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Development of three-roving ring yarn production system

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This study focuses on development of three-roving yarn production system that is inspired from siro-spun technology. Roving funnel and delivery cylinder used in siro-spun technology are redesigned for three-roving yarn production and attached on conventional system. Three-roving yarns produced in ring spinning machine are compared with three plied yarns in terms of physical, mechanical and structural properties. For better assessment of this new system, different raw material types are used in yarn production. Results show that three-roving yarns have better hairiness values and similar mechanical properties for all raw material types. However, unevenness still needs to be improved by further developments on this new system.

Keywords: Composite yarn, Multi-strand yarn, Siro-spun yarn, Three-roving yarn, Twist spinning

1 Introduction

Ring spinning is the oldest and most widely used spinning technology. In recent years, for the needs of yarns with different properties or for more efficient production processes, many alternative spinning technologies have been introduced. For the rough classification of alternative spinning technologies, (i) work in different principle than ring spinning and (ii) improvement from ring spinning can be the two main factors. Twist spinning (mostly known siro-spun spinning) is one of the spinning technologies, that shows improvement from ring spinning technology. After the introduction in the 1970s, twist spinning had a great market share and still being used for yarn production with the help of eliminating doubling and twisting machine from two-plied yarn production process. The working principle of twist spinning relies on simultaneously feeding two strands in the drafting zone with the help of the two-grooved delivery cylinder and two-strand funnel, thus producing produce two-strand yarn in a single process. The geometry of spinning triangle that appears, while two strands are spinning for doubled yarn structure, is one of the key factors that effects yarn properties. Tension on each strand during spinning between front cylinder and yarn formation point is related with the strand angle. Increasing strand angle causes greater strand length and it concluded more tension on each strand during spinning. In the other point of view, irregularities on strand angle during structure resulted in unsteady tension on each strand as well as irregular yarn structure[1]. Many researchers investigated the factors that affect spinning geometry and its effects on yarn properties[1-4]. Emmanuel and Plate[1] stated that strand space is the main character to determine the strand angle. Miao *et al.*[2] and Chang and Sun[3] also emphasized the strand space effects on strand angle, and besides they pointed the spinning speed as an another factor for strand angle. Gowda *et al.*[4] produced yarns at three different strand space, and comparing results showed that increasing strand space until optimum point has positive effect on yarn properties due to better fibre orientation in yarn structure. After certain point, increasing strand space negatively affects yarn properties. In many researches also, it is stated that until optimum point, increasing strand space has positive effects on yarn properties[5-8].

In other studies, siro-spun yarn properties were compared with other yarn types. Örtlek *et al.*[9] compared conventional, compact and siro-spun yarns with the strand space 8 mm. It was concluded that siro-spun yarns have better hairiness values than other two yarn types and higher breaking elongation than compact yarns. Yildiz and Kilic[10] compared siro-spun and two-plied yarns, and concluded that siro-spun yarns have better hairiness, mechanical properties and similar unevenness values than two-plied yarns. Soltani and Johari[11] compared siro-spun yarns that

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produced four different strand spaces with solo-spun and conventional yarns. They concluded that increasing tension in the spinning triangle results better fibre distribution in yarn structure. In the other study of Soltani and Johari[12], it was claimed that due to better fibre migration properties, siro-spun yarns have greater tenacity values than compact solo-spun and conventional yarns. Su *et al.*[13] compared siro-spun with compact-siro-spun yarns, and concluded that compact-siro-spun yarns are in more compact structure.

Recently, multi-strand staple yarn structures have been investigated by researchers. He[14] claimed that three-strand yarn can be used for technical textile in the future with the help of composite yarn structure. Su *et al.*[15]investigated yarn formation point for three-strand yarn production and claimed that tension on each strand is related with the flow movement of each strand. Matsumoto *et al.*[16]produced three-strand yarns and claimed that fibre distribution in yarn structure varies based on the geometry of spinning triangle. Matsumoto *et al.*[17] also studied fibre distribution in the yarn structure for different fibre fineness. In the other study of Matsumoto *et al.*[18] fibre length is taken into consideration in addition to fibre fineness to investigate fibre distribution for three-strand yarns.

In the early study of Demir and Kilic[19], three-strand yarns were successfully produced on ring spinning machine just placing with three-strand funnel that aid to provide third strand into the drafting zone simultaneously. Comparative results with three-plied yarns, that produced at same spinning count and same twist multiplier for different raw materials, showed that three-strand yarns have better hairiness values, similar mechanical properties but lower unevenness and imperfection values. The results of the previous study were promising for further study and it was assumed that some modifications on drafting zone for three-strand yarn production might help to produce better quality yarns. In this study, in addition to three-strand funnel, the three-grooved delivery cylinder is also assembled in the pre-drafting zone to control strands movement in the drafting zone. Three-strand yarns with and without three-grooved delivery cylinder have been produced from natural, regenerated and synthetic fibres to investigate the effects of delivery cylinder. Besides, three-plied yarns are also produced at same count and twist level and compared with three-strand yarns[20].

2 Materials and Methods

2.1 Materials

In the study, physical, mechanical and structural properties of three-strand yarns and three-plied yarns were measured. In order to find out that three-strand yarn production, as a proposed new method, works effectively for all main material groups, cotton, Tencel (1.3 dtex and 38 mm), PES (1.3 dtex and 38 mm) and micro Modal (1.0 dtex and 39 mm) fibres were used from natural, regenerated, synthetic and micro fibre groups, respectively. HVI results of cotton fibres are given in Table 1.

2.2 Experimental Methods

In the study, Ne 60/3 three-strand yarns with and without three-grooved delivery cylinder and three-plied yarns with Ne 60/3 and αe=3,4 twist multiplier were produced from 100% cotton, 100% PES, 100% Tencel, 100% micro modal fibres. Experimental design of the study is given in Table 2.

All slivers used in the study were produced with Rieter B34 Bale opener, Rieter A81 UniBlend, Rieter A79 UniStore and Rieter C60. Rieter SBD-45 draw frame was used for drawing process and Ne 0.120 slivers were produced. Rieter E76 was used as a combing machine for cotton fibres. Marzoli FTSDN was used for strand production and Ne 0.90 strands were produced. Pinter Merlin laboratory type spinning machine was used for all yarn production. For three-strand yarns, ring-spun machine was modified. Savio Itema spinning winding machines were used for winding process. After single ply yarns were produced, Schärer Schweiter Mettler doubling machine and Saurer Volkmann twisting machine were used for three-plied yarn production.

Three-Roving Ring Yarn Production System

In this study, from the same perspective of siro-spun technology, three individual strands were fed into drafting zone and three-strand yarns were produced. Investigating literature and some practical experience showed that strand space and controlled

Table 1 — Properties of cotton fibres (HVI results)

Fibre properties	Averaged value
Fineness, micronaire index	3.6
Length, mm	29.5
Tenacity, cN/tex	29.0
Elongation, %	4.85
Spinning consistency index	140
Uniformity, %	82.5
Maturity	0.88
Short fibre index , %	8.50

Table 2 — Experimental design of the study[20]

Yarn	Raw material	Number of single yarn, Ne	Number of produced yarn, Ne	Twist of single yarn component, T/m (Z)	Twist of produced yarn, T/m (Z)
Three-strand yarn (TSY)	Cotton, PES, Tencel, Micro Modal	60	60/3	600	600
Three-strand yarn with delivery cylinder (TSYWDC)	Cotton, PES, Tencel, Micro Modal	60	60/3	600	600
Three-plied yarn (TPY)	Cotton, PES, Tencel, Micro Modal	60	60/3	1200	600

delivery of strands into drafting zone directly effects multi-strand yarn properties. Two types of three-strand yarns were produced. For the first type which is called three-strand yarn (TSY), one more strand-funnels were added to siro-spun strand funnels before drafting zone [Fig 1(a)]. For TSY productions, strands were fed into drafting zone and it was seen that strand space is not regular during drafting. For the second type of three-strand yarn (TSYWDC), in addition to three-strand funnel, three-grooved delivery cylinder was also placed before main drafting area in order to investigate the effects of controlled strand space on the yarn properties [Fig1(b)]. Distance between each groove was set at 6 mm. Moreover, three-plied yarns (TPY) were also produced with conventional methods for better comparison. Physical, mechanical and structural properties of TSY, TSYWDC, and TPY were compared.

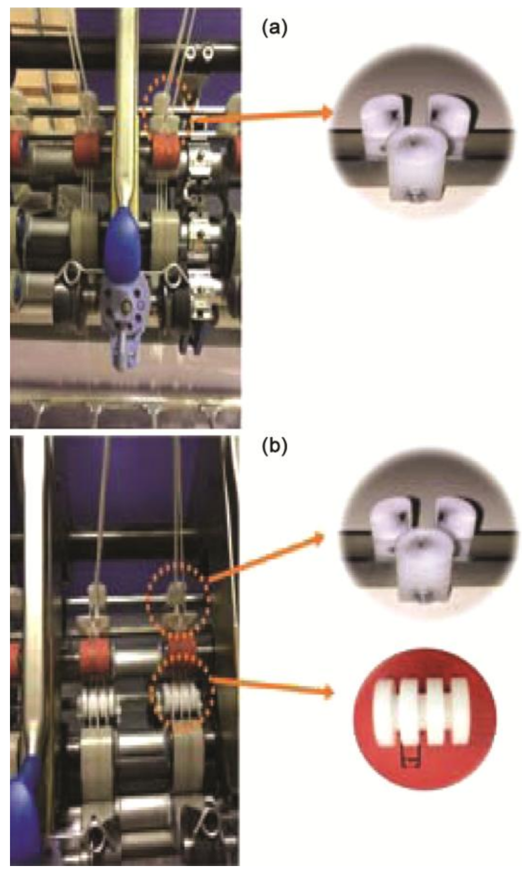

Fig. 1 — (a) Three-strand yarn – TSY and (b) three-strand yarn with delivery cylinder – TSYWDC

2.3 Tests Performed

Hairiness, unevenness, imperfections, diameter, density, roughness and roundness values of yarns were measured with USTER Tester 5 S800 at 400 m/min production speed and each test was performed during 2.5 min. Breaking force and breaking elongation values of yarns were measured with Uster Tensorapid 4. Every test was performed at 400 m/min and 500 mm gauge length. Yarn-to-yarn friction properties were measured with Lawson Hemphill CTT at 100 m/min test speed and 4 min test duration. Input tension was set at 30 cN for friction tests.

3 Results and Discussion

3.1 Hairiness

Hairiness values (*H* and *sh*) of TPY, TSY and TSYWDC are observed for all raw materials(Table 3) and 95% confidence intervals of these values are shown in Fig 2.

ANOVA tests performed for α=0.05 show that spinning technology is statistically significant on both *H* and *sh* values for all fiber groups.TPY have higher *H* and *sh* values than TSY and TSYWDC. This situation can be explained by less production processes for three-strand yarn productions as similar as siro-spun and two plied yarn comparison[21-23]. Although, three-grooved delivery cylinder creates additional friction surfaces during production, it is found to has positive effect to reduce hairiness values (Table 3 and Fig. 2). This might be related with the geometry of spinning triangle. For the TSYWDC, delivery cylinder sets strand space 6 mm and it causes greater spinning triangle than TSY. Force on each strand and strand length has positive ratio and when

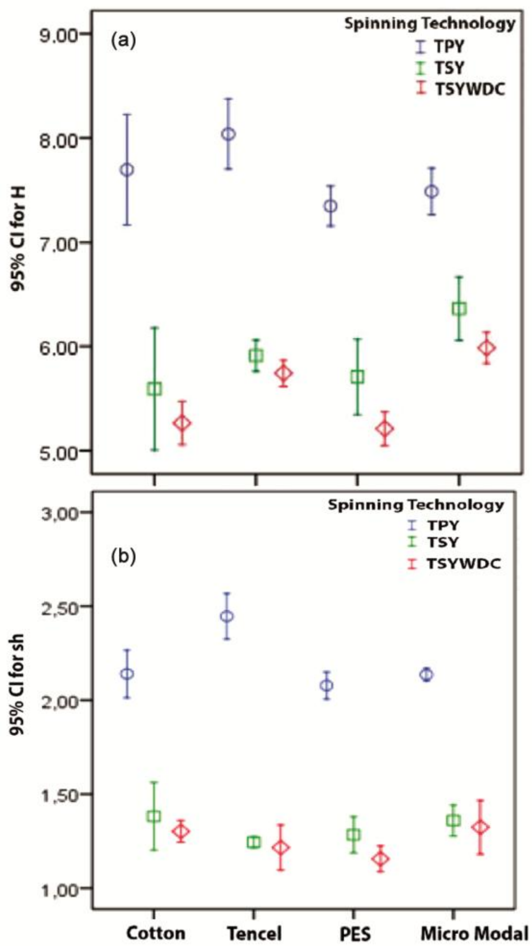

Fig. 2 — 95% confidence interval graphs for hairiness values of TPY, TSY, and TSYWDC

Table 3 — Hairiness values (H and sh) of TPY, TSY and TSYWDC yarns

Spinning type	Raw material	H	sh
Three-plied yarns (TPY)	Cotton	7.70	2.14
	Tencel	8.04	2.45
	PES	7.35	2.08
	Micro modal	7.49	2.14
Three-strand yarns (TSY)	Cotton	5.64	1.38
	Tencel	5.91	1.24
	PES	5.71	1.28
	Micro modal	6.36	1.36
Three-strand yarns with delivery cylinder (TSYWDC)	Cotton	5.27	1.30
	Tencel	5.74	1.22
	PES	5.21	1.16
	Micro modal	5.99	1.32

the strands are exposed to greater force in the spinning triangle, the fibres are better oriented in the yarn structure. Besides, delivery cylinder provides steady strand space and yarn convergence point during production. When yarn convergence point is not moving around, less friction forces between individual strands occur. This might be another reason for the less hairiness values for TSYWDC than TSY.

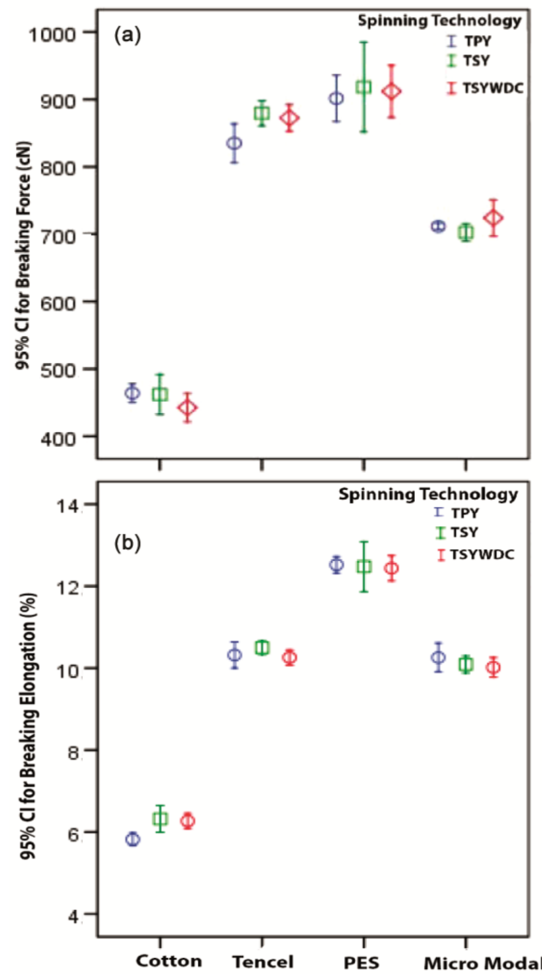

Fig. 3 — 95% confidence interval graphs for breaking force and breaking elongation of TPY, TSY and TSYWDC yarns

3.2 Mechanical Properties

Breaking force (cN) and breaking elongation (%) values of the yarns are given in Fig. 3 as 95% confidence interval graphs.

Breaking force results show that, there is no statistically significant difference between three-plied and both three- strand yarns. Breaking force is related with the number of fibres in cross-section and twist level. As all yarn types are produced with same count and same twist multiplier, it is expected to find similar results. For breaking elongation, there is also no statistically significant difference among all three types of yarn production technologies. Obtaining

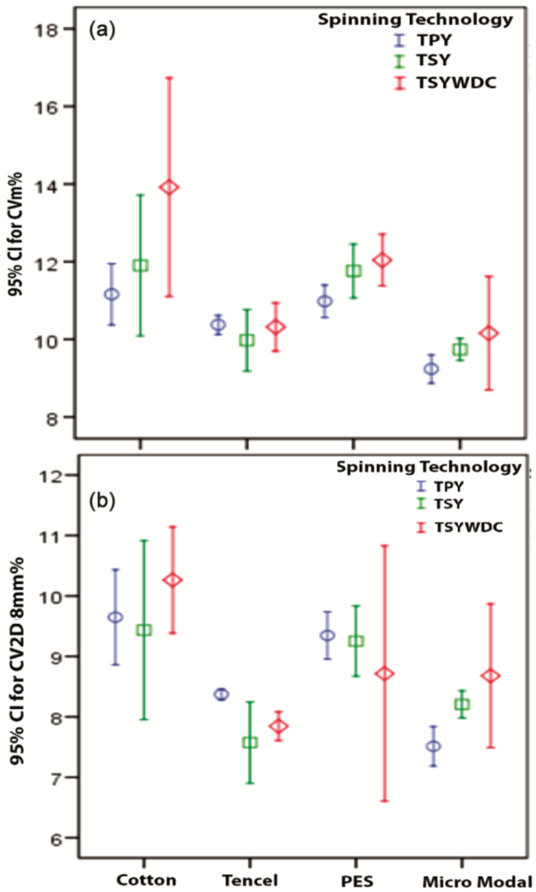

Fig. 4 — 95% confidence intervals for unevenness and optical unevenness values of TPY, TSY and TSYWDC

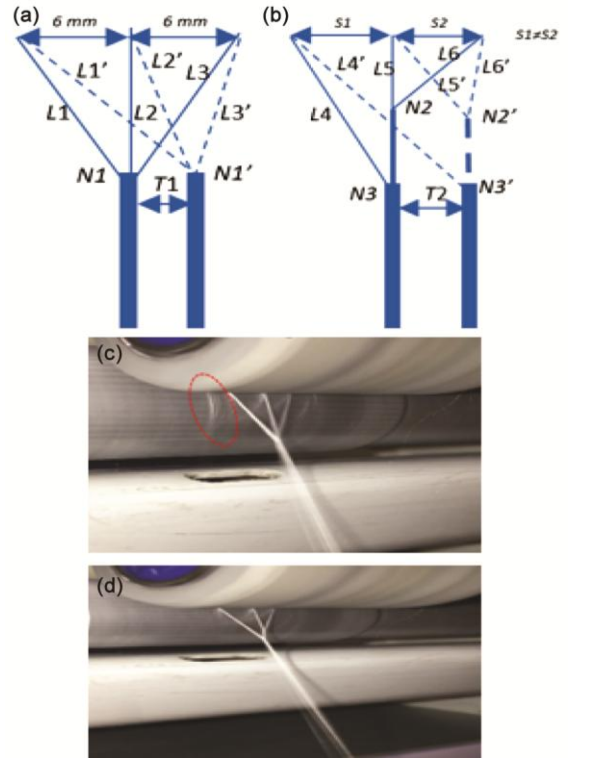

Fig. 5 — Changes in the geometry of spinning triangles during production for TSYWDC (a), and TSY (b), respectively (N= yarn formation point, L= strand length, S= strand space, T= displacement for yarn formation point), fibre loss caused from non-stationary spinning for TSYWDC (c), and two yarn formation points for TSY (d)

similar mechanical results with the TPY, commercially accepted for decades, is found promising. TSY or TSYWDC can be economic alternatives with the help of eliminating doubling and twisting machines from the production process.

3.3 Unevenness and Imperfections

Unevenness (CVm%) and optical unevenness (CV2D8mm%) values of TPY, TSY and TSYWDC are given in Fig. 4.

The results show that, TPY has better unevenness (% CVm) and optical unevenness (%CV2D8mm) values than TSY and TSYWDC. TPY structure is obtained by doubling single yarns that is produced individually, Therefore, it is expected to have better yarn properties. Similarly, as it is cited in literature, conventional two-plied yarns also have better unevenness values than siro spun yarns[22, 24]. However, irregular yarn structure in three-strand yarns can be explained by the non-stationary spinning triangle. For three-strand yarn production, unlike the other spinning technologies, two triangles generate a larger spinning triangle. For the TSYWDC, it is expected that these two triangles have equal common edge and stay stationary during spinning. However, with the rotational force from the spindle, the geometry of triangles, as well as the length and force on each strand change during the spinning. When the yarn formation point moves from N1 to N1', length of each strand from front cylinder to yarn formation point do not remain the same with the starting position (L1≠L1', L2≠L2' and L3≠L3') [Fig. 5(a)]. As a result, twist amount of single yarn before joining three-strand yarn structure is not kept constant and it results in irregularities on the final yarn structure. In addition, as the length of the outer strand becomes greater than fibre length, fibre loss also increases [Fig. 5(c)]. Considering that fibre amount in the yarn cross section is directly related with unevenness, this situation might be the main reason why TSYWDC have the greatest unevenness values. On the other hand, it is also reported in the literature by many researchers[1,4] that strand space affects the properties of twist yarns, and until a certain point, yarn properties and strand spaces increase simultaneously. After that point, increasing strand space has negative effect on yarn properties. In this study, strand space is set at 6 mm for TSYWDC production. Obviously, for future studies, this distance needs to be re-evaluated.

For TSY production, where the strand space is not equal (S1≠S2), two yarn formation points occur. First, closer two strands become the doubled yarn structure and first yarn joining point appears (N2). Third strand wrap around the doubled yarn structure and second yarn formation point (N3) occurs [Figs 5(b) and (d)]. Movement of yarn formation points can also be also seen,like with TSYWDC strand lengths are changed (L4≠L4', L5≠L5', L6≠L6') [Fig. 5(b)]. It is thought that better control on spinning triangle will improve unevenness values of the both three-strand yarns.

Moreover, because of similar reasons as explained for unevenness, it can be concluded that, in general, TPY have better imperfection values (thin places -50% /km, thick places +50% /km and neps +200% /km) than three strand yarns.

3.4 Other Structural Parameters

Diameter (2DØ, mm), density (D, g/cm^3), roughness (%CVFS) and roundness (shape) values of TPY, TSY and TSYWDC are given in Table 4. Results show that both types of three-strand yarns have smaller diameter (2DØ, mm) and higher density (D, g/cm^3) values than TPY. Additionally, three strand yarns have better roundness (shape) and roughness (%CVFS) values. All these differences of structural parameters among TSY, TSYWDC and TPY can be explained by fibre position in yarn structure. For the production of plied yarns, final twist direction of plied yarn is opposite way to single yarn direction and fibres are located more likely parallel to yarn axis. On the other hand, twist direction of three-strand yarns is the same with single yarn structure and fibres are located perpendicular to yarn axis. Therefore, TSY and TSYWDC yarns show more compact structure.

3.5 Frictional Properties

Results of yarn-to-yarn friction coefficients of all yarn types are given in Fig. 6 as 95% confidence interval graphs. The results show that spinning technology has statistically significant effect on yarn-to-yarn friction values. In general, TPY has the highest friction coefficients for all material types and it might be linearly correlated with roughness (%CVFS) and hairiness (H) values.

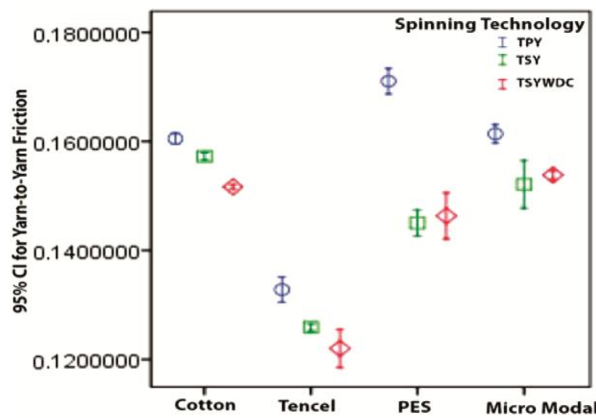

Fig. 6 — 95 % confidence interval graphs for yarn-to-yarn friction coefficients of TPY, TSY and TSYWDC

Table 4 — Diameter (2DØ, mm), density (D, g/cm^3), roughness (%CVFS) and roundness (shape) values of TPY, TSY, and TSYWDC yarns

Spinning technology	Raw material	Diameter (2DØ), mm	Roughness %CVFS	Density (D), g/cm^3	Shape
Three-plied yarns (TPY)	Cotton	0.33	8.49	0.35	0.77
	Tencel	0.30	8.38	0.41	0.71
	PES	0.30	9.40	0.43	0.77
	Micro modal	0.30	8.33	0.42	0.76
Three-strand yarns (TSY)	Cotton	0.29	7.15	0.44	0.82
	Tencel	0.26	5.95	0.57	0.84
	PES	0.25	6.81	0.60	0.85
	Micro modal	0.26	7.54	0.54	0.82
Three-strand yarns with delivery cylinder (TSYWDC)	Cotton	0.29	7.03	0.44	0.81
	Tencel	0.26	5.92	0.57	0.83
	PES	0.25	6.45	0.60	0.84
	Micro modal	0.26	7.30	0.55	0.82

4 Conclusion

In this study, inspired from siro-spun technology, three-strand ring yarn production has been done and investigated. Similar modifications with siro-spun have been made on conventional spinning technology for three-strand yarn production. First of all, three-strand funnel is placed on conventional system to feed three-strands simultaneously into drafting zone and three strand yarn (TSY) are produced. In order to investigate strand space and controlled strand delivery on yarn properties, three-grooved delivery cylinder and three-strand funnel are used together to produce three strand yarn with delivery cylinder (TSYWDC). In addition, three-plied yarns with same properties are also produced to compare with TSY and TSYWDC.

It is observed that three-strand yarns are successfully produced for all raw material types. Comparing results of TPY, TSY and TSYWDC show that, both of three-strand yarns have better hairiness values and similar mechanical properties with TPY yarns. During yarn production, it is observed that spinning triangle is not stationary and this situation conclude unevenness on yarn structure. For the future work, it is thought that better control on spinning triangle and choosing optimum strand space will improve yarn properties.

With the economic advantage of eliminating twisting and doubling machine from production process, three-strand yarn can be a rival for three-plied yarn. Beside, three-strand in one single yarn structure in same process can lead to produce technical yarns.

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