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Research article

Development of sustainable dual core-spun yarns using several filaments and recycled cotton sourced from pre-consumer fabric waste

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ABSTRACT

Textile industries are now focusing on sustainable issues in manufacturing operations to save the environment. The study focuses on the use of cotton fibers (recycled) sourced from fabric (knitted) waste (pre-consumer) to manufacture elastic yarn (dual-core) for denim fabric. The study involves the production of yarns (dual-core) using a redesigned ring spinning method with different elastomeric components, including T400® (Polyethylene terephthalate)/Polytrimethylene terephthalate), Polybutylene terephthalate (PBT), Polyester (PES), Lycra® (elastane), virgin cotton and cotton (recycled) fiber. The study investigates various yarn (Ne 18/1) characteristics such as strength, IPI (imperfection index), elongation %, unevenness %, and hairiness. It is noticed that the elongation and strength of recycled yarn (double core) are lower and IPI (Imperfection index), unevenness %, and hairiness values are higher than 100 % cotton (virgin) yarn (double core). One-way ANOVA (statistical analysis) is employed to assess the significance of differences among yarns manufactured from various core materials and found significant variation for all characteristics. Additionally, the article introduces the MOORA (multi-objective optimization based on ratio analysis) technique as a decision-making tool to determine the best yarn among three alternatives (PES yarn, PBT yarn, and T400 yarn) based on their properties, considering attributes and finding T400 filament containing yarn as the best option. The study introduces a sustainable approach using recycled cotton in yarn (double core) production and employs decision-making tools to assess and rank the performance of different yarn alternatives.

1. Introduction

In the context of sustainable textile practices, textile industries are constantly searching for innovative methods to upgrade the attributes of yarn as well as fabric and the development of stretchable yarns using recycled cotton extracted from fabric waste (pre-consumer) represents a promising avenue in this context. A stretchable structure is essential to enhance the recovery and elastic properties of the fabrics and to obtain this purpose, stretchable yarn is used [1]. Garments made with flexible yarns fulfill some vital requirements of clients [2]. Stretchable garments can elongate when subjected to the regular strains of daily activities and retain their initial shape on a substantial scale [3,4]. The yarns having increased stretchable properties have high importance in being utilized for

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stylish garments [5].

For the production of stretchable and comfortable apparel for patients, stretchable yarns (core spun) have been used [6]. To produce triaxial and biaxial auxetic fabrics (woven), stretchable yarns have been used [7]. Spun yarn (single core) consists of a minimum of two different elements: a core element and a staple sheath, on the other hand, spun yarn (double core) is composed of three elements: a multifilament, an elastic in the core, and sheath fiber [8]. As a core element PES (polyester) and PBT (polybutylene terephthalate) are utilized and to achieve more strength in yarn, PET filaments are utilized [9]. PBT filament expresses constant elastic properties after finishing operation [10] and T400® has more recovery and elastic characteristics than textured (intermingled) yarn [11]. The fast fashion concept has gained more attraction in terms of sustainability issues [12,13]. Industries deplete scarce assets such as water, land, basic materials, and energy, and also use hazardous substances that pollute natural resources[14]. Globally textile companies generate wastes of nearly 92 million tons each year, and the amount is assumed to increase remarkably by 2030 to approximately 134 million tons annually (Earth.org, 2023). Additionally, the textile industry produces about 20 % of wastewater and nearly 10 % of total carbon emissions globally ([15]; Earth.org, 2022).

The textile industry is one of the principal parts of the world that generates waste [16]. For global cotton cultivation more than 250 billion tons of water is necessary annually and for producing 1 kg of cotton fiber approximately ten thousand to twenty thousand liters of water is needed ([17]; Trvst. world, 2022). The frequent use of pesticides, normally in cotton cultivation fields is too dangerous for the environment [17]. To consider these issues, there is a stunning approach toward environment-friendly and sustainable ways to minimize the cultivation of fiber (cotton) [18]. In this concern, using cotton fibers (recycled) sourced from fabric waste may be a suitable alternative for cotton cultivation.

Taking the previously mentioned facts into consideration, it is tried to adopt a sustainable use of cotton (recycled) fibers collected from fabric waste (pre-consumer) to manufacture yarn (double core) for denim. Utebay, B. et al. [19] examined the effect of cotton (recycled) percentage, spinning method, and yarn count on yarn (ring, compact, and rotor) quality where a mixture of cotton (virgin) and cotton (recycled) was used. Babaarslan, O [20] discussed the technique of manufacturing yarn using viscose/polyester and lycra on an adjusted spinning frame (ring) to evaluate the properties of yarns. Erbil et al. [21] demonstrated the comparative analysis of various yarns and fabric's properties (performance) where the adjusted ring-spinning frame was used. Chen et al. [22] investigated the development of different yarns, where a redesigned (modified) spinning frame and for covering the core's hollow spindle was used to evaluate deformation behavior and auxetic performance.

Okandan, H. et al [23] investigated the impact of production parameters on yarn characteristics made from cotton (virgin) and recycled cotton (50:50) mixture. Erbil et al. [24] investigated the structural and physio-mechanical characteristics of yarns where an adjusted ring-spinning frame was used. Yao, W. H. et al. [25] tried to discuss the characteristics of yarn (nylon-covered) where Elasto Twister (Hamel) was used. Babaarslan et al. [26] tried to investigate the characteristics of different yarn types where a revised ring-spinning system was used. Elrys, S. M. et. al [27] discussed the effect of yarn count and construction on the performances of various yarns (dual core). Elrys, S. M. et al. [28] investigated the fabrics (knitted) properties based on structure and materials type where tri-core spun yarn was produced using an intermingling process. Uddin, A. J, & Rahman, M [29] compared the recycled yarn characteristics produced by compact spinning and ring spinning and found some differences in characteristics. Jabbar, A. et. al [30] demonstrated the properties (physical, and mechanical) of yarns (double core) based on the linear density of elastane and polyester.

Although there are some works to examine the characteristics of yarns manufactured from cotton, viscose, and polyester as sheath and different filaments as core materials by different methods and fabric produced from these yarns, no work has been found where several filaments and recycled cotton has been used to produce yarn (dual core). The article focuses on developing yarns (dual core) using several filaments and cotton fiber (recycled) sourced from waste (pre-consumer) and investigating the properties of yarns.

2. Materials and methods

In the work, 328 dtex (18/1 Ne) yarns (double core) have been produced by the redesigned spinning method (ring) from different elastomeric components (PES/PBT/T400), elastane, 100 % rigid cotton, and black recycled fiber. Fig. 1, represents the illustration of the redesigned spinning method (ring) for manufacturing yarns (double core) [26,31]. Elastane and filament (PES/PBT/T400) were inserted into the nip point of rollers (front) with the help of a roller (V-grooved) and core components were wrapped by cotton fiber (sheath materials). The filaments draft was confirmed by the speed variation between the roller (front and positive feed) of the drafting area. The draft of the elastane had also been confirmed with the speed variation between the roller (elastane package) and roller (front) of the drafting area [26,31].

For producing yarns, a mixture of 50 % cotton (recycled) fiber shredded from clips of knit garment (pre-consumer) and 50 % cotton (virgin) was utilized as a sheath, and characteristics of black cotton (recycled) and cotton (virgin) are expressed in Table 1 which were evaluated by Uster HVI 1000 instrument where the color module was changed in the settings. The black recycled cotton was collected from a recycling industry where recycled fibers were produced by mechanical recycling technique. Here three types of filaments, Polybutylene terephthalate (PBT), Polyester (PES), T400® (Polyethylene terephthalate, PET)/Polytrimethylene terephthalate, PTT), and Lycra® were used and the filament's properties were expressed in Table 2. Six dual-core spun yarns (PBT + elastane + virgin and recycled cotton), (PES + elastane + virgin and recycled cotton), (T400 + elastane + virgin and recycled cotton), (PBT + elastane + virgin cotton), (PES + elastane + virgin cotton) and (T400 + elastane + virgin cotton) with similar linear density (328 dtex) were produced and yarn properties (strength (cN/tex), imperfection index (IPI), unevenness%, hairiness, and elongation %) were examined to determine the impact of different filaments on the yarns. The produced yarn's composition is 76 % cotton, 16 % filament (PBT/PES/T400) and 8 % elastane. For comparison, yarn (double core) made with 100 % virgin cotton (denoted by PBT/T-400/PES + elastane + virgin cotton) was also incorporated.

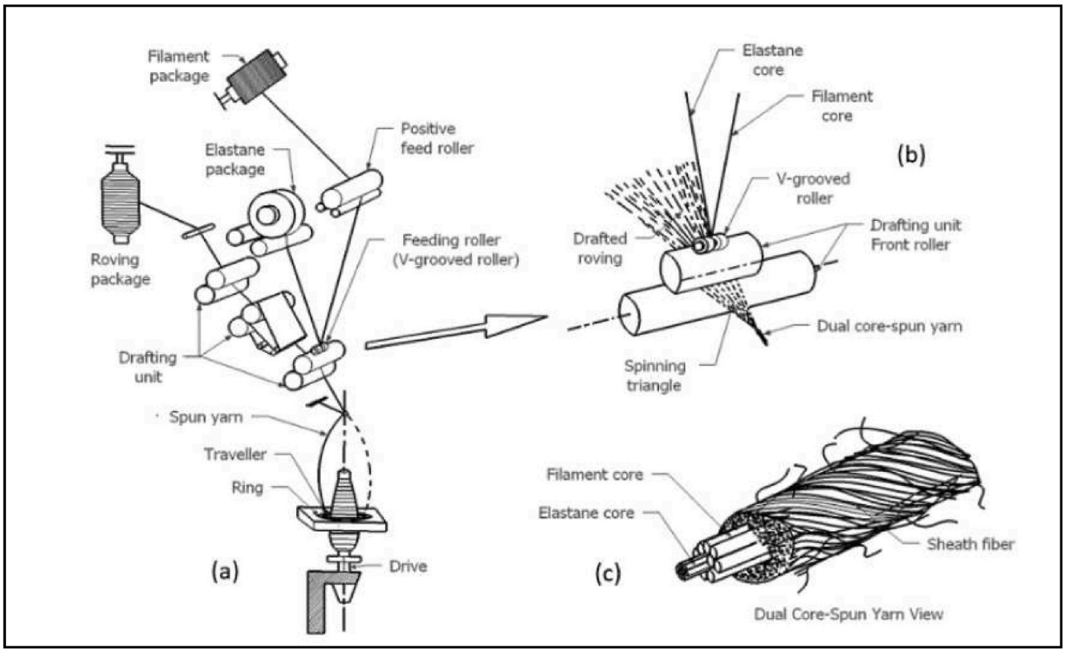

Fig. 1. Schematic representation of adjusted spinning technique (ring) of yarn (double core) manufacturing: (a) adjusted ring spinning instrumentation [26,31], (b) materials combination [26,31], (c) yarn's (double core) cross-sectional view [26,31].

Table 1
Properties of cotton (virgin) and cotton (recycled) fiber.

Fiber	Micronaire (μg/inch)	Length, mm	UI (percentage)	SFI	Strength (cN/tex)	Elongation (percentage)	SCI
100 % virgin cotton	4.1	27.8	82	9.9	30.4	5.6	111
Black recycled cotton	4.24	23.19	68.2	40.5	13.1	5.1	60

Table 2
Properties of filaments.

Filament	Strength, cN/tex	Elongation, %	Finness (dtex)
T400® (PET/PTT)	28.10	38.08	55
PBT	27.11	47.14	55
PES	30.61	40.01	55
Elastane [2]	6.2–11.5	(400–700) %	78

Table 3
The standard test method is used in the work [32].

Test of yarn	Standard of test	Test of yarn	Standard of test
Yarn count (denier/tex)	TS 244 EN ISO 2060 [33]	Hairiness (yarn) ('H')	TS 12863
Yarn irregularity (%CVm, %U, thin places, thick places, and Neps)	TS EN ISO 2060 [34]	Strength (cN/tex) and Elongation at break (%)	TS EN ISO 2062:2010 [35]

Twenty-five test values were taken and computed mean values were utilized for analysis. The test standard utilized in the study is shown in Table 3.

Statistical analysis (One-way ANOVA) was applied to analyze the properties of different yarns with SPSS 25.0. It was done at a 0.050 significance level or 95.0 percent confidence level, which indicates if the p-value is less than 0.050, the difference (properties) will be significant (statistically) [36]. Here null hypothesis (Ho) is that there is no significant variation among the yarn properties produced from different filaments as core components and the alternative hypothesis (H1) is that there is a significant variation among the yarn's properties produced from different filaments as core components. Here, the F value provides evidence against the null hypothesis for fabric and yarn properties.

Additionally, a multi-attribute decision-making method named MOORA was also applied to determine the best yarn among three yarns based on their properties. MOORA stands for multi-objective optimization based on ratio analysis and it indicates how alternatives respond to objectives using ratios." [37]. It consists of some steps and these are-

Step-1: Create a matrix (decision):

$$K = \begin{array}{c} \\ A1 \\ A2 \\ A3 \\ \dots \\ \dots \\ Am \end{array} \begin{array}{c} \begin{array}{cccccc} C1 & C2 & \dots & \dots & Cn \end{array} \\ \left[\begin{array}{cccccc} K11 & K12 & \dots & \dots & K1n \\ K21 & K22 & \dots & \dots & K2n \\ K31 & K32 & \dots & \dots & K3n \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ Km1 & Km2 & \dots & \dots & Kmn \end{array} \right] \end{array}$$

Here, (C_1, C_2, …. …., C_n) are attributes/objectives and (A_1, A_2, A_3, …. ….A_m) are alternatives.

Step-2: Normalizing the decision matrix:

The formula which was used to normalize the matrix is.

$k*ij = kij \div \sqrt{\sum_{i=1}^{m} \left[kij^2 \right]}$ [Here, (j = 1,2,3, … … …, n)]

$$K^* = \begin{array}{c} \\ A1 \\ A2 \\ A3 \\ \dots \\ \dots \\ Am \end{array} \begin{array}{c} \begin{array}{cccccc} C1 & C2 & \dots & \dots & Cn \end{array} \\ \left[\begin{array}{cccccc} K^*11 & K^*12 & \dots & \dots & K^*1n \\ K^*21 & K^*22 & \dots & \dots & K^*2n \\ K^*31 & K^*32 & \dots & \dots & K^*3n \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ K^*m1 & K^*m2 & \dots & \dots & K^*mn \end{array} \right] \end{array}$$

Step-3: Calculation of weighted value.

The weighted value of each attribute was calculated by multiplying each attribute with weight.

$$K^{*}.W = \begin{array}{c} \\ A1 \\ A2 \\ A3 \\ \dots \\ \dots \\ Am \end{array} \begin{array}{c} \begin{array}{cccccc} C1 & C2 & \dots & \dots & Cn \end{array} \\ \left[\begin{array}{cccccc} wjk^{*}11 & wjk^{*}12 & \dots & \dots & wjk^{*}1n \\ wjk^{*}21 & wjk^{*}22 & \dots & \dots & wjk^{*}2n \\ wjk^{*}31 & wjk^{*}32 & \dots & \dots & wjk^{*}3n \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ wjk^{*}m1 & wjk^{*}m2 & \dots & \dots & wjk^{*}mn \end{array} \right] \end{array}$$

Step-4: Estimation of Assessment value (yi):

The formula that was used to determine yi is,

$yi = \sum_{j=1}^{g} wj.k * ij$ - $\sum_{j=g+1}^{n} wj.k * ij$ [Here, (j = 1, 2, … …..,n)]

Step-5: Rank the alternatives and make a decision:

After determining the assessment value (yi), ranking was done based on the yi value and making a decision. The alternative that shows the highest assessment value was considered best and rank one is given to that and the alternative that shows the lowest assessment value was considered worst alternative.

In the study, three yarns were manufactured based on filament type (PES, PBT, T400) and a mixture of Cotton (virgin) and cotton (recycled). So, three alternatives for the MOORA method are PES yarn, PBT yarn, and T400 yarn. Here five properties of these manufactured yarns have been investigated, so there are five attributes and these are strength (cN/tex), IPI, unevenness %, hairiness, and elongation %. Here beneficial attributes are strength and elongation % and non-beneficial attributes are unevenness %, IPI, and hairiness. Here, the five attributes are considered equally important and the weight of the five attributes was given to 0.20 of each. Based on this attribute using the MOORA method which yarn was best had been determined.

3. Result and discussion

3.1. *Yarn properties*

Strength: The strength of various yarns (dual core) was illustrated in Fig. 2 and it is clear that there are differences in the strength values of Ne18/1 (328 dtex) yarns depending on the type of core material used. It has been shown in the previous study that the T400®

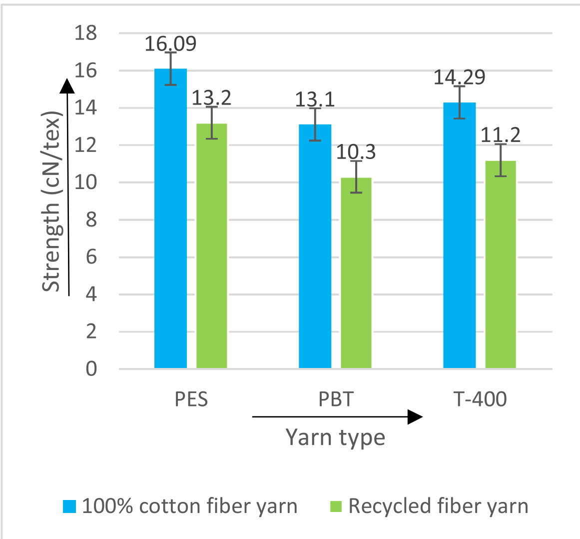

Fig. 2. Yarn strength.

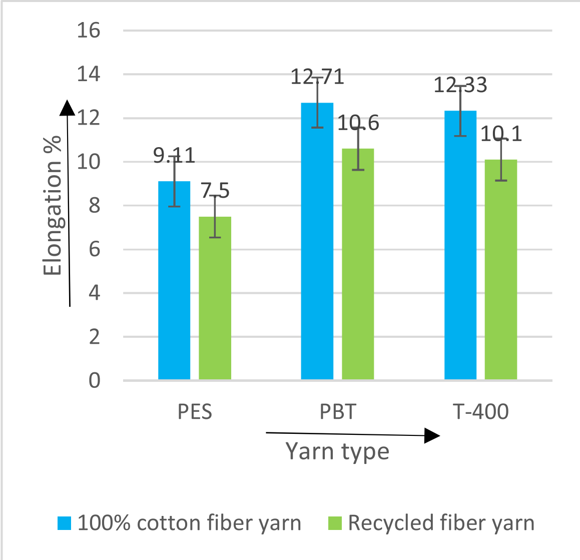

Fig. 3. Yarn elongation%.

core containing yarn (double core) shows more strength, while the PTT and PBT core containing yarn shows less strength [36]. Yarn made with PES filament and elastane gives higher strength, and yarn made with PBT filament and elastane gives lower strength because the used PES filament has higher strength than other used filaments. It was noticed that all recycled yarns (double core) give a low strength value compared to 100 % cotton yarns (double core) because fibers (recycled) contain more short fibers, and the fiber length was comparatively low. Among the twenty-five test results, CV% for strength was 6.3 %.

Elongation%: The elongation % of various yarns was illustrated in Fig. 3 and it has been expressed in the previous study that T400® core containing yarn (double core) shows more elongation %, and PTT and PBT core containing yarn gives less elongation % [36]. Yarn made with PBT filament and elastane gives more elongation% and yarn made with PES filament and elastane gives less elongation% because the used PBT filament had higher elongation % than other used filaments. It was found that all recycled yarns (double core) show a lower elongation value than 100 % cotton yarns (double core) because fibers (recycled) contain a huge amount of short fibers. The CV% for elongation was 7.21 % among the twenty-five test results.

Unevenness%: It has been expressed in the previous study that the PBT core containing yarn (dual core) shows less amount of unevenness% [36]. Fig. 4, illustrates the unevenness% of various yarns and yarn made with T400 filament and elastane gives less unevenness %, and yarn made with PES filament and elastane gives more unevenness% value. It was noticed that all recycled yarns (double core) show more unevenness value compared to 100 % cotton yarns (double core) because the quality of fibers (recycled) was not good compared to 100 % cotton. Among the twenty-five test results CV% for unevenness was 3.101 %.

Hairiness: It has been shown in the previous study that the PTT core containing yarn shows less value of hairiness and the elastane yarn shows more value of hairiness [36].

Fig. 5 illustrates the hairiness value of various yarns and yarn made with PES filament and elastane gives a lower hairiness value and yarn made with PBT filament and elastane gives a higher hairiness value. It was noticed that all recycled yarns (double core) show more hairiness value compared to 100 % cotton yarns (double core) because fibers (recycled) contain more short fibers, and the fiber length was comparatively low which has been previously discussed. The CV% for hairiness was 6.24 % among the twenty-five test results.

IPI (Imperfection index) of yarns: The thick place (+50)/km, neps (+200)/km, and thin place (−50)/km are normally considered to compute the IPI of yarn. In the study the value of thin place (−50)/km in the produced yarns was nearly nil, so for analysis thin place (−40)/km was taken for calculation. The imperfection index of yarns (recycled) was illustrated in Fig. 6 and it was noticed that yarn made with PES filament and elastane shows more IPI value and yarn made with T-400 filament and elastane shows less IPI value. It was also clear that all recycled yarns (double core) show more IPI value compared to 100 % cotton yarns (double core) because fibers (recycled) contain a huge amount of short fibers, and the fiber length was relatively low which has been previously described. Among the twenty-five test results CV% for IPI was 25.11 %.

In the case of statistical analysis (One-way ANOVA), it has been found in Table 4, that for all yarns properties, the 'P' value is less than 0.050, which indicates the rejection of the null hypothesis (Ho) and acceptance of the alternative hypothesis (H1) and there is a significant variation for all properties among manufactured yarns from various core materials.

Lastly, the performance of produced yarns was examined by utilizing in a weaving machine (modern) at an affordable speed (950 rpm) as weft and found suitable for weaving.

Based on the aforementioned discussion it was quite difficult to say which yarn is the best to select. So, a multi-attribute decision-making process (MOORA) has been applied to find which yarn was the best among all yarns based on their properties. According to this

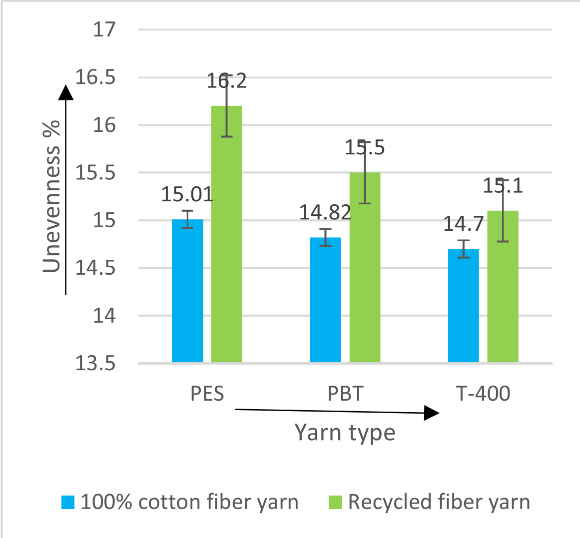

Fig. 4. Yarn unevenness %.

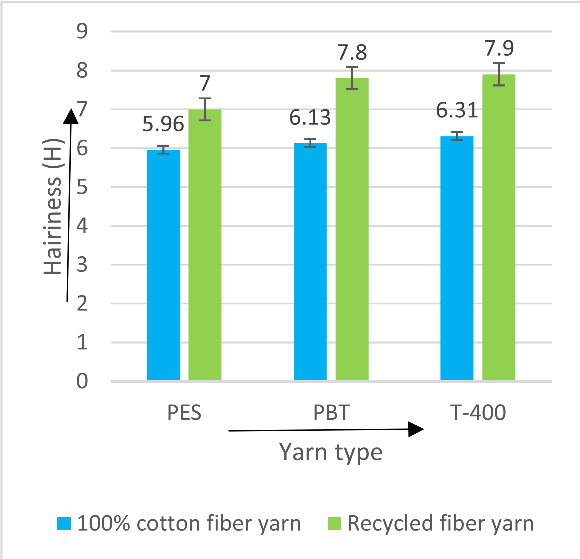

Fig. 5. Yarn hairiness (H).

method, the first step is to create a matrix (decision) based on the data and the matrix (decision) is below-

$$K=\begin{array}{c|ccccc} & \text{Strength(cN/tex)} & \text{Elongation \%} & \text{Hairiness (H)} & \text{Unevenness\%} & \text{IPI} \\ \hline \text{PES yarn} & 13.2 & 7.5 & 7 & 16.2 & 450 \\ \text{PBT yarn} & 10.3 & 10.6 & 7.8 & 15.5 & 422 \\ \text{T400 yarn} & 11.2 & 10.1 & 7.9 & 15.1 & 401 \end{array}$$

Here, PES yarn, PBT yarn, and T400 yarn are alternatives, and strength (cN/tex), unevenness%, hairiness, IPI, and elongation % are attributes/objectives.

The second step is to normalize the matrix by using the formula $k*ij = kij \div \sqrt{\sum_{i=1}^{m} \left[kij^2\right]}$ Here, (j = 1,2,3, … … …, n)

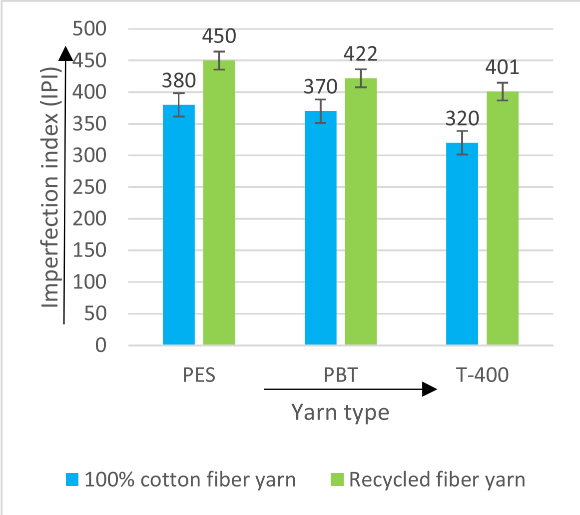

Fig. 6. Imperfection Index (IPI) of yarn.

Table 4
Statistical analysis for yarn properties (ANOVA).

Variable (dependent)	F value	Sig. Value
Strength	17.73	0.000
Elongation %	128.24	0.000
Unevenness	10.67	0.002
Hairiness	75.89	0.000
IPI	11.30	0.030

So, the normalized matrix is below-

K*=

	Strength(cN/tex)	Elongation%	Hairiness (H)	Unevenness %	IPI
PES yarn	0.655	0.456	0.534	0.599	0.612
PBT yarn	0.511	0.644	0.595	0.573	0.574
T400 yarn	0.556	0.614	0.602	0.559	0.545

In the third step, it had been calculated the weighted value by multiplying each column with 0.20 because all attributes are considered equally important and their weights are equal (0.20).

So, the weighted values of each attribute are below-

K*W=

	Strength(cN/tex)	Elongation %	Hairiness (H)	Unevenness %	IPI
PES yarn	0.131	0.0912	0.1068	0.1198	0.1224
PBT yarn	0.1022	0.1288	0.119	0.1146	0.1148
T400 yarn	0.1112	0.1228	0.1204	0.1118	0.109

The fourth step is to estimate the assessment value (yi) by using the formula-

$\mathbf{yi} = \sum_{j=1}^{g} wj.k * ij - \sum_{j=g+1}^{n} wj.k * ij$ (j = 1, 2, … …..,n)

So, the assessment values of each alternative are below-

$$yi = \begin{matrix} \text{PES yarn} \\ \text{PBT yarn} \\ \text{T400 yarn} \end{matrix} \begin{bmatrix} -0.1268 \\ -0.1174 \\ -0.1072 \end{bmatrix}$$

The fifth step is to rank the alternatives based on assessment value. So the rank of the alternatives is below-

Yarn type	Assessment Value (yi)	Rank
PES yarn	−0.1268	3
PBT yarn	−0.1174	2
T400 yarn	−0.1072	1

In the aforementioned discussion, it is clear that the T400 filament-containing yarn has a higher assessment value than other yarn, so the T400 filament-containing yarn was the best yarn concerning properties.

4. Sustainable approach

To cultivate cotton (virgin) above 250 billion tons of water are necessary every year globally and nearly ten to twenty thousand liters of water are essential to cultivating 1-kg cotton fiber ([17]; Trvst. world, 2022). It is too dangerous for the environment to use pesticides frequently, usually in cotton fields [17]. In this study, 50 % cotton (virgin) and 50 % cotton (recycled) were used instead of 100 % cotton (virgin) to produce yarn (dual core). This process of yarn manufacturing helps to minimize the pressure on the environment to cultivate more 100 % virgin cotton. It is clear that when using cotton (recycled) the consumption of water and pesticides (hazardous) is too less compared to a conventional process where only 100 % virgin cotton is utilized to produce yarn which is partially related and meets the Sustainable Development Goals, SDG- 12 (Responsible Consumption and Production) and that's why this yarn is called sustainable yarn.

5. Conclusion

The development of yarns utilizing cotton (recycled) sourced from fabric waste (pre-consumer) gives an innovative and sustainable approach to address environmental concerns in the textile and garments industry. Using cotton fibers (recycled) extracted from fabric waste (pre-consumer) emerges as a sustainable alternative to conventional cotton cultivation, mitigating the excessive water consumption and pesticide use associated with it. The results expressed significant differences in these characteristics based on the type of core material used, demonstrating the potential of recycled cotton in yarn production. It was noticed that PES-containing yarn (dual-core) shows higher strength and lower hairiness value, PBT-containing yarn shows a higher elongation % value, and T-400-containing yarn shows lower unevenness and imperfection index (IPI) value. To determine the significant differences among yarn properties, ANOVA (statistical analysis) was used and found significant variation for all properties among manufactured yarns from various core materials. MOORA method helped to determine the best yarn as T-400 filament containing yarn (double core) based on their properties. Finally, the research contributes to sustainable textile practices by offering insights into the development of yarns (dual core) using cotton (recycled) from fabric waste (pre-consumer).

Data availability

Data will be made available on request.

CRediT authorship contribution statement

Ahsan Habib: Writing – original draft, Conceptualization. **Md Abdullah al Mamun:** Writing – original draft, Conceptualization. **Osman Babaarslan:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] N. Özdil, Stretch and bagging properties of denim fabrics containing different rates of elastane, Fibres Text. East, Eur 16 (1) (2008) 66.
[2] S. Islam, S.M.M. Alam, S. Akter, Influence of thermal conduction on the stretching behavior of core spandex cellulosic fabrics, Mater. Today: Proc. 38 (2021) 2563–2571, https://doi.org/10.1016/j.matpr.2020.07.682.
[3] S.K. Sinha, P. Bansal, S. Maity, Tensile and elastic performance of cotton/lycra core spun denim yarn, J. Inst. Eng.: Series E 98 (2017) 71–78, https://doi.org/10.1007/s40034-017-0095-y.
[4] S. Mezarcıöz, R.T. Oğulata, A. Nergis, Investigation of elasticity and growth properties of denim fabrics woven with core and siro spun yarn, Textile and Apparel 30 (4) (2020) 312–320, https://doi.org/10.32710/tekstilvekonfeksiyon.634222.

[5] T. Hua, N.S. Wong, W.M. Tang, Study on properties of elastic core-spun yarns containing a mix of spandex and PET/PTT bi-component filament as the core, Textil. Res. J. 88 (9) (2018) 1065–1076, https://doi.org/10.1177/0040517517693982.
[6] L. Jiang, A. Zulifqar, A.M. Hai, F. Anwar, H. Hu, F. Liu, H. Chen, Effect of using alternate elastic and non-elastic yarns in warp on shrinkage and stretch behavior of bi-stretch woven fabrics, J. Eng. Fibers Fabr. 18 (2023) 15589250221137897, https://doi.org/10.1177/15589250221137897.
[7] B. Mushtaq, A. Ahmad, Z. Ali, M.B. Qadir, Z. Khaliq, M. Irfan, M.W. Iqbal, A. Jabbar, A. Zulifqar, A. Shahzad, Core spun based helical auxetic yarn: a Novel structure for Wearable Protective textiles, J. Nat. Fibers 19 (16) (2022) 15058–15070, https://doi.org/10.1080/15440478.2022.2070322.
[8] O.G. Ertaş, B. Zervent Ünal, N. Çelik, Analyzing the effect of the elastane-containing dual-core weft yarn density on the denim fabric performance properties, J. Text. Inst. 107 (1) (2016) 116–126, https://doi.org/10.1080/00405000.2015.1016319.
[9] A.P.S. Sawhney, K.Q. Robert, G.F. Ruppenicker, L.B. Kimmel, Improved method of producing a cotton-covered/polyester staple-core yarn on a ring spinning frame, Textil. Res. J. 62 (1) (1992) 21–25, https://doi.org/10.1177/004051759206200104.
[10] M. Bizjak, H. Kadoğlu, K. Kostajnšek, P. Çelik, G.B. Bayraktar, D. Duran, T.Ü. Bedez, M. Ertekin, K. Dimitrovski, Properties of elastic fabrics with treated and untreated Co/PBT yarns in the weft direction, in: IOP Conference Series: Materials Science and Engineering, vol. 254, IOP Publishing, 2017 092001, https://doi.org/10.1088/1757-899X/254/9/092001, 9.
[11] T. Bedez Ute, Analysis of mechanical and dimensional properties of the denim fabrics produced with double-core and core-spun weft yarns with different weft densities, J. Textil. Inst. 110 (2) (2019) 179–185, https://doi.org/10.1080/00405000.2018.1470451.
[12] S. Ray, L. Nayak, Marketing sustainable fashion: Trends and Future Directions, Sustainability 15 (7) (2023) 6202, https://doi.org/10.3390/su15076202.
[13] S. Claxton, A. Kent, The management of sustainable fashion design strategies: an analysis of the designer's role, J. Clean. Prod. 268 (2020) 122112, https://doi.org/10.1016/j.jclepro.2020.122112.
[14] C. De Ponte, M.C. Liscio, P. Sospiro, State of the art on the Nexus between sustainability, the fashion industry, and sustainable business model, Sustain. Chem. Pharm. 32 (2023) 100968, https://doi.org/10.1016/j.scp.2023.100968.
[15] B. Garcia-Ortega, J. Galan-Cubillo, F.J. Llorens-Montes, B. de-Miguel-Molina, Sufficient consumption as a missing link toward sustainability: the case of fast fashion, J. Clean. Prod. 399 (2023) 136678, https://doi.org/10.1016/j.jclepro.2023.136678.
[16] M.M. Reza, H.A. Begum, A.J. Uddin, Potentiality of sustainable corn starch-based biocomposites reinforced with cotton filter waste of spinning mill, Heliyon 9 (5) (2023), https://doi.org/10.2139/ssrn.4335483.
[17] The World Counts, 2023.
[18] M.B. Uddin, A.J. Uddin, A sustainable approach to manufacture mélange yarn from waste jute fiber and pre-consumer cotton fabric waste using an I-optimal mixture design, J. Clean. Prod. (2023) 138376, https://doi.org/10.1016/j.jclepro.2023.138376.
[19] B. Utebay, P. Celik, A. Cay, Valorization of fabric wastes through production of recycled cotton yarns by compact ring and open-end rotor spinning, J. Clean. Prod. 409 (2023) 137135, https://doi.org/10.1016/j.jclepro.2023.137135.
[20] O. Babaarslan, Method of producing a polyester/viscose core-spun yarn containing spandex using a modified ring spinning frame, Textil. Res. J. 71 (4) (2001) 367–371, https://doi.org/10.1177/004051750107100415.
[21] Y. Erbil, O. Babaarslan, M.R. Islam, S. Sirlibaş, Performance of core & dual-core cotton yarn structures on denim fabrics, J. Nat. Fibers 19 (14) (2022) 9500–9513, https://doi.org/10.1080/15440478.2021.1982837.
[22] J. Chen, Z. Du, Structural design and performance characterization of stable helical auxetic yarns based on the hollow-spindle covering system, Textil. Res. J. 90 (3–4) (2020) 271–281, https://doi.org/10.1177/0040517519862881.
[23] H. Okandan, N. Yildirim, M. Kertmen, H. Türksoy, The effects of OE-rotor spinning parameters on yarn properties produced from recycled/virgin cotton fibers Blend, Uluslararası Bilim Teknoloji ve Tasarım Dergisi 4 (1) (2023) 1–15. https://dergipark.org.tr/en/pub/istd/issue/78802/1108669.
[24] Y. Erbil, R. Islam, O. Babaarslan, S. Sırlıbaş, Effect of structural changes on the cotton composite yarn properties, J. Nat. Fibers 19 (5) (2022) 1899–1907, https://doi.org/10.1080/15440478.2020.1788687.
[25] W.H. Yao, J.T. Yeh, W.L. Chou, Y.C. Shu, A study on preparation and mechanical properties of UHMWPE/nylon composite covered yarn, in: Second International Conference on Smart Materials and Nanotechnology in Engineering, vol. 7493, 2009, pp. 625–632, https://doi.org/10.1117/12.840350. SPIE.
[26] O. Babaarslan, E. Sarıoğlu, M. Ertek Avcı, A comparative study on performance characteristics of multicomponent core-spun yarns containing cotton/PET/elastane, J. Textil. Inst. 111 (6) (2020) 775–784, https://doi.org/10.1080/00405000.2019.1662876.
[27] S.M. Elrys, F. Faheem El-Habiby, R. Abd Elkhalek, A.S. Eldeeb, A.M. El-Hossiny, Investigation into the effects of yarn structure and yarn count on different types of core-spun yarns, Textil. Res. J. 92 (13–14) (2022) 2285–2297, https://doi.org/10.1177/00405175211021447.
[28] S.M. Elrys, F.F. El-Habiby, A.S. Eldeeb, A.M. El-Hossiny, R. Abd Elkhalek, Comfort properties of knitted fabrics produced from dual-core and tri-core spun yarns, Textil. Res. J. 93 (7–8) (2023) 1760–1782, https://doi.org/10.1177/00405175221131056.
[29] A.J. Uddin, M. Rahman, Sustainable and cleaner production of elastic core-spun yarns for stretch denim with maximal utilization of recycled cotton extracted from pre-consumer fabric waste, Heliyon (2024), https://doi.org/10.1016/j.heliyon.2024.e25444.
[30] A. Jabbar, U. Tariq, T. Hussain, A. Basit, A. Hai, M. Zubair, Effect of polyester and elastane linear density on the physical and mechanical properties of dual-core-spun cotton yarns, J. Nat. Fibers (2018), https://doi.org/10.1080/15440478.2018.1500338.
[31] E. Sarloğlu, O. Babaarslan, M.E. Avcl, Effect of filament Fineness on composite yarn Residual Torque, Autex Res. J. 18 (2018) 7–12, https://doi.org/10.1515/aut-2016-0036.
[32] O. Babaarslan, M. Shahid, N. Okyay, Investigation of the performance of cotton/polyester Blend in different yarn structures, Autex Res. J. 23 (3) (2023) 370–380, https://doi.org/10.2478/aut-2022-0015.
[33] TS 244 EN ISO, (2060).
[34] TS EN ISO, (2060).
[35] TS EN ISO, (2062: 2010).
[36] O. Babaarslan, M.A. Shahid, F.B. Doğan, Comparative analysis of cotton-covered elastomeric hybrid yarns and denim fabric properties, Journal of Engineered Fibers and Fabrics 16 (2021) 15589250211059188, https://doi.org/10.1177/15589250211059188.
[37] W.K. Brauers, E.K. Zavadskas, The MOORA method and its application to privatization in a transition economy, Control Cybern. 35 (2) (2006) 445–469.