nep values and the yarn hairiness values (Table 13) increased. The differences of between 85.000 rpm and 100.000 rpm rotor speeds were not found statistically significant, so that it could be said that optimum yarn quality could be achieved up to 100.000 rpm. Yarn physical properties of silk/cotton blend yarns are adversely affected by the high rotor speed.

To see the effect of rotor type on yarn properties, paired samples t-test performed on test results. However, the effect of rotor type on the yarn properties were not found statistically significant for α = 0.05 significance level. Furthermore, the effect of opening roller type and opening roller speed (rpm) on yarn properties were not found statistically significant. Most probably, this is the result of the higher proportion of cotton fibers in blend compared to silk fibers. Therefore the higher opening roller speed did not affect the yarn properties adversely.

Finally, the variance analysis was performed for the evaluation of fabric test results. (Table 14). The effect of blending ratio on air permeability, fabric thickness and abrasion resistance was found statistically significant. In addition, Duncan test was applied for comparison. When the ratio of silk increased in knitted fabric, air permeability value decreased (Table 15). It is related with yarn hairiness.

When the silk ratio increased in fabric, it could be said that the weight and thickness values of fabrics decreased according to the test results (Table 16). The density of silk fiber is 1.34 g/cm^3 (23); thus the silk fiber lighter than the cotton fiber. It is considered that the situation of lighter fabric weight is related with lower fiber density of silk. When investigated abrasion resistance (weight loss) of fabrics (5,000, 10,000 and 15,000 tours), the values of 45/55% silk/cotton yarns were found the lowest. The cotton fabric has the highest abrasion resistance.When the silk ratio in the fabric increased, the amount of abrasion increased (Table 17).

Table 13. Comparison of yarn evenness and yarn hairiness values of 45/55% Silk/Cotton yarn (Duncan test)

Rotor speed (rpm)	Yarn evenness		Rotor speed (rpm)	Yarn hairiness H	
	1	2		1	2
85,000	14.470		**85,000**	4.540	
100,000	14.498		**100,000**	4.620	
115,000		15.004	**115,000**		5.104
Significance	0.889	1.0	**Significance**	0.696	1.000

Table 14. Statistical analyses of knitting fabric test results.

Factor	Fabric properties	F	Significance
Blend ratio	Air permeability (lt/m²/s)	64.268	0.000*
	Fabric thickness(mm)	143.138	0.000*
	Fabric weight (gr/m²)	1.200	0.342
	Bursting strength (kPa)	1.352	0.293
	Surface friction coefficient (µkin)	1.396	0.280
	Abrasion (%) (5000 tours)	915.103	0.000*
	Abrasion (%) (10000 tours)	300.090	0.000*
	Abrasion (%) (15000 tours)	277.634	0.000*

*significant for α= 0.05 level.

Table 15. Comparison of air permeability of knitted fabrics (Duncan)

Blend ratio	N	Air permeability			
		1	2	3	4
45/55% Silk/Cotton	5	1945.0			
30/70% Silk/Cotton	5		2065.0		
15/85% Silk/Cotton	5			2122.0	
100% Cotton	5				2295.0
Significance		1.0	1.0	1.0	1.0

Table 16. Comparison of thickness (mm) values of knitted fabrics (Duncan)

Blend ratio	N	Thickness	
		1	2
30/70% Silk/Cotton	5	0.5230	
45/55% Silk/Cotton	5	0.5300	
15/85% Silk/Cotton	5		0.6110
100% Cotton	5		0.6150
Significance		0.254	0.509

Table 17. Comparison of abrasion resistance (weight loss) of fabrics (Duncan)(15,000 tours)

Blend ratio	N	Abrasion resistance (weight loss)			
		1	2	3	4
100% Cotton	5	7.808			
15/85% Silk/Cotton	5		10.405		
30/70% Silk/Cotton	5			12.165	
45/55% Silk/Cotton	5				16.285
Significance		1.0	1.0	1.0	1.0

4. CONCLUSION

The aim of this study was to evaluate potentiality of producing high added-value, special products in short staple spinning system. Silk is a luxury protein fiber which has important properties such as lustre and soft handle. It affects lustre and handle properties of the products which it's used in. It was intended to produce silk-cotton blend yarns by not increasing the cost. For this reason, the highest silk ratio on the yarns was set on 45% level. Higher silk content also affected spinnability of the yarns, negatively. The waste silk fiber has lower price than silk fiber and open-end rotor spinning system has shorter process than ring spinning system. Therefore waste silk fiber and open-end rotor spinning system were chosen for cost reduction. In this study, spinnability of silk fiber in rotor system was evaluated. For this purpose, the effects of silk blend ratio in the yarn, rotor speed, rotor type, opening roller type, opening roller speed on yarn properties were investigated. Moreover effect of silk ratio on mechanical properties of fabric was also investigated.

When we investigated tensile strength properties, as similar to previous studies, the effect of silk fiber blend ratio on tensile strength could not be generalized for all types of yarns (Longhavi et al. 2008). Breaking elongation of yarn increases with increasing silk fiber ratio because of the higher fiber elongation (%) values of silk fibers. Moreover, the increase in twist coefficient resulted with increased tensile strength and breaking elongation.

Similar to previous studies, the silk fiber blend ratio has no significant influence on yarn evenness, thick places and thin places (Longhavi et al.,2008). The silk fibers tend to move towards the core of the yarn, while cotton fibers want to migrate towards the sheath. Thus yarn hairiness values of silk/cotton blend yarns can be explained by fiber migration and the yarn hairiness increased with higher silk fiber content. When the twist coefficient increased, the results of yarn hairiness decreased.

When we investigated the effect of rotor speed on the physical properties of the blended yarns, we found that the effect of rotor speed on tensile strength was not statistically significant. Breaking elongation decreased, yarn unevenness and IPI faults increased with the increase of rotor speed.

The effects of rotor type, opening roller type and its speed on yarn properties were not statistically significant for this study.

Weight, thickness, abrasion resistance, air permeability, bursting strength and friction properties of the fabrics were tested. In the matter of air permeability of fabrics, the fabrics contained silk fiber had lower air permeability than 100% cotton fabric; because the yarns contained silk fiber have higher yarn hairiness than cotton yarn. When the silk fiber ratio increased abrasion resistance of the fabrics decreased also because of their higher hairiness.

Open-end yarns are generally stiff yarns, but these yarns can be made softer to handle with the silk fiber blending. Different products can be produced considering silk fiber's effects of decreasing air permeability, increasing lustre and softness of the fabrics. Furthermore, to investigate evaluate the comfort properties of silk blended fabrics will have a considerable contribution for later studies.

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