# BEHAVIOR OF CELLULOSIC FIBERS AND CELLULOSIC FIBER DERIVATIVES IN KNITTED FABRIC PROPERTIES

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## Abstract

This study investigated the effect of bamboo fiber, which has recently begun to be commonly used in textiles, on some physical properties of knitted fabrics. In order to investigate the difference, the results are compared to that of similar fabrics produced from 100% viscose, 100% cotton and 100% mercerized cotton yarns. Every fabric type was knitted with three levels of loop length and two levels of fabric structure. At the end, fabrics were wet processing and followed the same finishing line. For the measured properties of fabrics, the fabric bursting strength, abrasion resistance, pilling, drapability, color difference and fabric shrinkage were evaluated. The results show that all the studied properties are dependent on the fiber type, fabric tightness, while, fabric structure had a significant effect on all the studied properties except the fabric pilling grade and color difference. Major findings were that cotton and mercerized cotton knits have better bursting strength and length dimensional stability than knits containing only bamboo or viscose fibers. Knitted fabrics from bamboo yarns tend to pill less and have better drapability. Bamboo knits exhibited superior dyeing absorption and aesthetic level. Single pique knitted fabric structure was found to result in less bursting strength than plain single jersey structure.

## Introduction

The growing consumer requests for textile products that give protection are comfort and environmentally friendly products. Therefore, there are many new developments in the textile production for the use of renewable and biodegradable resource [Gericke et al. 2010].

One of the newest developments in new fiber investigations is the use of bamboo fiber in different textile products that has been applied in hygienic products, geotextiles, filters, building construction, decorating items, land stabilization, industrial belts, furniture and high performance composite materials for the last many years [Erdumlu et al. 2008, Tyagi et al. 2011, Sekerden 2011, Majumdar et al. 2011and Svetnickienė et al. 2009].

Bamboo fiber is a kind of regenerated cellulose fiber and is taken from bamboo pulp, where it is extracted from the bamboo stem and leaves by wet spinning, including a process of hydrolysis alkalization and multi-phase bleaching that is quite like to that of viscose rayon fiber [Erdumlu et al. 2008, Gun et al. 2008, website of bambrotex and website of imgres].

Bamboo is one of the fastest growing plants and existing in great quantity in several countries. The raw material bamboo is widespread and well-selected from non-polluted regions in Yunnan and China and does not require replanting after harvesting due to the development of a vast root network. Bamboo yields 50 times as much fiber per acre as cotton [Gericke et al. 2010, Gun et al 2008, Erdumlu et al. 2008, Waite et al. 2011 and Rodie 2007].

Since the cross -section of the bamboo fiber is filled with unparalleled micro - structure, different micro-gaps and micro-holes, bamboo fiber clothing has high air permeability and can absorb and evaporate human sweat in a split second. Therefore, Bamboo textile products have high demands in the market. Additionally, it has an antibacterial character, eco-friendly, excellent temperature management properties, breathability, softness brightness and high flexibility under flexible and compressive levels. Regenerated bamboo cellulose fiber guarantees outstanding comfort in different applications. Currently, regenerated bamboo fibers are being used in apparels including intimate apparels, socks and sports textiles [Tyagi et al. 2011, Sekerden 2011, Majumdar et al. 2011 and Erdumlu et al. 2008].

Xu et al. (2007) analyzed the properties of bamboo viscose, Tencil and conventional viscose fibers to give an explanation the similarity and diversity in their molecular and fine structures. Viscose fibers are characterized by an irregular, serrated skin and cross section. The skin is said to consist of several small crystalline areas while the core develops a coarser crystalline structure. The density of cotton and bamboo fiber is identical (1.5 g/cm3). The bamboo fibers are having longer length than that of cotton fibers. In addition, the bamboo fibers have lower bending and torsional rigidity. Thus, they are more consistently and compactly twisted [Majumdar et al. 2011 and website of nearchimica].

Bamboo - based fabrics have low amount of pilling accumulation and creasing. Bamboo/cotton blend knitted fabrics have the lowest bursting strength and best pilling grade than Bamboo/viscose and Bamboo/Modal blend knitted fabrics [Sekerden 2011, Gun et al. 2008 and Alay 2010]. Nevertheless, Wang (2007) investigated the poor anti-pilling performance of bamboo pulp knitted fabrics where he applied anti-pilling finishing process of bamboo pulp knitted fabrics using cellulose treatment.

Although some sporadic efforts have been made to study and evaluate the properties of bamboo fiber blended yarns, there is a shortage of detailed research on the gamut of bamboo fabric properties. Therefore, the object of this work is to investigate the effect of bamboo fiber properties on some physical properties of knitted fabrics. The results are compared to that of similar fabrics produced from 100% viscose, 100% cotton and 100% mercerized cotton yarns.

Mercerization makes cotton easier to dye, produce brighter and fuller shades and enhances cotton with high luster. Moreover, it increases cotton fiber strength and improves its appearance and dimensional stability [Moghassem 2009, website of science in farming and website of fiberarts.org]. Also, enzymatic scoured and bleached knitted fabrics have enhanced softness, stitch density and thickness. After a number of launderings, the fabrics have higher weight, improved abrasion resistance and fewer tendencies toward pill creation [Mangovska 2004].

Stitch length, square root of linear density, machine gauge and twist factor affect the dimensional properties of the knitted fabrics where the stitch length is the dominating variable in influencing the dimensional behavior. Knit structure and fabric tightness seriously influence value of fabric shrinkage. There is a reverse proportion between fabric tightness and the lengthwise shrinkage while width shrinkage increases with the increased tightness factor as the laundering process continues [Singh 2011 and Onal 2003].

## Material and Methods

### Material

In this study, 30/1, 100 % bamboo, 100% cotton Giza 88, 100% Mercerized cotton (same cotton) and 100% viscose yarns were used to produce single jersey and single pique knitted fabrics. The properties of the Egyptian cotton Giza 88 used in this research work are given in Table 1. For the properties of the Bamboo and viscose fibers, the fiber length are 38 and 36.5 mm and the fineness are 1.4 and 1.52 dtex respectively. Moreover, table 2 shows the properties of the yarns applied in this work.

### Fabric Manufacture

The single jersey and single pique samples were knitted on the same single jersey knitting machine with 28 gauge Mayer & Cie, 15-inch diameter, 45 feeders and with total number of needles equal to 1320. The loop length was changed to produce three levels of knitted fabrics with different tightness level. Also, the yarn input tension was kept constant at a value equal to 5 CN.

All fabric samples were dyed in industry with a sky-blue color shade, and then finished through the same standard finishing line used for the knitting goods. Finally, the fabrics were compacted and each sample is separately heat set using the compressive shrinkage calendar to get the normal finishing targets. The sequence of wet processing was applied as follows: Overflow machine (Scour, half bleach, dye) followed by balloon squeezing Machine and then tubular dryer and finally compressive shrinkage calendar. Table 3 shows the specification and properties of the knitted fabric samples used in this study.

### Methodology

The influence of the experimental factors: yarn material, fabric structure and fabric loop length on the fabric bursting strength, abrasion resistance, pilling, drapability, color difference and fabric shrinkage was evaluated for significance using R statistical program through applying the ANOVA analysis .

**Fabric Testing**

After leaving the finished samples 72 hours in standard conditions (Relative humidity = 65 $\pm$ 2% - Temperature = 20 $\pm$ 2 c'), the fabric properties were measured. The fabric bursting strength and pilling was evaluated in accordance with the standards of ASTM D6797 and ASTM D3512 respectively. Furthermore, abrasion resistance and fabric shrinkage "after five washing times" were measured according to ASTM D4158 and AATCC 135-2003.

Drape coefficient was measured according to BSI 5058 by putting the sample on a circular disc and measure the radius of drapability at both sides of the disc. Then take the averages of the reading at both sides. The equation used to calculate the drape coefficient is:

Drape coefficient = $(r^2 - 56.25)/100$ (r = radius of drapability)

The color difference was evaluated on the data color instrument. Where, the reference sample which has been taken as a zero level to assess the color difference is the 100 % cotton, single jersey fabric sample having loop length equal to 2.9 mm.

Table 1. Fiber Properties

| | Len | Unif. % | Str | Elong. % | MIC | Rd | +b | Trash count | Maturity % |
|---|---|---|---|---|---|---|---|---|---|
| Egyptian Cotton Giza 88 | 35.2 | 86.9 | 44.7 | 3.7 | 3.92 | 66.4 | 11.6 | 52 | 84 |

Table 2. Yarn Properties

| | Bamboo 100% | Viscose 100% | Cotton 100% | Mercerized Cotton (Same Cotton) |
|---|---|---|---|---|
| Ne | 29.89 | 29.68 | 29.8 | 31 |
| TPI | 18.7 | 19 | 19.6 | 19.2 |
| Irregularity (CV %) | 9.41 | 9.5 | 10.9 | 9.5 |
| Thin places (-50%) | 0 | 0.5 | 0 | 0 |
| Thick places (+50%) | 18 | 19 | 8 | 10.8 |
| Neps | 51 | 48.5 | 60 | 55 |
| CN/Tex | 15.74 | 14.79 | 25.61 | 27 |
| Elongation (%) | 13.28 | 11.66 | 5.4 | 4.05 |
| Hairiness (H) | 4.88 | 6.5 | 6.2 | 6 |

Table 3. Fabric specification

| Sample Number | Fabric Structure | Loop Length (mm) | Yarn Material | Courses/ cm | Wales/ cm | Fabric Weight (g/m$^2$) | Fabric Thicknes s (mm) |
|---|---|---|---|---|---|---|---|
| 1 | Single Jersey | 2.65 | Bamboo 1oo% | 17.7 | 17 | 153 | 0.046 |
| 2 | Single Jersey | 2.9 | Bamboo 1oo% | 15.8 | 15.5 | 133 | 0.043 |
| 3 | Single Jersey | 3.15 | Bamboo 1oo% | 14.3 | 14 | 118 | 0.039 |
| 4 | Single Jersey | 2.65 | Viscose 100% | 19.1 | 16.1 | 140 | 0.043 |
| 5 | Single Jersey | 2.9 | Viscose 100% | 17.9 | 14.7 | 125 | 0.041 |
| 6 | Single Jersey | 3.15 | Viscose 100% | 16 | 13.3 | 114 | 0.038 |
| 7 | Single Jersey | 2.65 | Cotton 100% | 20.8 | 15.4 | 152 | 0.050 |
| 8 | Single Jersey | 2.9 | Cotton 100% | 18.3 | 14 | 143 | 0.046 |
| 9 | Single Jersey | 3.15 | Cotton 100% | 17.1 | 12.6 | 129 | 0.043 |
| 10 | Single Jersey | 2.65 | Mercerized Cotton 100% | 20.7 | 14.5 | 133 | 0.046 |
| 11 | Single Jersey | 2.9 | Mercerized Cotton 100% | 19.5 | 13.3 | 119 | 0.045 |
| 12 | Single Jersey | 3.15 | Mercerized Cotton 100% | 18.6 | 12 | 112 | 0.040 |
| 19 | Single Pique | 2.65 | Bamboo 1oo% | 19 | 14.9 | 159 | 0.052 |
| 20 | Single Pique | 2.9 | Bamboo 1oo% | 17.4 | 13.3 | 145 | 0.050 |
| 21 | Single Pique | 3.15 | Bamboo 1oo% | 16.1 | 12.3 | 127 | 0.047 |
| 22 | Single Pique | 2.65 | Viscose 100% | 20.5 | 14.4 | 153 | 0.050 |
| 23 | Single Pique | 2.9 | Viscose 100% | 19.2 | 12.9 | 141 | 0.048 |
| 24 | Single Pique | 3.15 | Viscose 100% | 17.6 | 11.6 | 122 | 0.044 |
| 25 | Single Pique | 2.65 | Cotton 100% | 21.6 | 13.5 | 167 | 0.056 |
| 26 | Single Pique | 2.9 | Cotton 100% | 20.2 | 12.2 | 148 | 0.053 |
| 27 | Single Pique | 3.15 | Cotton 100% | 18.3 | 11 | 144 | 0.049 |
| 28 | Single Pique | 2.65 | Mercerized Cotton 100% | 22.5 | 12.8 | 140 | 0.054 |
| 29 | Single Pique | 2.9 | Mercerized Cotton 100% | 21 | 11.4 | 125 | 0.051 |
| 30 | Single Pique | 3.15 | Mercerized Cotton 100% | 19.8 | 10.4 | 114 | 0.046 |

## Results and Discussion

The influence of the yarn material, fabric structure and fabric loop length on some fabric properties was assessed for significance using R statistical program through carrying out the ANOVA analysis as shown in table 4. Knowing that: S = Significant at 95% confidence level, NS = Non significant at 95% confidence level, B = Bamboo, V = viscose, C = cotton, M C = mercerized cotton, S J = single jersey and S P = single pique structure. It is clear from the statistical and experimental evaluations that all the physical properties: bursting strength, abrasion resistance, drapability, fabric shrinkage values are significantly affected at 5% significance level by fiber type, fabric structure and loop length except pilling grade and color difference which are significantly affected only by fiber type and fabric loop length.

Table 4. ANOVA test results

| Process factors | Fabric Properties | | | | | | |
|---|---|---|---|---|---|---|---|
| | Bursting strength | Piling grade | Abrasion resistance | Drapability | Color difference | Lengthwise shrinkage | Widthwise shrinkage |
| Fiber type | S | S | S | S | S | S | S |
| Loop length | S | S | S | S | S | S | S |
| Fabric structure | S | NS | S | S | NS | S | S |

S = Significant at 95% confidence level, NS = Non significant at 95% confidence level

**Fabric Busting Strength**

Comparing the values of bursting strength in relation to the fiber type used, it can be observed that fabrics made of 100 % cotton and 100% mercerized cotton yarns seems to have the highest values than bamboo fabric as observed in figure 1. This may be attributed to the fact that the bursting strength of the fabrics varies depending on the strength of the yarns. Also, this might be due to the smoothness of the Bamboo yarns which makes a low friction impact at the contact point between the loops and as a result the fabric will be easy to be penetrated and burst. While, the mercerized cotton fabric has a lower bursting strength than the pure cotton fabric, as a result for the drop in its yarn diameter after mercerizing operation in spite of its higher yarn strength.

Moreover, from the same figure, single jersey sample endured a higher bursting strength than the single pique structure. The single pique structure contains tuck loops which are more prone to penetrated easily through its small and week formed holes inside the fabric.

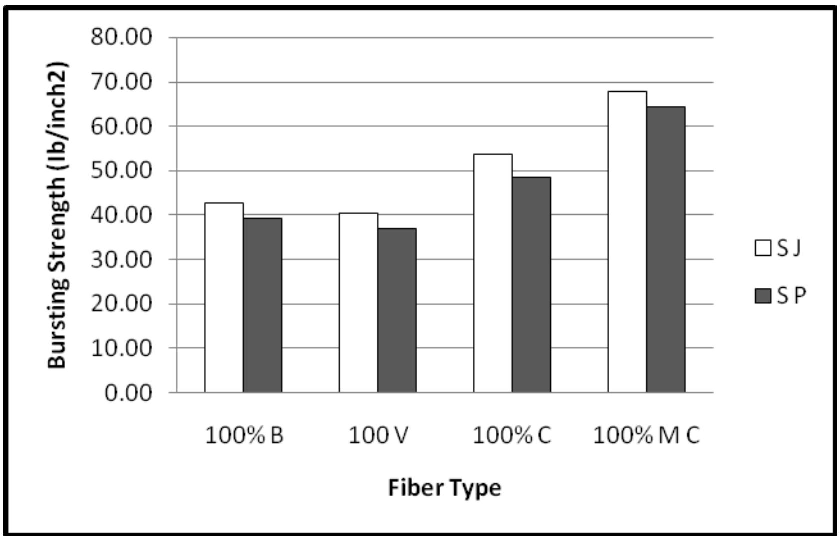


Figure 1 bursting strength values at different fiber type and fabric structure for medium fabric tightness

**Fabric Abrasion Resistance**

Fabric produced from 100% mercerized cotton and 100 % cotton samples have higher abrasion resistance values than the Bamboo fabric figure 2. Also, the variance analysis clearly indicates that the fiber material does play an important role in influencing abrasion resistance of studied fabrics. This case could be due to the higher tenacity of the yarns used to produce these fabrics than the Bamboo yarns. Besides, the cotton fabrics have the maximum hairy appearance while the bamboo fabrics have the least hairy level. Moreover, the bamboo yarns have lower bending rigidity, so the knitted loops can be compressed easily thereby reducing the fabrics thickness. Therefore, the fabrics knitted from bamboo fiber have a lower mass per square meter and thickness than others produced from cotton fibers. Additionally, the mercerized cotton fabric has a higher abrasion resistance than the pure cotton fabric, as a result for the improvement in its yarn tensile characteristics after mercerizing operation.

Because of its higher thickness, the *single* pique samples exhibits more abrasion resistance than single jersey fabrics. This trend is explained by the effect of the condensed loops which formed at the tuck points and help in increase fabric thickness and strengthen the ability of the abrasion resistance of this fabric.

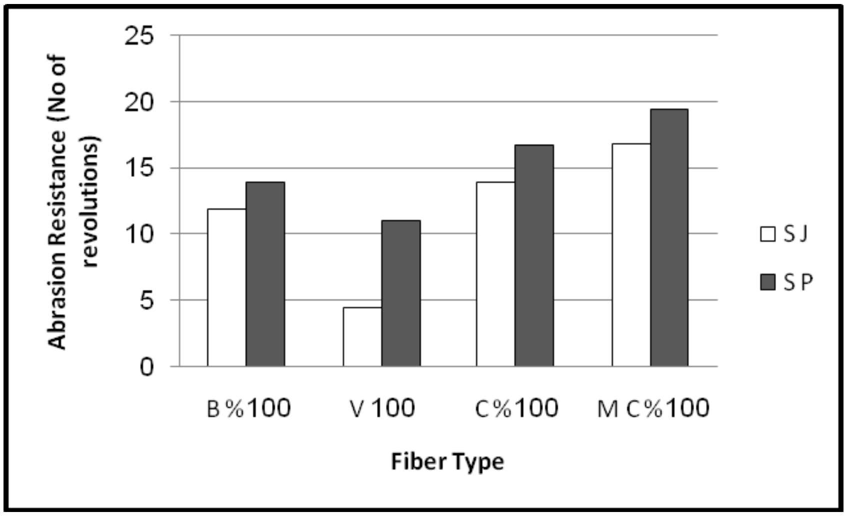


Figure 2 Abrasion resistance values at different fiber type and fabric structure for medium fabric tightness

**Fabric Drapability**

According to the statistical analysis and figure 3 there is a significant relationship between the fiber type and the fabric drape coefficient. Where, it is observed that the Bamboo fabric has the least drape coefficient against the other samples. The Bamboo fibers have a longer length than cotton and viscose fiber. Additionally, the Bamboo fibers have lower bending and torsional rigidity [Majumdar et al. 2011]. Hence, they are packed better inside the yarn structure than the cotton fibers. However, the least hairiness level, higher elongation and smoothness degree of the Bamboo yarns than the viscose, cotton and mercerized cotton yarns have enhanced the drape property of its knitted fabric. So, there is a high flexibility level for Bamboo fabric during end use which appears more during applying the drape test.

Fabric structure is a very important parameter from the point of view of fabric drapability. The sample contains tuck loops tend to be stiff during the drape test and this is the case for the single pique fabric.

The loop length has a great effect on the fabric drape coefficient as noticed in figure 4. As the loop length increases the fabric drape coefficient decreases. This is due to the fact that the decreasing of courses and wales density with the increase of loop length might me the cause for this decline, thus makes the fabric sample to drape easily during this test.

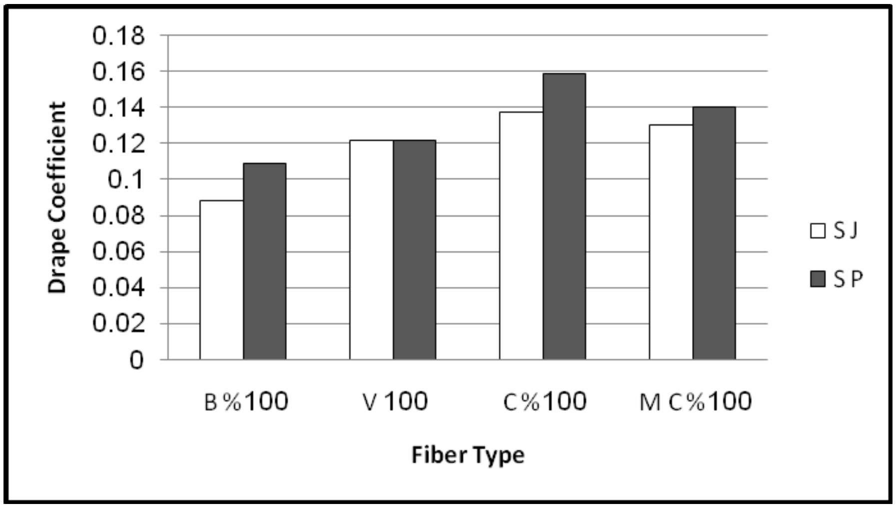


Figure 3 Fabric drape coefficient at different fiber type and fabric structure for medium fabric tightness

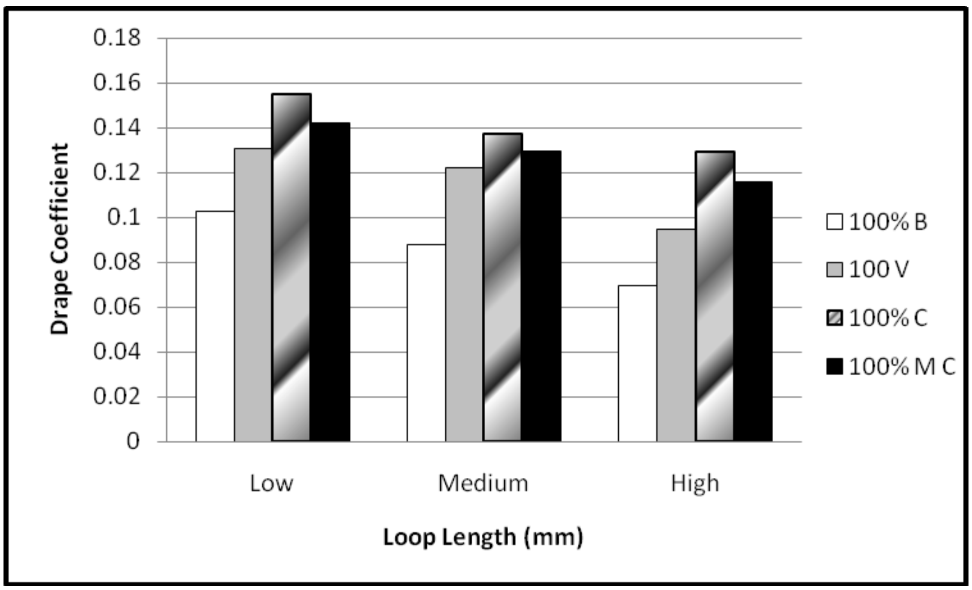


Figure 4 Fabric drape coefficient at different fabric loop length and fiber type for single jersey structure

**Fabric Pilling Grade**

From figure 5, it could be seen the values of fabric pilling grade with respect to fiber type for different fabric tightness. It is observed that as the knitted fabric produced from Bamboo yarn has a better pilling grade than other knitted from the other fiber types. As mentioned above, the possible reason of this is the lower hairiness level of the Bamboo yarn than the cotton yarn. Therefore, there is a lower friction degree during the end use of bamboo fabrics with any other surface and consequently these fabrics tend to form fewer pills. Additionally, the explanation for the pilling behavior can be that bamboo yarn has lower breaking strength and lower twist level, which makes the pills pull out of fabric surface easily.

As for mercerized cotton, the pilling grade is better than the 100 % pure cotton due to the singeing operation which decreases the hairiness percentage and the opportunity of the outside fibers to accumulate over the fabric surface and as a result minimizes the ability of the fabric to form the pills on its surface.

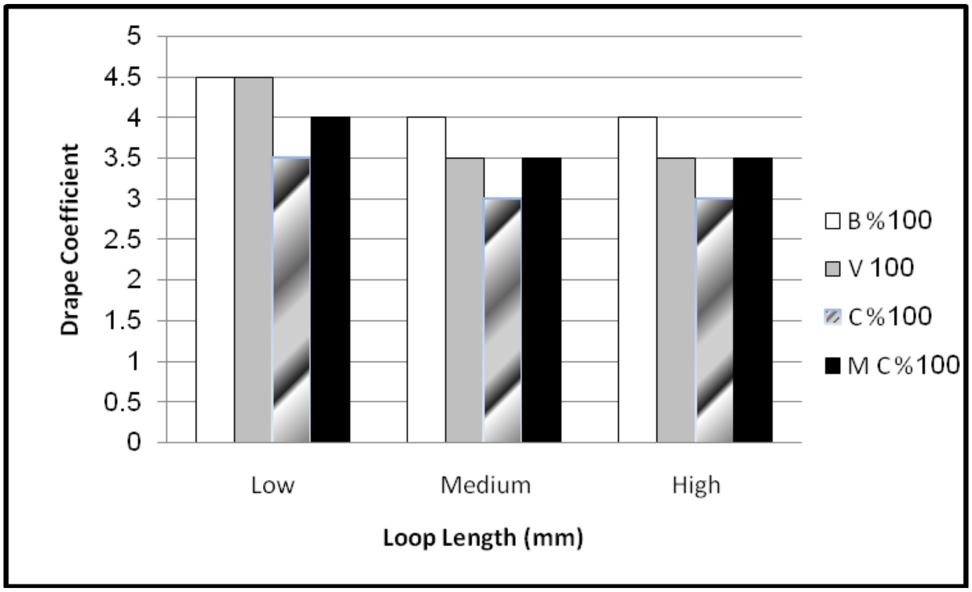


Figure 5 Pilling grade at different fabric loop length and fiber type
for single jersey structure

**Fabric Color Difference**

The results indicate that the color difference of the Bamboo sample is higher than the others produced from viscose, cotton and mercerized cottons as noticed in figure 6. The cross -section of the bamboo fiber is filled with unparalleled micro – structure and different micro-gaps, bamboo fiber clothing can absorb coloring agent by far. Bamboo exhibits fabric colors better than other fibers. When compared to cotton fabrics, bamboo fabrics require a lower amount of dye for the dying level required.

In addition, according to the same figure it could be observed that the mercerized cotton sample has a higher color difference than 100% pure cotton and this is owing to the absorption capability of the mercerized sample which increased after treating its yarn with NAOH during the yarn mercerizing process. Furthermore, this figure shows also that samples knitted from 100 % cotton -single jersey has zero color difference. This sample is the reference sample which is taken as a zero level to measure the color difference for all samples.

Furthermore, figure [6] illustrates the effect of loop length on the fabric color difference. It is cleared that as the loop length decreases the color difference increases. The tightest fabrics for all fibers types possess the highest quantity of material and high fabric thickness. This could be the reason for that tendency, which leads to an increase in absorbed dyestuff.

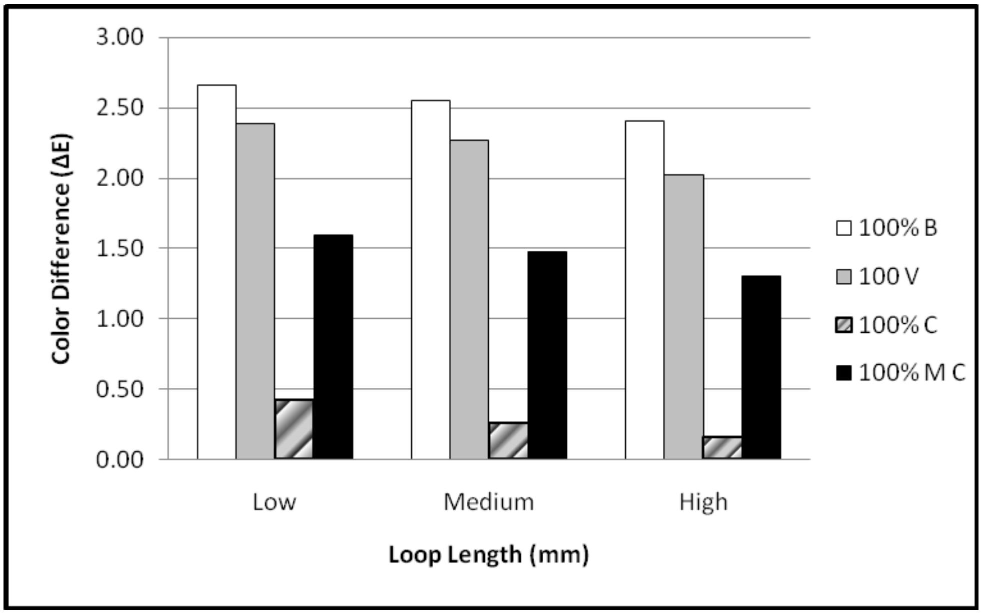


Figure 6 Color difference at different fabric loop length and fiber type for single pique structure

**Fabric Shrinkage**

The relation between the fabric lengthwise shrinkage after fifth wash with the fiber type is shown figure 7. The high elongation value and moisture absorption capacity of bamboo fiber can result in high shrinkage during wet processing. The higher elongation of bamboo fibers makes the yarn more extensible when it is applied inside the fabric to any lengthwise stress load during dyeing stage. The mercerized cotton fabric has the least lengthwise shrinkage due to its bulkiness and higher courses density. The mercerization process improves dimensional stability of knitted fabric [Moghassem 2009].

As mentioned before, it is clear that single pique fabric has higher courses density than single jersey sample which related to the more tuck loops contained on its structure than the plain single jersey fabric. Consequently, it leads to an increase in the fabric width and a decrease in the fabric length.

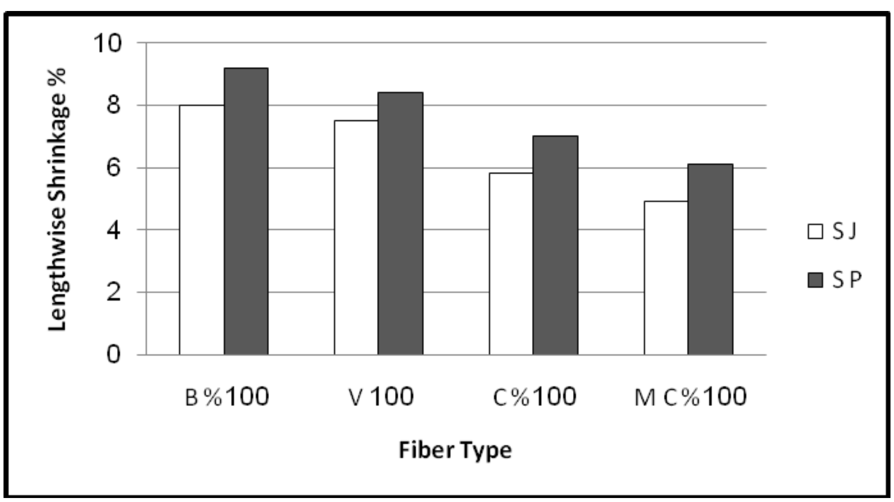


Figure 7 Lengthwise shrinkage at different fiber type and fabric structure for medium fabric tightness

It has been noticed that the Bamboo fabric tends to have less widthwise shrinkage than the other fiber samples, figure 8. This might be clarified by the effect of the thermosetting which applied for the samples during finishing them inside the compressive shrinkage calendar attached with a Teflon sheet.

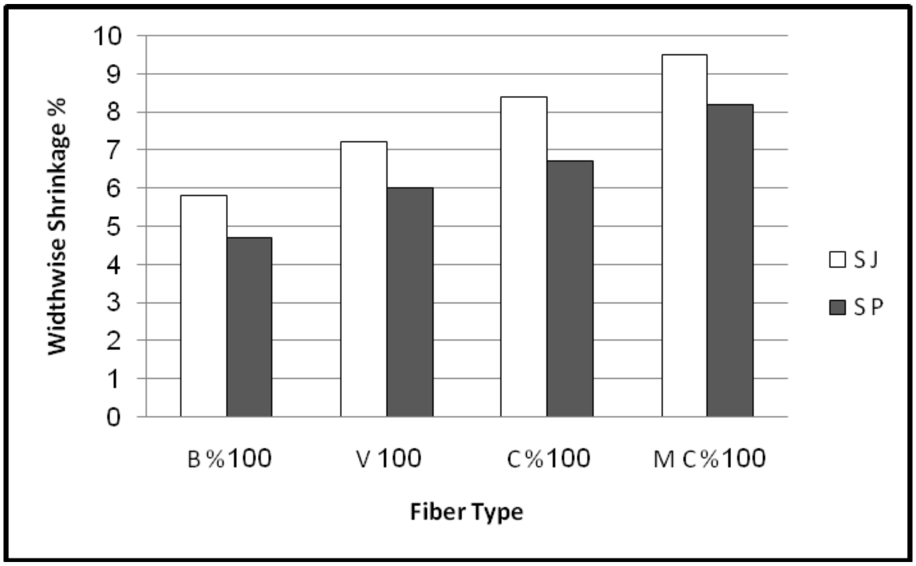


Figure 8 Widthwise shrinkage at different fiber type and fabric structure for medium fabric tightness

## Conclusions

In this research paper, physical properties of single jersey and single pique knitted fabric structures produced from bamboo fibers with different fabric tightness were studied. In order to investigate the difference, the results are compared to that of similar fabrics produced from 100% viscose, 100% cotton and 100% mercerized cotton yarns (produced from the same cotton).

It is clear from the statistical and experimental evaluations that all the physical properties: bursting strength, abrasion resistance, drapability, fabric shrinkage values are significantly affected by fiber type, fabric structure and loop length except pilling grade and color difference which are significantly affected only by fiber type and fabric loop length.

The fabrics knitted from 100 % cotton and 100% mercerized cotton samples seem to have the highest values of bursting strength and abrasion resistance than bamboo fabric. This might be due to the higher tenacity of these yarns and the smoothness of the Bamboo yarns which makes a low friction impact at the contact points between the loops.

Single jersey sample endured a higher bursting strength than the single pique structure. The single pique structure contains tuck loops which are more prone to penetrated easily through its small and week formed holes inside the fabric.

Although, this structure exhibits more abrasion resistance than single jersey fabrics due to the effect of the condensed loops which formed at the tuck points and help in increase fabric thickness and strengthen the ability of the abrasion resistance of this fabric.

The bamboo fabric has the least drape coefficient against the other fiber samples. The bamboo fibers have a longer fiber length, lower bending and torsional rigidity than cotton fiber. Hence, they are packed better inside the yarn structure and this enhanced the drape property of its knitted fabric.

The knitted fabric produced from Bamboo yarn has a better pilling grade and higher color difference than other knitted from the other fiber types. The explanation for the pilling behavior can be that bamboo yarn has lower hairiness level, lower breaking strength, and lower twist level, which makes the pills pull out of fabric surface easily. The cross -section of the bamboo fiber is filled with unparalleled micro – structure and different micro-gaps, bamboo fiber clothing can absorb dyestuff by far.

While for the mercerized cotton the pilling grade and color difference are better and higher respectively than the 100 % pure Cotton and this is due to the singeing operation and alkaline treatment applied for the mercerized cotton yarn.

The high elongation value and moisture absorption capacity of bamboo fiber results in high lengthwise shrinkage and less widthwise shrinkage after wet processing. The mercerized cotton fabric has the least lengthwise shrinkage due to its bulkiness and higher courses density.

With the increasing of fabric tightness, the bursting strength, brasion resistance, fabric drape coefficient, pilling degree and widthwise shrinkage are decreasing while the lengthwise shrinkage is increasing for the studied fabric structures.

Because of the different structural properties of the fabric samples selected, the results are appropriate only for these particular conditions. The reader should be cautioned that these assessments are only to provide a general opinion.

## Acknowledgements

I am grateful to the co-operation of El Nasr Clothing and Textile Company (*KABO*) for their support and contribution to use their production and testing facilities. Also, I would like to express my thanks to Mr. Osman AY, the Country Manager of CSA textile for his helpful contribution in providing the Bamboo yarn which helped us to introduce new and unusual material.

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