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Development of Dual-Core Spun Yarn Using Different Filaments as a Core and its Impact on Denim Fabric Properties

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Article

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ABSTRACT

Consumer preferences for comfortable and well-fitting clothing have led to an increased demand for yarns (elastic) in denim fabric production. The study focuses on the manufacture of yarns (dual core) with various core components including T400® (Polyethylene terephthalate) / poly trimethylene terephthalate), PBT (Polybutylene terephthalate), Polyester (PES), and elastane (Lycra®) and their impact on denim fabric properties. The study involves the production of Ne 18/1 yarns (dual core) using an adjusted spinning method (ring) with elastane and different filaments in the core and additionally, twill (3/1 'Z') fabric (denim) is manufactured using those yarns, and then fabric and yarn characteristics are evaluated. The results show significant variations in fabric and yarn characteristics based on the type of core material used. The yarn properties, such as the neps (+200), strength, thin place (-50), hairiness, elongation %, unevenness %, and thick place (+50) of yarns (dual core) are affected by the selection of filament. Fabric properties like weight, elasticity %, strength (tensile), strength (tearing), shrinkage %, and stiffness exhibit differences depending on the core filament. The statistical analysis employs one-way ANOVA to investigate the significance of differences in yarn and fabric properties within various core materials. The outcomes of this experimental work contribute valuable understandings of the production of yarns (dual core) with several filaments for enhancing fabric (denim) performance.

KEYWORDS

dual-core spun yarn, denim, elastane, filament, ring spinning, characteristics

INTRODUCTION

Now consumer choices, behaviour, and expectations are changing, and searching for comfortable dresses with well-fitting because using a stretchable garment enables one to feel more comfortable, and elastic yarns are chosen to enhance the recovery elastic characteristics of fabrics (denim) to achieve this comfortableness [1,2,3]. A flexible structure is necessary to enhance the recovery and elastic properties of the fabrics and to attain this objective the yarn (elastic) is used [4]. The arrangement and configuration of yarn (elastic) play a remarkable role in determining how much the characteristics change as a result of abrasion [5]. Yarns (dual core) meet the customer requirement of apparel by providing expected comfort properties [6].

Elastic garments can elongate when subjected to the regular strains of daily activities, and can subsequently revert to their initial dimensions and shape on a substantial scale [7,8]. Such materials remain structurally intact while worn, preserving their form and resisting excessive creasing even after washing and dry cleaning, thus retaining their original size and shape [8]. The yarns having enhanced elastic properties, have a high significance to be utilized for functional garments [9]. For the production of stretchable apparel for patients, yarns (elastic) have been utilized [10].

To minimize some challenges for elastic yarn (single core) such as lack of stability, dimensional change, and recovery, elastic yarn (dual core) has been manufactured [11,12]. Elastic yarns (dual core) have less hairiness, unevenness, and more elongation, durability, and strength than elastic yarns (single core) [9,13]. Spun yarns (single core) consist of a minimum of two different constituents: a core part and a staple sheath but spun yarns (double core) have at least three constituents, incorporating filament and multifilament in the core, and all are surrounded by a staple sheath fibre [14]. For the filament, PES (polyester), PBT (polybutylene terephthalate), and Polyethylene terephthalate (PET) / poly trimethylene terephthalate (PTT) are utilized as a core constituent, and to achieve more strength in yarn, filaments (PET) is utilized [15]. PBT filament gives constant stretchable properties after finishing operation [16].

Babaarslan investigated the technique of manufacturing yarn (elastic) on an adjusted spinning frame (ring) and evaluated the characteristics of yarn [17]. Erbil et al. discussed the comparative analysis of several yarns on fabric's (denim) performance where an adjusted spinning frame (ring) was used [18]. Chen et al. focused on the development of yarns where a hollow spindle covering technique was used to evaluate deformation behaviour and auxetic performance [19]. Erbil et al. discussed the structural and physio-mechanical characteristics of several yarns with the same count where a modified spinning frame (ring) was used [20]. Yao, W. H. et al. examined the characteristics of yarn (nylon-covered core) where the Elasto Twister (Hamel) technique was utilized [21]. Babaarslan et al. discussed some yarn (elastic) characteristics where a revised spinning system (ring) has been utilized [13]. It is noticed that the feeding method and production technique have a remarkable influence on yarn characteristics [12]. Babaarslan et al. focused on the comparative study of the performance of yarn (dual core) where an adjusted spinning method (ring) was utilized [22]. Türksoy et al. demonstrated the development of multicomponent yarns (elastic) where the intermingling technique was utilized to weld filaments and discussed the developed yarn's properties [12]. Elrys et al. examined the influence of yarn construction and count on the characteristics of several yarns (elastic) where an adjusted spinning technique (ring) was utilized [23].

Uddin & Rahman investigated the recycled elastic yarn properties manufactured by ring spinning and compact spinning and found some variations in the characteristics of yarn [24]. Jabbar examined the influence of elastane count on the characteristics (mechanical, physical) of yarns (dual core) [25].

Pourahmad tried to compare the characteristics of Solo, ring, and Siro yarns (elastic) and found Siro yarn as best [26].

Although there are some works to examine the characteristics of yarn (dual core) 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 filaments (PES, PBT, T400) and elastane were used collectively. The study aims to manufacture yarn (dual core) where elastane and several filaments (PES/PBT/T400) are used and to investigate their effect on yarn and fabric properties.

EXPERIMENTAL

Materials and methods

For the study, Ne 18/1 (328 dtex) yarns (dual core) were manufactured by an adjusted spinning technique (ring) from different elastomeric components (PES/PBT/T400), elastane, and 100% rigid cotton fibre. Stretchable yarn can be manufactured using different processes but the ring-spinning technique is the most utilized [27]. Figure 1 illustrates the adjusted spinning technique (ring) for manufacturing newly designed yarns (dual core).

For manufacturing yarns (dual core), 100% cotton fibre was utilized and the characteristics of cotton are expressed in Table 1 which were evaluated by the 'Uster HVI 1000' instrument. Three filaments, Polybutylene terephthalate (PBT), Polyester (PES), T400® (PET/PTT), and Lycra® were used as core elements for yarn and the characteristics of filaments are expressed in Table 2.

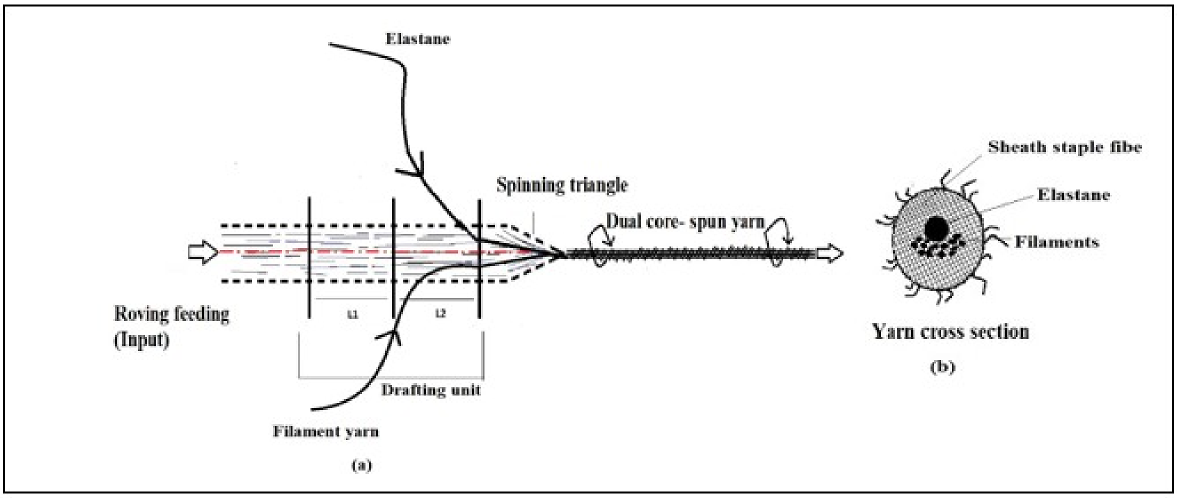

Figure 1. Schematic representation of the adjusted spinning system (ring) of yarn (double core) manufacturing: (a) adjusted spinning instrumentation (ring), (b) yarn's (double core) cross-sectional view

PTT/PET (T400®) filament has more recovery and stretch characteristics [28]. Three dual-core spun yarns (PBT + elastane + cotton), (PES + elastane + cotton) and (T400 + elastane + cotton) with similar linear density (328 dtex) were produced and yarn properties like neps (+200), strength, thin place (-50), elongation %, thick place (+50), hairiness and unevenness were examined to determine the influences of different filaments on yarns (dual core). The composition of each yarn is 79% cotton, 14% filament (PBT/ PES / T400), and 7% elastane. Moreover, twill (3/1 'Z') fabrics (denim) have been produced utilizing the developed yarns where manufactured yarns were used in a weft way, and indigo dyed 100% cotton yarn (Ne 14.1/1) was utilized as warp yarn. Fabric production was carried out on the Picanol OptiMax model weaving machine.

Table 1. Characteristics of cotton fibre

Micronaire (µg/inch)	Length (mm)	UI %	SFI	Strength (cN/tex)	Elongation %	SCI
4	27.5	79	10.1	29.2	5.49	111

Every fabric and yarn sample's characteristics were examined based on test standards. Twenty-five test values were taken and computed mean values have been utilized for analysis. The test standard used in the study is shown in Table 3. All tests specified in the table were performed by Calik Denim Textile R&D centre laboratories.

Table 2. Characteristics of filaments

Filament	Strength, cN/tex	Elongation, %	Fineness (dtex)
T400® (PET/PTT)	27.04	37.18	55
PBT	26.19	46.35	55
PES	30.41	39.26	55
Elastane [1,9,29]	6.2-11.5	(400-700)%	78

Table 3. The standard test method [13]

Test of yarn	Standard of test	Test of fabric	Standard of test
Yarn count (dtex)	TS 247 EN ISO 2061 TS EN ISO 2061: 2015	Weight test (GSM)	ASTM D-751-06
Yarn irregularity (%CVm, %U, thin places, thick places, and Neps)	TS EN ISO 2060	Strength (tear) Test (grf)	ASTM D-1424
Yarn hairiness ('H')	TS12863	Strength (tensile) Test (kgf)	ASTM D-5034
Strength (cN/tex) and Elongation at break (%)	TS EN ISO 2062:2010	Growth (Permanent Elongation) %	ASTM D-3107
Standard Conditioning and Testing	TS EN ISO 139: 2008	Stiffness Test (kgf)	ASTM D-4032
-	-	Elasticity (Extension) %	ASTM D-3107

Statistical analysis (One-way ANOVA) was applied to examine the difference (significant) in characteristics of various yarns with SPSS 25.0. It has been performed at a 0.05 significance level or 95.0% confidence level, which indicates if the 'p' value is less than 0.050, the variation (characteristics) will be significant (statistically) [1]. Here, Ho (null hypothesis) is that there is no significant variation among the yarn properties made from different filaments as core elements and the H1 (alternative hypothesis) is that there is a significant variation among the yarn's characteristics made from different filaments as core elements. The F value provides evidence against the null hypothesis for fabric and yarn properties.

RESULT AND DISCUSSION

Yarn properties

Strength (cN/tex): Figure 2 indicates several yarns (dual core) strength and it is clear that there are differences in the strength values of 328 dtex (Ne18/1) yarns. Yarn (dual core) made with elastane and PES filament shows higher strength, on the other hand, yarn made with elastane and PBT filament shows lower strength because the used PES filament has higher strength than another used filament. Elongation %: Figure 3 indicates the elongation % of several yarns (dual core). It has been expressed in the previous study that PET/PTT (T400®) filament containing yarns (dual core) shows more elongation % and PBT filament containing yarns shows low elongation % [1]. Yarns made with elastane and PBT filament show higher elongation %, and yarn made with elastane and PES filament shows lower elongation % because the used PBT filament has higher elongation % than another used filament.

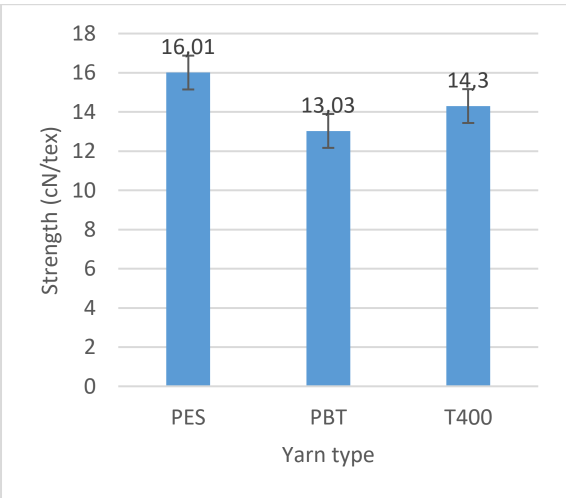

Figure 2. Yarn strength

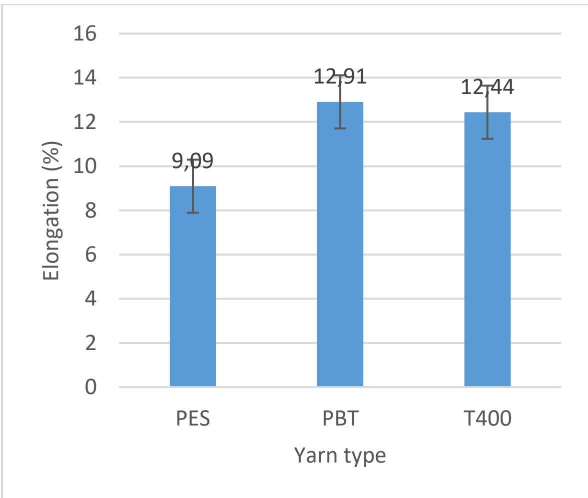

Figure 3. Yarn elongation %

Unevenness: It has been shown in the previous study that the PBT-based yarns (dual core) give less amount of unevenness [1]. Figure 4 indicates the unevenness % of several yarns (dual core) and yarns made with elastane and PBT filaments give low unevenness value and yarns made with elastane and PES filaments give more unevenness value because among the used filaments the PBT filament has more elongation % that helps to create more stable (less unevenness) yarn structure.

Hairiness: It has been shown in the previous study that the PTT-based yarn (dual core) gives a low hairiness value and the elastic yarn (single core) gives more hairiness value [1]. Figure 5 illustrates the hairiness value of several yarns (dual core) yarn made with elastane and PES filament gives a lower hairiness value, and yarn made with elastane and PBT filament gives a higher hairiness value because the smooth surface of PES (polyester) filament [30] helps to reduce the tendency of fibre to protrude from the surface of the yarn, resulting in less hairiness.

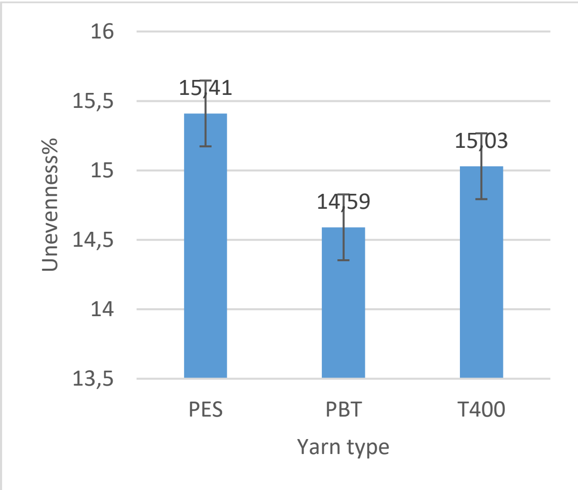

Figure 4. Yarn unevenness %

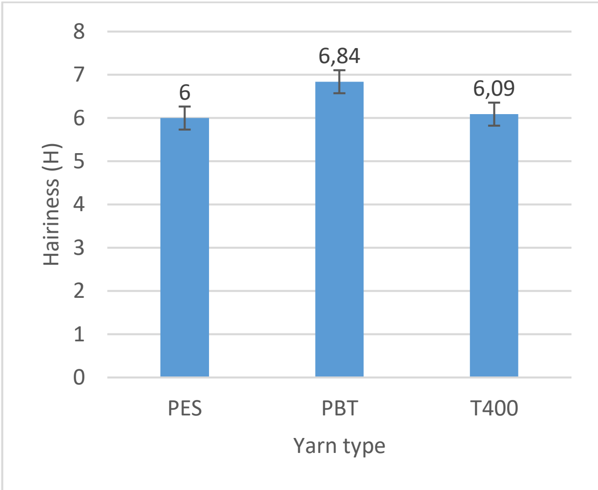

Figure 5. Yarn hairiness (H)

Neps (+200): Figure 6 illustrates the neps (+200)/km value of several yarns (dual core) and yarn made with elastane and PBT filament shows a lower neps (+200) value and yarn made with elastane and PES filament shows higher neps (+200) value because the used PBT filament has higher elongation % than another used filament which creates the more stable structure of yarn resulting in fewer neps (+200) generation but the smooth surface of PES (polyester) filament [30] has a tendency to reduce fibre cohesion during spinning time resulting in more neps (+200)/km generation.

Thick place (+50): Figure 7 illustrates the thick place (+50)/km value of several yarns (dual core) yarn made with elastane and PBT filament gives a lower thick place (+50) value and yarn made with elastane and PES filament gives higher thick place (+50) value because the used PBT filament has higher elongation % than other used filament and the surface of PES (polyester) filament is smooth [30].

Thin place (-50): Figure 8 illustrates the thin place (-50)/km value of several yarns (dual core) and yarn made with elastane and PES, T400 filament gives the same thin place (-50) value but yarn made with elastane and PBT filament shows no thin place (-50) value because, among the used filaments, the PBT filament has higher elongation % which creates a more stable structure of yarn resulting in no thin place (-50) generation but the smooth surface of PES filament [30] has a tendency to minimize fiber cohesion during spinning process resulting in thin place(-50)/km generation.

In the case of statistical analysis (One-way ANOVA), it has been shown in Table 4, that for all yarn's characteristics, the 'P' value is less than 0.05, which specifies the rejection of the null hypothesis (Ho) and acceptance of alternative hypothesis (H1), and there is a significant variation for all properties among produced yarns from various core materials (filaments) except the neps (+200) and thin place (-50) value. For thin place (-50) and neps (+200) values, it is seen that the 'P' value is greater than 0.05 which specifies the acceptance of the null hypothesis (Ho) and there is no significant variation for neps (+200) and thin place (-50) value among produced yarns from several core materials (filaments). From Table 4, the F value provides evidence against the null hypothesis for yarn properties.

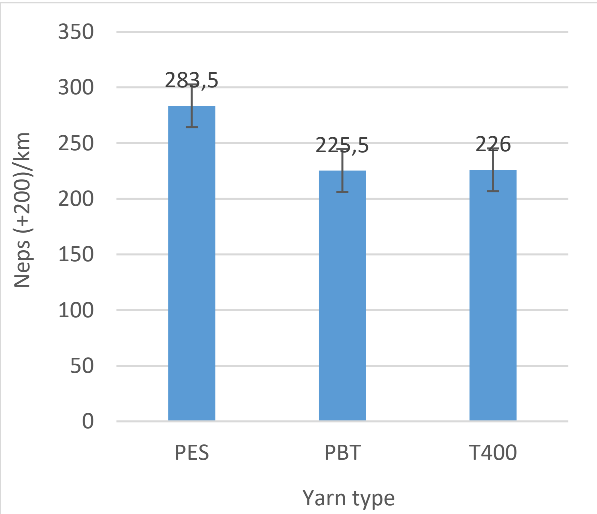

Figure 6. Yarn Neps (+200)/km

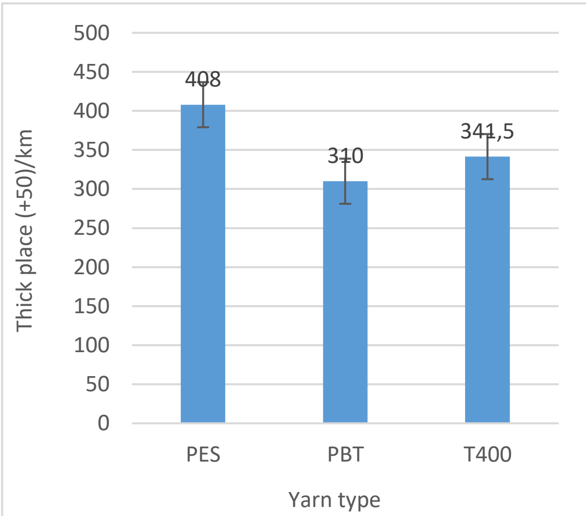

Figure 7. Yarn thick place (+50)/km

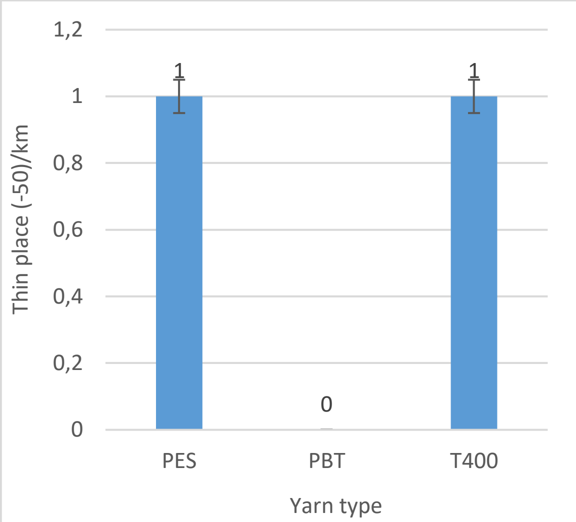

Figure 8. Yarn thin place (-50)/km

Table 4. Statistical analysis for yarn properties (One-way-ANOVA)

Variable (dependent)	F	Sig.
Strength	21.73	.000
Elongation %	229.22	.000
Unevenness	12.63	.001
Hairiness	96.99	.000
Neps (+200)	0.817	.460
Thick Place (+50)	5.99	.015
Thin Place (-50)	1.27	.315

Fabric properties

Dry weight of fabrics: It has been shown in the previous study that fabric made with PBT-based yarns (dual core) shows higher GSM than PES-based yarns (dual core) [2]. Figure 9 indicates the dry weight of several samples (fabric) and illustrates that fabric made with elastane and T400 filament-based yarn gives more GSM and fabric made with elastane and PES filament-containing yarn gives less GSM value. Washed (wet) of fabrics: Figure 10 indicates the washed (wet) weight of several samples (fabric) and illustrates that fabric made with elastane and PBT filament containing yarn gives more GSM and fabric made with elastane and PES filament containing yarn gives less GSM because the PBT-based yarn (dual core) has more elongation % than other yarns which have been discussed previously and the shrinkage % of PBT filament containing fabric is higher than others.

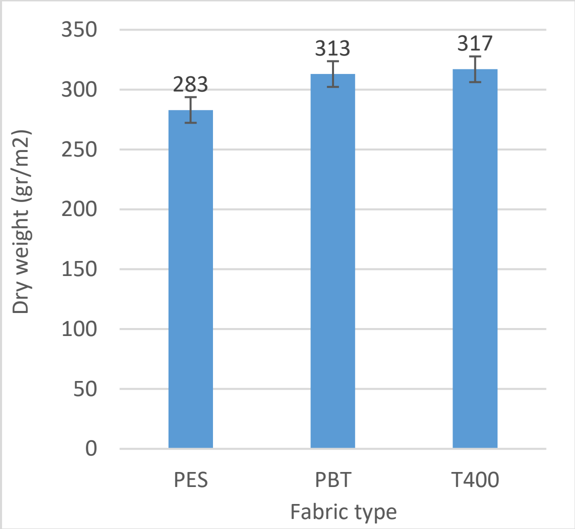

Figure 9. Weight (dry) of fabric

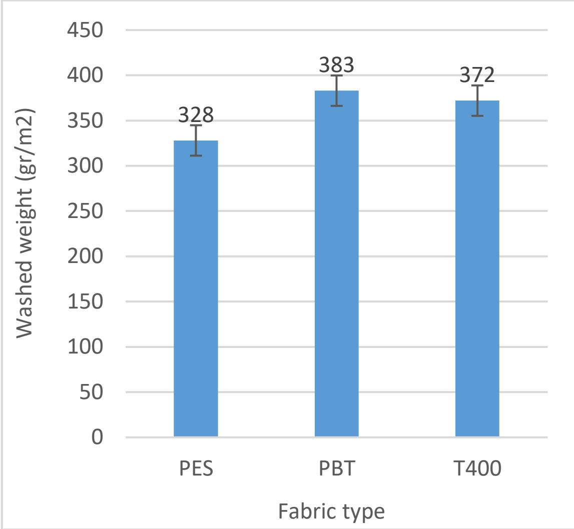

Figure 10. Weight (washed) of fabric

Elasticity %: To investigate elasticity % and growth %, tests were applied only to the fabrics in the weft direction by applying a load of 1.36 kg from the short edge and allowing the fabric to stretch while the weight block was slowly released for five seconds.

Figure 11 indicates the elasticity % of several samples (fabric) and illustrates that fabric made with elastane and PBT filaments containing yarn gives more elasticity % and fabric made with elastane and PES filaments containing yarn shows less elasticity % because the PBT containing yarn (dual core) has more elongation % than other yarns which contribute to higher elasticity % of fabric.

Growth %: The growth % of the fabric sample (after 2 hours of waiting) is shown in Figure 12 and it is seen that fabric made with elastane and PBT filament containing yarn gives high growth % and fabric made with elastane and PES filament containing yarn gives low growth % because the PBT filament containing yarn (dual core) has more elongation % among all yarns which contribute to higher growth % of fabric.

Fabric strength: The fabric’s strength (tearing, tensile) in the weft way has been considered because the developed yarn has been utilized in the weft direction only.

Figure 13 illustrates the fabric strength (tensile) for several samples in warp directions and it indicates that fabric made with elastane and PES filament containing yarn gives more strength (tensile) but fabric made with elastane and T-400 filament containing yarn gives less strength (tensile) because the PES filament containing yarn (dual core) has more strength among all yarns which contribute to higher strength (tensile) of fabric.

Figure 14 illustrates the fabric strength (tensile) for several samples in weft directions and it indicates that fabric made with elastane and PES filament containing yarn gives more strength (tensile) but fabric made with elastane and T-400 filament containing yarn gives less strength (tensile) because the PES-based yarn (dual core) has more strength than other yarns. The strength (tensile) in the weft way is lower than the strength (tensile) in the warped way.

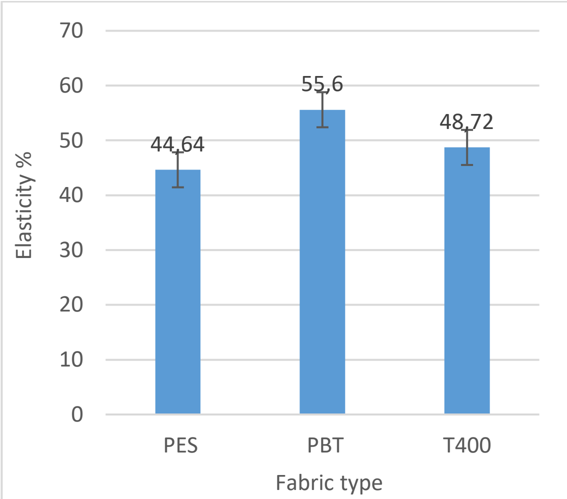

Figure 11. Elasticity % of fabric

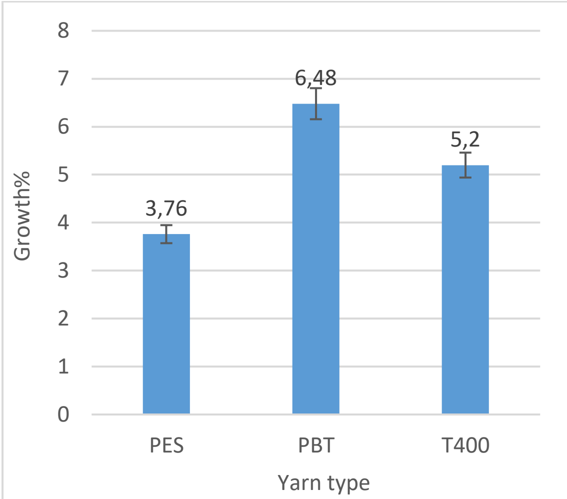

Figure 12. Growth % of fabric

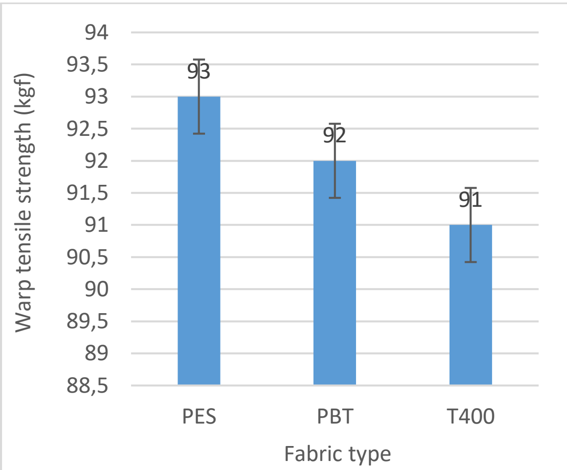

Figure 13. Warp tensile strength of fabric

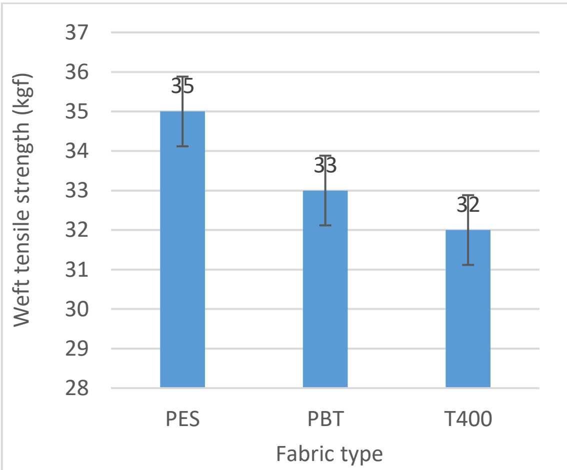

Figure 14. Weft tensile strength of fabric

Figure 15 indicates fabric strength (tearing) for several samples in warp directions and it is seen that fabric made with elastane and PES filament containing yarn gives more strength (tearing) and fabric made with elastane and T-400 filament containing yarn gives less strength (tearing) because the PES filament containing yarn (dual core) has more strength than other yarns that contribute to higher strength (tearing) of fabric which has been previously discussed.

Figure 16 shows the fabric strength (tearing) for several samples in weft directions and it is seen that fabric made with elastane and PES filament containing yarn gives more strength (tearing) and fabric made with elastane and T-400 filament containing yarn gives less strength (tearing) because the PES-based yarn (dual core) has more strength than other yarns.

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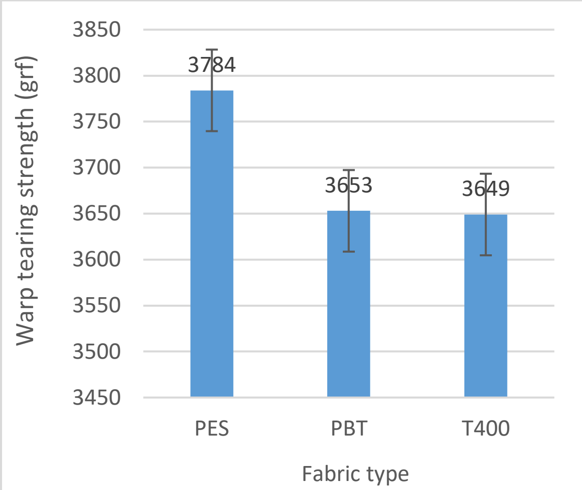

Figure 15. Warp tearing strength of the fabric

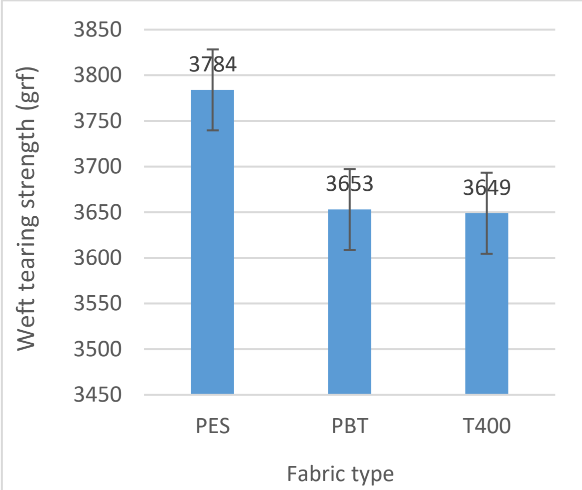

Figure 16. Weft tearing strength of the fabric

Fabric shrinkage: In the work fabric shrinkage % was investigated in all directions and the fabric's weft shrinkage % has been taken into consideration because the manufactured yarn has been used in the weft direction only.

Figure 17 shows the fabric shrinkage % for several samples (fabric) in warp directions and it is seen that fabric made with elastane and PBT filament containing yarn gives more shrinkage % and fabric made with elastane and PES filament core element gives less shrinkage % because the PBT filament containing yarn (dual core) has more elongation % than other yarns which contribute to higher shrinkage % of fabric.

Figure 18 shows the fabric shrinkage % for several samples (fabric) in weft directions and it is seen that fabric made with elastane and PBT filament containing yarn gives more shrinkage % and fabric made with elastane and PES filament containing yarn gives less shrinkage % because the PBT-based yarn (dual core) has more elongation % than other yarns which contribute to higher shrinkage % of fabric which has been previously discussed. It is also clear that the shrinkage % in the weft is more than the warp direction because the produced yarn (dual core) has been utilized in the weft direction.

Stiffness: Figure 19 shows the stiffness % of several samples (fabric) and illustrates that fabric made with elastane and PES filament containing yarn gives more stiffness value, and fabric made with elastane and PBT filament containing yarn gives less stiffness value because the PBT containing yarn (dual core) has more elongation % than other yarns which contribute to lower stiffness % of fabric.

For one-way ANOVA analysis from Table 5, for all characteristics of fabric, the 'P' value is less than 0.05, which specifies that the null hypothesis (Ho) is rejected and alternative hypothesis (H1) is accepted and the independent variables are statistically significant and there is a significant difference in all characteristics of fabric among the fabric manufactured from various core materials (filament) containing yarn. From Table 5, the F value gives evidence against the null hypothesis for fabric characteristics.

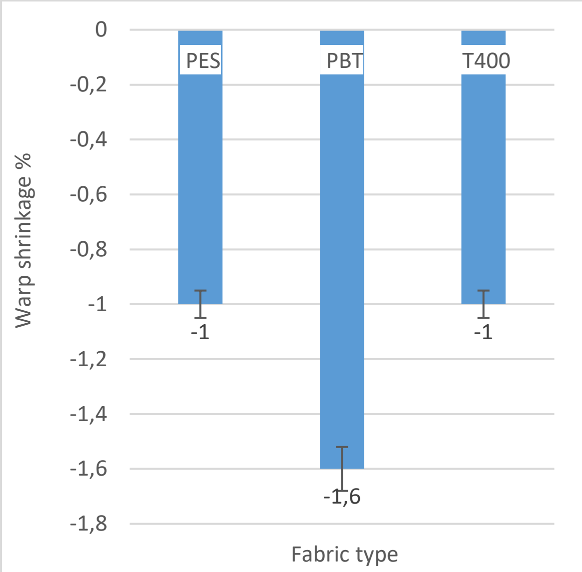

Figure 17. Warp shrinkage % of fabric

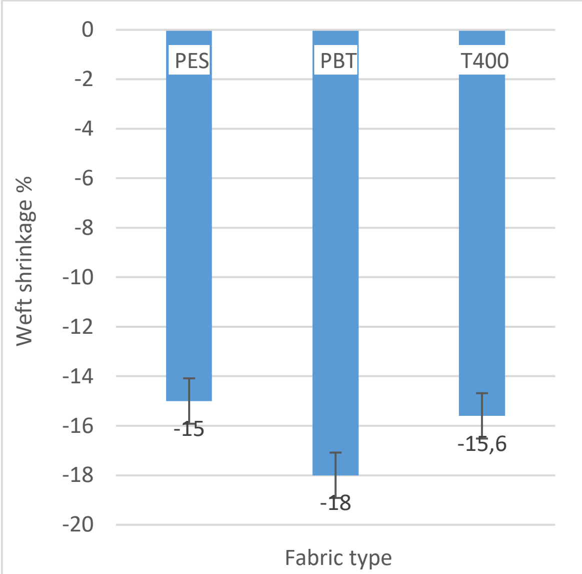

Figure 18. Weft shrinkage % of fabric

Table 5. Statistical analysis for fabric properties (one-way-ANOVA)

Variable (dependent)	F	Sig.
Dry weight	432.08	.000
Washed (wet weight)	720.58	.000
Elasticity %	273.96	.000
Growth %	26.70	.000
Warp tensile strength	58.23	.000
Weft tensile strength	25.33	.010
Warp tearing strength	26.60	.000
Weft tearing strength	151.10	.000
Warp shrinkage %	4.88	.008
Weft shrinkage %	5.66	.003
Stiffness	82.32	.000

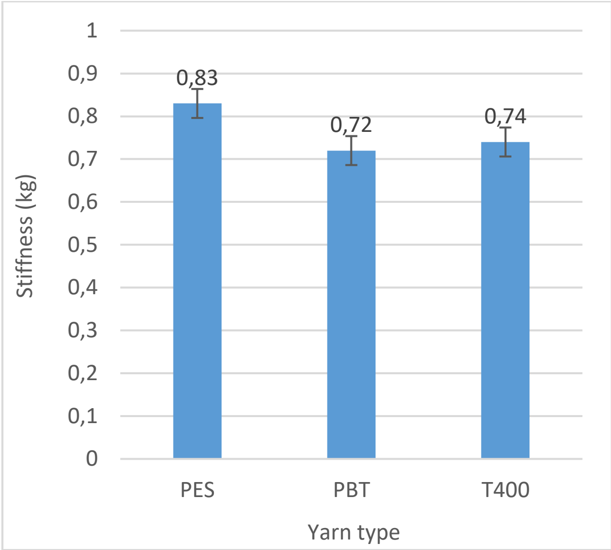

Figure 19. Stiffness of fabric

CONCLUSION

The development of yarn (dual core) using different fibres as a core element including elastane, PES, PBT, and T400® has been explored in this study with a specific focus on its impact on denim fabric properties. The study focused on yarn (dual core) properties produced with several core elements using an adjusted spinning method (ring) and these yarns were then used to produce twill (3/1 'Z') fabrics (denim). The results revealed significant variations in fabric and yarn characteristics based on several core materials used. It is found that yarn (dual core) made with PES filament shows more strength and less hairiness value and yarn made with PBT filament shows more elongation % and less neps, thin place, unevenness, and thick place value than other yarns. It is also noticed that fabric made with PES filament containing yarn (dual core) gives higher strength (Tearing and tensile) and fabric made with PBT filament containing yarn shows more elasticity %, growth %, and shrinkage %. One-way ANOVA confirmed the differences significantly, providing valuable insights into the production of yarns (dual core) with several core elements for enhancing fabric (denim) performance. The findings can guide future developments in the production of stretchable and adaptable garments like sportswear, intimate apparel, and denim jeans. However, the study lacks a discussion of a few yarn characteristics like dyeability, moisture management, and fabric characteristics such as air permeability, abrasion resistance, and water permeability which may be analyzed in future studies.

Author Contributions

Conceptualization – Habib A, Olgun Y and Babaarslan O; methodology – Olgun Y and Babaarslan O; formal analysis – Olgun Y and Babaarslan O; investigation – Habib A and Babaarslan O; resources – Olgun Y and Babaarslan O; writing-original draft preparation – Habib A and Olgun Y; writing-review and editing – Babaarslan O; visualization – Habib A; supervision – Babaarslan O. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare that they have no competing financial interests that could have appeared to affect the work reported in this article.

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