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# İPLİK TÜRÜ VE PAKETLEME YOĞUNLUĞU ARASINDAKİ İLİŞKİNİN ARAŞTIRILMASI: TEK KATLI, İKİ KATLI VE SİRO-SPUN İPLİKLERİ ÜZERİNE ÇALIŞMA

# EXPLORING THE RELATIONSHIP BETWEEN YARN TYPE AND PACKING DENSITY: A STUDY OF SINGLE-PLY, TWO-PLY, AND SIRO-SPUN YARNS

Murat DEMIR

Dokuz Eylul University, Department of Textile Engineering, Izmir, Turkey

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***Araştırma Makalesi / Research Article***

# EXPLORING THE RELATIONSHIP BETWEEN YARN TYPE AND PACKING DENSITY: A STUDY OF SINGLE-PLY, TWO-PLY, AND SIRO-SPUN YARNS

**Murat DEMIR**[1*]
[1]Dokuz Eylul University, Department of Textile Engineering, Izmir, Turkey

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***Abstract**:* Studying the fiber positioning in the yarn structure is the essential point to understand the different characteristics of yarns that counted as alternatives to each other. This study explores the packing densities of single-ply, two-ply and Siro-spun spun yarns that have been stated as the alternative yarn types considering the production method or yarn structure. In the study, Modal, Tencel, polyethylene teraphtalete, and cotton fibers represent micro, regenerated, synthetic, and natural fibers were used for the production of the 29.50 Tex yarns. Cross-sectional views of the yarns were acquired according to the hard sectioning method, and the packing densities of yarns were calculated with image processing tools. Yarn packing densities were calculated as the ratio of total fiber area within the yarn cross-section to yarn cross-section. Results showed that single ply ring-spun and siro-spun yarns are in a more circular shape and have greater packing densities values than two-ply yarns. Besides, yarns produced from cotton fibers have the least packing density values in each spinning technology. Similar packing density values were obtained for micro Modal, Tencel, and PET single-ply and siro-spun yarns. Packing density values were also compared with USTER diameter and density values and significant relations between those values were found.

**Keywords:** packing density, yarn cross-section, image process, siro-spun yarn, two-ply yarn

## İPLİK TÜRÜ VE PAKETLEME YOĞUNLUĞU ARASINDAKİ İLİŞKİNİN ARAŞTIRILMASI: TEK KATLI, İKİ KATLI VE SİRO-SPUN İPLİKLERİ ÜZERİNE ÇALIŞMA

***Özet***: İplik yapısı içindeki liflerin yerleşimini incelemek, birbirine alternatif olan iplik türlerinin farklı özelliklerini anlamak için önemlidir. Bu çalışma, üretim yöntemi veya iplik yapısı göz önünde bulundurularak alternatif iplik türleri olarak belirtilen tek katlı, iki katlı ve Siro-spun ipliklerin paketleme yoğunluklarını araştırmaktadır. Çalışmada, Modal, Tencel, polyester ve pamuk liflerini temsil eden mikro, rejenere, sentetik ve doğal lifler kullanılarak 29,50 Tex iplikler üretilmiştir. İpliklerin kesit görüntüleri sert kesim yöntemi kullanılarak elde edilmiştir ve ipliklerin paketleme yoğunlukları görüntü işleme araçları kullanılarak hesaplanmıştır. İplik paketleme yoğunlukları, iplik kesitindeki toplam lif alanının iplik kesitine oranı olarak hesaplanmıştır. Sonuçlar, tek katlı ring ve Siro-spun ipliklerin daha dairesel bir şekle sahip olduğunu ve iki katlı ipliklerden daha yüksek paketleme yoğunluğu değerlerine sahip olduğunu göstermektedir. Ayrıca, her iplik teknolojisinde pamuk liflerinden üretilen ipliklerin en düşük paketleme yoğunluğuna sahip olduğu bulunmuştur. Mikro Modal, Tencel ve PET tek katlı ve siro-spun iplikler için benzer paketleme yoğunluğu değerleri hesaplanmıştır. Paketleme yoğunluğu değerleri ayrıca USTER çap ve yoğunluk değerleriyle karşılaştırılmıştır ve bu değerler arasında anlamlı ilişkiler bulunmuştur.

***Anahtar kelimeler*:** paketleme yoğunluğu, iplik enine kesiti, görüntü işleme, siro-spun iplik, iki katlı iplik

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***Sorumlu Yazarlar/Corresponding Author:** murat.demir@deu.edu.tr*
***DOI:** https://doi.org/10.7216/teksmuh.1320576* *www.tekstilvemuhendis.org.tr*

## 1. INTRODUCTION

Twisting fiber bundles into the form of yarn is the essential basis structure of producing traditional textile products and the history of the industrial spinning machine dates back to the 18th century with the ring spinning machine [1-2]. Since then, the basic spinning principle of ring technology has remained the same, but, modifications have led to the development of different structures and more economical methods of yarn production [3].

Siro-spun yarn is counted as a derivative technology that developed from conventional ring spinning [4]. In the development of the siro-spun yarn technology, conventional ring spinning was modified by adding auxiliary parts and two separate rovings were twisted in a single yarn structure. Therefore, siro-spun yarns have similarities with single-ply ring yarns in terms of production techniques and also have structural similarities with two-ply yarns in terms of containing two separate fiber bundles in a single yarn structure. From this approach and similarities, comparing ring spun yarns with siro-spun and two-ply yarns has been the subject of many types of research [5-8], but limited studies have taken into consideration of yarn packing density. As the packing density of fibers in yarn structure influences the physical and mechanical properties as well as the heat and moisture transmission characteristics [9] the arrangement of fibers in the yarn structure could give a detailed explanation for performance differences of the yarns that counted as an alternative to each other.

Fiber packing density is one of the major parameters that affects yarn internal structure and yarn properties such as diameter, density and compactness [9-12]. There are several approaches for calculating packing densities of yarns, and Guo and Tao [9] categorized these approaches into three groups. The first approach assumes that fibers are perfectly arranged into the hexagonal configuration in the yarn cross-section [13-15], but, it has been found unsuitable for the staple yarns [10,12]. In the second approach, the yarn cross-section is divided into circular zones of equal widths or areas, and fibers are in a circular arrangement in the yarn cross-section. However, for the reason of the variations of fiber cross-sectional area, especially for the natural fibers [16], Nechar *et al.* [17] proposed the use of the ratio of the sum of the cross-section area of fibers in yarn cross-section to the area of that zone for better packing density results. In the third approach, it is assumed that fibers are virtually distributed in the combination of ring and hexagonal configuration [18].

In the literature, there are studies that investigate the effects of spinning parameters and spinning technology on the yarn packing densities. Kilic *et. al.* [10] studied the packing densities of yarns that produced with the ring, compact, and vortex technologies and concluded that spinning technologies are statistically significant on the yarn packing densities and show similar trends with Uster diameter values. Hussain et al. [19] investigated the spinning variables on the yarn packing densities and showed that increasing spindle speed results in higher packing densities of the yarns. Zheng *et. al.* [20] researched the fiber distribution in the cross-section of vortex spun yarns and concluded that vortex yarns have lower packing densities values than conventional ring yarns. Guo and Tao [12], also studied the yarn packing density of low torque ring spun yarns based on the equal area method and concluded that axial forces are effective on yarn packing densities. Yılmaz *et. al.* [21] researched the packing densities of compact spun yarns based on equal width zone. They calculated the packing densities of yarns as the ratio of the total fiber area to the yarn area and resulted that compact yarns have higher packing densities than conventional systems. Regar *et. al.* [9] compared fiber distribution and packing of Eli-Twist, Siro and ring-spun yarns. They pointed out that Eli-twist yarns have higher packing densities. Salehi and Johari [22] also investigated the packing densities of lyocell ring-spun yarns and analysed the effects of several spinning parameters. They obtained greater packing density values with increasing spindle speed, traveller weight and twist factor. Sinha *et al.* [23] also investigated the packing densities of structurally modified ring spun yarns. There are also some studies that relate yarn packing density in the yarn cross section with fabric comfort and vertical wicking [24,25].

In this study, to identify internal structures of single-ply ring, two-ply, and siro-spun yarns from different material groups, which are considered as alternatives to each other, fiber packing densities were investigated. The packing densities of yarns were calculated the ratio of the total fiber area in the defined yarn cross-section to the defined yarn-cross section. Calculated packing density results were also compared with the diameter and density values that measure with the USTER tester.

## 2. MATERIAL AND METHODS

### 2.1 Materials

In the scope of the study, micro Modal from micro fiber groups (1.0 dtex and 39 mm), polyester from synthetic fiber groups (1.3 dtex and 38 mm), Tencel from regenerated fiber groups (1.3 dtex and 38 mm) and cotton from natural fiber group were used for the production of 29.50 Tex single-ply ring, two-ply, and siro-spun yarns. All slivers used in the study were produced with Rieter B34 Bale opener, Rieter A81 UniBlend, Rieter A79 UniStore and Rieter C60. Rieter SBD-40 draw frame was used for drawing process and 4.92 ktex slivers were produced. Marzoli FTDSN was used for strand production and 0.65 ktex strands were produced. Pinter-Merlin laboratory type spinning machine were used for all yarn production. Final twist amount was set 500 T/m for all yarn types. For the production of two-ply yarns, first single yarns produced with 1000 T/m (Z) then ply 500 T/m (S). HVI results of cotton fibers are given in Table 1 and details of yarn production parameters are given in Table 2.

**Table 1**. Properties of cotton fibers (HVI)

| Fibres Properties | Averaged Value |
|---|---|
| Fineness (micronaire index) | 3.6 |
| Length (mm) | 29.50 |
| Tenacity (cN/tex) | 29 |
| Elongation (%) | 4.85 |
| Spinning consistency index | 140 |
| Uniformity (%) | 82.5 |
| Maturity | 0.88 |
| Short fibre index (%) | 8.50 |

**Table 2.** Yarn production parameters

| Yarn Type | Raw Material | Linear Densities of Yarns | Twist of Single Yarn Component (T/m) | Twist of Produced Yarn (T/m) |
|---|---|---|---|---|
| **Single-ply** | Micro Modal, PET, Tencel, Cotton | 29.50 tex | 500 | 500 |
| **Siro-spun** | | 29.50 tex | 500 | 500 |
| **Two-ply** | | 2x14.75 tex | 1000 | 500 |

## 2.2 Method

### 2.2.1 Preparation of yarn samples for sectioning

For the yarn cross-sectional samples, the hard sectioning method was used. For the hard sectioning method, each of the yarn samples is placed in the circular specimen clamp and then placed on the mould. At this point, yarn samples should be straight, long enough for sectioning but not to touch the mould (Figure 1a). Infiltration solution is prepared from 50 ml 2-Hydroxyethyl-methacrylate (basic resin) and 0.5 g benzoyl peroxide (activator). A magnetic stirrer was used to ensure to mix both components of the solution. 1mL of dimethyl sulfoxide as hardener per 15 mL infiltration solution is added for embedding samples and wait for 24 hours at room temperature (Figure 1b). Prepared samples were sectioned by using Leica Rotary Microtome and the thickness of each sample was set as 3 µm (Figure 1c). The cross-section views of yarns were acquired with camera integrated Olympus BX43 microscope at 100X zoom.

### 2.2.2 Calculation of Yarn Packing Densities

Image processing techniques were used to calculate the packing densities of the yarns in this study. The direct method was employed, which involves detecting the real fiber area from the acquired images [10]. MATLAB image processing toolbox and Photoshop program were used for the calculation of packing densities of yarns. The four steps are described to the calculation of packing densities according to the direct method as follows (Figure 2); In the first step, acquired 8-bit-deep RGB images were converted to the grey-level image with MATLAB. In the second step, grey-level images were cropped around the yarn and then the noises and background of the images were cleared with the Photoshop program. In the literature, there are different approaches to calculate yarn packing density and most of the studies calculate the packing density of yarns based on equal zone or equal width principle. In either method, yarn cross-sections were assumed to be circular. However, separate yarn axis centres for each of the single yarn components in the plied yarn structures form not circular cross-sections. Therefore, acquired images were cropped in a rectangular shape that covers all fibres, and yarn areas were defined as in elliptical shape that fits in the cropped image. Assuming that size of the cropped image is K x L and in that case, the area of the yarn (A) is defined as ($A=\pi KL/4$) [10]. Figure 3 illustrates the prediction of total yarn area for single-ply ring, two-ply and siro-spun yarns. In the third step, grey-level images were converted to binary images with MATLAB. The pixels of binary images have two intensity values which are 0 defines black colour and 1 defines the white colour. A suitable threshold value was defined based on the histogram for each of the acquired images and converted to 1 if the pixel values of the grey level images were equal or greater than the threshold value, and 0 if the value was less than the threshold value. At this level, black pixels define the fibers in the yarns and white pixels define the pore in the yarns. In the last step, the packing densities of yarns were calculated as the ratio of the yarn area to the sum of fiber area in the yarn cross-section. Five images of each yarn samples were processed and packing densities of yarns were calculated. Results were compared at 95% confidence level.


a b c

**Figure 1.** Illustration of a) prepared yarn samples b) prepared samples for sectioning c) sectioned sample [26]

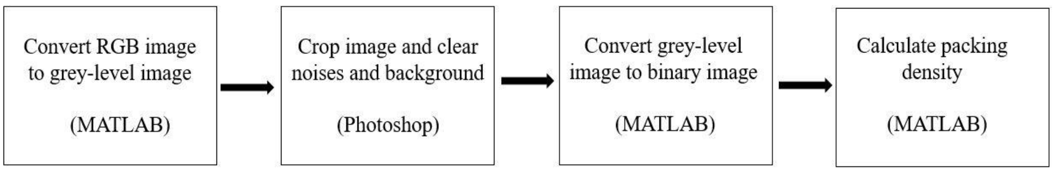


**Figure 2.** Illustration of four-steps of yarn packing density calculation

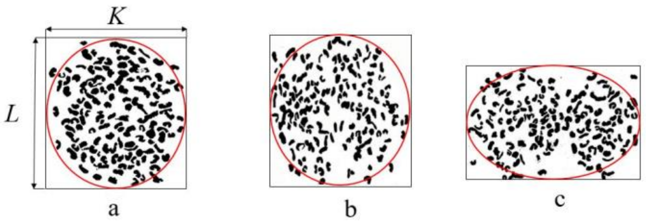


**Figure 3.** Illustration of total yarn area a) single-ply ring b) siro-spun, c) two-ply yarns

### 2.2.3 Yarn Density, Diameter and Roundness

Density (D g/cm$^3$), diameter (2DØ mm), and roundness (shape) values of the yarns was related with the packing densities of the yarns [7]. To validate the calculated packing density results of single-ply ring, two-ply and siro-spun yarns, these values were also measured with Uster Tester 6. The test was performed at 400 m/min test speed and test duration was 2.5 minutes.

## 3. RESULTS AND DISCUSSION

Cross-section images of single ply ring-spun, siro-spun, and two-ply yarns are given in Figure 4, Figure 5, and Figure 6, respectively. The first columns of the figures illustrate the raw images acquired from the microscope, the second columns illustrate the grey-level images processed in Photoshop. As shown in the figures, the cross-sections of single ply and siro-spun yarns are in a more circular shape [9] while two-ply yarns exhibit an elliptical structure (Figure 4-6). Visual assessment of the cross-section images of the yarns also reveals similarities with USTER roundness values (Figure 7). The variance analysis (ANOVA) indicates that spinning technology has a statistically significant effect on USTER roundness values at a significance level of α=0.05 (0.00<0.05). Pairwise comparison of the produced yarns for all material groups is presented in Table 3, revealing that there are no statistically significant differences in roundness values between single-ply and siro-spun yarns, but significant differences exist between two-plu and other spinning technologies.

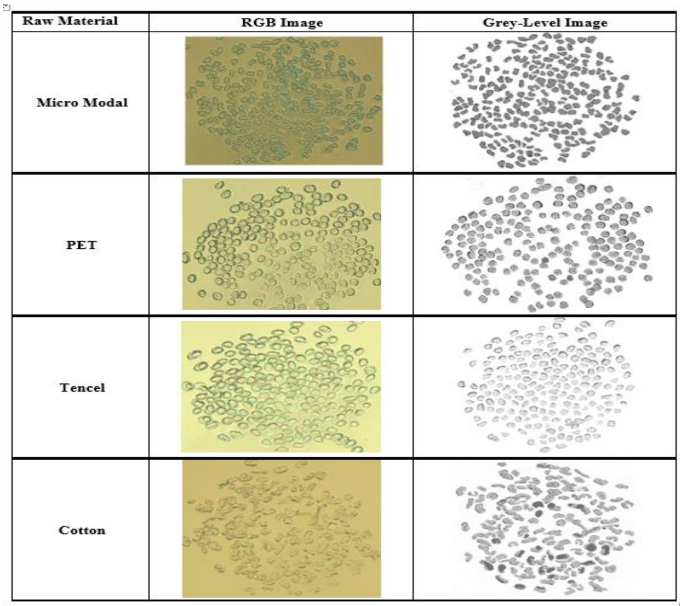


**Figure 4.** Cross section views of single-ply yarns

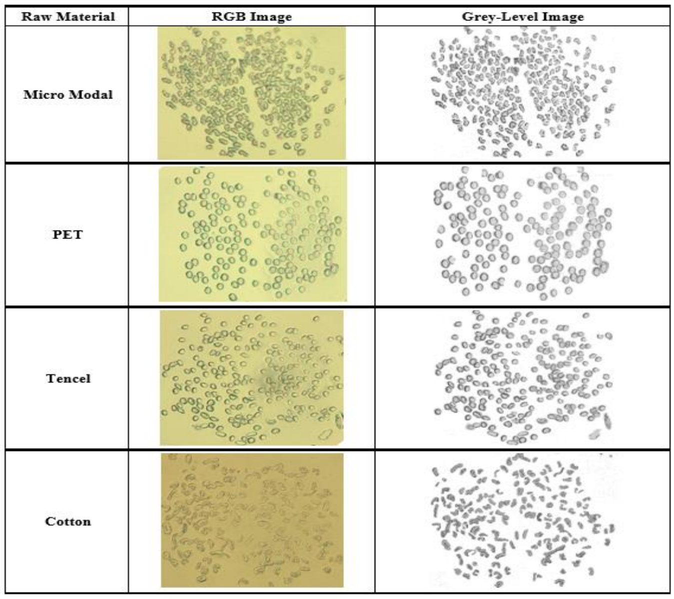


**Figure 5.** Cross section views of siro-spun yarns

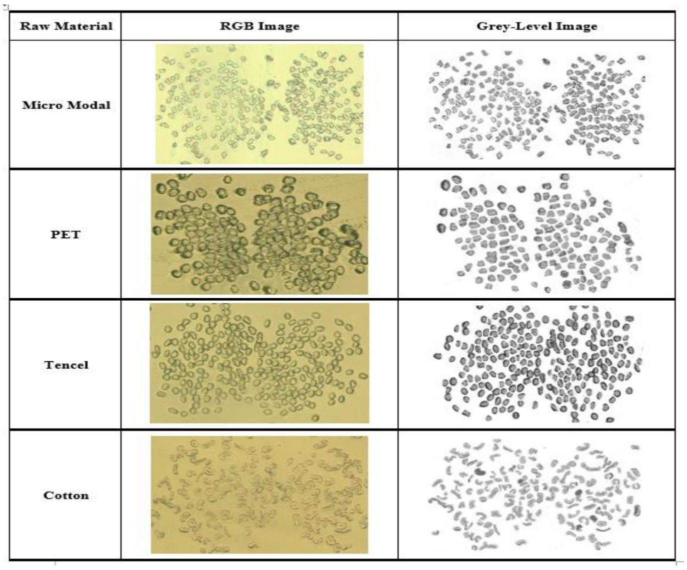


**Figure 6.** Cross section views of two-ply yarns

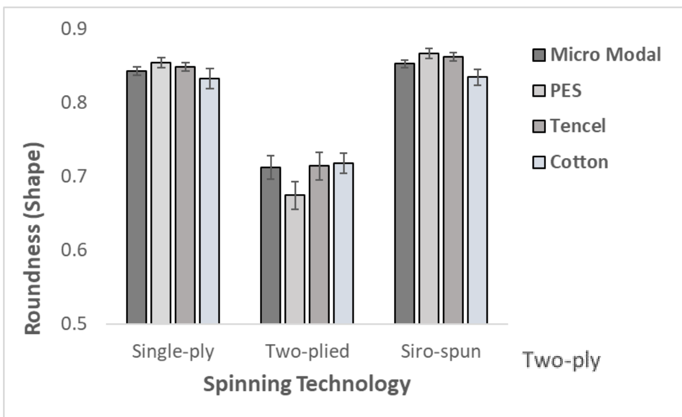


**Figure 7.** Roundness (shape) values of single ply, two-ply and siro-spun yarns

**Table 3.** Pairwise comparisons of for roundness value as dependent variable for single-ply, two-ply and siro-spun yarns

| Raw Material | Spinning Technology | Mean Difference (I-J) | Standard Error | Significance |
|---|---|---|---|---|
| Micro Modal | Single ply – Two-ply | 0.130 | 0.005 | 0.000 |
| | Single ply – Siro-spun | -0.010 | 0.005 | **0.083** |
| | Two-ply -Siro-spun | -0.140 | 0.005 | 0.000 |
| PET | Single ply – Two-ply | 0.180 | 0.006 | 0.000 |
| | Single ply – Siro-spun | -0.012 | 0.006 | **0.078** |
| | Two-ply -Siro-spun | -0.192 | 0.006 | 0.000 |
| Tencel | Single ply – Two-ply | 0.134 | 0.006 | 0.000 |
| | Single ply – Siro-spun | -0.014 | 0.006 | **0.038** |
| | Two- ply-Siro-spun | -0.148 | 0.006 | 0.000 |
| Cotton | Single ply – Two-ply | 0.114 | 0.007 | 0.000 |
| | Single ply – Siro-spun | -0.002 | 0.007 | **0.765** |
| | Two-ply -Siro-spun | -0.116 | 0.007 | 0.000 |

Figure 8 illustrates the average packing density values for the produced yarns in all material groups. It is evident from the figure that the packing densities of single-ply ring and siro-spun yarns are similar and higher than those of two-ply yarns in each raw material group. This finding is consistent with a previous study [9], which reported that siro-spun yarns exhibit higher packing density values than plied-yarns. This can be attributed to the twist direction of the single components and final yarn structure for siro-spun and two-plied yarns. In siro-spun yarn production, the twist direction of single yarn and final yarn is the same. Axial forces towards the yarn center arising from the same twist direction create compressive forces [12] and result in a non-circular single-component structure, but a circular final yarn structure (Figure 5). In contrast, produced two-plied yarns have different twist directions for the single yarn and plied-yarn, leading to circular structures in single yarns and non-circular structures in plied-yarns (Figure 6). ANOVA results also showed that spinning technology is statistically significant for packing density (%) values for α=0.05 significance level (0.000<0.005). In pairwise comparison (Table 4), it was found that differences for packing density values (%) between single-ply ring and siro-spun yarns are not statistically significant while differences between two-ply and other spinning technologies are statistically significant. Furthermore, USTER diameter and density values of yarns were found to be correlated with packing density values [10]. As shown in Figure 9, the diameters of two-ply yarns are greater than those of single-ply and siro-spun yarns, while their density values are lower.

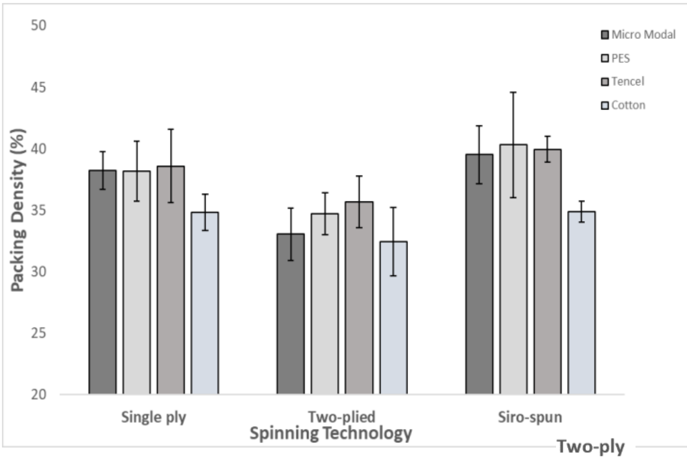


**Figure 8.** Packing densities (%) of single ply, two-ply and siro-spun yarns

**Table 4.** Pairwise comparisons of for packing densities value as dependent variable for single ply- two-plyand siro-spun yarns

| Raw Material | Spinning Technology | Mean Difference (I-J) | Standard Error | Significance |
|---|---|---|---|---|
| Micro Modal | Single ply – Two-ply | 5.186 | 1.036 | 0.000 |
| | Single ply – Siro-spun | -1.300 | 1.036 | **0.233** |
| | Two- ply-Siro-spun | -6.486 | 1.036 | 0.000 |
| PET | Single ply – Two-ply | 3.619 | 1.558 | 0.039 |
| | Single ply – Siro-spun | -1.966 | 1.558 | **0.231** |
| | Two- ply-Siro-spun | -5.585 | 1.558 | 0.004 |
| Tencel | Single ply – Two-ply | 3.212 | 1.145 | 0.016 |
| | Single ply – Siro-spun | -1.062 | 1.145 | **0.372** |
| | Two- ply- Siro-spun | -4.274 | 1.145 | 0.003 |
| Cotton | Single ply – Two-ply | 2.386 | 0.967 | 0.030 |
| | Single ply – Siro-spun | -0.062 | 0.967 | **0.950** |
| | Two- ply -Siro-spun | -2.448 | 0.967 | 0.026 |

Furthermore, when comparing the packing densities of yarns within each spinning technology in terms of raw materials, it is observed that the packing densities of yarns made from synthetic, regenerated, and micro fibers are similar and higher than those made from cotton fibers. This may be attributed to the variation in cross-sectional area of cotton fibers, which does not exist for synthetic and regenerated fibers [9,16]. On the other hand, although many studies reported that there is a linear relation between fiber packing density and the number of the fibers in yarn cross-section [20,21,24], similar packing density values were calculated for micro Modal, PET, and Tencel yarns. It is seen from Figure 11 that, the numbers of micro Modal fibers are greater than the number of Tencel and PET fibers in the yarn cross-sections. Similar packing densities of those fibers which do not have a variation of linear densities could be explained by the packing density calculation. As the packing densities of yarns were calculated the ratio of the sum of fiber area to the yarn area, the higher number of micro Modal fibers with lower linear densities covered the same area as the smaller number and higher linear densities of Tencel and PET fibers within the similar diameter of the yarns. (Figure 10). It should be also noted that circular cross sections of Tencel and PET fibres enable the close association in yarn cross-section and higher packing density values [23] (Figure 8).

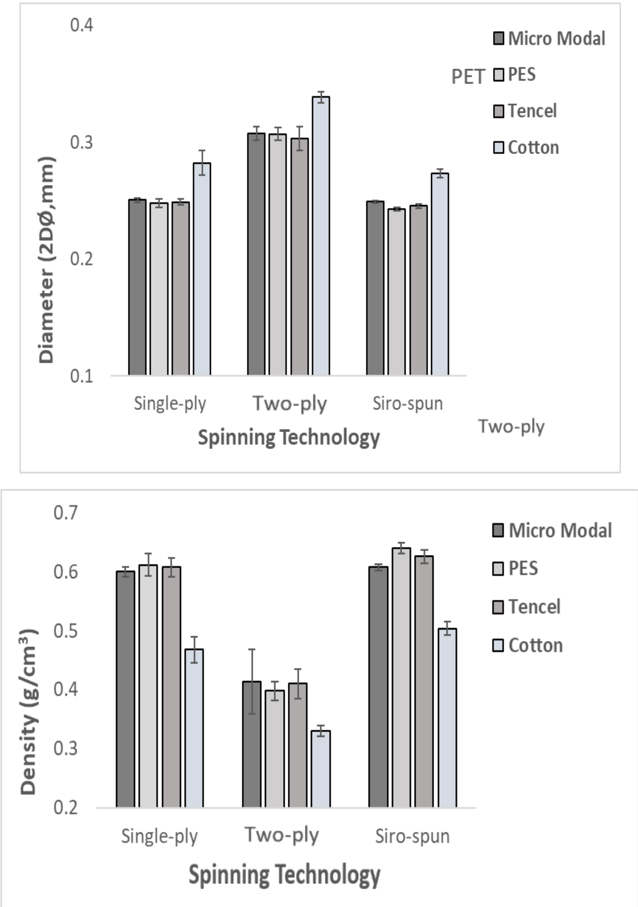


**Figure 9.** Diameter and density values of single ply, two-ply and siro-spun yarns

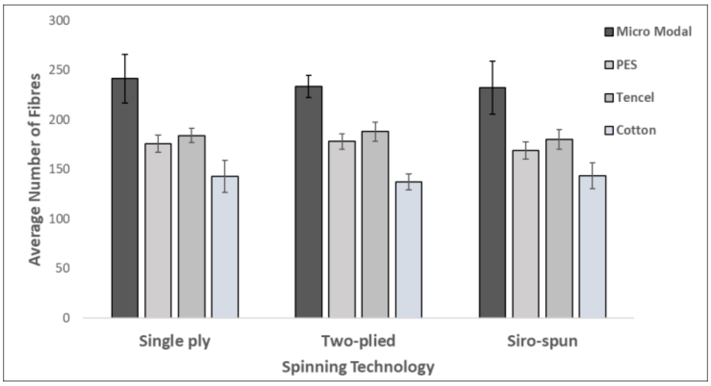


**Figure 10.** Average number of fibers of single ply, two-ply and siro-spun yarns

## 4. CONCLUSIONS

In this study, the aim was to gain a better understanding of the internal structure of single-ply ring, siro-spun, and two-ply yarns, which have been compared in many studies regarding their physical, structural, and mechanical properties. Cross-sectional views of yarns produced from micro Modal, Tencel, PET, and cotton fibers were investigated, and packing densities were calculated and compared. Cross-section samples of the yarns were obtained according to the hard sectioning method and the thickness of each sample was set as 3 µm. Image processing tools were used for the packing density calculation based on the ratio of total fiber area in yarn cross-section to defined yarn cross-section. Comparing results showed that single-ply ring and siro-spun yarns in circular shape while two-ply yarns are in a more elliptical shape. It's also observed that packing density values of single-ply ring and siro-spun yarns are similar for all raw material groups and higher than two-ply yarns. Yarns produced from cotton fibers have the least packing density values for all spinning technologies. It's also seen that fibers with different linear densities in regenerated and synthetic fiber groups showed similar packing density values as related to the number of fibers in yarn cross-section. However, the porosity values of those yarns may differ. Packing density values of yarns also showed a correlation with USTER diameter and density values. Yarns with the greater diameter and lower density values also have lower packing density values.

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