(REFEREED RESEARCH)

COMPARISON OF QUALITY PARAMETERS OF SINGLE, PLIED AND SIROSPUN YARNS AND FABRICS WOVEN BY THESE YARNS

TEK KAT, KATLI VE SİRO İPLİKLER VE BU İPLİKLERLE DOKUNMUŞ KUMAŞLARIN KALİTE PARAMETRELERİNİN KARŞILAŞTIRILMASI

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ABSTRACT

Yarn folding and twisting are processes that have positive effects on yarn unevenness, average strength and fabric wrinkle resistance, but also cause significant cost increase. On the other side, siro yarn manufacture is a production method in which spinning, folding and twisting can be done in a single step. The distance between the rovings (strand spacing) is the most important factor determining the yarn quality in siro yarn production. In this study, physical tests of single yarns, plied yarns and siro yarns with different strand spacings were performed and the results were compared. In addition, woven fabric samples were obtained by using these yarns as weft yarn. The fabrics were subjected to physical tests and the differences were analyzed. The strand spacing of each sirospun yarns were chosen as 6 mm, 8 mm, 10 mm and 12 mm, respectively. According to yarn and fabrics test results, the most suitable values were seen in the larger strand spacings. When comparing the yarn quality, yarn hairiness, yarn strength and yarn elongation, fabric tensile strength and fabric elongation, fabric abrasion resistance, pilling resistance and air permeability properties are taken into consideration.

Keywords: Single Yarn, Plied Yarn, Sirospun Yarn, Woven Fabric

ÖZET

İplik katlama ve büküm işlemi iplik düzgünsüzlüğü, ortalama mukavemet ve buruşma dayanımı üzerinde pozitif etkiye sahip olması yanında üretim maliyetini önemli ölçüde arttıran bir uygulamadır. Diğer yandan, siro iplik üretimi, eğirme, katlama ve büküm işlemlerinin tek bir adımda yapılabileceği bir üretim yöntemidir. Siro iplik üretiminde iplik kalitesini belirleyen en önemli faktör, bacaklar arasındaki mesafedir. Bu çalışmada, tek katlı iplikler, katlı iplikler ve farklı aralıkta siro ipliklerinin fiziksel testleri yapılmış ve sonuçlar karşılaştırılmıştır. Ayrıca, bu ipliklerin atkı ipliği olarak kullanılmasıyla dokuma kumaş numuneleri elde edilmiştir. Elde edilen kumaşlar fiziksel testlere tabi tutulmuş ve farklılıklar analiz edilmiştir. Her farklı iplik kalınlığı için aralık mesafesi sırasıyla 6 mm, 8 mm, 10 mm ve 12 mm olan siro iplikler üretilmiştir. İplik ve kumaş test sonuçlarına göre en uygun sonuçlar geniş bacak aralığı değerlerinde elde edilmiştir. İplik ve kumaşların kalitesi analiz edilirken, iplik tüylülüğü, iplik mukavemeti, iplik uzaması, kumaş kopma mukavemeti ve kopma uzaması, kumaş aşınma dayanımı, boncuklanma dayanımı ve hava geçirgenlik özellikleri göz önüne alınmıştır.

Anahtar Kelimeler: Tek kat iplik, Çift katlı iplik, Siro iplik, Dokuma Kumaş

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1. INTRODUCTION

Yarn plying is the process of combining two or more yarns by twisting them together to improve the yarn quality and usually adopted in short staple spinning, however the process increase the cost of yarn considerably. In recent years, two-strand spinning, which was essentially designed for wool raw material, became widespread as an alternative to the conventional plying of short staple yarns. This system is a modified ring spinning system and is already known as siro-spinning. In this system two rovings are fed to a ring frame, with separators to ensure that each roving is drafted individually. Emerging from the nip point of the front rollers of the drafting system, the two strands start to twist together at a convergence point. In this way a plied yarn is formed before the pigtail guide. Undoubtedly, integrating the plying process with yarn production is a very important advantage of this system, resulting in the reduction of production cost of the product greatly [1]. With these advantages many researchers have attempted to produce short staple yarn with this system. Some of these researchers investigated the effects of spinning parameters such as twist, spindle speed, roving number, draft and strand spacing on yarn quality [2-10]. Some other researchers investigated the quality properties of yarns produced by different spinning systems in comparison to siro spinning technology [6-8,10-12]. According to these studies, it is observed that sirospun technology has a decreasing effect on yarn hairiness. El-Sayed and Sanad (2011) aimed to present and analyze the quality parameters of the siropun yarns in comparison to conventional two-fold yarns and also obtained woven fabric samples with these yarns. They investigated the yarn physical properties, fabric tensile, color reflectance and color strength [13]. Kireçci et al. (2011) studied the quality parameters of knitted fabrics produced from single, two-ply and sirospun yarns. They used cotton fiber as raw material. They observed that sirospun yarn may be a good alternative for plied yarn due to its low production cost and high quality values [1].

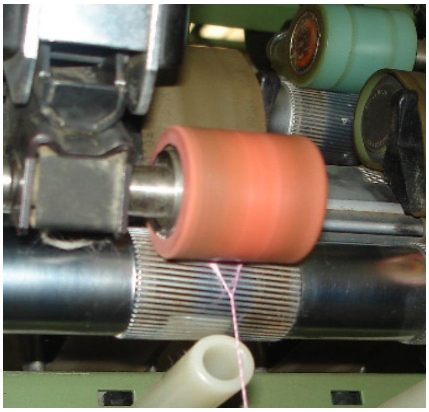

Figure 1. Spinning of siro yarns [1]

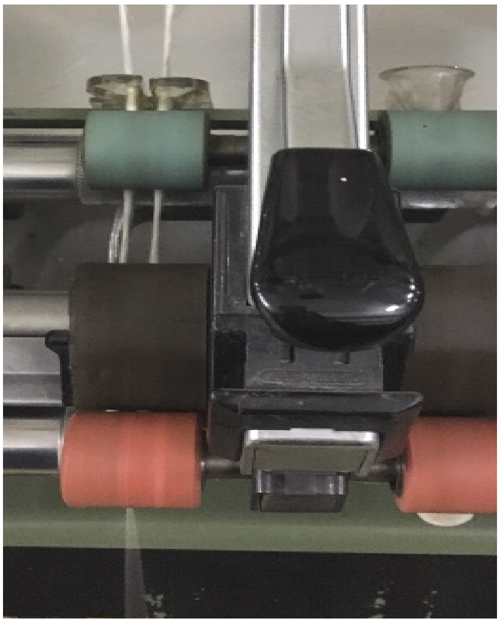

Figure 2. Two rovings and strand spacing

Apart from the previous studies, in this experimental study, the performance properties of woven fabrics, produced from siro yarn, single yarn and plied yarn, were analyzed on the basis of yarn spinning technology. For this aim, yarn quality parameters (strength, elongation, hairiness) and fabric tensile strength, abrasion resistance, pilling resistance properties and air permeability values were analyzed.

2. MATERIAL AND METHOD

In this study, combed cotton fiber was used for the production of sample yarns. The fiber properties are shown in Table 1. The properties of fibers were measured by Uster HVI. The sample yarns were produced by ring spinning frame with the yarn linear density of 39 Tex, 30 Tex and 24 Tex. Six samples were manufactured for each yarn linear density such as; single yarn, two-plied yarn, sirospun yarn with 6mm, 8mm, 10mm and 12mm strand spacings. Yarn production parameters are shown in Table 2.

Table 1. Properties of the cotton used in the experimental study

Fiber Properties	Value
Length (mm)	27.71
Fiber Fineness (micronaire)	4.48
Uniformity Index (I)	81.5
Strength (g/tex)	30.0
Elongation (%)	7.0
Short Fiber Index (SFI)	8.4
+b	10.1
Rd	78.4
Spinning Consistency Index (SCI)	128

Table 2. Production parameters of the yarns used in the experimental study

Production Parameters	Value
Linear density of card slivers (ktex)	4.9
Linear density of draw frame slivers (ktex)	4.5
Linear density of rovings (ktex)	0.4
Diameter of ring (mm)	45
Spindle revolution (rev/min)	13000
Yarn twist multiplier (αe)	4.2

In the next step, yarn samples were used in only weft direction and woven fabric samples obtained. The weaving machine was Picanol, with electronic dobby shedding mechanism and rapier weft insertion. All of the samples were 1/1 plain weave and produced with 1.60 meters width and 2 meters length with 450 rev/min loom speed. The yarn samples were used as weft yarn. The weft sett was 18 wefts/cm for 39 Tex, 19 wefts/cm for 30 Tex and 20 wefts/cm for 24 Tex. The warp yarn was 15 Tex combed cotton and the warp sett was 53 warps/cm for all samples. After the weaving process, desizing and washing processes were applied. The fabric sett, weight and thickness parameters are given in Table 3.

All yarn and fabric samples were conditioned at 20 ± 2 °C and 65 ± 4 % relative humidity for 8 hours according to TS 240 EN 20139 before testing the samples. Uster Tester 5 device was used for testing the yarn quality parameters. Five bobbins were tested for each sample. Uster Tensojet 4 device was used for testing yarn tensile strength and yarn breaking elongation values by applying 500 measurements for each sample. A sensitive scale and specimen cutter were used for fabric weight measurement according to the TS EN 12127 standard. Schmit fabric thickness tester device was used for measuring fabric thickness by using TS 7128 EN ISO 5084 standard. The fabric tensile strength and fabric breaking elongation values were tested on Titan test device by taking the average of five measurements. TS EN ISO13934-1 standard was used for this application. The abrasion resistance of the sample fabrics was tested according to TS EN ISO 12947-3 by using a Martindale abrasion and pilling tester. The abrasion resistance was determined with respect to the mass loss after 5000 abrasion cycles by taking the average value of four measurements. The pilling resistance of samples was determined by using Martindale abrasion and pilling tester device according to TS EN ISO 12945-2. The values were obtained by taking the average of three measurements. The appearances of the specimens after 125, 500, 1000, 2000 and 5000 cycles were analyzed according to ASTM pill grade photographic views.

In order to understand the statistical importance of spinning technology and yarn linear density on woven fabric performance properties namely; air permeability, tensile strength and elongation and abrasion resistance, two-way ANOVA was performed. For this aim the statistical software package SPSS 21.0 was used to interpret the experimental data. All test results were assessed at 95% confidence interval.

3. RESULTS AND DISCUSSION

3.1. Unevenness and Imperfections

In this study single, plied and sirospun yarns were produced for different yarn linear densities. The unevenness test results show that the best CVm% and yarn imperfection index (total number of thin places -50%, thick places +50% and neps +200%) were seen at plied yarns. The CVm% and yarn imperfection index of the yarns are given in Table 4.

Table 3. The fabric sett, weight and thickness parameters of the fabric samples

Yarn Linear Density	Yarn Type	Weft Sett	Warp Sett	Fabric Weight (g/m²)	Fabric Thickness (mm)
39 Tex	Single yarn	18	53	152.8	0.32
	Plied yarn	18	53	149.1	0.31
	Sirospun 6 mm	18	53	153.8	0.32
	Sirospun 8 mm	18	53	151.2	0.32
	Sirospun 10 mm	18	53	151.7	0.31
	Sirospun 12 mm	18	53	150.5	0.31
30 Tex	Single yarn	19	53	135.9	0.29
	Plied yarn	19	52	134.4	0.29
	Sirospun 6 mm	19	53	136.5	0.29
	Sirospun 8 mm	19	53	137.8	0.30
	Sirospun 10 mm	19	52	135.7	0.29
	Sirospun 12 mm	19	52	135.2	0.28
24 Tex	Single yarn	20	52	126.2	0.27
	Plied yarn	20	52	126.6	0.27
	Sirospun 6 mm	20	52	126.3	0.27
	Sirospun 8 mm	20	53	128.4	0.27
	Sirospun 10 mm	20	52	126.7	0.27
	Sirospun 12 mm	20	52	126.7	0.27

Table 4. Yarn unevenness and imperfection values

	Yarn Linear Density	Single Yarns	Plied Yarns	Sirospun 6 mm	Sirospun 8 mm	Sirospun 10 mm	Sirospun 12 mm
CVm%	39 Tex	10.6	9.9	10.5	10.2	10.3	11.0
	30 Tex	12.1	10.7	12.9	13.1	11.6	11.1
	24 Tex	12.4	11.7	11.5	11.6	11.8	11.4
Yarn imperfection index	39 Tex	6	7	8	9	8	8
	30 Tex	20	11	36	23	19	15
	24 Tex	46	26	35	52	48	28

3.2 Hairiness

Hairiness of single, plied and sirospun yarns are given in Figure 3.

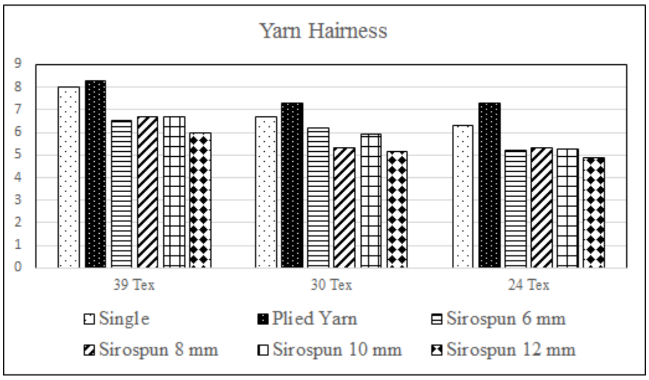

Figure 3. Yarn hairiness

According to the yarn hairiness results, siro yarns have approximately 22% better hairiness value then single yarn. On the other hand, higher hairiness values were obtained in plied yarn, but theoretically a lower hairiness value was expected when compared to single yarn. A probable reason for this situation is the friction that occurs during folding and twisting operations. Performing the operations at high speeds might cause the hairiness values to be even higher due to friction. Among siro yarns, although there are some outliers, the general trend is that, as the strand spacing increases, the hairiness decreases.

3.3. Yarn Tensile Strength and Elongation

Yarn tensile strength and breaking elongation of single, plied and sirospun yarns are given in Figure 4 and Figure 5.

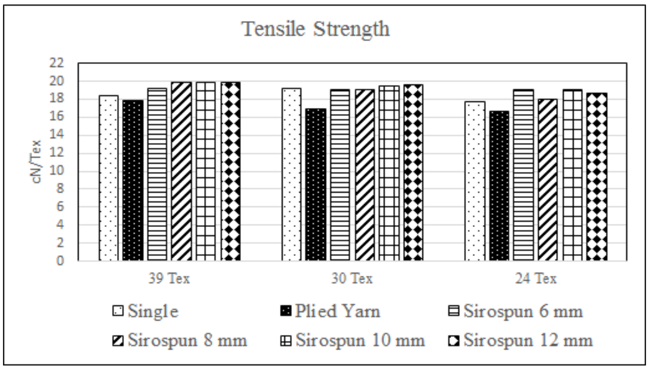

Figure 4. Yarn tensile strength

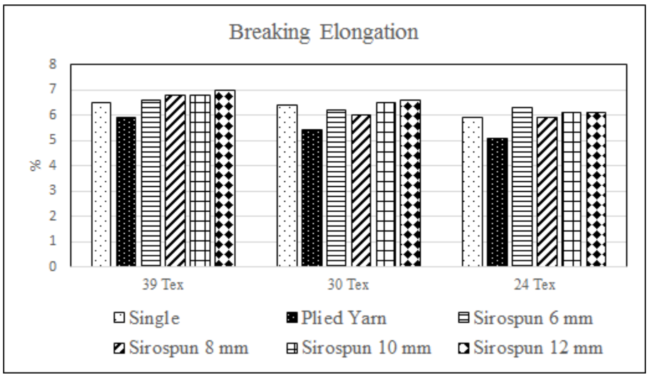

Figure 5. Yarn breaking elongation

Among all yarn samples, sirospun yarns have slightly higher yarn strength as parallel to the lower yarn hairiness. Correspondingly, sirospun yarns provide better yarn elongations than other yarns. However, the results also show that the increase in strand spacing generally results in a positive effect on yarn strength of sirospun yarns. When the siro yarn elongation values are taken into consideration, the longer strand spacing generally indicates an increase in yarn elongation. Thus, the longer stand spacing gives better elongation values.

3.4. Fabric Tensile Strength and Elongation

The sample fabrics were examined only in weft direction since the yarn samples were used only in weft direction. The analysis of fabric tensile strength and elongation values show that lower strand spacings (such as 6mm and 8mm) have lower performance but higher ones (such as 10mm and 12mm) produce higher tensile strength and elongation. The fabric tensile strength and fabric breaking elongations of samples are given in Figure 6 and Figure 7.

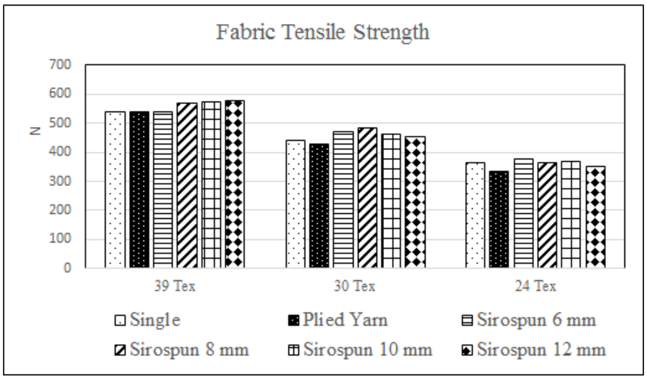

Figure 6. Fabric tensile strength

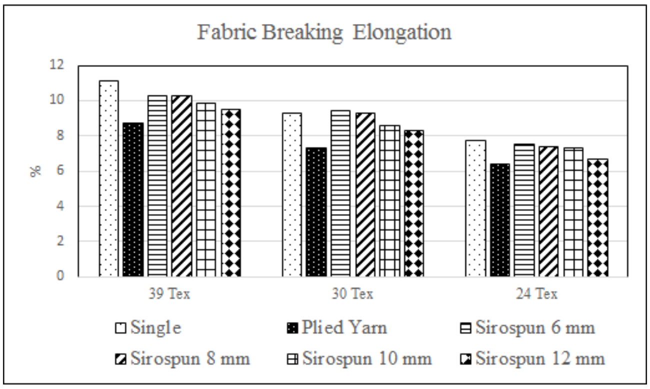

Figure 7. Fabric breaking elongation

The test results show that the tensile strength of fabrics decreases as the yarns get finer as predicted. The fabrics woven by sirospun yarns have slightly higher fabric tensile strength values than that of single and plied yarn fabrics as parallel to the yarn strength values. However, the fabrics woven by plied yarns have the lowest fabric tensile strength. In general, the breaking elongation values decrease as the yarns get finer similar to the strength values. Breaking elongation of the samples produced by single yarns was much better than that of plied yarn samples. Accordingly, the elongation values of the samples produced by single yarns and sirospun yarns are similar for 30 Tex and 24 Tex.

According to ANOVA (Table 5), yarn type has a statistically significant effect on fabric tensile strength (p=0.041<0.05). Also, yarn linear density has a statistically significant effect on fabric tensile strength (p=0.000<0.05) in 95% confidence interval. Besides, the effect of yarn linear density on fabric tensile strength is higher (F=320.291) than that of yarn type (F=3.561). This is also seen from higher Partial Eta Square value of yarn linear density than yarn type.

In order to evaluate the effect of yarn type on fabric tensile strength, the results of post-hoc test should be analyzed (Table 6). It is seen from post-hoc test results that, there are two groups for fabric tensile strength that single and plied samples consist one group and siro samples consist another group. Also siro samples have higher fabric tensile strength than single and plied samples. On the other hand there is no significant difference on the tensile strength between the other yarn types because of p>0.05.

According to ANOVA (Table 7), yarn type (p=0.000<0.05) and yarn linear density (p=0.000<0.05) have statistically significant effects on fabric breaking elongation in 95% confidence interval. Besides, the effect of yarn linear density on fabric breaking elongation is higher (F=184.497) than that of yarn type (F= 23.391). This is also seen from higher Partial Eta Square value of yarn linear density than yarn type.

In order to evaluate the effect of yarn type on fabric breaking elongation, post-hoc test results seen in Table 8 should be analyzed. It was observed that there is no significant difference on the breaking elongation between single and sirospun 6 mm with the value of p=0.179>0.05, sirospun 6 mm and 8 mm with the value of p=0.985>0.05. On the other hand there is significant difference on the breaking elongation between the other yarn types because of p<0.05.

3.5. Pilling

Pilling resistance is an important performance that shows the wear tendency that form on the surface of the fabric due to friction. Since the pills are dependent on the yarn hairiness, the fabrics produced from sample yarns were tested for pilling tendency to examine the effects of yarn spinning technology and strand spacing on the pill formation. Pilling test results are given in Table 9.

Table 5. Two-way ANOVA for fabric tensile strength

Source		Type IV Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	Hypothesis	18813203.930	1	18813203.930	64.135	0.015	0.970
	Error	586671.576	2	293335.788[a]			
Yarn type	Hypothesis	16304.544	5	3260.909	3.561	0.041	0.640
	Error	9158.417	10	915.842[b]			
Yarn linear density	Hypothesis	586671.576	2	293335.788	320.291	0.000	0.985
	Error	9158.417	10	915.842[b]			
Yarn type * Yarn linear density	Hypothesis	9158.417	10	915.842	1.967	0.050	0.215
	Error	33528.652	72	465.676[c]			

Table 6. Multiple comparisons for fabric tensile strength

(I) Yarn type	(J) Yarn type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	(I) Yarn type	(J) Yarn type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Single	Siro10mm	-19.7620	7.87973	0.135	-42.8328	3.3088	Siro6mm	Single	13.8267	7.87973	0.501	-9.2441	36.8974
	Siro12mm	-13.4087	7.87973	0.535	-36.4794	9.6621		Siro10mm	-5.9353	7.87973	0.974	-29.0061	17.1354
	Siro6mm	-13.8267	7.87973	0.501	-36.8974	9.2441		Siro12mm	0.4180	7.87973	1.000	-22.6528	23.4888
	Siro8mm	-24.9007*	7.87973	0.027	-47.9714	-1.8299		Siro8mm	-11.0740	7.87973	0.724	-34.1448	11.9968
	Plied	15.4053	7.87973	0.378	-7.6654	38.4761		Plied	29.2320*	7.87973	0.005	6.1612	52.3028
Siro10mm	Single	19.7620	7.87973	0.135	-3.3088	42.8328	Siro8mm	Single	24.9007*	7.87973	0.027	1.8299	47.9714
	Siro12mm	6.3533	7.87973	0.965	-16.7174	29.4241		Siro10mm	5.1387	7.87973	0.986	-17.9321	28.2094
	Siro6mm	5.9353	7.87973	0.974	-17.1354	29.0061		Siro12mm	11.4920	7.87973	0.691	-11.5788	34.5628
	Siro8mm	-5.1387	7.87973	0.986	-28.2094	17.9321		Siro6mm	11.0740	7.87973	0.724	-11.9968	34.1448
	Plied	35.1673*	7.87973	0.000	12.0966	58.2381		Plied	40.3060*	7.87973	0.000	17.2352	63.3768
Siro12mm	Single	13.4087	7.87973	0.535	-9.6621	36.4794	Plied	Single	-15.4053	7.87973	0.378	-38.4761	7.6654
	Siro10mm	-6.3533	7.87973	0.965	-29.4241	16.7174		Siro10mm	-35.1673*	7.87973	0.000	-58.2381	-12.0966
	Siro6mm	-0.4180	7.87973	1.000	-23.4888	22.6528		Siro12mm	-28.8140*	7.87973	0.006	-51.8848	-5.7432
	Siro8mm	-11.4920	7.87973	0.691	-34.5628	11.5788		Siro6mm	-29.2320*	7.87973	0.005	-52.3028	-6.1612
	Plied	28.8140*	7.87973	0.006	5.7432	51.8848		Siro8mm	-40.3060*	7.87973	0.000	-63.3768	-17.2352

Table 7. Two-way ANOVA for fabric breaking elongation

Source		Type IV Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	Hypothesis	6686.362	1	6686.362	112.991	0.009	0.983
	Error	118.353	2	59.176[a]			
Yarn type	Hypothesis	37.513	5	7.503	23.391	0.000	0.921
	Error	3.207	10	0.321[b]			
Yarn linear density	Hypothesis	118.353	2	59.176	184.497	0.000	0.974
	Error	3.207	10	0.321[b]			
Yarn type * Yarn linear density	Hypothesis	3.207	10	0.321	2.354	0.018	0.246
	Error	9.812	72	0.136[c]			

Table 8. Multiple comparisons for fabric breaking elongation

(I) Yarn type	(J) Yarn type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	(I) Yarn type	(J) Yarn type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Single	Siro10mm	0.8153*	0.13480	0.000	0.4207	1.2100	Siro6mm	Single	-0.3200	0.13480	0.179	-0.7147	0.0747
	Siro12mm	1.2413*	0.13480	0.000	0.8467	1.6360		Siro10mm	0.4953*	0.13480	0.006	0.1007	0.8900
	Siro6mm	0.3200	0.13480	0.179	-0.0747	0.7147		Siro12mm	0.9213*	0.13480	0.000	0.5267	1.3160
	Siro8mm	0.4100*	0.13480	0.037	0.0153	0.8047		Siro8mm	0.0900	0.13480	0.985	-0.3047	0.4847
	Plied	1.9333*	0.13480	0.000	1.5387	2.3280		Plied	1.6133*	0.13480	0.000	1.2187	2.0080
Siro10mm	Single	-0.8153*	0.13480	0.000	-1.2100	-0.4207	Siro8mm	Single	-0.4100*	0.13480	0.037	-0.8047	-0.0153
	Siro12mm	0.4260*	0.13480	0.027	0.0313	0.8207		Siro10mm	0.4053*	0.13480	0.041	0.0107	0.8000
	Siro6mm	-0.4953*	0.13480	0.006	-0.8900	-0.1007		Siro12mm	0.8313*	0.13480	0.000	0.4367	1.2260
	Siro8mm	-0.4053*	0.13480	0.041	-0.8000	-0.0107		Siro6mm	-0.0900	0.13480	0.985	-0.4847	0.3047
	Plied	1.1180*	0.13480	0.000	0.7233	1.5127		Plied	1.5233*	0.13480	0.000	1.1287	1.9180
Siro12mm	Single	-1.2413*	0.13480	0.000	-1.6360	-0.8467	Plied	Single	-1.9333*	0.13480	0.000	-2.3280	-1.5387
	Siro10mm	-0.4260*	0.13480	0.027	-0.8207	-0.0313		Siro10mm	-1.1180*	0.13480	0.000	-1.5127	-0.7233
	Siro6mm	-0.9213*	0.13480	0.000	-1.3160	-0.5267		Siro12mm	-0.6920*	0.13480	0.000	-1.0867	-0.2973
	Siro8mm	-0.8313*	0.13480	0.000	-1.2260	-0.4367		Siro6mm	-1.6133*	0.13480	0.000	-2.0080	-1.2187
	Plied	0.6920*	0.13480	0.000	0.2973	1.0867		Siro8mm	-1.5233*	0.13480	0.000	-1.9180	-1.1287

Table 9. Pilling degrees of sirospun yarns

Yarn linear density	**Yarn Type**	**Pilling Resistance 125**	**500**	**1000**	**2000**	**5000**
39 Tex	**Single**	4	3 - 4	3 - 4	3	3
	Plied	4 - 5	4	3 - 4	3 - 4	3
	Siro 6 mm	4 - 5	4	3 - 4	3 - 4	3
	Siro 8 mm	4 - 5	4	3 - 4	3	2 - 3
	Siro 10 mm	4 - 5	4	3 - 4	3	3
	Siro 12 mm	4 - 5	4	3 - 4	3 - 4	3
30 Tex	**Single**	4	3 - 4	3	3	2 - 3
	Plied	4 - 5	4	3 - 4	3	2 - 3
	Siro 6 mm	4 - 5	4	3 - 4	3 - 4	3
	Siro 8 mm	4 - 5	4	3 - 4	3	2 - 3
	Siro 10 mm	4 - 5	4	3 - 4	3	3
	Siro 12 mm	4 - 5	4 - 5	4	3 - 4	3
24 Tex	**Single**	4	3 - 4	3	2 - 3	2
	Plied	4 - 5	4	3 - 4	3	2 - 3
	Siro 6 mm	4	3 - 4	3	3	2 - 3
	Siro 8 mm	4	4	3 - 4	3	2 - 3
	Siro 10 mm	4 - 5	4	4	3 - 4	3
	Siro 12 mm	4 - 5	4 - 5	4	3 - 4	3

The results show that the fabrics woven by single yarns have poor pilling resistance among all samples. This is a result that matches with the yarn hairiness values. Lower hairiness results in less fuzz formation on fabric surface as expected. Experimentally, the pilling resistance behaviors of fabric samples clearly match with the theory of low hairiness produces less pilling. On the other hand, the longer strand spacing of siro yarns improves the pill formation slightly.

3.6. Abrasion Resistance

Wear is the physical damage of fibers, yarns and fabrics resulting from the rubbing of the textile surface to another surface. Wear results in loss of performance characteristics such as strength, but also affects the appearance of the fabric. Fabric abrasion resistance values of samples are given in Figure 8.

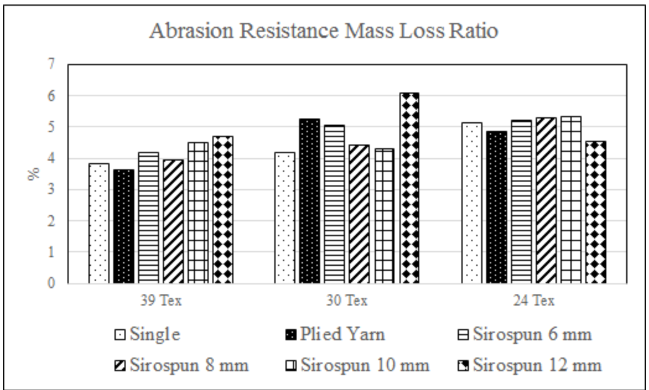

Figure 8. Fabric abrasion resistance

The results clearly show that the amount of mass loss increases as the yarns in fabric become finer. The abrasion resistance of the samples produced by single yarns was much better than that of plied ones. Results show that, the abrasion resistances of samples produced by single yarns and sirospun yarns have similar values.

According to ANOVA (Table 10), yarn type does not have a statistically significant effect on fabric abrasion resistance ($p=0.681>0.05$). But, yarn linear density has a statistically significant effect on fabric abrasion resistance ($p=0.037<0.05$) in 95% confidence interval.

3.7. Air permeability

The air permeability of a fabric can affect the comfort behavior. The air permeable material has the potential to be permeable to water in vapor or liquid phase. Therefore, permeability to water vapor and transmission of liquid moisture are normally associated with air permeability. The air permeability depends on the construction of fabrics, fineness of yarn, thickness of fabrics and the yarn hairiness. Fabric air permeability results of samples are given in Figure 9.

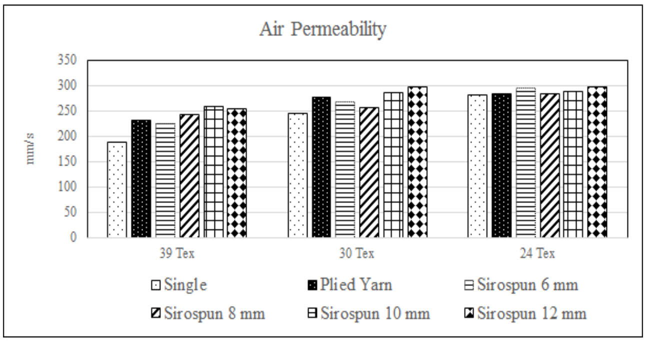

Figure 9. Fabric air permeability

The test results clearly show that the amount of air permeability increases as the yarns in the fabric become finer. The fabric samples woven by sirospun yarns have higher air permeability values than that of single and plied ones. On the other side, the samples woven by single and plied yarns have similar values of air permeability. The reason for this situation is probably the lower yarn hairiness of sirospun yarns. With higher yarn hairiness, the spaces between yarns are covered by protruding fiber ends. This situation reduces the air passage through the fabric. So, the air permeability decreases.

According to ANOVA (as seen in Table 11), yarn type has a statistically significant effect on fabric air permeability ($p=0.026<0.05$). Also, yarn linear density has a statistically significant effect on fabric air permeability ($p=0.000<0.05$) in 95% confidence interval. Besides, the effect of yarn linear density on fabric air permeability is higher ($F=27.276$) than that of yarn type ($F=4.203$). This is also seen from higher Partial Eta Square value of yarn linear density than that of yarn type.

Table 10. Two-way ANOVA for fabric abrasion resistance

Source		Type IV Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	Hypothesis	1584.894	1	1584.894	277.897	0.004	0.993
	Error	11.406	2	5.703[a]			
Yarn type	Hypothesis	3.838	5	0.768	0.630	0.681	0.240
	Error	12.178	10	1.218[b]			
Yarn linear density	Hypothesis	11.406	2	5.703	4.683	0.037	0.484
	Error	12.178	10	1.218[b]			
Yarn type * Yarn linear density	Hypothesis	12.178	10	1.218	5.321	0.000	0.496
	Error	12.359	54	0.229[c]			

Table 11. Two-way ANOVA for fabric air permeability

Source		Type IV Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	Hypothesis	12567465.800	1	12567465.800	266.347	0.004	0.993
	Error	94369.033	2	47184.517[a]			
Yarn type	Hypothesis	36356.667	5	7271.333	4.203	0.026	0.678
	Error	17298.900	10	1729.890[b]			
Yarn linear density	Hypothesis	94369.033	2	47184.517	27.276	0.000	0.845
	Error	17298.900	10	1729.890[b]			
Yarn type * Yarn linear density	Hypothesis	17298.900	10	1729.890	13.178	0.000	0.449
	Error	21265.600	162	131.269[c]			

Table 12. Multiple comparisons for fabric air permeability

(I) Yarn type	(J) Yarn type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval		(I) Yarn type	(J) Yarn type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound						Lower Bound	Upper Bound
Single	Siro10mm	-39.6667*	2.95826	0.000	-48.1987	-31.1347	Siro 6mm	Single	23.6667*	2.95826	0.000	15.1347	32.1987
	Siro12mm	-44.2667*	2.95826	0.000	-52.7987	-35.7347		Siro10mm	-16.0000*	2.95826	0.000	-24.5320	-7.4680
	Siro6mm	-23.6667*	2.95826	0.000	-32.1987	-15.1347		Siro12mm	-20.6000*	2.95826	0.000	-29.1320	-12.0680
	Siro8mm	-22.8333*	2.95826	0.000	-31.3653	-14.3013		Siro8mm	0.8333	2.95826	1.000	-7.6987	9.3653
	Plied	-26.1667*	2.95826	0.000	-34.6987	-17.6347		Plied	-2.5000	2.95826	0.959	-11.0320	6.0320
Siro 10mm	Single	39.6667*	2.95826	0.000	31.1347	48.1987	Siro 8mm	Single	22.8333*	2.95826	0.000	14.3013	31.3653
	Siro12mm	-4.6000	2.95826	0.629	-13.1320	3.9320		Siro10mm	-16.8333*	2.95826	0.000	-25.3653	-8.3013
	Siro6mm	16.0000*	2.95826	0.000	7.4680	24.5320		Siro12mm	-21.4333*	2.95826	0.000	-29.9653	-12.9013
	Siro8mm	16.8333*	2.95826	0.000	8.3013	25.3653		Siro6mm	-0.8333	2.95826	1.000	-9.3653	7.6987
	Plied	13.5000*	2.95826	0.000	4.9680	22.0320		Plied	-3.3333	2.95826	0.870	-11.8653	5.1987
Siro 12mm	Single	44.2667*	2.95826	0.000	35.7347	52.7987	Plied	Single	26.1667*	2.95826	0.000	17.6347	34.6987
	Siro10mm	4.6000	2.95826	0.629	-3.9320	13.1320		Siro10mm	-13.5000*	2.95826	0.000	-22.0320	-4.9680
	Siro6mm	20.6000*	2.95826	0.000	12.0680	29.1320		Siro12mm	-18.1000*	2.95826	0.000	-26.6320	-9.5680
	Siro8mm	21.4333*	2.95826	0.000	12.9013	29.9653		Siro6mm	2.5000	2.95826	0.959	-6.0320	11.0320
	Plied	18.1000*	2.95826	0.000	9.5680	26.6320		Siro8mm	3.3333	2.95826	0.870	-5.1987	11.8653

In order to evaluate the effect of yarn type on fabric air permeability, the results of post-hoc test should be analyzed (Table 12). It was observed that there is no significant difference on the air permeability between sirospun with a 6 mm and 8 mm, sirospun with a 10 mm and 12 mm, plied and sirospun 6 mm, plied and siropspun 8 mm yarn types with the values of $p=1.000>0.05$, $p=0.629>0.05$, $p=0.959>0.05$, $p=0.870>0.05$ respectively. Besides, there are significant differences on the air permeability between the other yarn types because of $p<0.05$.

4. CONCLUSION

In this study, it is intended to investigate the properties of single and plied yarns in comparison to sirospun yarns and fabric properties produced therefrom. Additionally, the effect of strand spacing on the quality of sirospun yarns was examined. The results of this research indicate that the unevenness and imperfection values (thin place, thick place and neps) of sirospun yarns were not evidently different than that of single and plied yarns. However, hairiness values of sirospun yarns obviously lower than single and plied yarns. Also, larger strand spacing reduces the hairiness slightly. Other properties of sirospun yarns such as tensile strength and breaking elongation were better than that of other yarn types.

The fabric test results show that the tensile strength of the samples woven from sirospun yarns were better than that of the single and plied yarns. Similarly, breaking elongation values of fabrics produced from sirospun yarns were higher than that of single and plied yarns. Theoretically, it is expected that the performance of the plied yarn should be better than the single and sirospun yarns. However, experimental results show that the performance of the sirospun yarn is better. This situation overlaps with previous studies. The reason can be explained as the application of two additional processes to obtain the final form of the plied yarn namely folding and twisting processes. Since, during these operations, the friction between the yarn and the machine elements will cause the hairiness increase, resulting in fiber breaks and thus loss of yarn tenacity. On the other hand, the abrasion resistance of samples produced by single and sirospun yarns is similar. It is seen that sirospun yarns have higher air permeability because of less hairiness. Generally, less pilling was expected from the fabrics woven by yarns with low yarn hairiness. The pilling resistance of samples woven from sirospun yarn clearly matches with this theory. The pilling resistances of fabrics increase as the strand spacing increases of sirospun yarns. Additionally, using finer yarns in fabric structure and lower yarn hairiness cause higher air permeability.

Consequently, sirospun yarns have better performance than plied and single yarns. In addition, when the yarn costs are compared, it is seen that the unit cost of sirospun yarn is 25-30% higher than single yarn. However, the unit cost of the plied yarn is 20-25% higher than sirospun yarn. Thus, sirospun yarns provide both cost advantages and better results in yarn and fabric performance compared to plied yarns.

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