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Application of ANOVA and AHP in Assessing the Quality of Roving Cotton-Polyester Siro Yarn

Uporaba analize variance (ANOVA) in analitičnega hierarhičnega procesa (AHP) pri ocenjevanju kakovosti bombažno-poliestrske siropreje

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Abstract

Siro spinning, an evolution of ring spinning, optimizes parameters, such as roving strand distance and twist multiplier, thereby enhancing yarn quality according to numerous studies. Experts have differing opinions on the benefits of roving distances for yarn quality. However, the effect of roving distance on the roving blending technique in the ring frame has not been fully investigated. An integrated analysis of variance (ANOVA) and the analytical hierarchy process (AHP) based methodology are presented in this work to close the research gap between yarn quality attributes and roving strand distance in the context of roving blending. For this purpose, five yarn samples of 19.68 tex were developed using different roving distances, specifically 2 mm, 4 mm, 6 mm, 8 mm and 10 mm, within the drafting zone using a 50/50 cotton-polyester roving blending technique in a ring frame. Subsequently, the quality metrics of the yarn were studied, including variation concerning yarn mass ($CVvm\%$), the imperfection index (IPI_Y) value, hairiness (HI), the count strength product (CSP_{LS}) value, elongation at break ($\varepsilon_{br}\%$) and the total quality index (TQI_{YQ}). The results revealed that yarn sample B, made using a distance of 4 mm, resulted in good yarn quality. An ANOVA demonstrated that roving distance had no significant effect on HI, $\varepsilon_{br}\%$ or TQI_{YQ}. However, AHP assisted in determining the ideal roving strand distance among various options. The study's findings provide practical suggestions for determining the ideal roving strand distance for better blended yarn quality.
Keywords: siro spinning, cotton-polyester roving blended yarn, analysis of variance, analytical hierarchy process

Izvleček

Številne raziskave so pokazale, da se pri siropredenju, ki je nadgradnja prstanskega predenja, z optimizacijo parametrov, kot sta razdalja med stenjema v raztezalni coni in faktor zasuka, lahko bistveno izboljša kakovost preje. Strokovna mnenja o vplivu razdalje med stenjema na kakovost preje so različna, vpliv te razdalje na učinkovitost mešanja obeh stenjev v prstanskem predilniku pa do sedaj še ni bil celovito raziskan. V tej raziskavi je

predstavljena integrirana metodologija, ki temelji na analizi variance (ANOVA) in analitičnem hierarhičnem procesu (AHP), njen namen pa je bil zapolniti raziskovalno vrzel med atributi kakovosti preje in razdaljo med stenjema glede na mešanje stenjev pri predenju. Za ta namen je bilo izdelanih pet vzorcev preje z dolžinsko maso 19,68 tex pri različnih razdaljah med stenjema v raztezalni coni (2 mm, 4 mm, 6 mm, 8 mm in 10 mm) z uporabo mešanice bombaž/poliester v razmerju 50/50. Proučeni so bili izbrani kazalniki kakovosti preje: variacija mase preje (CVvm %), indeks nepopolnosti (IPIY), lasavost (HI), produkt finosti in trdnosti (CSPLS), raztezek pri pretrgu (Ebr %) in skupni indeks kakovosti (TQIYQ). Pokazalo se je, da je najboljšo kakovost dosegla preja vzorca B, izdelana pri razdalji med stenjema 4 mm. Analiza ANOVA je pokazala, da razdalja med stenjema ni imela statistično pomembnega vpliva na lasavost preje (HI), raztezek pri pretrgu (Ebr %) ali skupni indeks kakovosti (TQIYQ). Metoda AHP pa je omogočila določitev optimalne razdalje med stenjema med preizkušenimi možnostmi. Ugotovitve iz raziskave ponujajo praktične smernice za določanje optimalne razdalje med stenjema v raztezalni coni pri predenju, kar pripomore k izboljšanju kakovosti mešane bombažno-poliestrske siropreje.
Ključne besede: predenje siro, preja iz mešanice bombaža in poliestra, analiza variance (ANOVA), analitični hierarhični proces (AHP)

1 Introduction

In the textile sector, backward linkage begins with yarn manufacturing or spinning, which transforms fibres into yarns [1–2]. Several yarn manufacturing methods are useful for this transformation, including ring spinning, open-end spinning such as rotor spinning, and air vortex spinning. Because of its adaptability, ring spinning is especially widely used. There have been numerous technical improvements made to this spinning technique in recent years, but the fundamental technology behind it has stayed virtually the same. There have been some improvements to ring spinning in recent decades in terms of yarn quality and production rates. As a result, unique and efficient spinning technologies such as compact spinning, siro spinning and solo spinning have emerged [3]. The International Wool Secretariat (IWS) and the Division of Textile Industry Laboratories of the Australian CSIRO created the relatively new and extensively utilized technique of siro spinning in 1975–1976. Two rovings are drawn in parallel in the drafting zone, emerge from the front roller through twisting, and are then combined in siro spinning [4].

The roving strand distance, spindle speed, traveller, twist multiplier, drafting method and other factors all had an impact on the quality of siro spun yarn. Siro spinning has been studied for a variety of process parameters. Many researchers have made important contributions to overcome the difficulties relatedto these qualities.

Numerous studies have been conducted on siro spinning in literature taking into account various process parameters, such as the twist multiplier (TM) and roving spacing etc., as indicated in Table 1. Those studies concentrated on the use of natural-based textile yarn. Today, however, studies focus on the use of man-made fibre-based yarn, especially for advancing functional and sustainable properties rather than conventional textile usage. For example, Zachariah et al. found that yarns for ballistic and woven aramid fabric play a crucial role in providing exceptional strength and protection [5]. The yarn is meticulously crafted to maintain consistent quality and performance. Designed to endure extreme conditions, it provides reliable protection while remaining lightweight and strong. Aramid yarn ensures comfort and mobility without compromising on safety. The main aim of using aramid yarn is to obtain high tensile strength, heat resistance and abrasion resistance, which enables the resulting yarn to be suitable for the applications of ballistic vests, helmets and other protective gear [6]. Khan et al. carried out another study in which researchers developed a sustainable blending approach employing cotton, banana, and Tencel fibres in siro spinning, resulting in fabrics with 6.61% and 12% higher tear and tensile strength, respectively, than conventional woven fabrics. Another significance of their study is that all the raw materials are obtained from waste cotton and banana fibres [7]. Moreover, yarns, especially micro and nano-sized variants, possess distinctive characteristics that are advantageous for micro electromechanical systems (MEMS). These specialty yarns are designed to fulfil the specific requirements of MEMS applications, necessitating narrow diameters, great strength and, when required, electrical conductivity. They can function as structural elements, offering support and stability to fragile MEMS structures. Moreover, these yarns can serve as electrical connectors or sensing components, enhancing a system's overall usefulness. The production procedure for these yarns is meticulously regulated to guarantee uniformity and dependability in MEMS devices. The adaptability of these yarns facilitates their incorporation into intricate geometries, fostering inventive designs that improve both performance and usefulness. The appropriate yarn can markedly enhance the durability, reliability and efficiency of sensors, actuators or other MEMS components. The potential of micro/nano yarns in MEMS has been examined in various studies, with an emphasis on the essential function of specific yarns in guaranteeing optimal performance in MEMS devices, particularly for mechanical strength, electrical characteristics and integration capabilities. Yarns manufactured from fibres with diameters of micrometers or nanometers are known as micro/nano yarns. They are often developed via electrospinning, melt spinning or advanced twisting, resulting in fine, flexible and lightweight structures [8–10].

Despite the fact that functional yarns for advanced applications and siro spinning have made great progress, there are still a number of unanswered questions. Few in-depth studies have investigated how siro technology, which combines natural and synthetic fibres, might improve sustainability and performance in a range of industrial contexts. Optimizing process parameters, such as roving spacing and twist multiplier, to enhance the mechanical properties of specific yarns, especially for MEMS devices, requires additional research. Moreover, in order for these advanced yarns to be commercially viable, further research into their scalability and environmental impact is necessary. Furthermore, further research is needed to fully understand how roving distance effects the roving blending process, as there is limited existing literature on the topic. In order to optimize the siro spinning process, it is essential to understand the intricate relationship between roving distance and blending efficiency. To learn more about the effects of roving distance variations on fibre alignment, blending uniformity and yarn qualities, further research is needed. These findings have the potential to enhance the performance of yarns used in niche applications such as MEMS and high-tech protective clothing. To elucidate the matter further, research has examined the impact of process parameters on the mechanical and functional qualities of yarn during manufacture. Improving yarn quality for new textile applications can benefit greatly from the more in-depth study of these issues [8, 11].

To close the present gap in research, this study applied the combined use of various roving spacing with a combined approach of using the analytic hierarchy process (AHP) and one-way ANOVA to produce good-quality siro spun yarn in the case of roving blending. The following research questions are required to find the optimum outcome of this current study:

- How does roving distance affect roving blending for both natural and synthetic fibres?
- Do varying roving distances have a significant impact on essential quality indicators such as mass variation, imperfection index, hairiness, strength, elongation and overall quality index?

- Which statistical analysis is most suitable for finding the optimum roving distance?

To address the research issues stated above, the following objectives have been developed:

- To determine the impact of different roving distances in the case of roving blended cotton-polyester (50/50) siro yarn.
- To evaluate the significant impact of roving distances from the different yarn quality metrics such as CV_{vm}%, IPI_Y, H_I, $CSPL_S$, E_{br}% and TQI_{YQ} using one-way ANOVA.
- To identify the optimum roving distance from different options for producing good quality yarnusing the AHP method.

Table 1: Overview of prior research studies

No.	Author	Objective	Materials	Methodology	Key findings
1.	Subramaniam et al. [12]	To identify the impact of processing parameters such as spacing between top and bottom aprons, twist multiplier (TM) and the speed of the spindles on produced blended yarn properties such as tensile strength elongation, and evenness.	100% cotton	Central composite rotatable design (CCRD).	Reduced break draft in the ring frame and closer apron spacing improved all but one of the investigated attributes.
2.	Cheng et al. [13]	To determine the effect of TM and spacing among the strands of rovings on produced cotton siro yarn quality.	100% cotton	Empirical data	Increased strand spacing increases the tenacity of 36.9 tex siro spun yarn, peaking at 9 mm for 28.1 and 18.5 tex yarns, while yarn hairiness decreases gradually.
3.	Liu WY et al. [14]	To study how filament-roving strand-spacing influences siro yarn properties.	50 % wool/50 % polyester	Empirical data	Yarn qualities include evenness, tensile strength and breaking elongation, yarn hairiness, as well as ideal strand spacing for different spinning methods.
4.	Soltani P et al. [15]	To ascertain how the structural and mechanical characteristics of siro yarns are influenced by the TM and the spacing of the roving strands.	100% lyocell	ANOVA	Lower hairiness and higher mean fibre standing, fibre migrating factor, broken fibre proportion and strand spacing of 8 mm increase in toughness. A statistical investigation also demonstrated that yarn durability is affected by TM and roving strand spacings.
5.	Liu SQ et al. [16]	To determine how siro yarn manufacturing variables affect cotton- flax blended yarn.	55% flax/45% cotton. Flock blending carried out in a blow room.	ANOVA	The specification of the traveller and spacing between two strands greatly affected the yarn's H_I and CV_m%. A heavier traveller and more space resulted in lower hairiness with higher unevenness values, where 8 mm roving strands were suitable for high-quality yarn.
6.	Sundaresan et al. [17]	To establish how the siro compact yarn's strand spacing influences the fabric's characteristics.	100% cotton	Regression analysis	Higher overall yarn quality was reported when roving strands were spaced 8 mm apart and there was 24 mbar of negative pressure. Siro compact yarn on the fabric's properties.

7.	Wang et al. [18]	To investigate elastic-conductive composite yarns' tensile response on the strand spacing.	Core spun using rayon and filament	Least significant difference (LSD) method and ANOVA	The findings showed that the breaking strengthand length at yarn break increase with increased spacingup to a value of 14.0 mm, afterwhich they decrease, and themean values were deemed substantially different.
8.	Temel E et al. [19]	To examine both polyester and combined polye ster-cotton siro yarn's spinnability.	100% polyester and cotton-polyester blended yarn	ANOVA	The quality of theyarn was significantly affected by the types of fibres, count of yarns, twist multiplier and spacing between strands.
9.	Ute et al. [20]	T create a statistical approach toforecast siro yarn evenness.	100% cotton	Linear regression	The study assessed cottonblends from Turkish spinningmills using AFIS, identifying yarn production parameters as independent variables, and manufacturing siro spun yarns under standardized conditions.

2 Experimental part

2.1 Materials

The primary components of this experiment were fibres of cotton and polyester. Table 2 illustrates the fibres' characteristics, obtained from a high-volume instrument (HVI) according to ASTM D7642 [21].

Table 2: Attributes of fibres

Attributes of fibres	Cotton fibre	Polyester fibre
Fibre length (mm)	29.2	38
Fibre fineness (den) [a)]	1.6	1.4
Strength (N/tex)	282.52	309.02
Short fibre content (%)	9.2	-

[a)] 1 den = 0.9 dtex

2.2 Methods

2.2.1 Research outline

The research work was conducted following the diagram depicted in Figure 1.

2.2.2 Working procedure

In this study, 19.68 tex siro spun yarns made of 50% polyester and 50% cotton were produced. Roving blending was performed in the ring-spinning frame with a 50/50 blend ratio. During this experiment, three samples were prepared with five different roving strand distances: 2 mm, 4 mm, 6 mm, 8 mm and 10 mm. The working procedure is described below: First, carded slivers of cotton and polyesterfibre were collected from the carding portion. The slivers were then fed individually into the breaker and finisher draw frames, resulting in individually drawn slivers of cotton and polyester. Individual slivers of cotton and polyester were fed to the simplex machine to produce the required roving hank at a 50:50 blend ratio. After that, 437.40 tex roving of cotton and 407.24 tex roving of polyester were fed into the ring frame to produce siro spun cotton and polyester blended yarn. In this experiment, five samples were produced, as shown in Table 3, while the other process parameters of the various machines remained constant, as indicated in Table 4.

Table 3: Data matrix for the experiment

Samples	Roving strand distance (mm)
I	2
II	4
III	6
IV	8
V	10

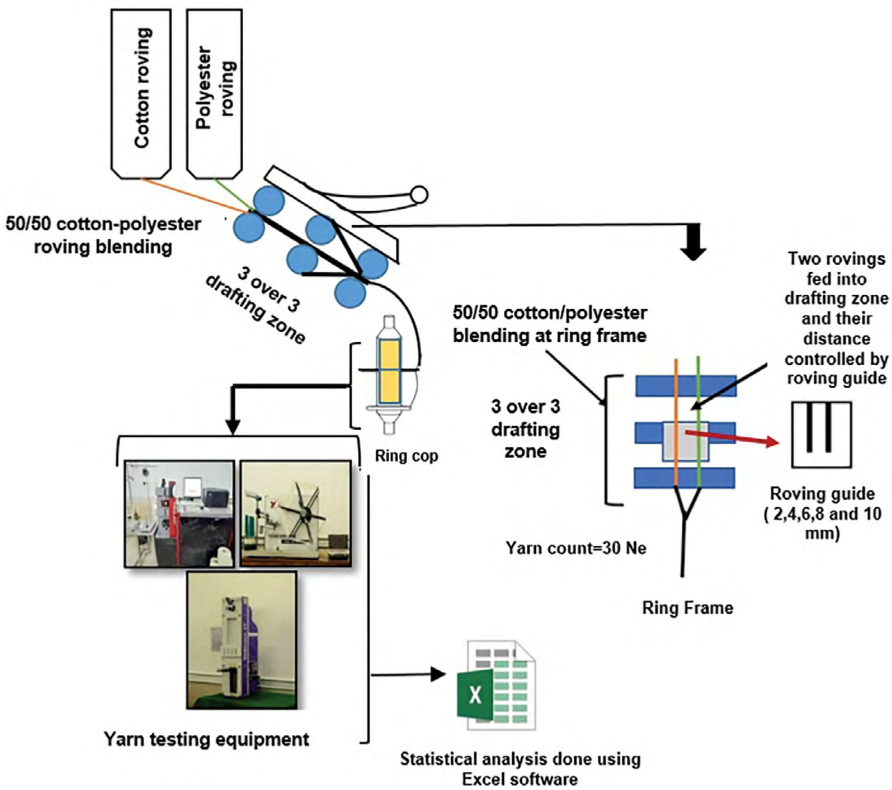

Figure 1: Approach for this study

Table 4: Technical parameters of various machines

Name of the equipment	Model	Origin	Name of the equipment's parameters	Values of each parameter
Carding	Rieter C-70	CH	Turns of the carding cylinder (m^{-1})	750
			Sliver count (ktex/Ne)	10/0.1
Drawframe	Rieter SB-D22 (Breaker), Rieter RSB D30 (Finisher)	CH	Speed of the delivery roller (m/min)	700 (breaker), 600 (finisher)
			Sliver count (ktex/Ne)	9.09/0.11
Simplex	FXM4-5-HY/L	CN	Twist of roving (cm^{-1}/ $inch^{-1}$)	7.87/1.1
			Roving count (tex/Ne)	437/1.35 (cotton); 407/1.45 (polyester)
			Roller gauge (mm)	37.5 mm × 48.5 mm × 49.5 mm
			Spacer size (mm)	6.5
			Flyer speed (m^{-1})	1000
Ring frame	G-32	CH	Spindle gauge (mm)	70
			Roller gauge (mm)	44 × 60
			Spindle speed (m^{-1})	14.800
			Twist of yarn (cm^{-1}/ $inch^{-1}$)	7.229/18.34
			Spacer size in (mm)	2.5
			Yarn fineness (tex)	19.86
			Roving distance (mm)	2, 4, 6, 8, 10

The quality parameters of five yarn samples, including variation concerning yarn mass (CV_{vm}%), the imperfection index (IPI_Y) value, hairiness (HI), the count strength product (CSP_{LS}) value and elongation at break (E_{br})%, were tested using a Uster tester-5, Wrap reel, Lea strength testers and Uster Tensorapid, following the standard test methods given in Table 5. Testing equipment details are given in Table 6. Finally, test results were analysed to determine the impact of five levels of roving strand distances on the quality of siro spun yarns. The total quality index (TQI) can be calculated using Equation 1.

Table 5: Test standards

Parameters	Test method	Reference
Yarn count	ASTM D 1907	[22]
Evenness, imperfection and hairiness values of yarn	ASTM D1425M-14	[23]
Bundle yarn strength	ASTM D 1578	[23]
Tenacity (cN/tex)	ASTM D 2256	[24]

Table 6: List of testing equipment

Machine name	Model	Manufacturer	Country
HVI	HVI 1000	USTER	CH
USTER evenness tester	UT-5	Zellewger USTER	CH
Wrap reel	Ele Warp XT	MAG	IN
Lea strength tester	Me Stretch XT	MAG	IN

$$\text{Total Quality Index} = \frac{\text{Tenacity} \times \text{Elongation}}{\text{Mass variation}} \quad (1)$$

In Equation 1, tenacity (cN/tex) represents the strength of a single yarn, mass variation (CV_m%) quantifies the percentage variation in yarn mass and elongation (%) defines the highest extension before breaking.

2.3 Evaluation using statistical methods

2.3.1 ANOVA technique for analysing variance

When comparing the mean values of three or more groups, a one-way analysis of variance (ANOVA) is employed to determine if there are significant differences among the groups' means. This statistical technique assesses whether the means vary significantly from one another. The ANOVA yields an F-statistic, which represents the ratio of the differences between the group means to the difference within each group. This F-statistic is crucial in deciding whether to accept or reject the null hypothesis. A statistical table provides the F-critical value, which is compared with the F-value obtained from the test results. If the calculated F-value exceeds the F-critical value, the null hypothesis can be rejected. Additionally, the null hypothesis, which posits that all groups have the same mean, should be rejected if the one-way ANOVA produces a P value lower than 0.05 [26–28]. Yarn quality indicators, such as the coefficient of variation of yarn mass (CV_{vm}%), imperfection index (IPI_Y), hairiness index (HI), count strength product (CSP_{LS}) and elongation at break (E_{br}%), were evaluated using this approach to determine the impact of varying roving distances.

2.3.2 Briefly about the analytic hierarchy process (AHP)

The Satty-developed AHP is a widely used decision-making tool for determining the most usable alternatives among all the alternatives. It was used to choose the highest quality yarn sample form with five different roving strand distances. According to this technique, the consistency ratio (CR) is obtained from the ratio between the consistency index (CI) to the random index (RI) in a matrix of the same size. Equations 2 and 3 were also used to calculate the CI and CR [29-30]. Figure 2 depicts a statistical model for a problem analysis. Various criteria have been developed using the Satty scale, as shown in Table 7 where the inputs from industry experts are very crucial. A pair-wise matrix for AHP analysis is presented in Table 8.

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

where n represents the number of items, λ max represents the consistency vector and CI represents the consistency index.

$$CR = \frac{CI}{RI} \quad (3)$$

where RI represents the random consistency index, CI represents the consistency index and CR represents the consistency ratio.

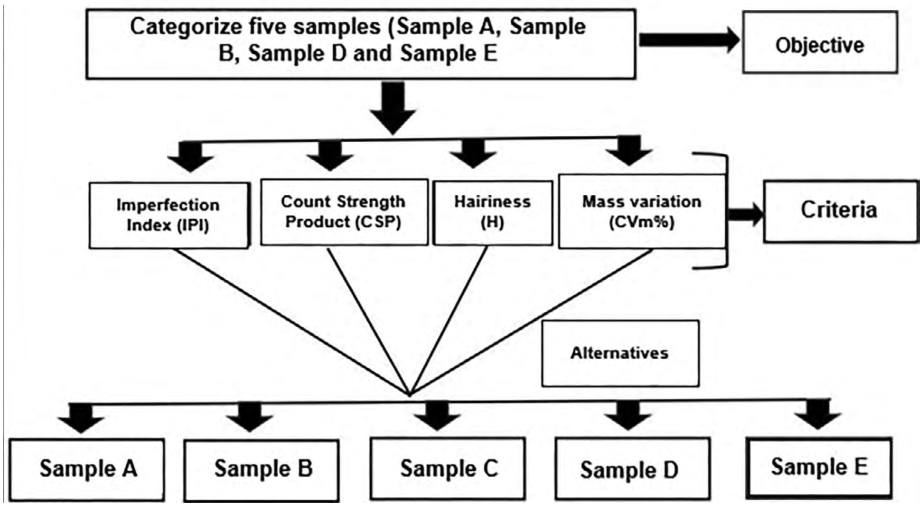

Figure 2: Methodology for problem analysis

Table 7: Scale for comparing two things in AHP [29–30]

Priority or inclination degree	Explanation in words
1	Equal weight is given to the two components
3	One factor is moderately significant to the other
5	One factor is highly significant to the other
7	One factor is very significant to the other
9	One factor is extremely significant to other
2, 4, 6, 8	Values positioned intermediately

Table 8: Pair-wise matrix

Yarn characteristics	IPI_Y	CSP_{LS}	HI	$CV_{vm}\%$
IPI_Y	1	3	5	5
CSP_{LS}	1/3	1	3	3
HI	1/5	1/3	1	2
$CV_{vm}\%$	1/5	1/3	1/2	1

3 Results and discussion

In this study, five yarn samples of 30 Ne were prepared using different types of roving strand distances in a ring frame machine. Test results from different samples against various distances are summarized in Table 9. In order to minimize random errors, each experiment was carried out three times using a total of five samples. When examining the data using standard deviation (±0.5) and coefficient of variation (CV: 1.5–2%), there was little difference between runs.

3.1 Graphical representation

3.1.1 Effect of different levels of roving distance on $CV_{vm}\%$ of siro spun yarn

The impact of spacing on yarn evenness is demonstrated in Figure 3, which shows the mass variation (CVm%) of yarn produced at five various roving strand distances.

Table 9: Uster test results for 30 Ne cotton/polyester roving blended yarn

Sample	CV_{vm}%	IPI_Y	HI	CSP_{LS}	E_{LB}%	Total qualityindex (TQI_{YQ})
I	13.78	278	5.84	2846	6.55	8.01
II	13.15	240	4.65	2955	7.12	9.57
III	13.21	257	5.15	2928	6.91	9.01
IV	13.34	268	5.46	2890	6.83	8.47
V	14.19	310	6.47	2733	6.65	7.72

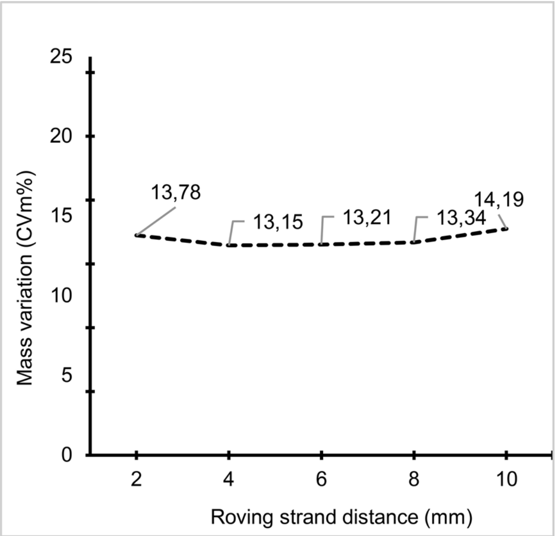

Figure 3: CV_{vm}% of siro spun yarn at different roving distances

It can be concluded from the above figure that the values of mass variation were higher for samples made from 2 mm and 10 mm distances compared to other samples. The 2 mm gap between rovings was insufficient to spread out the fibres in the drafting zone, resulting in the higher mass variation of the yarn. After that, the mass variation in the drafting zone was reduced for a distance of 4 mm and then progressively increased as the roving strand distance rose. A distance of 4 mm provided a good result because the narrow space between two rovings in the drafting zone improves the controlling of fibres during drafting, resulting in a lower mass variation (CV_{vm}%).

These findings support previous studies showing that too small or large strand spacing causes slippage and poor fibre control, which deteriorates the yarn structure [13, 19]. Additionally, the current research's findings are in line with previous research that found that yarn evenness was enhanced by moderate strand spacing and decreased by higher spacing [13, 14].

3.1.2 Effect of different levels of roving distance on IPI_Y of siro spun yarn

The imperfection index (IPI) values of yarn are shown in Figure 4. These values are determined by adding the neps (+200%), thick areas (+50%) and thin places (-50%) per kilometre [31]. The figure illustrates the variation in yarn imperfections with varying roving strand spacing.

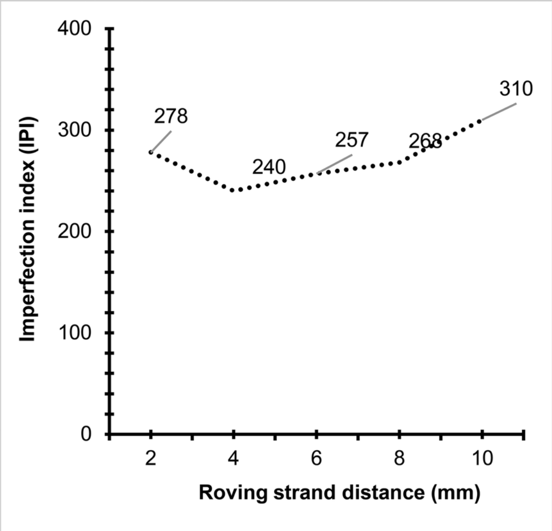

Figure 4: IPI value of siro spun yarn at different roving distances

Yarn samples with roving strand intervals of 4 mm, 6 mm and 8 mm showed a gradual increase in IPI, showing that imperfections increase with roving spacing.

This pattern can be explained by the spinning triangle's expansion at longer distances, which lessens the drafting rollers' ability to regulate edge fibres, and increases fibre migration and nep generation. [17].

Moreover, the blending efficiency between cotton and polyester fibres declines with increasing roving spacing, especially in the ring frame drafting zone, resulting in a weaker fibre network and more imperfections. Conversely, roving distances of less than 4 mm cause the yarn sample's imperfection values to increase. A shorter distance causes an issue for fibre spreading during drafting and also helps to promote fibre entanglement. These results are consistent with other studies that showed that yarn structure is adversely affected by both extremely tiny and very large strand spacings, mostly as a result of ineffective fibre control or ineffective blending dynamics in the drafting zone [17].

3.1.3 Effect of different levels of roving distance on hairiness (HI) of siro spun yarn

Figure 5 depicts the hairiness values of siro spun yarns with varied roving spacing. The yarn's hairiness is primarily the protruding fibres at the yarn surface. Hairiness has a big impact on fabric performance and is a key component in evaluating yarn quality [32]. The hairiness value is also affected by twist level.

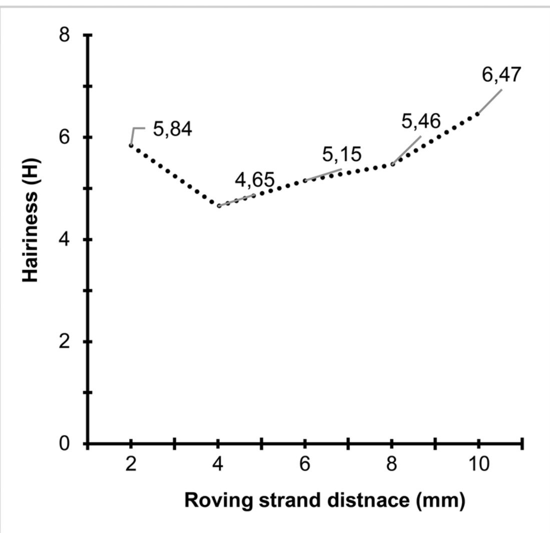

Figure 5: Hairiness (HI) of siro spun yarn at different roving distances

The findings show that increased roaming distance is associated with higher hairiness scores. Remarkably, yarn samples spun at distances of 4 mm, 6 mm and 8 mm showed less hairiness than those made at distances of less than 4 mm or more than 8 mm. This shows that both insufficient and excessive strand spacing compromise the yarn's structural integrity by lowering the converging point in the spinning triangle which produces more protruding fibres [17]. When blending varying lengths of fibre, shorter fibres consistently tend to cause slippage between the nipping and convergence points, which further adds to the hairiness of the yarn.

The results, however, differ from earlier research that indicated a decrease in hairiness with strand spacing at distances greater than 8 mm. However, as strand spacing increased from 8 mm to 12 mm, a slight rise in hairiness was noted, most likely as a result of uneven fibre movement and a loss of control at greater distances. This finding emphasizes the need to control roving strand spacing in maintaining yarn smoothness and fibre cohesiveness, which has not been thoroughly addressed in previous research [13]. This study contributes to the understanding of how strand spacing influences hairiness by focusing on the combined effect of roving distance and fibre cohesion in cotton-polyester blends. The findings suggest that the spacing between rovings influences not just the yarn structure but also the cohesive strength of cotton and polyester fibres during blending, an attribute that has received less attention than hairiness.

3.1.4 Effect of different levels of roving distance on strength (CSP_{LS}) of siro spun yarn

The CSP_{LS} of siro yarn is shown in Figure 6 at varying roving distances. This figure indicates that yarn samples taken at distances of 4 mm, 6 mm and 8 mm showed greater strength than samples taken at distances of 2 mm and 10 mm.

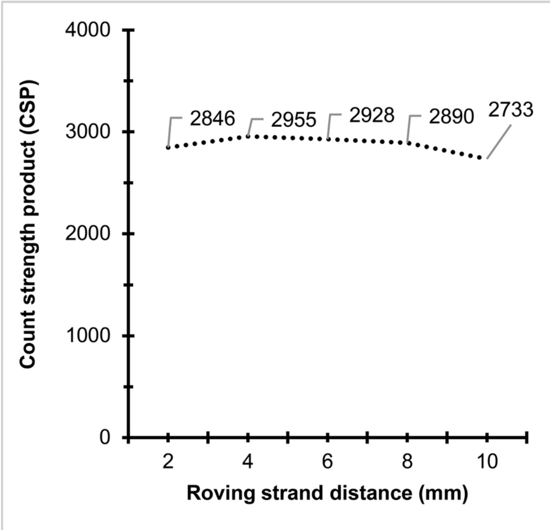

Figure 6: Strength of siro spun yarn at different roving distances

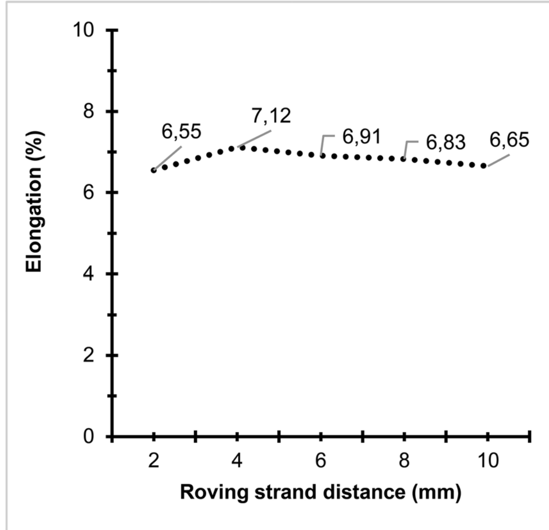

Figure 7: Elongation at break (E_{LB}) % of siro spun yarn at different roving distances

The yarn strength gradually decreased when increasing roving spacing. Higher spacing is also related to a higher amount of imperfection in the yarn samples, resulting in inferior yarn strength. Increased strand spacing, which results in longer strands, may induce increased fibre slippage in strands above the convergence point. This slippage may result in weaker areas and a possible decrease in the strength of the yarn [12]. Roving spacing of less than 4 mm interrupts fibre processing in the drafting zone, resulting in increased yarn imperfections and decreased strength. Yarn quality is further deteriorated when the spacing exceeds 8 mm because it reduces the drafting roller's control over individual fibres. Furthermore, whereas prior research reported higher tenacity at 8 mm strand spacing, the current study demonstrates that distances greater than 8 mm reduce yarn strength due to a lack of fibre cohesion and control inside the drafting zone.

3.1.5 Effect of different levels of roving distance on elongation at the break (E_{LB}) % of siro spun yarn

The elongation values of siro spun yarn at different roving distances are presented in Figure 7.

The overall extensibility and performance of the end product are determined by the right breaking elongation of the strands, which is crucial when turning yarn into fabric. A load is distributed between the individual fibres that make up yarn and the arrangement of the fibres inside the yarn's structure, while fibre extension affects the yarn's breaking elongation. The data shown above in Figure 7 indicates that there was no significant change in elongation percentage among the five samples, indicating that roving strand distance did not affect the elongation property of the yarn. When compared to samples taken at distances of 2 and 10 mm, yarn samples taken at 4 mm, 6 mm and 8 mm had good elongation properties. Poorer elongation property results from poorer fibre integration within the yarn structure caused by roving distances greater than 10 mm and less than 4 mm. These two distances also have an impact on the yarn's spinning triangle, which makes twisting the yarn inappropriate because of the inadequate insertion of the fibres therein. These results align with earlier research that found that greater strand spacing typically leads to a loss in breaking elongation because of increased fibre slippage and irregular fibre arrangement.

3.1.6 Effect of different levels of roving distance on total quality index (TQI_{YQ}) of siro spun yarn

Figure 8 depicts varied TQI_{YQ} values for different yarn samples at various roving distances.

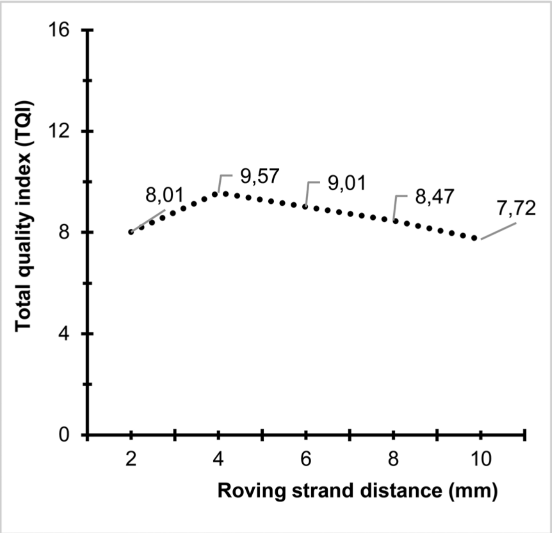

Figure 8: Total quality index (TQI_{YQ}) of siro spun yarn at different roving distances

Yarn tenacity, elongation at break and evenness are important characteristics for determining the quality of yarn. It is simpler to compare a single descriptive number than several. The total quality indexgives the overall quality idea of the yarn samples. Higher TQI_{YQ} values suggest that multiplication values of strength and elongation were higher, but mass variation was lower. Yarn samples made from 4, 6, and 8 mm had greater TQI values than those made from 2 and 10 mm. Distances of less than 2mm and greater than 10 mm affect yarn quality factors, such as elongation at break and mass variation, resulting in lower TQI_{YQ} values for the yarn.

3.2 Statistical analysis

3.2.1 ANOVA with a single-way test

In the case of ANOVA with a single-way test, the null hypothesis was "There is no correlation between yarn quality characteristics and roving strand distances". On the other hand, the alternative hypothesis was "There is a correlation between yarn quality characteristics and roving strand distances". The test results of several samples from Table 8 were utilized to calculate the one-way ANOVA analysis. A summary of the results is presented in Table 10. This statistical analysis was done using Excel software.

Table 10: Results of one-way ANOVA for different yarn samples

Yarn Quality Parameters	F-statistics	P value	F-critical
CV_{vm} (%)	27.83	0.007	5.32
IPI_Y	504.56	0.000	
HI	0.112	0.754	
CSP_{LS}	5402.64	0.000	
E_{LB}%	0.3280	0.528	
TQI_{YQ}	3.094	0.1165	

The ANOVA results in Table 9 indicate that the values of F-statistics are significant because, in terms of mass variation, imperfection index and count strength product, F-statistics values are higher than F-critical values for a 0.05 significance obtained from the table [33], indicating the acceptance of alternative hypothesis and the rejection of the null hypothesis. P values for CV_{Vm}%, IPIY and CSPLS are always less than alpha 0.05,which denotes a 95% confidence level [34]. Thus, based on this analysis, it can be concluded that the quality of yarn is greatly impacted by varying roving strand spacing in terms of quality parameters suchas CV_{vm}%, IPIY and CSP_{LS}. The F-statistical values are less than the F-critical values, however, because the values of the hairiness elongation% and total quality index of the various yarn samples did not change significantly. P values greater than the alpha value of 0.05 were identified for hairiness, elongation and overall quality index. The various roving distances thus have little to no effect on these quality parameters.

3.2.2 Analytic hierarchy process (AHP)

Based on the input from industry experts, four criteria were chosen. Excel software was used to determine the weighting of the criteria. First, the

CI and CR were calculated. The CR was presented in Table 11 following verification. The random consistency index value is 0.89 for the four number of elements. The acquired value of the consistency ratio was 0.0389, which was acceptable because it is less than 0.1 [35]. Finally, the weights assigned to the three options were calculated. When calculating weights, the lowest imperfection index (IPI), lowest mass variation, lowest hairiness and highest count strength product (CSP) were considered for each alternative shown in Table 12. During this calculation, the quality parameters of yarn from different samples shown in Table 8 were used. Following that, Table 12 displayed the final performance value.

Table 11: Determination of CI and CR

CI and CR				
Criteria's	Average consistency vector (λ_{max})	Consistency index, $CI=\frac{\lambda_{max}-n}{n-1}$	Consistency ratio= $\frac{\text{Consistency index}}{\text{Random Consistency index}}$	Consistencyratio (CR) [24–25]
IPI_Y	4.104	0.034	0.0389	Because a CR of 0.0389 < 0.1, it is acceptable
CSP_{LS}				
HI				
CV_{vm} %				

Table 12: Calculation of weights for various alternatives

Weightage calculation for different alternatives					Alternatives criteria weight	Performancescore
Criteria weightage	0.533	0.243	0.115	0.079		
Alternatives	IPI_Y	CSP_{LS}	HI	CV_{vm} (%)		
I	0.46	0.23	0.09	0.075	0.86	5
II	0.53	0.24	0.12	0.079	0.97	1
III	0.50	0.24	0.10	0.079	0.92	2
IV	0.48	0.24	0.10	0.078	0.89	3
V	0.41	0.22	0.08	0.073	0.79	4

The statistical analysis of five-roving spacing's is presented in Table 12, which displays the ranking in significance of the various choices. Sample II, obtained from a 4 mm roving distance, had the highest weightage, showing that this distance is ideal for creating high-quality yarn in the roving blending process, with a score of one. As shown in Table 12, the statistical analysis places the alternatives in the following performance order: II > III > IV > I> V. Samples A and E, which were produced with different roving spacing, had lower scores. This occurred at a lower and higher distance, which causes issues with fibre processing during drafting and also affects the spinning triangle's convergence point, which has a major impact on the parameters affecting yarn quality.

4 Conclusion

This study identified and analysed the relationship between roving strand distance with the quality of siro yarn. It can be concluded that sample A made from a 4 mm distance showed better yarn quality than the others. This happened because minimum distance reduced the fibre slippage in the strands above the convergence point as a result increased inter-fibre cohesion. Additionally, this distance helps to preserve the inter-fibre cohesiveness between two different fibre types of roving blending technique and is appropriate for improved fibre processing in the drafting zone of a ring frame machine. In comparison to Sample II, Sample I's yarn quality attributes were of lesser qualitydue to its production using a 2 mm roving strand spacing. A 2 mm spacing also disturbed the spinningtriangle and inhibited the fibre processing in the drafting zone. Furthermore, extending the roving distance beyond acceptable levels reduced yarn quality because higher lengths compromised fibre- to-fibre cohesion, resulting in lower yarn quality. In an ANOVA analysis, variable roving strand spacing had a substantial impact on yarn quality measures such as CV_{vm}%, IPI_Y and CSP_{LS}. However, the hairiness, elongation at the break, and overall quality index were not significantly affected by these disparities in distance. Furthermore, the analytic hierarchy process (AHP) method identified 4 mm as the optimal roving strand distance for producing high-quality siro yarn, as it had the highest criteria weight compared to other samples. Thus, while Sample II stood out favourably, Samples IIIand IV were seen as viable options worth considering within the context of this study.

5 Future research directions

Siro spinning must explore several essential domains to improve yarn performance and optimize processes. The impact of roving distance on different yarn blends and fibre compositions warrants significant attention. Examining the effects of varying roving distances on the structural integrity and functional properties of blends, including natural and synthetic fibres, is essential for the progression of yarn technology. Broadening the analysis to include a wider variety of yarn counts and qualities would yield insights into the optimization of spinning parameters for various textile applications [36]. Additionally, examining the relationships between roving distance and other spinning variables, such as twist multiplier, tension and draft, provides a means to optimize the overall spinning process. This may result in more uniform yarns exhibiting improved mechanical and functional characteristics, particularly for specialized uses such as protective textiles and MEMS devices. Long-term studies evaluating the durability, abrasion resistance and overall performance of yarns produced with different roving distances are essential for predicting their behaviour in practical applications, particularly in demanding fields such as ballistic protection and advanced sensors [8]. Moreover, integrating advanced technologies, including machine learning and artificial intelligence, into the siro spinning process has the potential to enhance efficiency and quality control significantly. Utilizing predictive models to ascertain optimal roving distances and other process parameters enables manufacturers to improve product consistency, minimize waste and optimize material utilization. These innovations may facilitate large-scale production of high-performance yarns suitable for various advanced applications, such as wearable electronics, smart textiles and MEMS-based systems [8].

Furthermore, some other studies emphasize the necessity for a more comprehensive understanding of the intricate relationships between processing parameters and yarn properties [37–38]. Future research should focus on integrating computational models with experimental data to enhance the efficiency and sustainability of yarn manufacturing processes. The integration of textile engineering and data-driven technologies is crucial for addressing the increasing requirements of next-generation textile applications.

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References

1. RAIAN, S., HOSSEN, J. Effect of lattice apron age on the quality of compact ring-spun yarns. *Trends in Textile Engineering and Fashion Technology,* 2018, **3**(4), 348–357, doi: 10.31031/TTEFT.2018.03.000567.
2. AHMAD, N., HOSSEN, J., ALI, S.M. Improvement of overall equipment efficiency of ring frame through total productive maintenance: a textile case. *The International Journal of Advanced Manufacturing Technology,* 2018, **94**(1), 239–256, doi: 10.1007/s00170-017-0783-2.
3. XU, W., XIA, Z., WANG, X., CHEN, J., CUI, W., YE, W., DING, C., WANG, X. Embeddable and locatable spinning. *Textile Research Journal,* 2011, **81**(3), 223–239, doi: 10.1177/0040517510380780.
4. SU, X., GAO, W., LIU, X., XIE, C., XU, B. Research on the compact-siro spun yarn structure. *Fibres & Textiles in Eastern Europe*, 2015, **3**(111), 54-57.
5. ZACHARIAH, S. A., SHENOY, S., PAI, D. Experimental analysis of the effect of the woven aramid fabric on the strain to failure behavior of plain weaved carbon/aramid hybrid laminates. *Facta Universitatis, Series: Mechanical Engineering,* 2024, **22**(1), 13–24, doi: 10.22190/FUME200819022Z.
6. DEVARAJAN, B., LAKSHMINARASIMHAN, R., MURUGAN, A., RANGAPPA, S.M., SIENGCHIN, S., MARINKOVIC, D. Recent developments in natural fiber hybrid composites for ballistic applications: a comprehensive review of mechanisms and failure criteria. *Facta Universitatis, Series: Mechanical Engineering,* 2024, **22**(2), 343–383, doi: 10.22190/FUME240216037D.
7. KHAN, A., AWAIS, M., MOHSIN, M., KHAN, A., CHEEMA, K. Sustainable yarns and fabrics from tri-blends of banana, cotton and tencel fibres for textile applications. *Journal of Cleaner Production,* 2024, **436**, 1–12, doi: 10.1016/j.jclepro.2023.140545.
8. HE, J.-H., HE, C.-H., QIAN, M.-Y., ALSOLAMI, A.A. Piezoelectric biosensor based on ultrasensitive MEMS system. *Sensors and Actuators A: Physical,* 2024, **376**, 1–7, doi: 10.1016/j.sna.2024.115664.
9. HE, J.-H. Periodic solution of a micro-electromechanical system. *Facta Universitatis, Series: Mechanical Engineering,* 2024, **22**(2), 187–198, doi: 10.22190/FUME240603034H.
10. NARITA, F., WANG, Z., KURITA, H., LI, Z., SHI, Y., JIA, Y., SOUTIS, C. A review of piezoelectric and magnetostrictive biosensor materials for detection of COVID-19 and other viruses. *Advanced Materials,* 2021, **33**(1), 1–24, doi: 10.1002/adma.202005448.
11. FEYZIAZAR, M., AMINI, M., JAHANBAN-ESFAHLAN, A., BARADARAN, B., OROOJALIAN, F., KAMRANI, A., MOKHTARZADEH, A., SOLEYMANI, J., DE LA GUARDIA, M., Recent advances on the piezoelectric, electrochemical, and optical biosensors for the detection of protozoan pathogens. *TrAC Trends in Analytical Chemistry,* 2022, **157**, 1–23, doi: 10.1016/j.trac.2022.116803.
12. SUBRAMANIAM, V., V. R. SRINIVASAMOORTHI, A. PEER MOHAMED. Effect of processing parameters on the properties of double-rove spun yarn produced on a short staple spinning system. *Textile Research Journal,* 1989, **59**(12), 762–767, doi: 10.1177/004051758905901210.
13. CHENG, K.P.S., SUN, M.N. Effect of strand spacing and twist multiplier on cotton sirospun yarn. *Textile Research Journal,* 1998, **68**(7), 520–527, doi: 10.1177/004051759806800709.
14. LIU, W. Y., YU, Y. P., HE, J. H., WANG, S. Y. Effect of strand-spacing between roving and filament on sirofil yarn properties. *Textile Research Journal,* 2007, **77**(4), 200–204, doi: 10.1177/0040517507080614.

15. SOLTANI, P., JOHARI, M.S. Effect of strand spacing and twist multiplier on structural and mechanical properties of siro-spun yarns. *Fibers and Polymers,* 2012, **13**(1), 110–117, doi: 10.1007/s12221-012-0110-3.
16. LIU, S.Q., DAI, J.M., JIA, H.S., LIU, X.G., XU, B.S. Effect of siro-spun processing parameters on properties of 55/45 flax/cotton blended yarn. *Advanced Materials Research*, 2011, **331**, 502–511, doi: 10.4028/www.scientific.net/AMR.331.502.
17. SUNDARESAN, S., BALU, S., MOHANRAJ, R. Effect of strand spacing of SIRO Compact yarn on fabric properties. *IJARIIE*, 2016, **2**(4), 172–179.
18. WANG, Y., YU, W., WANG, F. Strand-spacing dependency on the tensile response of tri-component elastic-conductive composite yarns. *Textile Research Journal,* 2019, **89**(7), 1237–1245, doi: 10.1177/0040517518767151.
19. TEMEL, E., ÇELIK, P. A research on spinnability of 100% polyester and polyester R11; cotton blend sirospun yarns. *Textile and Apparel,* 2010, **20**(1), 23–29.
20. **ÜTE, T. B., KADOĞLU, H. A statistical model for predicting yarn evenness of cotton** sirospun yarns. *European Journal of Engineering and Natural Sciences,* 2015, **1**(1), 57–63.
21. DELHOM, C. D., HEQUET, E. F., KELLY, B., ABIDI, N., MARTIN, V. B. Calibration of HVI cotton elongation measurements. *Journal of Cotton Research,* 2020, **3**(1), 1–10, doi: 10.1186/s42397-020-00073-1.
22. ASTM D1907-01. Standard test method for linear density of yarn (yarn number) by the skein method. West Conshohocken : ASTM International, 2017, 1-9.
23. HOSSEN, J., SAHA, S.K. Influence of blending method and blending ratio on ring-spun yarn quality – a MANOVA approach. *Tekstilec,* 2023, **66**(3), 227–239, doi: 10.14502/tekstilec.66.2023023.
24. ASTM D2256/D2256M-21. Standard test method for tensile properties of yarns by the single-strand method. West Conshohocken : ASTM International, 2022, 1-13.
25. HALIMI, M. T., HASSEN, M. B., AZZOUZ, B., SAKLI, F. Effect of cotton waste and spinning parameters on rotor yarn quality. *The Journal of the Textile Institute,* 2007, **98**(5), 437–442, doi: 10.1080/00405000701547649.
26. PUJAR, P.M., KENCHANNAVAR, H.H., KULKARNI, R.M., KULKARNI, U.P. Real-time water quality monitoring through Internet of Things and ANOVA-based analysis: a case study on river Krishna. *Applied Water Science,* 2020, **10**(1), 1–6, doi: 10.1007/s13201-019-1111-9.
27. F statistic / F value: simple definition and interpretation [online]. Statistics How To [accessed 15 October 2025]. Available on World Wide Web: <https://www.statisticshowto.com/probability-and-statistics/f-statistic-value-test/>.
28. One-way ANOVA computes a P value <0.05 (significant effect of treatment), but a Tukey multiple comparisons test finds no statistically significant differences between any pairs of means. Is this a contradiction? [online]. GraphPad [accessed 15 October 2025]. Available on World Wide Web: <https://www.graphpad.com/support/faq/one-way-anova-computes-ap-value-005-significant-effect-of-treatment-but-a-tukey-multiple-comparisons-test-finds-no-statistically-significant-differences-between-any-pairs-of-means-is-this-a-contradiction/>.
29. SAATY, T.L. *Decision Making with Dependence and Feedback: the Analytic Network Process*. Pittsburgh : RWS Publications, 1996.
30. RAJPUT, V., SHUKLA, DR. A.C. Decision-making using the analytic hierarchy process (AHP). *International Journal of Scientific Research,* 2012, **3**(6), 135–136.
31. CHAKRABORTTY, A., HOSSAIN, A., GHOSH, J. Study on the effect of air suction pressure on the quality of compact yarn by changing the frequency of inverter. *Tekstil ve Mühendis,* 2020, **27**(119), 154–158.
32. HALEEM, N., WANG, X. Recent research and developments on yarn hairiness. *Textile Research Journal,* 2015, **85**(2), 211–224, doi: 10.1177/0040517514538692.

33. Table of critical values for the F distribution (for use with ANOVA) [online]. University of Sussex [accessed 15 October 2025]. Available on World Wide Web: <https://users.sussex.ac.uk/~grahamh/RM1web/F-ratio%20table%202005.pdf>.
34. FLECHNER, L., TSENG, T.Y. Understanding results: P-values, confidence intervals, and number need to treat. *Indian Journal of Urology,* 2011, **27**(4), 532–535, doi: 10.4103/0970-1591.91447.
35. FARMAN, H., JAVED, H., JAN, B., AHMAD, J., ALI, S., KHALIL, F.N., KHAN, M. Analytical network process based optimum cluster head selection in wireless sensor network. *PLoS ONE,* 2017, **12**(7), 1–28, doi: 10.1371/journal.pone.0180848.
36. AFROZ, F., ISLAM, M.D.M. Study on mechanical property of woven fabrics made from 50/50 cotton-tencel blended siro yarn. *Heliyon,* 2021, **7**(10), 1–10, doi: 10.1016/j.heliyon.2021.e08243.
37. YANHONG, W., LIU, X., SU, X., ZHIMIN, Z. Effects of spinning process and core yarn contents on yarn shape retention. *International Journal of Clothing Science and Technology,* 2020, **32**(4), 457–469, doi: 10.1108/IJCST-11-2018-0142.
38. RUZIBOEV, N.N., ISAQULOV, V.T., JURAYEV, A.J., TULAGANOVA, M.V. Study of the effect of the spindle speed on the properties for the baked siro yarn, which made from cotton and polyester fibres. *International Journal of Engineering Science,* 2022, **171**, 1–10.
39. CHAKRABORTTY, A., RAIAN, S., SAHAIN, S, HOSSEN, J. Application of ANOVA and AHP in assessing the quality of roving cotton-polyester siro yarn. *Zenodo*, November 6, 2025, doi: 10.5281/zenodo.17539792.