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ORIGINAL ARTICLE

Moisture properties of raised 3-thread fleece fabric knitted with different face and fleecy yarns

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Abstract The sportswear sector in textile industry has expanded on the worldwide and the producers and wearers want to indicate their comfort performance in addition to the aesthetic demands. Sportswear should possess good moisture transmission property. Moisture flow through various materials is a complex phenomenon as in three-thread fleece knitted fabric produced with different face and fleecy yarn material.

So, in this study, nine three-thread fleece fabrics of different composition materials have been studied, where these knitted fabrics are produced in a special circular knitted machine. The developed fabrics are taken to measure, water vapor permeability "WVP", gain%, air permeability, drying time, color difference, immersion time and bursting strength. The test results were discussed statistically with single factor ANOVA. From the experimental results, it has been observed that the difference between face and fleecy yarns material was highly significant for the whole fabric in the water vapor permeability, gain%, color difference and immersion time. Three-thread Fleece fabric knitted with Egyptian cotton for the face and fleecy yarns has the maximum bursting strength compared to other samples having Bamboo and Tencel yarns.

1. Introduction

Moisture management is one of the main performance criteria in today's garment manufacturing and is defined as the ability of an apparel to transfer moisture away from the skin to the cloth's external surface. The human body produces moisture in the form of sweating, this perspiration should be taken away the surface of skin to the attached clothing. The fabric should permit moisture to be transferred from the skin to the weather so as to refresh the body [1].

Moisture transfer is a serious factor in regulation of body temperature. This action prevents perspiration from remaining next to the skin [2]. The moisture in skin and cloths raises the heat loss beside that, it influences the body comfort and general performance [3]. After the human body has stopped perspiring, the fabric should let off the detained vapor to lessen the humidity on the skin surface. Prahsarn et al. [4] investigated the influence of fiber cross section, fabric areal density,

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thickness, and porosity on moisture vapor transference properties of the fabrics.

Zhang et al. [5] concluded that the air and water vapors go through a fabric in various ways. In general, textile fibers, regardless of their chemical structure, are impermeable to air and thus the crossing of air over a fabric can only happen through voids between fibers and between yarns.

Air and water vapor transport properties are mostly associated with heat and moisture transfer features of textile material [1]. The WVP of a fabric acts as a key role in determining the apparel comfort and keeping human body comfort [6]. Water vapor gets into textiles due to water vapor concentration differences, while fibers absorb water vapor related to their chemical structure. Therefore, once fabrics have similar structures but vary in fiber type, it shows dissimilarity in WVP [7]. The WVP is mostly affected by the air gaps circling the fibers in both yarns and fabrics. These air gaps make a resistance to the flow of moisture from one side to the other side of the fabric [8]. The WVP of garment materials is an important property for maintaining clothing thermal equilibrium for the wearer. Garment with high WVP gives the human body an improvement in its ability to offer cooling due to sweat production and evaporation. High WVP is also essential to avoid or lessen water build-up in garment leading to feel uncomfortable [7,9].

There are several important factors affecting the permeability properties of the textile fabrics such as fiber orientation, morphological structure, fiber material, yarn flattening, yarn structure, fabric loop length, fabric thickness, tightness factor and fabric structure [10,11]. The air permeability of the fabrics produced from natural yarns is more than textured polyamide, above elastane knitted socks [12].

The interactions of yarns and fabrics with liquids rely on the chemical structure of the fiber, liquid properties such as viscosity and surface tension. The mechanism by which moisture is transported in textiles (wicking) depends on the fiber-liquid molecular attraction at the surface of fibers, which is determined at most by fiber's diameter, surface tension and capillary pore distribution. Wicking in a fabric can take place in two different ways, transverse wicking (perpendicular to the plane of the fabric) and longitudinal wicking (along the plane of the fabric) and it occurred on a perspiring body [13,14].

The surface energy in a textile fabric depends mostly on the chemical structure of the exposed surface of the fiber, where hydrophilic fibers have a high surface energy and therefore they pick up moisture more easily than hydrophobic fibers. On the contrary, hydrophobic fibers, have low surface energy and repel moisture. As a result, special finishing treatments can be applied to lessen the difference in surface energy between the face and back of the fabric in order to improve its ability to wick [15].

With the advanced technology, new regenerated fibers such as Tencel LF, Tencel STD and Bamboo and their blends with natural cotton fibers are making a comeback in high-performance, outdoor activities.

Tencel "Lyocell" fibers are characterized by their great strength in both dry and wet states. In wet state, Lyocell keeps 85% of its dry strength and considered as the only man-made cellulosic fiber which is stronger than cotton when wet. Tencel fibers absorb moisture and have a high modulus that leads to small shrinkage in water. Therefore garments exhibit good stability when washed. Lyocell fibers are famous by their particular ability to fibrillate in a wet state under the influence of external mechanical processes [16–18]. In addition, fabrics in Tencel are characterized by their silk touch, unique drape and fluidity. Fabrics with Tencel fiber wefts showed better crease resistance and air permeability in comparison with fabrics with cotton and viscose wefts [19].

Natural Bamboo fibers have numerous groves, cracks, voids and micro-holes on the surface that affect the capillary property. Bamboo viscose is now known for its antibacterial properties. The main feature of bamboo material is its unbelievable capability to breathe and genuine coolness, lovely luster, superior drape and extremely comfortable soft feel [20–23].

The Three-Thread Fleece fabrics have relatively high mass and thickness and are widely used as an outdoor garment for active and sportswear. Sportswear should possess good liquid moisture transmission property. So, our goal is to develop an optimized sportswear in order to transport humidity to the outer surface as quickly as possible, to evaporate the humidity as fast as possible for making the skin feel dry. Therefore, in this present study, nine three-thread raised fleece fabrics of different inner and outer layer yarn materials have been studied, where these fabrics are produced in a special circular knitted machine. The developed fabrics are taken to measure water vapor permeability, gain%, air permeability, drying time, color difference and time of immersion.

2. Material and methods

2.1. Material

In this study, 30/1, 100% Tencel LF, Tencel STD, Bamboo and Egyptian cotton yarns were used. Also, 20/1, 100% Tencel LF, Bamboo and Egyptian cotton yarns were used with previous yarns to knit three-thread fleece knitted fabrics. The properties of Tencel LF, Tencel STD, Bamboo and cotton fibers are cleared in Tables 1 and 2. Additionally, the properties of the yarns applied to produce all fleece fabrics are shown in Table 3.

2.2. Fabric manufacture

The structure of the three-thread fleece fabric is formed from back fleecy yarn, binding yarn and face yarn and is shown in Fig. 1. This structure is manufactured on special single-jersey circular knitting machine with 20 gauge, Mayer & Cie, MLBF model, 30-in. diameter, 96 feeders and with total number of needles equal to 1872. The loop length was kept constant at 3.97 mm for all face and binding yarns, and at 1.59 mm for all fleecy yarns. The yarn feeding tension was adjusted at 5 CN.

Furthermore, Fig. 2 shows the development view of the 3 consecutive cam segments and the arrangement of the 4 needles types used for producing this fabric structure.

After knitting process, all gray three-thread fleece fabric samples were finished according to the flowchart indicated in Fig. 3. The information about the experiments studied in this research is revealed in Table 4, where yarn material for face, binding and fleecy yarns is determined for every sample.

Table 1 Cotton fiber properties.

	Length	Uniformity (%)	Strength	Elongation (%)	MIC	Rd	b+	Neps (g)	Maturity (%)
Cotton Giza 86	32.5	87.1	45	5.8	4.4	76	8	64	95

Table 2 Regenerated fiber properties.

Fiber type	Fiber length (mm)	Fiber fineness (dtex)
Tencel LF	38	1.3
Tencel STD	38	1.3
Bamboo	38	1.56

2.3. Methodology

The influence of the fiber material for the face and fleecy yarns of the three-thread fleece on the fabric water vapor permeability, gain%, air permeability, drying time, color difference, immersion time and bursting strength was evaluated for significance using single factor analysis of variance.

2.4. Fabric testing

After leaving the fleece samples 72 h in standard conditions (Relative humidity = 65 + 2% – Temperature = 20 + 2 c′), the fabric properties were measured.

The fabric water vapor permeability, gain%, air permeability, bursting strength and immersion time were evaluated in accordance with the standards of ASTM E96, BS 3449, ASTM D737, ASTM 6797 and "Textile testing by Jewel, Jewel Raul, 2005, page 58, sinking test" respectively.

For the drying time test, fleece fabrics were first cut into circular samples of 100 cm^2 and then wetted with 1 ml of distilled water dropped onto it using an accurate dropper whose tip was 10 mm directly above the fabric surface. The remaining water ratio (RWR) and the drying time of fabrics were evaluated. For measuring, the drying rate, the samples were weighted in the dry state (dry weight - W_f) using an electronic balance and instantly after wetting (wet weight at the initial stage - W_0). The change in weight (W_i) was recorded at 10 min intervals and the remaining water ratio (%) was then calculated, for each interval, using the following equation:

$$\text{Remaining water ratio (RWR\%)} = (W_i - W_f) * 100/(W_0 - W_f)$$

The remaining water ratios were used to express the drying ability of the fabrics as wetted by sweat [24].

3. Results and discussion

The specifications of all the knitted fabric samples are shown in Table 5. Also, the effect of the fiber material for the face and fleecy yarns of three-thread fleece on some comfort fabric properties was discussed for significance using ANOVA analysis.

Scanning Electronic Microscope (SEM) analysis was performed for all Three-Thread fleece samples for the face and back side. This microscopic inspection was carried out to inspect the surface features of the fabrics. SEM microscopic views for samples numbers 3, 7, 8 and 9 seen in Fig. 4 "from a to h" displayed that the best compactness is cleared after using Tencel and Bamboo material. It was as well shown that three-thread fleece samples contained Tencel STD ground "face" yarns seemed to be peach skin touch with dark shade than other samples contained ground Egyptian cotton yarns.

From the statistical and experimental evaluation, all the studied properties: water vapor permeability "WVP", gain%, air permeability, color difference (ΔE), immersion time and bursting strength values are significantly affected at 5% significance level by yarn material for the face and fleecy yarns.

3.1. Water vapor permeability

Water vapor permeability is the ability to transmit vapor from the body. The sweat from the body is to be removed from the surface of the skin to the atmosphere via clothing (next to skin). Surrounding temperature, humidity and the moisture resistance of garment are the leading factors that determine the evaporation rate of sweat from the body surface. If the moisture resistance is excessively high, because of the worse

Table 3 Yarn properties.

	Cotton 100%	Bamboo 100%	Tencel LF 100%	Tencel STD 100%	Cotton 100%	Bamboo 100%	Tencel LF 100%
Ne	30/1	30/1	30/1	30/1	20/1	20/1	20/1
TPI	20.8	19.1	19.1	19.1	18	19.1	19.1
Irregularity (CV%)	11	9.41	9.50	8.76	9.54	6.72	7.36
Thin places (−50%)	0	0	0	0	0	0	0
Thick places (+50)	4	18	16	6	27	4	18
Neps	6	51	48	24	18	8	27
CN/Tex	18.5	15.74	22.41	26.94	21.13	17.27	23.14
Elongation (%)	5.8	13.28	7.17	10.12	4.78	8.30	7.87
Hairiness (H)	5.9	4.88	5.85	5.60	8.02	5.09	6.79

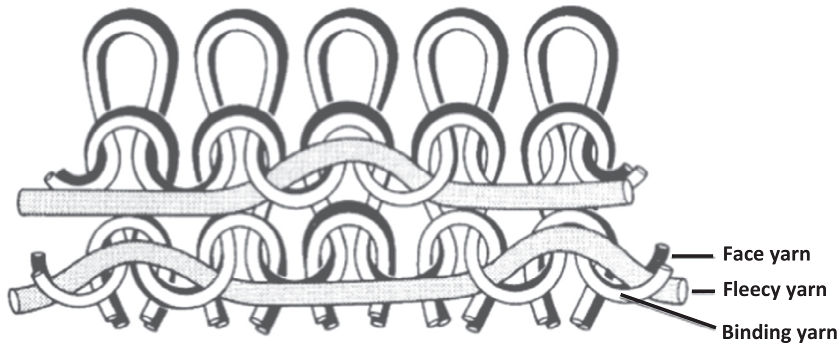


Figure 1 Three-thread fleece structure.

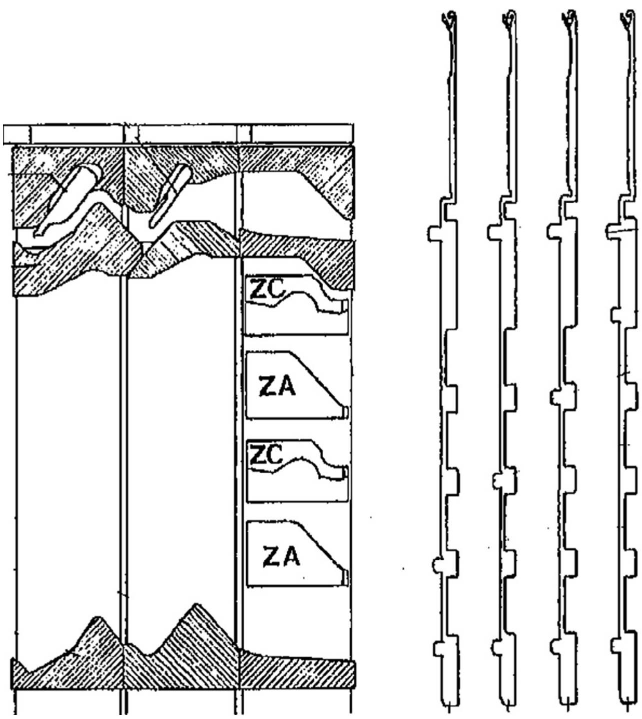


Figure 2 Three consecutive cam segments and arrangement of the 4 needle types used for producing 3-thread fleece structure.

rate of evaporation, the stored heat in the body could not go out which causes an uncomfortable feeling [12].

ANOVA shows significant difference in the water vapor permeability of fleece fabrics knitted with different face and fleecy yarn materials [$F_{1322.74} > F_{\text{critical}}$], Table 6. Also, Fig. 5 shows the relation between water vapor permeability and different yarn materials of face and fleecy yarns. The kind of raw materials in three-thread fleece fabrics is an important factor. For the fabrics knitted from regenerated yarns for the face and fleecy yarns, it could be noticed that these fabrics have the maximum WVP which refer to their low thickness, weight "g/m^2", high smoothness and absorbency. The fabric thickness and weight serve as important factors since they control the distance through which the moisture vapor and heat pass in traversing from one side of the fabric to the other surface of the fabric. Moreover, in convection mass flow, mass flow rate is directly related to the surface area beside the direction of the flow, where the principle of water vapor permeability test is matched with the convection mass transfer law. Therefore, higher fiber surface area of channeled structure for Tencel and Bamboo fibers improves water vapor permeability features.

Moreover, for the fleece fabrics produced from Tencel STD yarns located for the face only, the WVP is the highest and this is due to the peach skin feeling of the Tencel STD which improves the wettability of the produced fabric. Also, the lower thickness of this fabric supports this trend.

Furthermore, we can find out that higher thickness fleece fabrics knitted from Egyptian cotton yarns for the face and fleecy yarns have the least capability of water vapor permeability. The WVP of the 100% cotton fabric cuts down with time on account of swelling behavior of its hygroscopic fiber. The swelling phenomenon of the cotton materials, blocks the pores in its structure, as a consequence of moisture absorption. As a result, this swelling influences the vapor transmission by spreading over the time period [25].

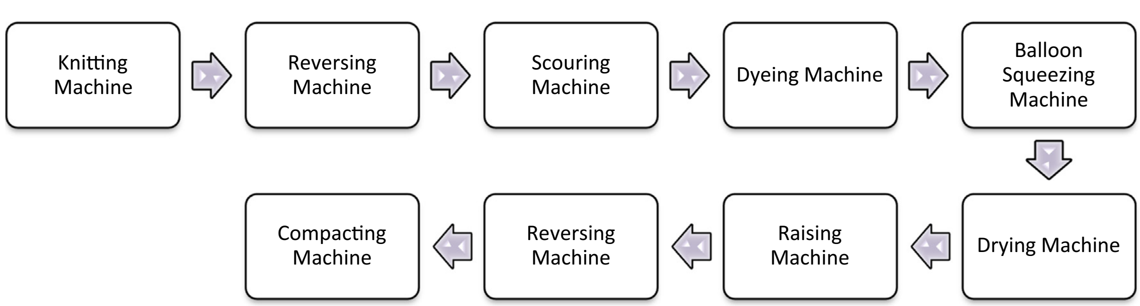


Figure 3 Flowchart of producing 3-thread fleece fabrics.

Table 4 Design of experiments.

Sample no.	Face yarn	Binding yarn	Fleecy yarn
1	30/1 100% cotton	30/1 100% cotton	20/1 Tencel LF %100
2	30/1 100% cotton	30/1 100% cotton	20/1 Bamboo %100
3	30/1 100% cotton	30/1 100% cotton	20/1 100% cotton
4	30/1 Tencel LF %100	30/1 100% cotton	20/1 100% cotton
5	30/1 Tencel STD %100	30/1 100% cotton	20/1 100% cotton
6	30/1 Bamboo %100	30/1 100% cotton	20/1 100% cotton
7	30/1 Bamboo %100	30/1 100% cotton	20/1 Bamboo %100
8	30/1 Tencel LF %100	30/1 100% cotton	20/1 Tencel LF %100
9	30/1 Tencel STD %100	30/1 100% cotton	20/1 Tencel LF %100

Table 5 Specification of the three-thread fleece knitted fabric samples.

Sample no.	Yarn material "Face/Binding/Fleecy"	Courses (cm)	Wales (cm)	Fabric weight (g/m^2)	Thickness (mm)
1	Cotton/Cotton/Tencel LF	11.5	14.2	302	0.938
2	Cotton/Cotton/Bamboo	11	14.5	297	0.928
3	Cotton/Cotton/Cotton	12	14	332	0.978
4	Tencel LF/Cotton/Cotton	10.8	15.2	316.0	0.965
5	Tencel STD/Cotton/Cotton	11.7	14.6	324.8	0.988
6	Bamboo/Cotton/Cotton	10.6	15.2	309	0.957
7	Bamboo/Cotton/Bamboo	10.3	15.9	282	0.918
8	Tencel LF/Cotton/Tencel LF	10.5	15.6	285	0.925
9	Tencel STD/Cotton/Tencel LF	11	15	291	0.95

3.2. Gain%

The relation between the percentage of water gain for the fleece fabric with different yarn materials of the face and fleecy yarns is shown in Fig. 6. Generally, the structure of any fiber contains crystalline and amorphous regions. The water gain of the fabric depends on the percentage of amorphous region and its location. Accordingly, in general, this figure could be divided into 3 groups:

For the 1st group, which represents three-thread fleece samples having regenerated yarns for the face and back of the fabric, it could be noticed that this group has the least gain% which refers to the high absorbency and moisture management of these types of fabrics. The more amorphous region constitutes of these fibers materials attract water molecules. Therefore, their yarns have the ability to absorb water and get rid of it very fast. This is a very important property for the sportswear, underwear and medical garments.

Also, for the 2nd group which has regenerated yarn for the fabric back only, the fleecy yarn absorb the water first and cannot take all the water out of the fabric due to the location of the cotton yarn on the fabric face. So, the water goes out slower than the 1st group.

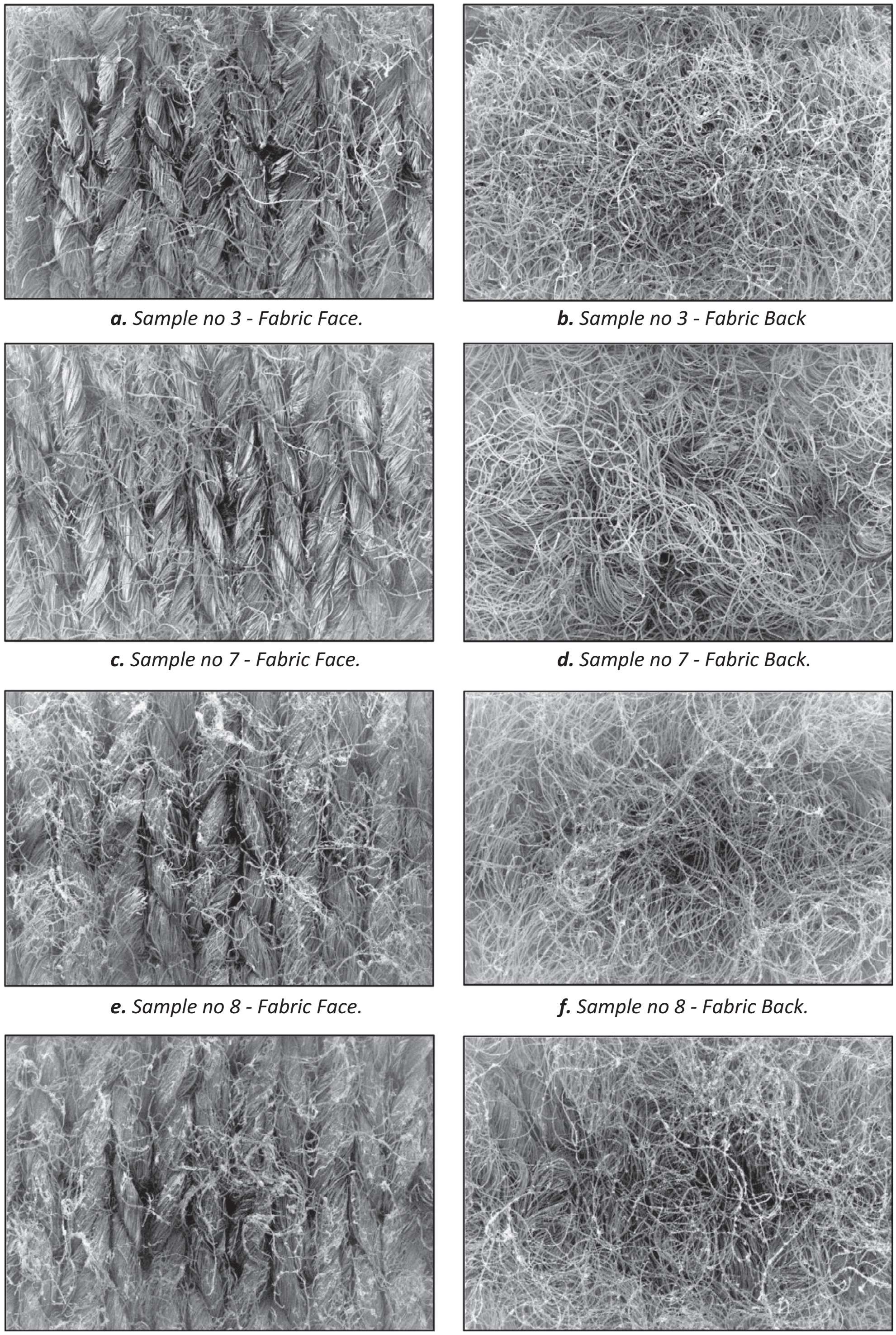
Finally, for the 3rd group, representing thread-thread fleece fabrics having cotton yarns on the fabric back, the water is absorbed by the thicker cotton yarn "20/1" and cannot go out quickly of the fabric in spite of the location of regenerated yarn on the fabric face for most samples of this group. The binding cotton yarn blocks the water to reach the fabric face causing the water to accumulate inside the fabric.

Furthermore, the analysis of variance (ANOVA) confirmed that there is a significant difference in the test results obtained from 3-thread fleece fabrics having different face and fleecy yarn materials, where Table 7 shows the *F*-value is greater than *F*-critical value (868.12 > 2.208).

3.3. Air permeability

The air permeability of a fabric can influence its comfort behavior in several ways. An air permeable material is, generally, likely to be permeable to water in either the vapor or the liquid phase. Thus, the moisture vapor permeability and the liquid moisture transmission are normally closely to air permeability.

ANOVA displays significant difference in the air permeability of fleece samples knitted with different face and fleecy yarn materials [$F_{670.938} > F_{critical}$], Table 8. Moreover, Fig. 7 shows the air-permeability values of all the three-thread fleece fabrics under study. The results show that fabrics knitted with Tencel STD face yarn/Tencel LF fleecy yarn are the most permeable to air. Air permeability is an essential property of textiles which impacts the flow of vapor from the human body to the environment and the flow of fresh air to the body. The results exhibited that for a fabric of given composition, the air permeability increases as the fabrics become thinner. The improvement is more marked when the Tencel STD fiber is used. It may be noted from Table 8 that the thickness and weight of this fabric sample are low. They are also lower than those of the fabric made from cotton for the face and fleecy yarns.



a. *Sample no 3 - Fabric Face.*
b. *Sample no 3 - Fabric Back*
c. *Sample no 7 - Fabric Face.*
d. *Sample no 7 - Fabric Back.*
e. *Sample no 8 - Fabric Face.*
f. *Sample no 8 - Fabric Back.*
g. *Sample no 9 - Fabric Face.*
h. *Sample no 9 - Fabric Back.*

Figure 4 Microscopic inspection SEM analysis for some samples on the face and back side.

Furthermore, among the fleece fabrics, which have different yarn compositions in their both sides, the cotton face/Tencel LF fleecy yarn fabric, has higher air permeability than cotton face/Bamboo fleecy yarn fabric, as expected. The raising reduces more the air permeability of Bamboo fleece fabrics because of the increased air gap of the bamboo fibers accompanied with their coarser fiber size "1.56 dtex".

3.4. Drying time

To study the fabric ability to lose water, the drying time experiment was carried out. The drying properties of the fabrics samples as shown in Fig. 8, indicated that three-thread fleece fabrics having cotton yarns on the fabric back only have poorer drying properties. This could be due to the fact that

Table 6 ANOVA single factor data analysis for WVP.

Source of variation	SS	df	MS	*F*	*P*-value	*F* crit.
Between fabrics	48277.20	8	6034.6500	1322.74	4.50643E−59	2.1152
Within fabrics	246.360	54	4.5622			

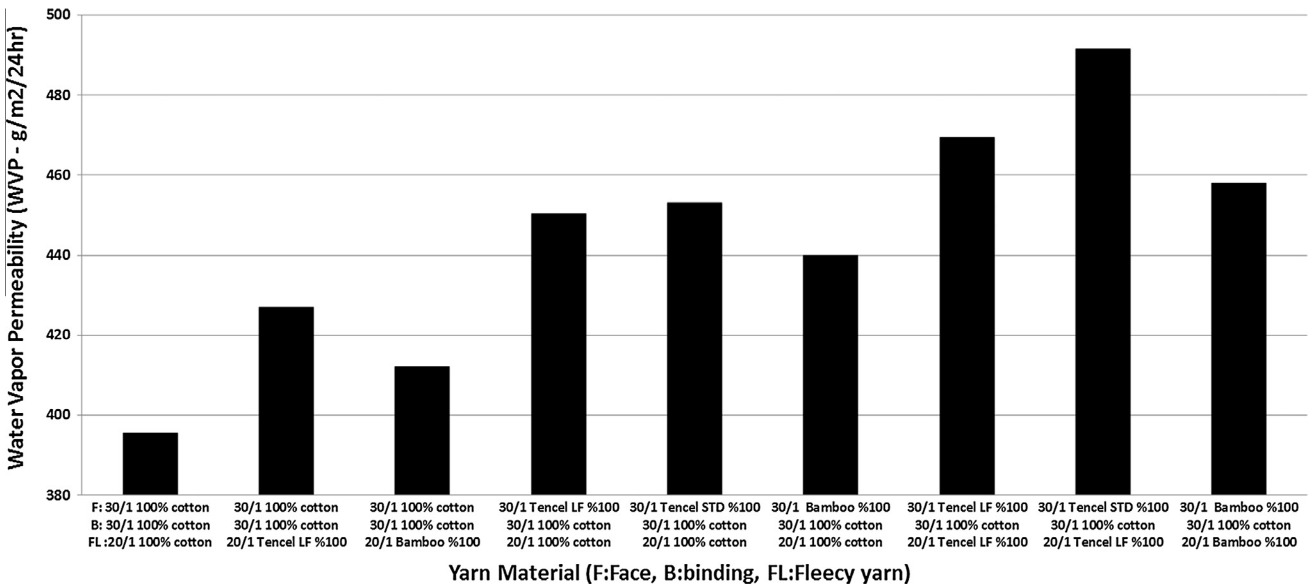


Figure 5 Water vapor permeability at different yarn materials of face and fleecy yarns.

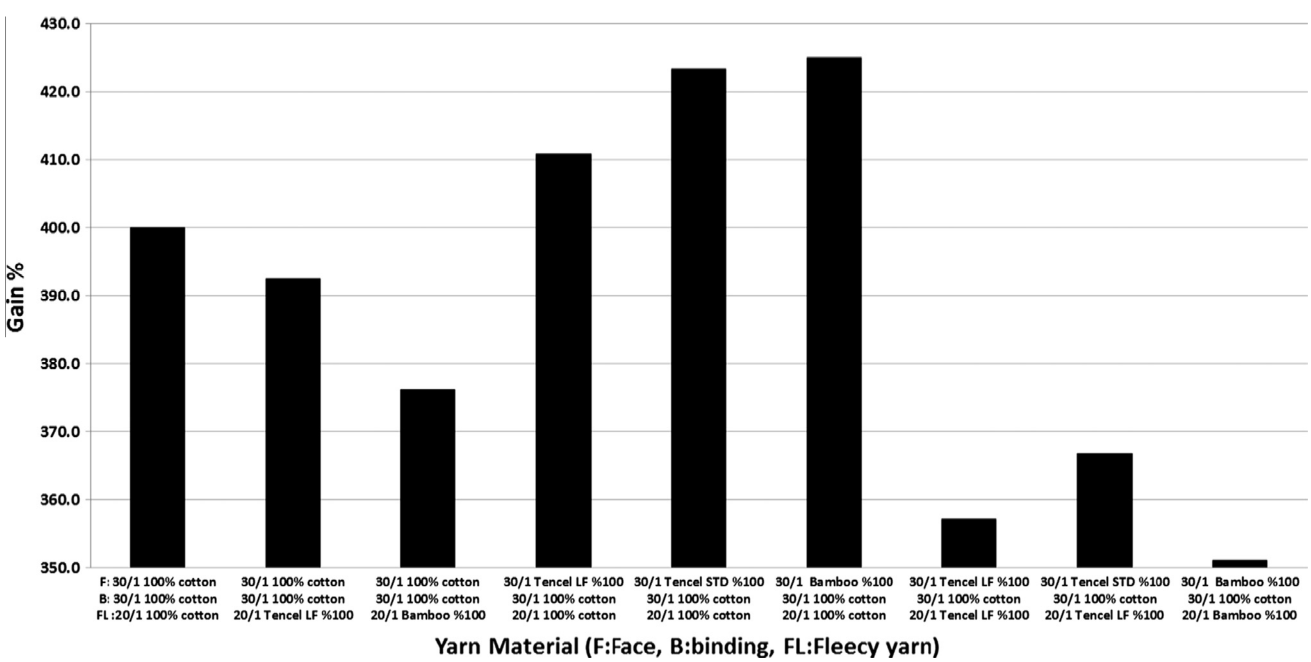


Figure 6 Gain% at different yarn materials of face and fleecy yarns.

they were comparatively thicker and heavier than the other samples as shown in Table 4. The fleece samples produced from Tencel LF for the face and fleecy yarns were among the thinner samples, so it was not surprising, when it recorded one of the best drying characteristics. Generally higher drying ability corresponds to lower fabric thickness.

Table 7 ANOVA single factor data analysis for gain%.

Source of variation	SS	df	MS	*F*	*P*-value	*F* crit.
Between fabrics	30972.11	8	3871.51	868.12	8.7184E−39	2.2085
Within fabrics	160.547	36	4.4596			

Table 8 ANOVA single factor data analysis for air permeability.

Source of variation	SS	df	MS	*F*	*P*-value	*F* crit.
Between fabrics	4472.92	8	559.115	670.938	3.54278E−51	2.1152
Within fabrics	45	54	0.8333			

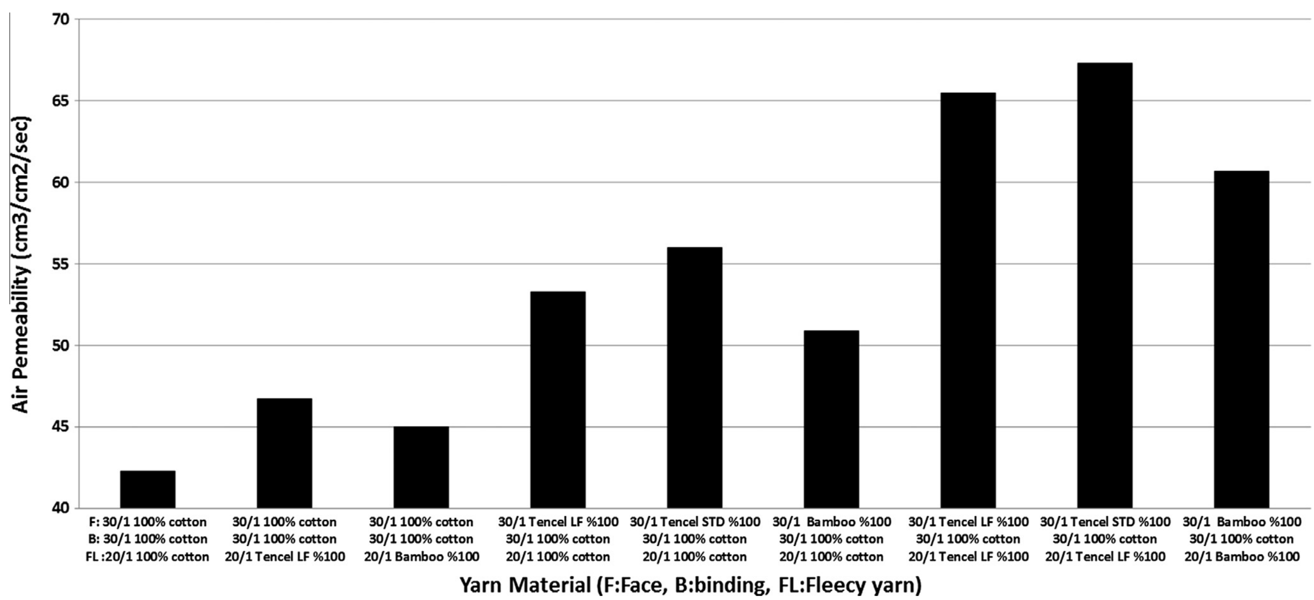


Figure 7 Air permeability at different yarn materials of face and fleecy yarns.

All the curves, around 10–13% of the remaining water ratio, show an inversion point after which the drying rate begins to decrease. The first part of the curve (with higher slope) corresponds to moisture release from the void spaces between yarns; the second part (with lower slope) corresponds, to the release of moisture within the fiber.

Yarn material for face and fleecy yarns affects drying ability of the 3-thread fleecy fabric. In Tencel STD face yarn/Tencel LF fleecy yarn fabric demonstrated the highest drying rate (and also the largest water diffusion area). This is probably due to hydrophilic and hygroscopic property of Tencel fibers and due to fabric characteristics, namely low thickness and mass per unit area.

3.5. Color difference

Fig. 9 shows the color difference after dyeing all fleece fabrics having different yarn materials for the face and fleecy yarns. For this test method, a fabric sample knitted with face and fleecy cotton yarns was taken as a reference on the data color device. Also, color difference was measured on the face side of the fabric, viewer side.

We can notice that knitted sample with Tencel STD face/Tencel LF fleecy yarns in general has higher color difference than knitted with Tencel LF face/Tencel LF fleecy yarns and Bamboo face/Bamboo fleecy yarns. Standard Tencel fiber fibrillates under conditions of wet abrasion, creating micro-fibrils on the surface of the fiber which critically, remain attached to the main body of the fiber. Fibrillation is the longitudinal splitting of a single fiber into microfibers of 1–4 μm in diameter. The splitting occurs as a result of wet abrasion against fabric or metal. The fibrils created are so fine that they are almost transparent, giving a white or 'frosty' appearance (known as peach skin) to the finished fabric and this is the reason for such high dye uptake [26]. The space between these microfibrils, represents like capillaries giving promotion to enhanced capillary effect and hygroscopic property. In addition, such crystalline arrangement of microfibrils is consistently distributed in Tencel STD unlike in the case of Bamboo and Cotton.

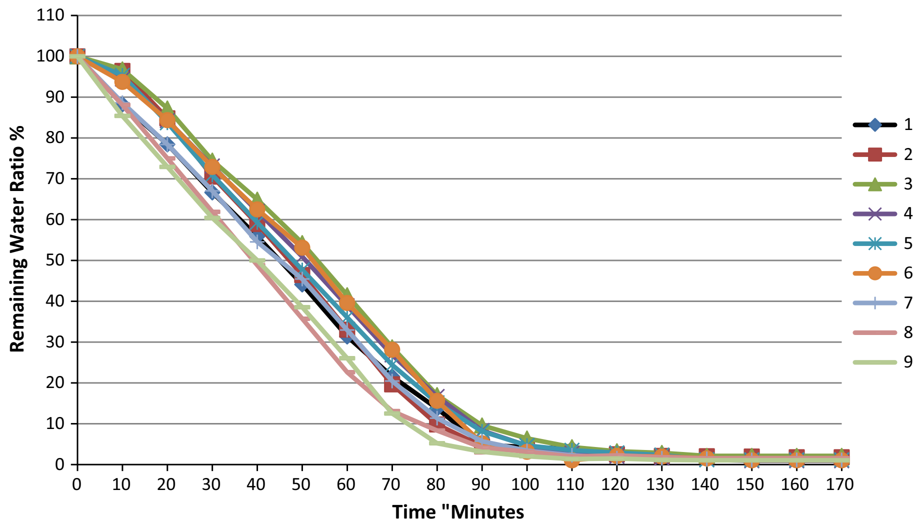


Figure 8 Remaining water ratio at different yarn materials of face and fleecy yarns.

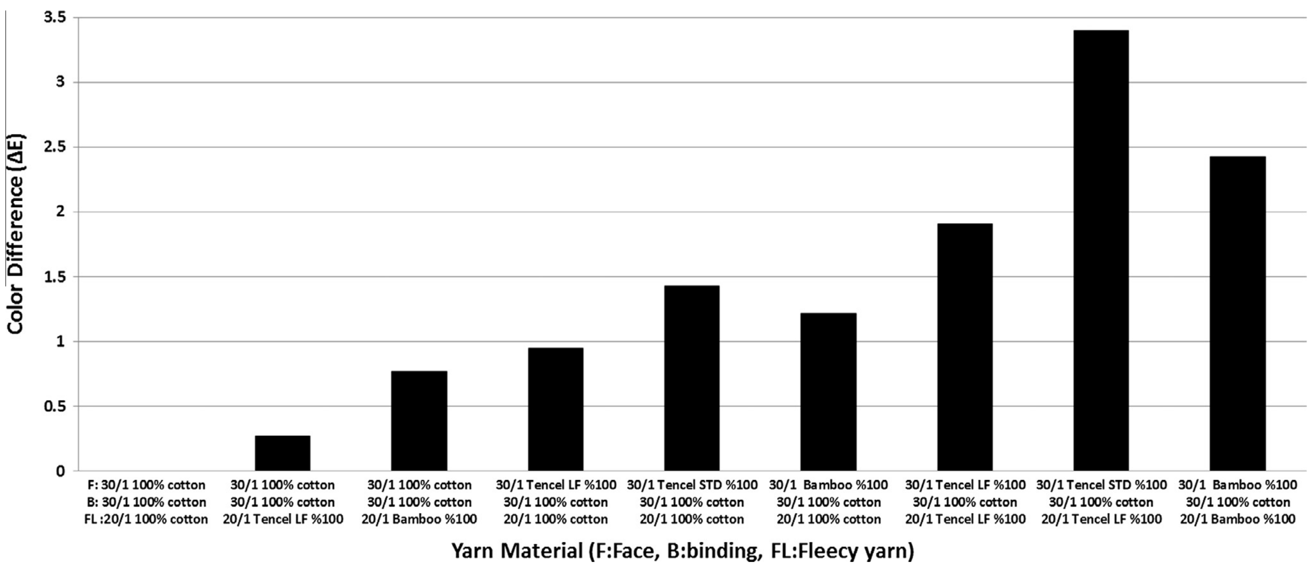


Figure 9 Color difference at different yarn materials of face and fleecy yarns.

Also samples produced with face bamboo yarns give more color difference than others knitted with face Tencel LF and face cotton yarns. There are several voids in the cross section of bamboo fibers, which give them a higher moisture absorption capacity [27]. Using fabric structures with higher porosity like three-thread fleece and hydrophilic fibers like bamboo will lead to a modification of the water wicking properties and this exhibits better wicking characteristics. This may lead to a controlled loss of water vapor leading to better clothing comfort.

The competitive dye uptake of cotton is the lowest in the union dyeing of bamboo and Tencel. Cotton is characterized by only 30% amorphous region and this is the reason for its lowest dye uptake.

Also, the ANOVA analysis confirmed that there is a significant difference in color difference for fabrics having different face and back yarn materials, where Table 9 shows the F-value is more than F-critical value (1924.28 > 2.208).

3.6. Immersion time

Fig. 10 illustrates the relation between Immersion time and different yarn materials of face and fleecy yarns for three-thread fleece fabric. Additionally, ANOVA analysis cleared in Table 10 confirmed that there is a significant difference for samples having different materials for the face and fleecy yarns, (F-value 4239.63 > F-critical value 2.208).

The immersion time of the fabric depends on the percentage of amorphous region and the location, distribution of the amorphous region. It could be seen that samples knitted with face and fleecy cotton yarns take longer time to immerse than others produced with Tencel and bamboo yarns. Cotton has bad absorbance properties so it takes much time to absorb and hold water as long as possible before the immersion.

Table 9 ANOVA single factor data analysis for color difference.

Source of variation	SS	df	MS	*F*	*P*-value	*F* crit
Between fabrics	45.926	8	5.7408	1924.278	5.54258E−45	2.2085
Within fabrics	0.1074	36	0.00298			

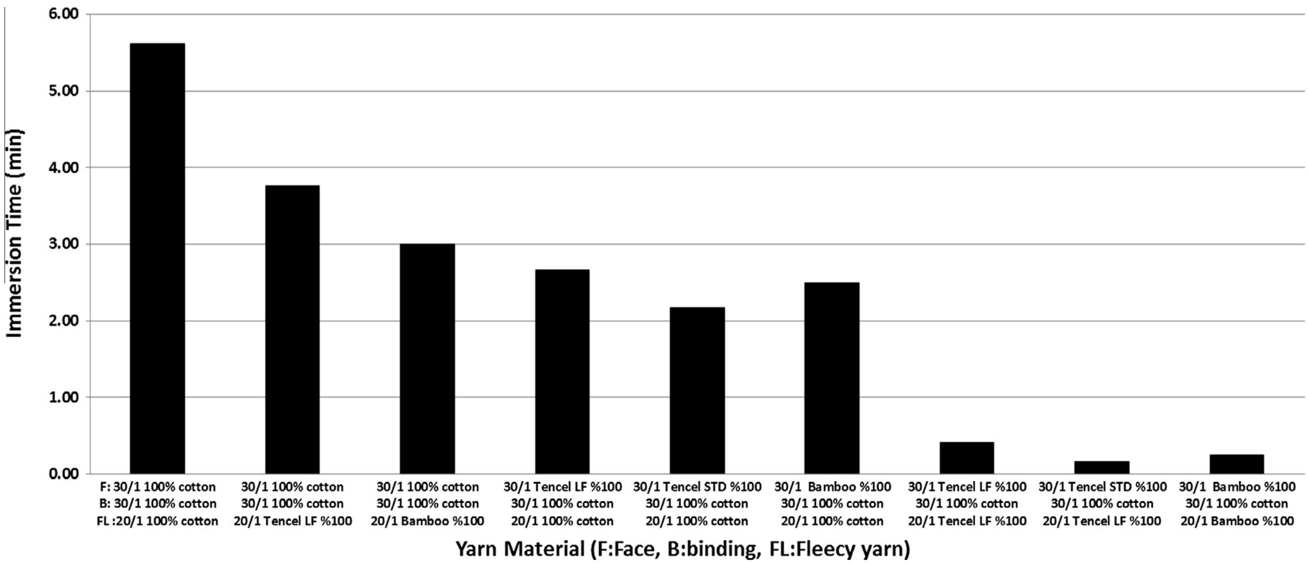


Figure 10 Immersion time at different yarn materials of face and fleecy yarns.

Table 10 ANOVA single factor data analysis for immersion time.

Source of variation	SS	df	MS	*F*	*P*-value	*F* crit.
Between fabrics	130.398	8	16.2998	4239.623	3.80341E−51	2.2085
Within fabrics	0.13841	36	0.00384			

Tencel consists of numerous, high hydrophilic, crystalline nano-fibrils, which are arranged in a very consistent manner. The fibrils themselves do not absorb water; water absorption only happens in the capillaries between the fibrils "voids", i.e. water is absorbed into the fiber structure. A single Tencel fiber, hence, will act like a perfectly wetting bundle of nano-fibrils with pores in nanometer range, something which does not occur in the synthetic fiber world. This is the reason for the outstanding water management and the high good comfort in wear of textiles containing Tencel [28].

3.7. Bursting strength

Three thread fabric produced from 100% Egyptian cotton for face and fleecy yarns has the maximum bursting strength compared to other samples having Bamboo and Tencel yarns, Fig. 11. On the other hand, it's noticed that the fleece fabric produced with the following: 100% Tencel LF for face and fleecy yarns has a higher bursting strength than other produced with 100% Tencel LF face yarn and 100% cotton fleecy yarn. This case could be due to the higher strength properties of Tencel LF fibers at the dry and wet states than cotton fibers. In addition, the Tencel LF fibers have the greatest orientation and uniformity level which make a harmony between the face and fleecy yarns to contribute more in supporting the fabric during bursting test.

Although many researchers have discussed a lot about the lower strength of the bamboo fibers, our results show that fleece knitted fabrics from 100% Bamboo for face and fleecy yarns have a higher bursting strength than others produced with 100% Bamboo, Tencel LF, Tencel STD for face yarns and 100% cotton for fleecy yarns. This controversial trend may be related to the serrated configuration of the bamboo fibers found in the face and fleecy yarns which create griping force with the binding cotton yarn located between these two yarns. So, using weak bamboo yarns to manufacture three-thread fleece structure improves, enforces and heightens the resultant bursting strength of the produced fabrics. 3-Threaded fleece structure improves the durability of the weak Bamboo yarn inside the fabric.

Also, fleece knitted with Tencel STD face yarn/Tencel LF fleecy yarn has least bursting strength than others produced with Tencel LF face yarn/Tencel LF fleecy yarn and Bamboo face yarn/Bamboo fleecy yarn.

The fibrillation of STD Tencel makes it possible to achieve special surface effect such as peach skin effect, sand-washed, soft touch. Though the fibrillation enables the fibers to be used in special finished effect, it affects negatively bursting test,

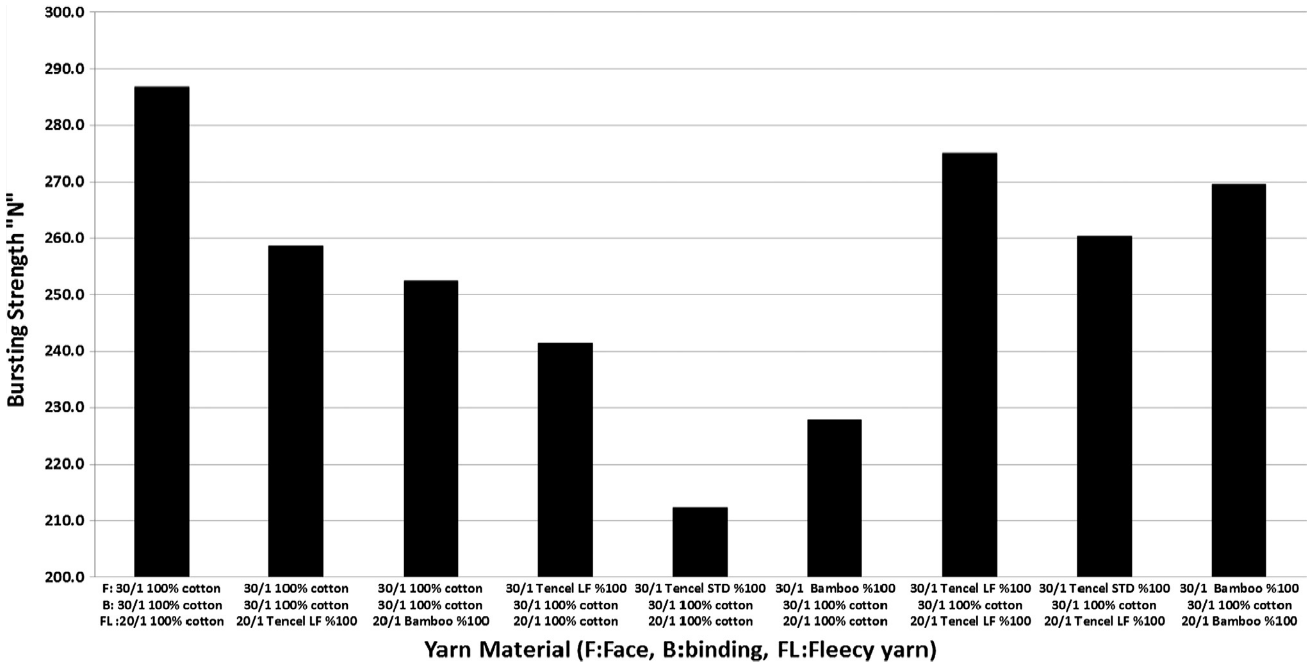


Figure 11 Bursting strength at different yarn materials of face and fleecy yarns.

Table 11 ANOVA single factor data analysis for fabric bursting strength.

Source of variation	SS	df	MS	*F*	*P*-value	*F* crit.
Between fabrics	21668.36	8	2708.54	321.074	4.33309E−31	2.2085
Within fabrics	303.691	36	8.4359			

where it make a slippage with cotton binding yarn which as a result weakens the fabric.

In general, the variance analysis obviously clears that the fiber material does play an important role in influencing bursting strength of the studied samples, Table 11, (*F*-value 321.07 > *F*-critical value 2.208).

4. Conclusion

To get no sweat accumulation and more comfortable feelings for sport wears, underwears and medical wears, 3-Thread fleece fabric having regenerated yarns for the face and fleecy is recommended.

Three-thread fleece fabric having Tencel yarn for the face and back of the fabric has the least gain%. The more amorphous region constitutes of their fibers material attract water molecules. Therefore, their yarns have the ability to absorb water and get rid of it very fast. This is a very important property for the sportswear garments.

To improve the durability of the weak Bamboo yarn inside the knitted fabric, 3-thread fleece structure is recommended. 3-Thread Fleece Structure improves the durability of the weak Bamboo yarn inside the fabric.

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