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Investigating the Ideal Combination of Virgin Cotton Fibre Length with Recycled Fibre for Better Yarn Quality

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Article

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ABSTRACT

This study examines the effects of blending virgin cotton fibres of selected lengths with a fixed percentage of recycled fibres on yarn quality. By choosing three different lengths of virgin cotton fibres and incorporating 20% recycled fibre, we investigate the resultant yarn properties through detailed statistical analysis. Our research identifies significant enhancements in yarn quality with increased virgin fibre length, offering new insights into effective fibre blending strategies. This investigation supports the textile industry in refining fibre blend ratios for improved yarn qualities while advocating for sustainable practices through the utilization of recycled fibres. It sets the stage for future exploration aimed at optimizing the balance between virgin and recycled fibres to achieve superior yarn characteristics.

KEYWORDS

cotton, fibre length, recycled fibre, yarn quality, fibre length optimization

INTRODUCTION

The optimal blending of virgin cotton fibre length with recycled fibre holds paramount importance in achieving high-quality yarn within the textile industry. The profound impact of fibre length and its associated parameters on cotton fibre quality cannot be overstated. Variability in length and characteristics within fibres from the same cotton cultivar annually at a given location is well-documented [1]. A reduction in fibre length has been identified as a factor adversely affecting yarn strength and introducing issues such as hairiness, thinness, thickness, and neps, contributing to overall yarn imperfections. Yarns derived from shorter fibres exhibit negative effects on tenacity, hairiness, and imperfections [2]. Additionally, the sustainable aspects of utilizing recycled fibres enhance yarn quality, bringing unique characteristics to the blend that influence yarn properties alongside virgin cotton fibre length [14]. The distribution of variations in fibre length plays a crucial role in predicting yarn properties; an increase in yarn linear density leads to increased hairiness, and the inclusion of

recycled fibres introduces specific considerations in this context [3]. fibre length significantly influences hairiness, with longer fibres associated with reduced hairiness. Conversely, an increase in short-fibre percentage results in higher hairiness. The quantity of short cotton fibres in a sample is vital for affecting yarn production efficiency [4-6]. Short fibre content directly impacts the quality of cotton yarns, contributing to lower tenacity and evenness, higher imperfections, elevated hairiness, and reduced spinning efficiency [7,8]. Standards for measuring short fibre content vary, with the American Standard Test Method (ASTM) [9] defining it as the percentage of fibres shorter than ½ inch (S.F.C.½"), while Chinese Standards Test Methods define it as fibres shorter than 16 mm (S.F.C.16 mm) [10]. There is also a positive and highly significant association between yarn hairiness and short fibre content [11]. The short fibre index and fibre strength exert significant but opposing effects on yarn strength [12].
A positive correlation in fibre length changes across various phases [13]. On average, fibre length increased during carding, breaker drawing, finisher drawing, and simplex stages but decreased during card mat and ring stages. The inclusion of recycled fibres adds a sustainable dimension to the investigation, offering insights into the synergistic effects of combining virgin cotton and recycled fibres on yarn quality. This study aims to explore the intricate dynamics of fibre length and its influence on yarn properties, with a specific focus on the interplay between virgin cotton fibre length and recycled fibre.

MATERIALS AND METHODS

Fibre Characteristics and Preparation

Virgin cotton fibres and recycled fibres, with detailed characteristics outlined in Tables 1 and 2, were subjected to processing in spinning preparatory machines. The experimental design involved varying the ratio of virgin cotton to recycled fibres in the blending process. Slivers were produced according to the specified Virgin Cotton-Recovered fibre Mixing Ratio (Virgin Cotton-80%: Recycle fibre-20%). The recycled fibre used is 100% pure cotton, sourced from RBD Fibres Limited, located in Rupganj, Narayanganj, Bangladesh. Three distinct fibre lengths (26.65 mm, 28.25 mm, and 30.22 mm) were considered in the sliver production process.

Table 1. Properties of Virgin cotton and recover fibres recorded from USTER HVI 1000

Properties	Benin Cotton			Recycle fibres
	Fibre Length 26.65 mm	Fibre Length 28.25 mm	Fibre Length 30.22 mm	
Micronaire value (µg/in)	3.91	4.80	4.39	4.55
UHML (Upper half mean length) mm	26.65	28.25	30.22	19.6
Strength (g/tex)	24.0	29.8	30.2	25

Properties	Benin Cotton			Recycle fibres
	Fibre Length 26.65 mm	Fibre Length 28.25 mm	Fibre Length 30.22 mm	
Maturity index	0.85	0.89	0.87	0.88
Uniformity index (%)	78.4	81.7	82.7	68.6
Elongation (%)	6.3	4.6	5.6	3.7
Short fibre index (%)	14.0	9.5	7.4	52.2

Table 2. Properties of Virgin cotton and recover fibres recorded from USTER AFIS Pro 2

Properties	Benin Cotton			Recycle fibres
	Fibre Length 26.65 mm	Fibre Length 28.25 mm	Fibre Length 30.22 mm	
Fibre Nep (Cnt/g)	356	306	216	801
Seed Coat Nep (Cnt/g)	15	10	10	43
SFC(w)-Short fibre Content (%)	14.6	9.6	9.4	53.5
UQL(w)-Upper Quarter Length	28.3	32.4	30.1	16.6
SFC(n)-Short fibre Content (%)	35.1	27.0	26.0	76.0
5%L(n)-Span Length	33.1	34.1	36.9	20.0
Maturity Ratio	0.84	0.85	0.89	0.81
IFC% (Immature fibre Content)	7.5	7.6	6.2	6.7

Roving and Yarn Production

Following sliver production, a roving frame was employed to produce 0.8 Ne rovings with a count of 1.28 TM. Subsequently, a ring spinning frame was utilized to spin 30 Ne yarns with a count of 3.90 TM

Yarn Quality Testing

The initial assessment of yarn quality involved conducting unevenness tests using the Uster Tester 6. Bundle strength analysis was then performed using a Lea strength tester machine, adhering to established standards. Yarn performance was calculated as the average of eight samples, each measured using the aforementioned yarn quality testing equipment.

Experimental Setup

The research experiment was conducted under the operational conditions of Mondol Spinning Mills Ltd. Three distinct mixing types were considered for fibre length analysis, each representing pure cotton with varying fibre lengths. The details of the three mixing ratios are presented in Table 3.

Table 3. Mixing ratio of produced yarn

Mixing Type (MT)	Virgin Cotton fibre Length (mm)	Virgin Benin Cotton Percentage, %	Recover fibres Percentage, %
Mixing type-1 (MT1)	26.65	80	20
Mixing type-2 (MT2)	28.25	80	20
Mixing type-3 (MT3)	30.22	80	20

This method section outlines the comprehensive approach undertaken to investigate the influence of recovered fibre content in virgin cotton-recovered blends, encompassing fibre characteristics, processing steps, and yarn quality testing procedures. The experimental setup at Mondol Spinning Mills Ltd. ensured real-world applicability and relevance to industry practices.

Machinery used

A comprehensive array of machinery was employed to ensure the precision and efficiency of the experimental process. The machinery lineup included the following key components: Blow room, Carding, Breaker Drawing, Finisher Drawing, Simplex, and Ring Frame. Each machine played a crucial role in different stages of fibre processing and yarn production.

These machines were selected for their precision and reliability in the textile industry, ensuring the consistency of experimental conditions. The values and parameters of each machine are meticulously documented in Table 4, providing a comprehensive reference for the equipment used throughout the study.

Table 4. Machine parameters used in the card-spinning process

Process	Machine & Model	Parameter	Value
Blow Room	Trutzschler	CL-P	Beater Speed = 550 Rpm
			Wing Setting = 4.0
		CL-U	Roller Speed = 380 Rpm
			PMS = 90%
			Deflector = 60%
Carding	TC19i	Sliver weight (Ktex)	4.96 Ktex
		Del. Hank	0.119
		Productivity (kg/h)	70.0
		Licker-in speed (rpm) $1^{st}/2^{nd}/3^{rd}$	1020/1600/2100
		Big Cylinder (rpm)	560
		Revolving Flats (mm/min)	380
		PMS Blade	6.0
Breaker Drawing	Rieter SBD26	Sliver weight (Ktex)	4.96 Ktex
		Del. Hank	0.119

Process	Machine & Model	Parameter	Value
Breaker Drawing	Rieter SBD26	Del. Speed (m/min)	700
		Doubling	6
		Roller Gauge (mm)	40/44
		Draft	5.89
		Back Draft	1.30
Finisher Drawing	Rieter RSB-D26	Sliver weight (Ktex)	4.96 Ktex
		Del. Hank	0.119
		Del. Speed (m/min)	650
		Doubling	8
		Roller Gauge (mm)	39/43
		Draft	7.75
		Back Draft	1.15
Simplex	Toyota FL-200	Roving count (Ne)	0.80
		Flyer Speed (rpm)	1150
		TPI/TM	1.15/1.28
		Total Draft	6.72
		Back draft	1.21
		Roller Gauge (mm)	37.5/49.5/52
		Spacer Size	Green 5.9 mm
Ring Frame	Jingwei JWF1566	Count	30 Ne
		TPI/TM	21.45/3.90
		Avg.Speed (rpm)	14500
		Ring Traveller Size	3/0 (Kanai)
		Roller Gauge (mm)	44/60

RESULTS AND DISCUSSION

Raw cotton, carded sliver, breaker-drawn sliver, finisher-drawn sliver, and roving were sampled at each stage from raw cotton to the roving frame. Finally, all the samples underwent numerical testing using USTER AFIS PRO 2, as shown in Table 5.

Table 5. Change in fibre length for different mixing types in different processing stages

Sample Type	Carding Sliver			Breaker Drawn Sliver			Finisher Drawn Sliver			Roving		
Parameter	MT1	MT2	MT3	MT1	MT2	MT3	MT1	MT2	MT3	MT1	MT2	MT3
Total Neps cnt/g	122	148	124	143	156	119	145	140	114	89	134	95
SFC (w)%	18.7	14.0	13.1	18.0	14.1	13.6	16.2	13.7	14.0	15.6	13.7	12.9
UQL (w) mm	26.8	29.7	29.1	27.1	29.9	29.1	27.7	30.0	29.3	28.2	30.1	30.5

Sample Type	Carding Sliver			Breaker Drawn Sliver			Finisher Drawn Sliver			Roving		
Parameter	MT1	MT2	MT3	MT1	MT2	MT3	MT1	MT2	MT3	MT1	MT2	MT3
SFC (n)%	40.1	34	32.2	38.9	33.7	32.3	35.2	32.4	33.1	34.5	32.8	31.6
5%L (n)	31.4	34.5	33.5	31.9	34.6	33.3	32.5	34.5	33.7	33.1	35.7	34.4
Maturity Ratio	0.79	0.82	0.89	0.81	0.85	0.98	0.90	0.90	1.04	0.91	0.92	0.96

Table 5 and Figures 1 provide a comprehensive illustration of the observed increase in fibre length, attributable to the inherent variability in the raw material. Notably, the carding process played a crucial role in this augmentation by strategically removing short fibres as strips and dropping-1. Consequently, there was a notable enhancement in the average length of the fibres.

A detailed analysis presented in both Table 5 and Figure 1 delineates a further increase in fibre length from the breaker drawing to the roving frame for MT1, MT2, and MT3. This phenomenon underscores the significance of drawing action, specifically within the breaker draw frame, where the removal of trailing and leading hooks occurs.

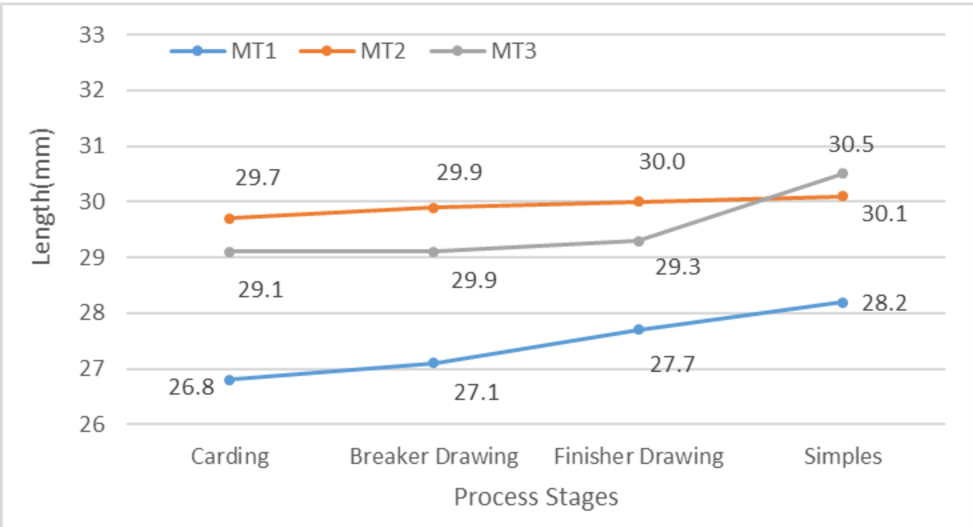

Figure 1. Change in fibre length

The orchestrated removal of these hooks through drawing action leads to an overall elevation in fibre length throughout the processing stages, contributing to the observed trends outlined in the data.

Moreover, Table 5 and Figure 2 highlight a concurrent reduction in short-fibre content. This reduction in short fibre content further aligns with the overall enhancement in fibre length, signifying the efficacy of the processing stages in promoting favourable textile characteristics.

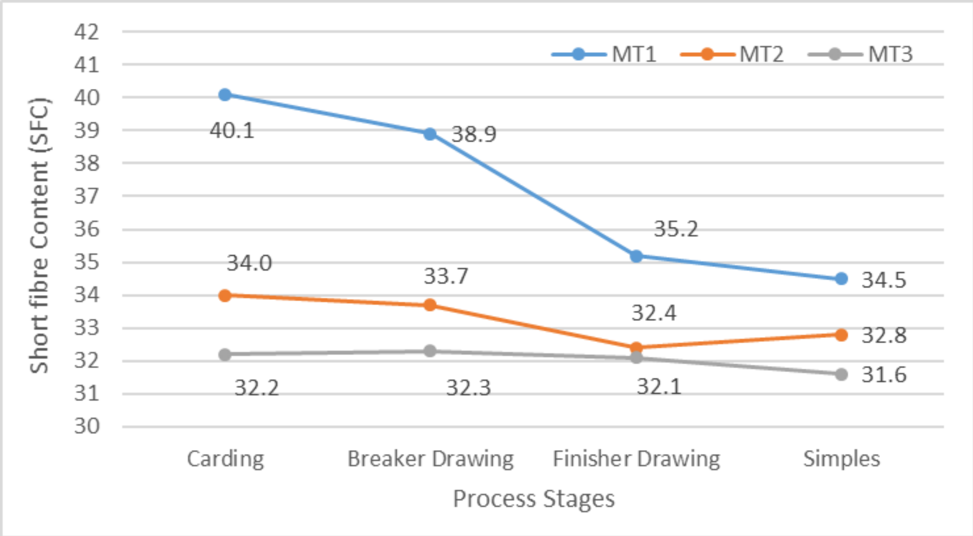

Figure 2. Change in short fibre content

Table 6. Properties of produced yarn of different mixing types

Quality Parameters	MT1 fibre length 26.65 mm (80:20)	MT2 fibre length 28.25 mm (80:20)	MT3 fibre length 30.22 mm (80:20)
Yarn count (Ne)	29.33	29.16	29.15
Strength (CSP-Count Strength Product)	1856	2226	2389
U%	13.36	12.80	12.48
CVm%	17.03	16.24	15.82
Thin place (-50%)/Km	33	20	9
Thick place (+50%)/Km	400	330	261
Neps (+ 200%)/Km	268	274	254
Hairiness(H)	6.67	6.29	6.27
Imperfection Index (IPI)	701	624	524
Total classimat faults/100km	149 053.8	110 083.5	100 383.1

Table 6 presents a comprehensive overview of key quality parameters crucial for evaluating the performance of the yarn produced in our project. The table outlines values for various essential metrics, including U% (uniformity index), CVm% (coefficient of variation), Thin Place (-50%)/Km, Thick Place (+50%)/Km, Neps (+200%)/Km, Hairiness (H), Imperfection Index (IPI), and Total Classimat Faults/100km. These metrics collectively offer insights into the yarn's uniformity, strength, thickness variations, presence of imperfections, and overall quality. The meticulous analysis of these parameters is instrumental in gauging the effectiveness of our experimental processes in achieving the desired yarn characteristics, contributing valuable data to the broader understanding of yarn quality in textile production.

A notable trend observed in Figure 3 suggests that a higher proportion of high fibre length in the yarn corresponds to lower irregularity. MT1 and MT2 yarns exhibit the highest values in terms of irregularity, while MT3 follows a different pattern due to variations in fibre length between Virgin cotton and recovered fibre.

Finally, Figure 3 illustrates a decrease in the imperfection index with the incorporation of a higher fibre length portion in MT3 yarn. This reduction is attributed to the increased length and reduced short fibre content in the yarn, consolidating the imperfection parameters into a singular imperfection index term.

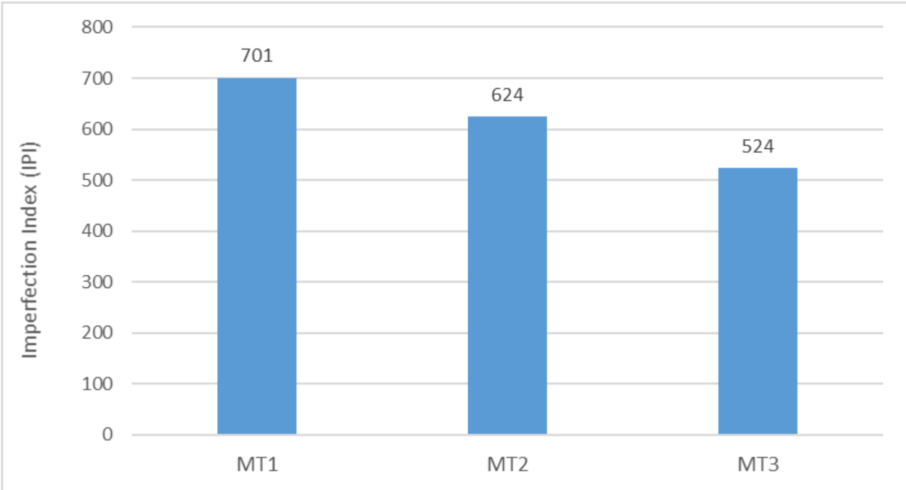

Figure 3. Imperfection Index (IPI) of the yarns

In Figure 4, a compelling and evident correlation emerges, showcasing a significant impact on the hairiness index of MT3 yarn as the fibre length of virgin cotton increases within the mixing ratio. The graphical representation provides a clear visual narrative, indicating that a higher proportion of longer virgin cotton fibres in the blend corresponds to a consistent and notable decrease in the average values of the hairiness index for MT3 yarn. This compelling observation aligns seamlessly with the broader findings of our research, underlining the pivotal role of fibre length in influencing yarn characteristics and reinforcing the importance of thoughtful fibre blending strategies in achieving desired textile outcomes.

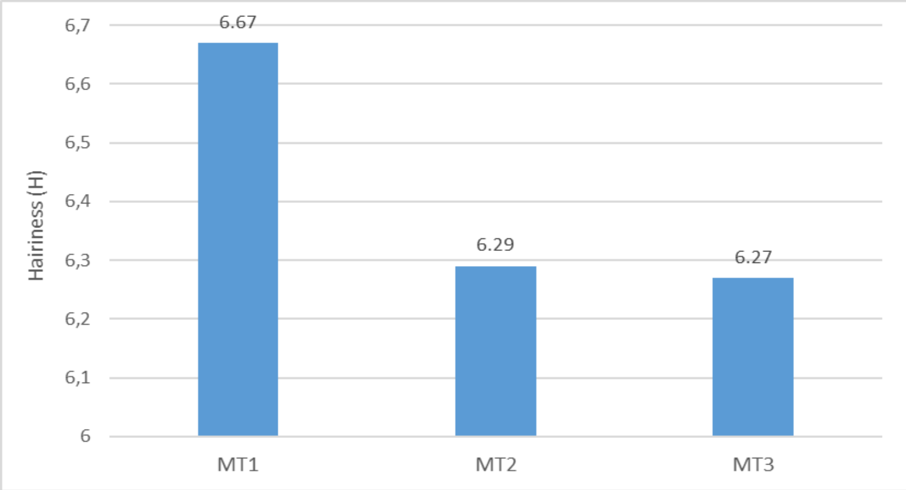

Figure 4. The hairiness of the yarn

Figure 5 encapsulates a profound insight into the influence of fibre length on yarn elongation, reflecting a compelling relationship that aligns seamlessly with the core principles delineated throughout our research. The graphical representation vividly illustrates a noteworthy effect: The data indicates that elongation increases with the quality of the fibre mix, showing values of 47.4 mm for MT1, 49.8 mm for MT2, and 51.0 mm for MT3. This progression demonstrates the improved elasticity and potential durability of the yarns as the blend shifts towards longer virgin cotton fibres. This elevation in elongation aligns with a reduced presence of short fibres, evidencing a twofold advantage: as the fibres extend in length, there is a concurrent enhancement in the yarn's stretching capacity, further affirming the positive correlation between fibre length and the reduction of undesirable short fibre content.

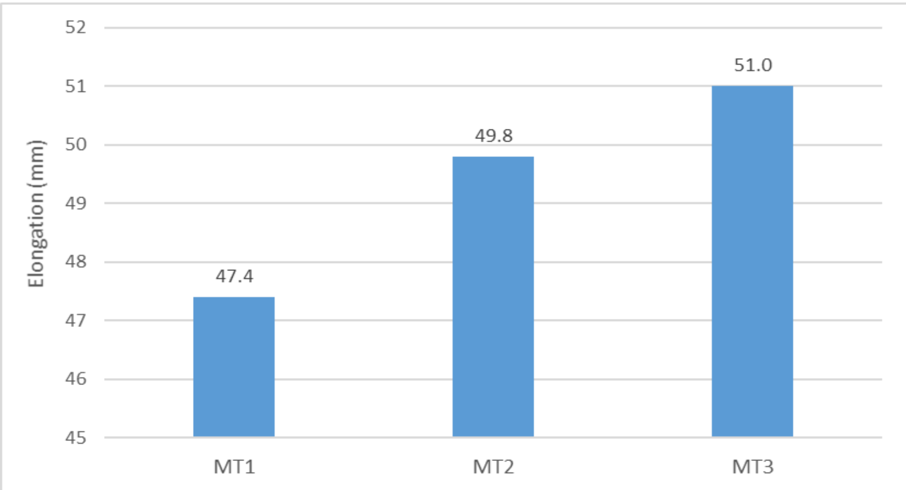

Figure 5. Elongation (mm) of the single yarn

Fibre length stands out as a key influencer in the strength of ring-spun yarns, a central theme reiterated in our research. Figure 6 visually conveys this relationship, demonstrating that an increase in fibre length corresponds directly to a higher Count Strength Product (CSP).

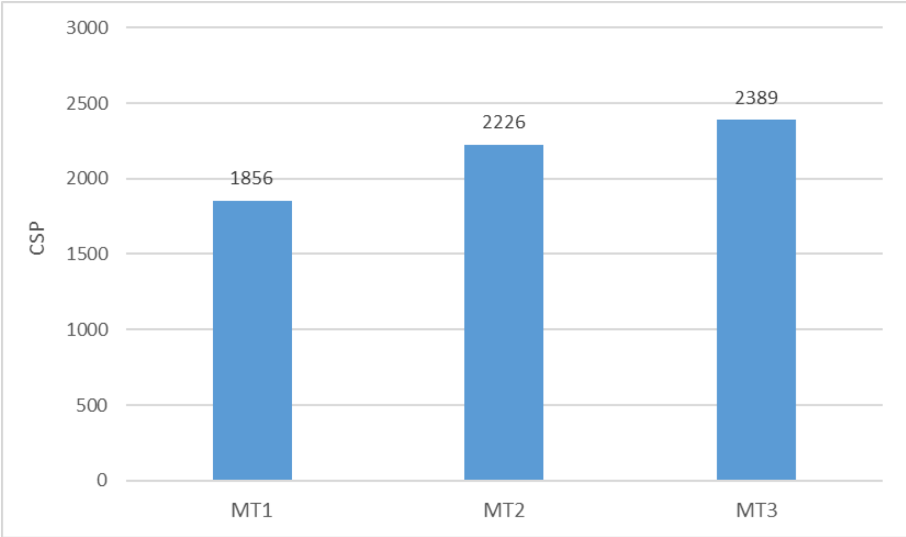

Figure 6. CSP of the yarn

Longer fibres, possessing greater mass, play a significant role in the twist zone, thereby exerting a more pronounced effect on yarn strength. The interplay of fibre length and wrapping twist emerges as critical in shaping yarn strength characteristics. This succinct exploration, supported by Figure 6, enhances our understanding of how fibre characteristics impact ring-spun yarn strength, illuminating essential dynamics in textile production.

CONCLUSION

The length measurements obtained through USTER AFIS PRO2 consistently revealed a discernible pattern across all mixing types, showcasing an increase in fibre length and a simultaneous decrease in short fibre content during carding, breaker drawing, finisher drawing, and simplex processes. This observed trend underscores the pivotal role of fibre length in determining yarn strength, a factor critical to the overall robustness of the fabric. Furthermore, the length and distribution of fibres have far-reaching implications on fibre processing and subsequent yarn performance during mechanical processes such as weaving and knitting. The experimental results emphasize the significance of considering staple length concerning yarn quality, as shorter fibres correlate with a decline in yarn Count Strength Product (CSP), heightened hairiness, and increased imperfections. It is essential to recognize that yarn quality experiences a downturn with decreasing staple length, particularly impacting yarn strength, hairiness, and imperfections. Notably, the integration of recycled fibre forms an ideal combination with longer lengths, further enhancing the overall quality of the yarn. Therefore,

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the central takeaway from this study is the recommendation to utilize fibres with the longest length and the lowest short fibre content for optimal results in producing robust fibres and yarns, with the added advantage of incorporating recycled fibre to form an ideal combination for enhanced performance.

Author Contributions

Conceptualization – Haq HM, Motin MM, Khan AN; methodology – Haq HM, Motin MM, Khan AN; formal analysis – Haq HM, Ali MO; investigation – Haq HM, Motin MM; resources – Motin MM, Rahman MO; writing-original draft preparation – Haq HM, Motin MM; writing-review and editing – Haq HM, Ali MO; visualization – Haq HM, Motin MM, Rahman MO; supervision – Khan AN. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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