Investigation of Manufacturing and Processing Techniques on Shade Variation and Performance Characteristics of Woven Fabrics

Khurram Shehzad Akhtar, Ali Afzal, Kashif Iqbal, Zahid Sarwar, Sheraz Ahmad

National Textile University, Materials & Testing, Punjab PAKISTAN

Correspondence to:
Sheraz Ahmad email: itsadeelnaz@hotmail.com

ABSTRACT
The purpose of this research is to examine the properties of vortex and ring spun yarns and their influence on the properties of woven fabrics. Cotton/PET fibers with the same blend ratio were used to produce vortex and ring spun yarns of 24.6 tex. These yarns were woven into a fabric with a satin weave construction. Heat setting was done to control the dimensional shrinkage and its effect on results was investigated. The woven fabric was dyed using exhaust and continuous dyeing methods. The vortex yarn fabric yields superior shade depth, pilling and fastness properties in comparison to the ring yarn fabric.

Keywords: Ring Spinning, Morata vortex Spinning, K/S value, Pilling and Rubbing fastness

INTRODUCTION
Staple yarns are commonly produced with ring and rotor systems. During recent years, a number of new yarn manufacturing techniques have been developed to increase yarn production and impart new features other than those found in conventional ring spun yarns [1]. There is significant interest in the development of newer systems such as vortex spinning. This system represents the next logical development, and there is no doubt that experience gained with the system and ongoing refinements in component design will lead to potential improvements in both yarn quality and productivity. One of the main production differences between ring and vortex yarns is that ring spinning requires two additional processes. These extra processes, roving and winding, make ring spun yarn more expensive to produce [2, 3, 4].

Ring spinning is a yarn manufacturing technique that uses a small circular traveler for twist insertion. Twist insertion and winding of yarn on the ring bobbin occur simultaneously in this technique. The structure of ring yarn is usually considered as the basic structure in spun yarn technology [5]. The properties of spun yarns mainly depend on the structure of the yarn. Ring spinning is a common spinning system and wide range of counts can be produced on it. Limited spindle speed and resulting low production rate is the main limitation of this system [6].

Vortex spinning can be considered as a modified form of jet spinning. The structure of vortex yarn has two parts. Untwisting of a vortex yarn shows that it has a simple core and sheath of fibers [7]. In vortex spinning, fibers leave the front roller of the drafting device and are drawn into the fiber strand passage by air suction created at the nozzle. The distance between the drafting roller and the nozzle tip is vital in generating the false twist in the yarn. There are several benefits to this technique such as ring like appearance, low hairiness, better abrasion resistance, low pill formation, better color fastness, higher moisture absorption and quick drying characteristics [8]. Murata vortex spinning has a production speed of 400~500 meters per minute and can produce a large range of fine counts similar to that of a ring spun yarn. It is also used as direct spinning from sliver to packaged Yarn [9].

In yarn production, the twist insertion mechanism influences the structure as well as the properties and characteristics of the yarn produced. Significant differences between Murata Vortex Spinning (MVS) and Reiter air-jet spinning technologies in terms of maximum loading, minor differences were observed in work of rupture and no change was found in initial modulus and maximum elongation [10].

Low hairiness and pill formation were observed in vortex yarn compared to ring and open-end rotor spun yarns [11]. However, drapability is poor due to stiffer yarn structure [12]. Vortex spinning can be regarded as a modified form of jet spinning. The core of parallel fibers are held together by wrapper fibers in vortex yarn [9]. The properties of a vortex yarn depend upon the process parameters [13]. Vortex yarn has low packing densities, resulting in darker shades [14]. The yarn produced by vortex spinning has a different structure in comparison to ring and open end yarn. Increased wrapping angles used in vortex spinning result in decreasing in yarn hairiness. The structural analysis of vortex yarn showed that the center fibers have almost no twists, but vary in slow waves along the yarn axis. Vortex yarns show a tendency to be soft in compression but stiff in bending deformation, as compared with ring-spun yarn. It was found that increased yarn hairiness leads to increased fabric air resistance [15].

A comparison of the properties of MVS and conventional yarns showed that hairiness values of ring yarns are higher than those obtained for vortex yarns. Unevenness of compact ring spun yarns is low and vortex yarns show high values. When the effect of spinning systems is evaluated in terms of breaking force and elongation, results show that compact yarns have the highest values whereas vortex yarns have the lowest [16].

The characteristics of manufactured fabric mainly depend on the properties of spun yarns used. This also influences the quality of end product. Strength, abrasion resistance, dyeing, feel, handle, comfort and elongation are the key properties of fabric influenced by the yarn. Yarn properties depend mainly on the type of fiber used and yarn structure [17].

Erdumlu et al [11] compared ring, rotor and vortex yarns. It was found that vortex yarns give low hairiness, less pill formation and ultimately smooth appearance of fabric as compared to ring and rotor spun yarns. Bursting strength and dimensional properties of vortex spun knits are better than those of the ring and rotor spun yarns.

Klara Kostajnšek and Krste Dimitrovski [18] used blended yarns to study the properties of ring and vortex spinning. The ring spun yarn characteristics depended on the blend ratio used. Abrasion properties of vortex yarns were significantly better than those of ring spun yarn. Worse tensile properties were found for vortex spun yarns.

Dinesh Bhatia and S. K. Sinha reported a study of the effects of different parameters such as loop length, yarn linear densities and number of washing cycles on fabric spirality, pilling, dimensional stability and reflectance. It was found that fabric spirality is mainly influenced by loop length and spinning technique. The results showed that knitted fabric made of spun yarn has higher spirality compared to fabric made from vortex yarn. The spinning system is the key factor influencing pilling propensity and dimensional stability. Visual appearance of the fabric is influenced by both of these factors. Reflectance, which is generally influenced more by the washing cycle, was also found to be influenced by the spinning system and loop length used in producing the fabric [19].

Hyunah Kim [20] made air vortex yarn using PTT and wool. The feel of the vortex yarn knitted fabrics was harsher than ring and compact spun fabrics. Air vortex yarn knitted fabrics exhibited worse formability and sewability than ring and compact yarn knitted fabrics. However, air vortex knitted fabric showed good results in terms of wicking, drying, thermal properties and pilling.

Woven fabrics are formed by the interlacement of two orthogonal sets of yarns. The yarns that are vertically arranged are known as the warp and those are horizontally placed are called the weft yarns. By the placement of these yarns a large number of weave designs can be formed [21].

Blends of polyester and cotton are widely used because of their tensile strength, abrasion resistance dimensional stability, pilling resistance, absorbency and comfort. There are several methods for dyeing polyester and cellulose blended fabrics such as exhaust, continuous or semi continuous. In these methods disperse, reactive, direct, sulphur and vat dyes are used [22].

Rafique et al [23] developed a new environment friendly method for the dyeing of blended PC fabric by using pigments. Ortlek et al [24] studied the color differences of viscose fabrics knitted from vortex, ring and open-end rotor-spun yarns after abrasion. Dyeing was done in an HT dyeing machine by using reactive dye. A study concerning the comparison of properties of vortex, ring and open end spun yarn knitted fabrics was reported. Reactive dyes were used for dyeing [11]. Wan et al [25] compared the dyeing behavior of conventional ring spun and torque-free ring spun yarn knitted fabrics. Torque-free ring spun yarn knitted fabric showed better color yield than conventional ring-spun yarn knitted fabrics.

There are numerous studies about the blending and comparison of manufacturing techniques used for spinning yarn into fabric. But no study has been reported in the literature comparing the effect of dyeing processes on the properties of ring and MVS woven fabrics. This study compares the dyeing of ring and MVS by using the exhaust and continuous root processes. Following dyeing, K/S values, pilling and rubbing fastness (dry & wet) were analyzed.

EXPERIMENTAL

In this study, two types of fibers, cotton and polyester were used. The properties of cotton fibers were measured on a Uster HVI 1000 testing instrument and are found in *Table I*. The properties of the polyester fiber are given in *Table II*.

TABLE I. Properties of Cotton fiber.

Attribute	Mean Value	Standard deviation	C.V%
Maturity	0.86	0.01	0.7
Mean Length (in)	0.835	0.042	5
Upper half mean length (in)	1.037	0.03	2.9
Uniformity (%)	80.5	2.2	2.7
Short fibers (%)	11.1	2.3	20.5
Strength (g/tex)	27	2.8	10.3
Breaking elongation (%)	5.4	0.8	15
Micronaire value (mic)	4.31	0.23	5.4

TABLE II. Properties of Polyester fiber.

Attribute	Value
Length (mm)	38
Linear density (dtex)	1.33
Tenacity (cN/tex)	56.2
Breaking elongation (%)	10.8
Modulus (cN/tex)	698.9

A blend ratio of 50/50 polyester/cotton was used in all cases. The polyester and cotton fibers were processed separately through blow room and carding processes followed by mixing at the drawing step. Three passage drawings were performed before reaching the vortex spinning machine. The finished drawn sliver was produced using a Rieter draw frame with an auto-leveler device to a linear density of 4.77 ktex. The drawn slivers were spun into 24.6 tex polyester/cotton yarn by using a Murata vortex spinning machine (MVS 861) with different spindle air pressure combinations.

Weaving was carried out on sample loom to produce woven fabric with a satin weave construction. Settings and conditions were kept constant during the weaving process, the only difference being the type of yarn used. A number of 36 ends per centimeter and 30 picks per centimeter construction was used in the current research project. The greige fabric was de-sized by the industrial pad batch method, scoured, bleached by the pad-steam method and heat set at the stenter before dyeing. Heat setting was done at 180°C and 220°C for 45 seconds. Samples of fabric were dyed using the jigger and pad thermosol processes. A shade of 2% on weight of fabric was used for dyeing in both methods.

The recipes were prepared according to the manufacturer's recommendations. Disperse dye (RED RD_RLS) and dispersing agent 1 g/l, anti-migrant agent 1 g/l and penetration accelerant agent 1 g/l were used for the dyeing of polyester portion. The cotton portion was dyed using reactive dye (Drimaren Red CL4BN) along with a penetration accelerant agent at 1 g/l, soda ash (10g/l) and common salt (40 g/l). In exhaust dyeing the temperature was set at 130 ^{o}C for 45 minutes for polyester while a temperature of 60^{o}C for 45 minutes was used for cotton fiber dyeing. The pH of the dyeing solution for polyester dyeing was maintained at 4-5 by acetic acid and for cotton dyeing the pH was maintained at 9.5-10.5 by using alkali. In continuous dyeing the temperature was set at 210^{o}C for 2 minutes for polyester while 102^{o}C for 3 minutes was used for cotton fiber dyeing. Reductive clearing was done after polyester dyeing for the removal of unfixed dye by using 5 g/l of sodium hydroxide and sodium hydro sulphide at 60-70^{o}C for 20 minutes. Dyes and additives were provided by Archoroma. Soda ash and common salt used were commercial grade. The two modes of dyeing, continuous and exhaust process are shown in *Figure 1* and *Figure 2* respectively.

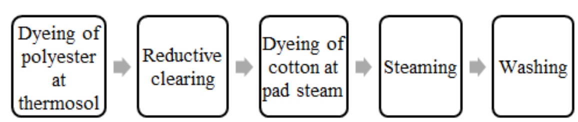

FIGURE 1. Dyeing at Thermosol & Pad Steam.

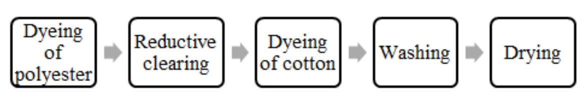

FIGURE 2. Dyeing at Jigger.

In this study, yarn manufacturing technique, dyeing process and heat setting were used as variable factors. Twelve individual samples were developed using two levels of the first two factors and three levels of last the variable to execute the design of experiment in *Table III*. The change of yarn manufacturing systems results in yarns with different structures and properties. Each system has its limitations and advantages in terms of technical feasibility and economic viability. Shade depth, pilling and rubbing fastness are considered as response factors.

TABLE III. Design of experiment.

Serial No.	Yarn manufacturing techniques	Heat Setting	Dyeing process
1	Ring	Without	Pad thermosol/ Pad steam
2			Jigger
3		180	Pad thermosol/ Pad steam
4			Jigger
5		220	Pad thermosol/ Pad steam
6			Jigger
7	MVS	Without	Pad thermosol/ Pad steam
8			Jigger
9		180	Pad thermosol/ Pad steam
10			Jigger
11		220	Pad thermosol/ Pad steam
12			Jigger

The color properties of the dyed samples were determined with an X-Rite Ci7800 spectrophotometer. The K/S values were determined using the expression:

$$K/S = (1-R)^2 / 2R$$

Where, R is the reflectance at complete opacity, K is the absorption coefficient and S is the scattering coefficient. Based on the Kubelka–Munk theory, dye uptake is better at higher K/S values. K/S values of dyed samples were evaluated according to the standard test method AATCC 6-2008.

The pilling rating of the fabric specimens was determined in accordance with ASTM D4970-02 using a Nu-Martindale pilling tester (M235 4 Position Martindale). It consists of four testing plates on which the abrading fabrics are attached. Each sample was abraded for 1000 cycles.

Dry and wet rubbing fastness values of the dyed samples were evaluated according to AATCC 8-2007 on a crock meter. Each dyed sample was rubbed against white bleached fabric for 10 cycles and evaluated by comparing the staining depth against the gray scale.

RESULTS AND DISCUSSION

Fabric samples were compared based on yarn manufacturing technique and dyeing process. Polyester cotton blended yarns having linear densities of 24.6 tex woven into satin weave fabric from two different spinning systems were tested and results were evaluated for shade depth, pilling resistance and rubbing fastness properties.

Shade Depth

The K/S values of fabric samples woven from ring and vortex yarns dyed under lab conditions with same dye concentration were measured. The results were used to compare the effect of spinning system on color shades (K/S, color efficiency) of the fabric samples. Effects of heat setting and dyeing process on color efficiency were also analyzed and results are shown in *Figure 3*. The color efficiencies of the fabric woven with vortex yarns (MVS) were higher than those woven from ring spun yarns. The results revealed that vortex yarns have darker shades compared to ring yarns. Similar trends were observed in case of jigger dyeing as shown in *Figure 4*.

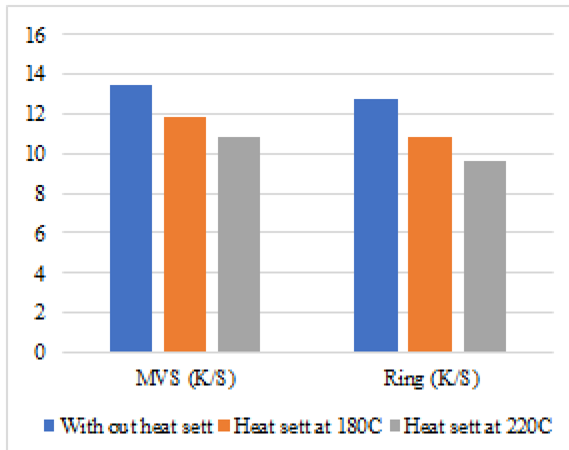

FIGURE 3. K/S results of Pad Thermosol dyed fabric.

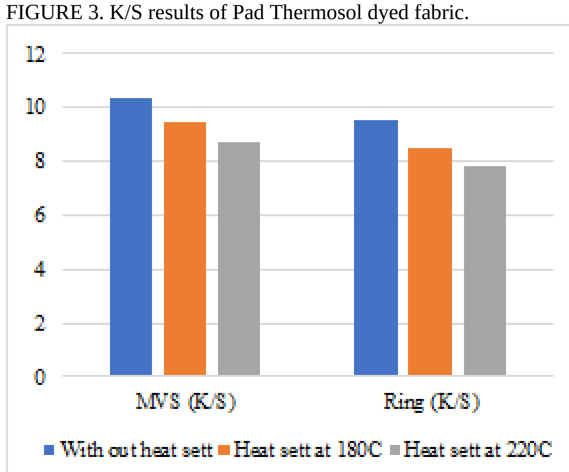

FIGURE 4. K/S results of Pad Jigger dyed fabric.

The results were in agreement with results reported in literature [26] because of the fact that structure of MVS yarn is loose and penetration of dye is higher compared to ring spun yarn. It may also due to less hairiness on MVS fabric [11]. It was also observed that heat setting affects the K/S value. Heat setting reduced the color strength of both the MVS and ring spun yarns as a result of increased crystallinity and decreased dye uptake. The results also indicate that k/s value of pad thermosol dyed fabric is higher than the jigger dyed fabric. This is due to the fact that in the pad thermosol process dyeing done at a higher temperature than in jigger dyeing. At higher temperatures the rate of dye penetration in polyester is increased.

Pilling

Pilling is a phenomenon that arises in wear due to the formation of little pills. The pill is a ball of tangled fibers that is held to the fabric surface by several anchor fibers. Pilling tendency of ring and MVS fabrics were evaluated in terms of pilling grade and presented in *Figure 5*.

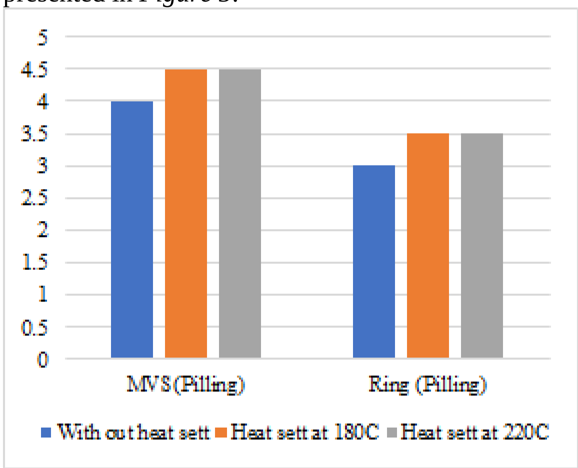

FIGURE 5. Pilling results of Pad Thermosol dyed fabric.

The pilling resistance of MVS fabric was higher compared to ring fabric due to its wrapping structure. It was also observed that pilling resistance was increased by the introduction of heat setting, which is in accordance with literature [27]. Heat setting sets the fibers within the yarn surface and improves relative pilling resistance. Similar trends were observed in case of jigger dyeing as shown in *Figure 6*. Comparison of exhaust dyed and continuous dyed fabrics shows that pill formation is lower on jigger dyed fabric due to less friction in the process.

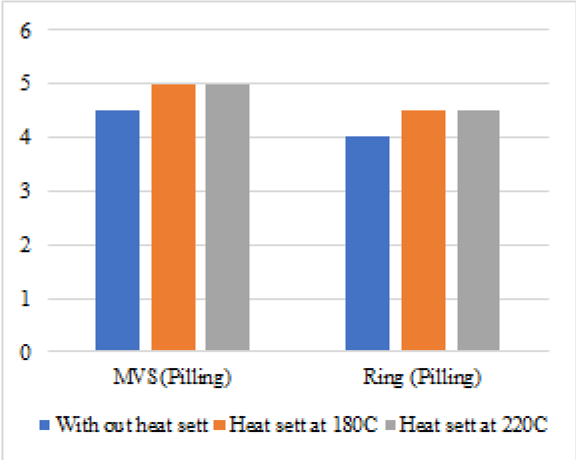

FIGURE 6. Pilling results of Jigger dyed fabric.

Rubbing Fastness

Dry and wet rubbing fastness of dyed samples was evaluated according to AATCC 8-2007 using a crock meter. The results are graphically shown in *Figure 7*. The rubbing fastness of fabric was measured under both wet and dry conditions. The obtained results show that dyed fabric did not exhibit any remarkable change by application of heat setting in both wet and dry conditions [27]. It is known that the heat setting affects the dye uptake but not the fastness properties of fabrics. That is why the heat set dyed fabrics showed similar results to the non-heat set dyed fabrics. This might be attributed to the fact that although less dye was taken by the fabric in terms of the k/s value; it is well penetrated, thus avoiding any fastness flaws. Rubbing fastness (wet) obtained from MVS fabric was better compared to ring spun fabric. A possible reason lies in the fact that MVS yarn has low packing densities and dye penetrates into the structure. The compact structure makes MVS yarn less vulnerable to rubbing at the surface. Therefore, the fabric showed very good crocking fastness.

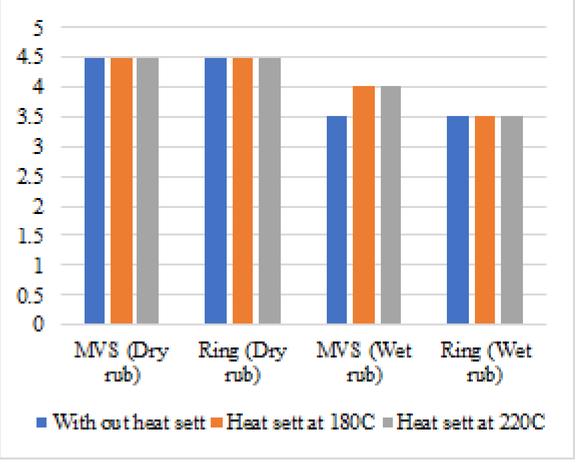

FIGURE 7. Rubbing Fastness results of Pad Thermosol dyed fabric.

Similar trends were observed on jigger dyed fabric as shown in *Figure 8*. Comparison of exhaust dyed and continuous dyed fabric shows that wet rubbing fastness of jigger dyed fabric is higher compared to continuous dyed fabric due to the fact that is a longer process, allowing higher penetration of dye. Dry rubbing fastness of both pad thermosol and jigger dyed fabric is same due do the absence of water, which acts as a carrier and hydrolyzes the dye in wet rubbing.

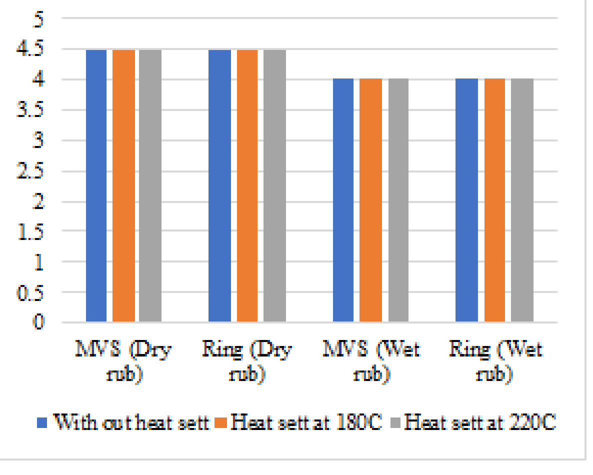

FIGURE 8. Rubbing Fastness results of Jigger dyed fabric.

CONCLUSION

In this study, woven fabric samples developed by conventional ring spun yarn and vortex spun yarn were used to investigate shade variation and performance characteristics. The influence of spun yarn manufacturing technique, heat setting and mode of dyeing were investigated in relation with shade depth, pilling resistance and rubbing fastness properties. Vortex spun yarn was found to be superior to ring spun yarn with respect of shade depth, hairiness values and wet rubbing fastness. The dry rubbing fastness of both fabrics was equivalent. The K/S (color efficiency) results indicate that vortex spun yarns have darker shades than ring yarn due to lower packing densities. This difference might due to more even yarn structure and lower hairiness values of vortex yarns. These results indicate that yarn hairiness and yarn surface regularity should be considered independently when evaluating dyed fabrics because the surface characteristics affect the reflectance values after dyeing. Heat setting also affects the shade depth.

FUNDING

The research has been carried out without any financial support.

DECLARATION

The authors declare that there is no conflict of interest.

REFERENCES

[1] Salhotra, K. R., "An overview of spinning technologies: Possibilities, applications and limitations", *Indian Journal of Fibre & Textile Research*, 17, 1994, 255-262.

[2] Oxenham, W., "Innovations in spun yarn technologies - Present and future", *Indian Journal of Fibre & Textile Research*, 31, 2006, 116-124.

[3] Oxenham, W., "Current and Future trends in yarn produciton", *Journal of Textile & Apparel Technology & Management*, 2, 2, 2002, 1-10.

[4] Gupta, N., "Analysis on the Defects in Yarn Manufacturing Process & its Prevention in Textile Industry", *International Journal of Engineering Inventions*, 2, 7, 2013, 45-67.

[5] Afroz, F., *et al.*, "Comparative study of mechanical properties, tpi , hairiness and evenness of conventional ring and modern rotor spun yarn", *European Scientific Journal*, 10, 33, 2014, 212-219.

[6] Ahmed, S., *et al.*, "Comparative Study on Ring, Rotor and Air-Jet Spun Yarn", *European Scientific Journal*, 11, 3, 2015, 1857-7881.

[7] Moučková, E., *et al.*, "Properties of viscose vortex yarns depending on technological parameters of spinning", *Autex Research Journal*, 15, 2, 2015, 138-147.

[8] Basal, G., "Effects of some Process Parameters on the Structure and Properties of Vortex Spun Yarn", *Textile Research Journal*, 76, 6, 2006, 492-499.

[9] Basal, G. and Oxenham, W., "Vortex spun yarn vs. air-jet spun yarn", *Autex Research Journal*, 3, 3, 2003, 96-101.
[10] Eldessouki, M., *et al.*, "Dynamic properties of air-jet yarns compared to rotor spinning", *Textile Research Journal*, 85, 17, 2015, 1827-1837.
[11] Erdumlu, N., *et al.*, "Investigation of Vortex Spun Yarn Properties in Comparison with Conventional Ring and Open-end Rotor Spun Yarns", *Textile Research Journal*, 79, 7, 2009, 585-595.
[12] Rameshkumar, C., *et al.*, "Comparitive studies on ring rotor and vortex yarn knitted fabrics", *Autex Research Journal*, 8, 4, 2008, 100-105.
[13] Zou, Z. Y., "Influence of the Yarn Formation Process on the Characteristics of Viscose Fabric Made of Vortex Coloured Spun Yarns", *Fibres & Textiles in Eastern Europe*, 23, 3(111), 2015, 58-63.
[14] Kilic, M., *et al.*, "Comparing the packing densities of yarns spun by ring, Compact and vortex spinning systems using image analysis method", *Indian Journal of Fibre and Textile Research*, 39, 2014, 351-357.
[15] Suzuki, Y. and Sukigara, S., "Mechanical and tactile properties of plain knitted fabrics produced from rayon Vortex yarns", *Textile Research Journal*, 83, 7, 2013, 740-751.
[16] Kilic, M. and Okur, a., "The properties of cotton-Tencel and cotton-Promodal blended yarns spun in different spinning systems", *Textile Research Journal*, 81, 2, 2011, 156-172.
[17] Farid, A. F. and Subramaniam, V., "Effect of Chemical Treatments on the Characteristics of Regular and Compact Cotton Spun Yarns", *International Journal of Research in Engineering and Technology*, 3, 11, 2014, 43-51.
[18] Kostajnšek, K. and Dimitrovski, K., "Comparative study on the properties of vortex and ring spun yarn and the properties of woven fabrics containing those yarns in weft", *Fibres and Textiles in Eastern Europe*, 24, 2, 2016, 59-65.
[19] Dinesh Bhatia, S. K. S., "Comparative assessment & empirical modeling for aesthetic behavior of vortex & ring yarn knitted fabrics on laundering", *International Journal of Fiber and Textile Research*, 4, 4, 2014, 62-70.
[20] Kim, H., "Wearing Performance and Comfort Property of PTT / Wool / Modal Air Vortex Yarn Knitted Fabrics", *Journal of the Korean Society of Clothing and Textiles*, 40, 2, 2016, 305-314.
[21] Mathur, K. and Seyam, A.-f. M., Color and Weave Relationship in Woven Fabrics, In: *Advances in Modern Woven Fabrics Technology* (Ed. Vassiliadis, S.), InTech: Croatia, 2011. pp. 129-151.
[22] Bhardwaj, S. and Juneja, S., "Performance of Jute Viscose / Polyester and Cotton Blended : Yarns for Apparel Use", *Studies on Home and Community Science*, 6, 1, 2012, 33-38.
[23] Rafique, S., *et al.*, "Colour fastness properties of polyester/cotton fabrics treated with pigment orange and various functional finishes", *Asian Journal of Chemistry*, 27, 12, 2015, 4568-4574.
[24] Ortlek, H. G., *et al.*, "Assessing colour differences of viscose fabrics knitted from vortex- , ring- and open-end rotor-spun yarns after abrasion", *The Journal of The Textile Institute*, 101, 4, 2010, 37-41.
[25] Wan, M. L., *et al.*, "Comparative study of colour yield of cotton knitted fabric made by torque-free ring-spun yarns", *Coloration Technology*, 126, 1, 2010, 18-23.
[26] Özdemir, H. and Oğulata, R. T., "Comparison of the properties of a cotton package made of vortex (MVS) and open-end rotor yarns", *Fibres & Textiles in Eastern Europe*, 19, 1(84), 2011, 37-42.
[27] Khandaker, S., *et al.*, "Scope of Polyester Cotton Blended Single Jersey Knit Fabric Finishing Without Heat Setting", *International Journal of Sientific Engineering and Technology*, 3, 6, 2014, 725-729.

AUTHORS' ADDRESSES
Khurram Shehzad Akhtar
Ali Afzal
Kashif Iqbal
Zahid Sarwar
Sheraz Ahmad
National Textile University
Materials & Testing
Sheikhpura Road
Faisalabad, Punjab 37610
PAKISTAN