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Prediction and Experimental Investigation of Knitted Fabric Thickness and its Influence on Single Jersey Fabric Properties

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Abstract
This study focussed on the investigation of the properties of knitted fabrics produced from blended yarns made of different proportions of modal (M) and cotton (C) fibres. For this purpose, single jersey knitted fabric samples were produced from modal and modal-cotton blended yarns consisting of three different blend ratios of MC fibres (M:C – 100:0, 70:30 & 50:50) in three different loop lengths from both ring and compact yarns. Eighteen samples were obtained to observe the effect of the MC blend ratio, type of yarn and loop length on the bursting strength and air-permeability of single jersey knitted fabrics. ANOVA was performed at a 95% significance level to find the influence of the blend ratio on the test results. The results show that the modal cotton blend ratio influenced the bursting strength and air-permeability of knitted fabric significantly. It is also observed that the type of yarn and loop length show a significant impact on the fabric quality parameters measured.

Key words: *modal, blend ratio, compact yarn, loop length, bursting strength, air-permeability.*

Introduction

In the recent decades, the demand for textiles has dynamically varied with the changing fashion in knitted fabrics, which are formed by inter looping spun yarn in a series of connected loops using needles [1]. The performance of knitted fabrics for various end uses such as sportswear, summer wear, inner wear etc. is assessed by their comfort and durability. The comfort of a fabric is mainly influenced by the air permeability, as it helps to transport moisture vapour from the wearer's skin to the outside atmosphere [2]. Bursting strength is a durability characteristic which measures the strength of fabrics against forces acting in multi-directions. Many researchers have studied and optimised these knitted fabric properties by different methodologies and reported that fabric thickness is an important knitted fabric parameter which affects fabric properties like air permeability, bursting strength, handling, UV protection, material consumption etc.

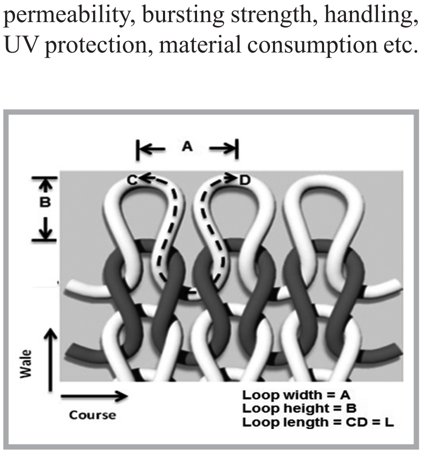

Figure 1. *Knitted fabric parameters.*

[2-4]. Some of the investigations which show the influence of fabric thickness on the properties of knitted fabrics, especially air-permeability and bursting strength, are reported below. Wilbik-Halgas.B investigated the influence of various parameters on the air and water permeability of double layered knitted fabrics made from various fibre raw materials and concluded that air permeability is a function of the thickness and surface porosity of fabrics [5]. Bhattacharya S. S et al. also reported that air-permeability depends on the thickness, tightness factor and porosity of knitted fabrics [6]. Serin Mavruz and R. Tugru Ogulata determined the correlation between the air permeability and thickness of knitted fabrics [7]. Yamini Jhanji et. al observed that the air permeabilty of plated knitted fabrics is found to be lower with an increse in the thickness and mass per squae meter of fabric [8].

Ogulata R.T et al. developed a theoretical model involving the geometrical parameters of knitted fabric, including the thickness to predict the air permeability and porosity of fabric, and successfully experimented on knitted fabrics produced from both ring and compact yarn [2]. Suganthi T et al. observed the significant influence of thickness on the air permeability and thermal comfort properties of bi-layered knitted fabrics [9]. Degirmenci Z et al. proved that knitted fabric bursting strength and extension are significantly influenced by the fabric thickness and fibre mix ratio of denim viewed knitted fabrics and reported that denim viewed knitted fabric made from modal-bamboo blended fleecy yarn exhibited lower bursting strength than other types of yarns due to the lower thickness values of the fabrics [10]. Feng A.F. studied the various properties of honycomb polyester knitted fabrics and reported that the thickness of knitted fabrics influenced their bursting strength [11].

Furthermore, knitted fabric thickness mainly depends on two types of parameters, namely basic knitted fabric parameters and yarn parameters [12-14]. Loop width specified by the wale density, loop height specified by the course density and the loop length are knitted fabric parameters, shown in ***Figure 1***.

Using various knitted fabric parameters, different loop models which exhibit the relationship between the geometry and properties of fabric have been developed for knitted structures [14-16]. Among these models, a valid mathematical model based on multiple linear regression developed by Alenka Pavko-Cuden et al. is more suitable for single jersey fabrics made from various types of yarns, shown in ***Equation (1)***. [15].

$$L = 0.8A + 2.45B - 1.17d + 3.43t \quad (1)$$

It is a general linear model involving four predictors viz. loop width (A), loop height (B), yarn thickness (d) and knitted fabric thickness (t). It was also proven experimentally that this model correlates well (> 99%) with respect to the loop length variations. [15].

The important yarn parameters are the blend ratio of fibres, the type of yarn and yarn thickness (diameter). Thus, the performance and comfort properties of knitted fabrics are influenced by the basic knitted fabric parameters and yarn parameters above. Nowadays. in textile industries the performance and properties of knitted fabrics are enhanced by using blended spun yarns produced by mixing different types of natural, regenerated and synthetic fibres. Recently, modal and modal cotton blended spun yarns have been increasingly used to produce knitted fabrics for better comfort and durability. Modal is a regenerated cellulose fibre which is soft, smooth, highly absorbent, cool to touch, and highly breathable [6]. Few studies have been reported in literature about the characteristics of knitted fabrics made from 100% modal and modal cotton blended yarn or their comparison with those of other spun yarns [17, 18].

In this work, the effect of the modal cotton fibre blend ratio on the properties of knitted fabrics were studied. For this purpose, the air-permeability and bursting strength of knitted fabrics made from modal and different modal-cotton blended yarns spun in ring and compact systems were analysed. Furthermore, the effect of the blend ratio on the blended yarn thickness was observed by using scanning electron microscopy. By applying the knitted fabric parameters and yarn thickness, the fabric thickness was predicted by a multi-regression model and evaluated by measuring with a Mitutoyo thickness gauge.

Materials and methods

In order to assess the impact of yarn parameters and knitted fabric parameters on the properties of knitted fabrics, the work methodology proposed is shown in ***Figure 2***.

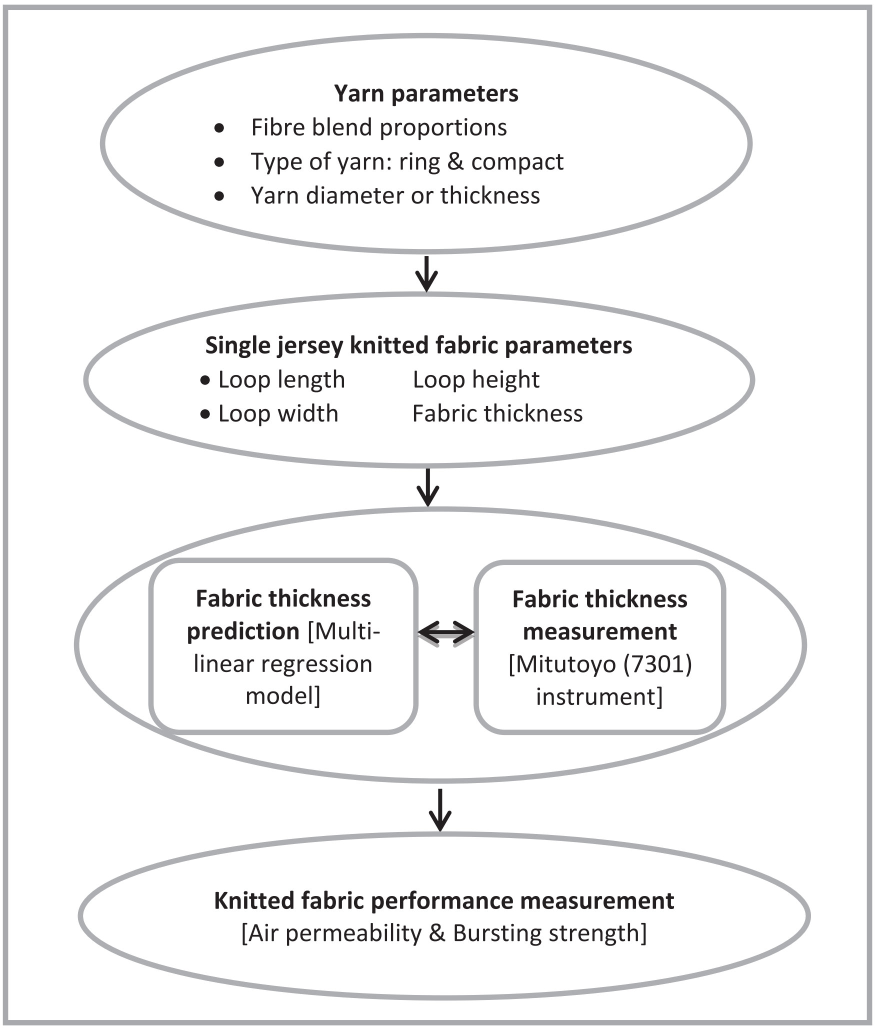

Figure 2. *Proposed work methodology.*

Table 1. *Yarn quality parameters.*

Parameters	MC-100:0		MC-70:30		MC-50:50	
	Ring yarn	Compact yarn	Ring yarn	Compact yarn	Ring yarn	Compact yarn
Linear density, Tex	14.72	14.76	14.75	14.71	14.69	14.78
Uniformity, U%	9.95	9.54	10.04	9.67	10.12	9.74
Hairiness index, H	5.81	4.63	5.04	3.51	5.17	4.04
Tenacity, g/tex	22.7	23.76	18.44	19.40	17.55	18.12
Elongation, %	8.51	8.66	6.49	6.52	5..5	5.51

Yarn parameters

The various yarn parameters considered for the present work are the fibre composition, type of yarn and yarn diameter. Blended yarn samples were produced using modal (M) and cotton (C) fibres mixed in three different compositions, such as M:C – 100:0, 70:30 and 50:50. Furthermore, these yarn samples were prepared by processing the raw material through both ring and compact spinning systems. In this way, 3 ring yarn and 3 compact yarn samples were obtained. Quality parameters of the yarn samples are given in ***Table 1***. The diameters of all six MC blended yarn samples were measured by taking an FESEM image of all the samples using a Zeiss Sigma V instrument at SITRA, Coimbatore (India).

Single jersey knitted fabric parameters

Single jersey knitted fabric samples were produced from all six MC blended yarn samples of 14.75 tex with three different tightnesses viz. loose, medium and tight (loop lengths: 3.4 mm, 3.1 mm & 2.8 mm, respectively). The samples were produced on a Knitmac circular knitting machine of 20 gauge, 24 feeders and 18 inch diameter, fitted with a positive yarn feeding system. In total, 18 knitted fabric samples were produced from both ring and compact yarn.

The samples were conditioned at standard atmospheric conditions for 48 hours before performing the various tests. Basic knitted fabric parameters such as loop length, wales per centimmeter and courses per centimeter were determined according to the relevent standards (TS251,1991; TS EN 14970, 2006).

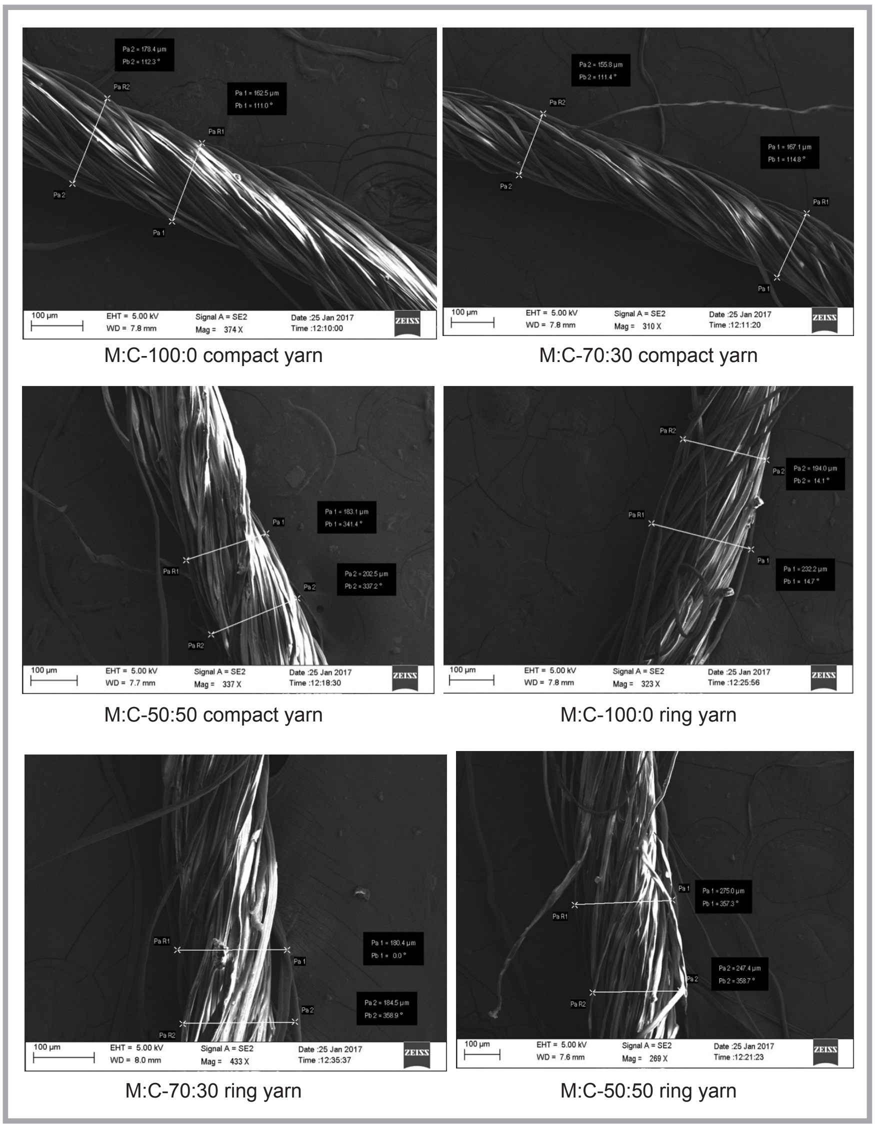

Figure 3. *FESEM images of modal cotton blended yarns.*

Table 2. *Blended yarn diameter values.*

Modal cotton ratio, %	Yarn diameter, mm	
	Ring yarn	Compact yarn
M:C-100:0	0.222	0.185
M:C-70:30	0.180	0.158
M:C-50:50	0.249	0.205

Prediction of knitted fabric thickness

Among the various loop models, a valid mathematical model based on multiple linear regression [8] was effective to study the impact of independent variables of single jersey knitted fabrics produced from all types of yarns on the loop length. Since this model involves the knitted fabric thickness value, whose correlation is very good, the following mathematical modal below, which is derived from ***Equation (1)*** was proposed to predict the knitted fabric thickness value (t).

$$t = \frac{L-(0.8A+2.45B-1.17d)}{3.43} \quad (2)$$

The thickness values of all 18 MC blended knitted fabric samples were calculated using this model.

Fabric thickness measurement

Actual thickness values of the knitted fabric samples were obtained by measuring their thickness on a Mitutoyo (7301) thickness tester. The fabric thickness and fabric weight per unit area (GSM) of the samples were determined according to the relevent standards [TS1728 EN ISO 5084; TSEN 1497, 2006]. Then these values were compared with predicted values to find the correlation.

Fabric property measurement

In order to asses the impact of all yarn and fabric parameters on fabric properties, the bursting strength and air permeability of the fabrics were measured. The bursting strength of the samples was tested by the Mullen bursting (modified) method as per ASTM D 3786/D 3786, 2013. The air permeability of the samples was measured using a Textest FX3300 air permeability tester in $cm^3/s/cm^2$ according to ASTM D 737 for a 38 cm^2 test area.

Results and discussion

Effect of fibre blending and spinning system on yarn diameter

Yarn diameter depends on the fibre blend ratio and type of yarns for the same linear density. Diameter values of the MC blended yarn samples measured by FESEM (Zeiss Sigma V) are given in ***Table 2***. The average of six readings were considered for each sample. A longitudinal view of the six MC blended yarn samples obtained from FESEM is shown in ***Figure 3***.

It is observed that the diameter values of 100% modal yarn is medium, and the addition of cotton in the blend first decreases the yarn diameter (M:C-70:30) and then increases it as the cotton percentage increases in the blend (M:C-50:50). A decreasing trend in yarn diameter is noted in M:C-70:30 yarn because of the presence of a lower number of fibres in the yarn cross-section (calculated from the fibre blend ratio and fineness) than for 100% modal yarn. On the contrary, in M:C-50:50 yarn, an increasing trend in yarn diameter is observed due to the presence of a higher number of cotton fibres in the blended yarn cross-section. In general, the compact yarn samples show a lower diameter than corresponding ring yarn samples for all blended yarn samples. This is due to the better consolidation of fibres in the drafting zone using air suction in the compact spinning system.

Fabric thickness prediction and measurement

Parameters of knitted fabric samples

Basic parameters of the eighteen knitted fabric samples were obtained by taking the average of 5 tests for each sample. The relationship between the loop length and loop parameters for all samples is depicted in ***Table 3***.

It is observed that a significant increase in courses/cm values is noticed when there is a decrease in the loop length of all fabric samples, since the course density of knitted fabric is mainly influenced by the loop length. Whereas only an insignificant increase in wales/cm values is noticed as the loop length value is decreased. Loop parameters such as loop height and loop width can be determined from the courses/cm and wales/cm values, respectively. Fibre blending does not show any significant influence on both the wales and courses per centimeter values. This may be due to the setting of a constant loop length for all blend types.

Fabric thickness

The fabric thickness values measured were obtained by taking the average of five readings at different places for each sample. Predicted and experimental values of the thickness of all eighteen single jersey knitted fabric samples are shown in ***Table 4***.

It is observed that the predicted and measured values of fabric thickness are close to each other (the R^2 value for ring yarn is 0.706 and for compact yarn 0.805) and found to show the same trend in all fabric samples. The trend shows that an increase in the cotton proportion in the blend mixing increases single jersey fabric thickness. Additionally, an increase in loop length decreases the fabric thickness due to the reduction in loop density. Moreover, the ring yarn fabrics show a comparatively higher thickness value than the corresponding compact yarn fabrics due to the higher diameter of ring yarn than that of compact yarn. ANOVA performed for the thickness values showed that the MC blend ratio, loop length and type of yarn have a significant impact ($P < 0.05$) on fabric thickness.

Measurement of fabric properties

Knitted fabric properties such as the bursting strength and air permeability of fabrics were measured for the present analysis. Ten readings were taken for each sample and the average value considered for both the bursting strength and air-permeability. ANOVA was performed on these values to find the impact of the fibre blend ratio on the fabric properties measured.

Effect of fabric thickness on fabric properties

Knitted fabric properties such as the bursting strength and air-permeability for all eighteen fabric samples are shown in ***Table 5***.

Bursting strength

A comparison of bursting strength values for all eighteen fabric samples is depicted in ***Figure 4***. The bursting strength values of the samples follow an increasing order while increasing the cotton proportion in the blend mix (M:C – 100:0 < 70:30 < 50:50), even though the yarn tenacity and elongation value show a decreasing trend. Here, an increase in the cotton content from 100% modal yarn to M:C-50:50 blend yarn leads to increase in the fabric thickness and weight per unit area, and hence the bursting strength value also increases in the same trend. The knitted fabric produced from both ring and compact yarn was found to

Table 3. *Loop length and loop parameters of single jersey samples.*

Fabric samples	Loop length – 3.4 mm		Loop length – 3.1 mm		Loop length – 2.8 mm	
	Courses/cm	Wales/cm	Courses/cm	Wales/cm	Courses/cm	Wales/cm
Ring yarn						
M:C-100:0	14	11	17	12	22	12
M:C-70:30	14	12	18	12	22	14
M:C-50:50	14	11	17	12	22	13
Compact yarn						
M:C-100:0	14	11	17	12	21	13
M:C-70:30	14	12	18	12	22	14
M:C-50:50	14	11	17	12	22	13

Table 4. *Thickness values of knitted fabric samples.*

Fabric samples		Thickness value, mm (ring yarn samples)		Thickness value, mm (compact yarn samples)	
Modal cotton, %	Loop length	Predicted	Measured	Predicted	Measured
M:C-100:0	3.4 mm	0.345	0.362	0.332	0.331
	3.1 mm	0.365	0.374	0.352	0.346
	2.8 mm	0.373	0.382	0.360	0.372
M:C-70:30	3.4 mm	0.348	0.373	0.341	0.342
	3.1 mm	0.374	0.386	0.366	0.358
	2.8 mm	0.386	0.392	0.379	0.376
M:C-50:50	3.4 mm	0.356	0.389	0.357	0.374
	3.1 mm	0.376	0.403	0.374	0.392
	2.8 mm	0.399	0.410	0.382	0.405

Table 5. *Properties of single jersey fabrics knitted using ring and compact yarn.*

Knitted fabric samples	Fabric density	Ring yarn			Compact yarn		
		Mass per unit area, g/m^2	Bursting strength, kPa	Air permeability, cm^3/s/cm^2	Mass per unit area, g/m^2	Bursting strength, kPa	Air permeability, cm^3/s/cm^2
Mod 100%	Loose	76.4	298.54	291	73.2	299.92	303
	Medium	87.7	332.33	270	84	326.12	280
	Tight	96.8	388.86	258	96.9	359.91	260
Mod 70%/ Cot 30%	Loose	79.8	321.30	280	76.3	313.02	327
	Medium	90	341.30	258	86	326.12	296
	Tight	99.1	402.65	237	100.1	384.73	270
Mod 50% Cot 50%	Loose	82.3	355.08	262	80.1	366.80	288
	Medium	91.8	376.45	240	89.3	386.80	253
	Tight	101.5	410.24	218	101.9	388.17	223

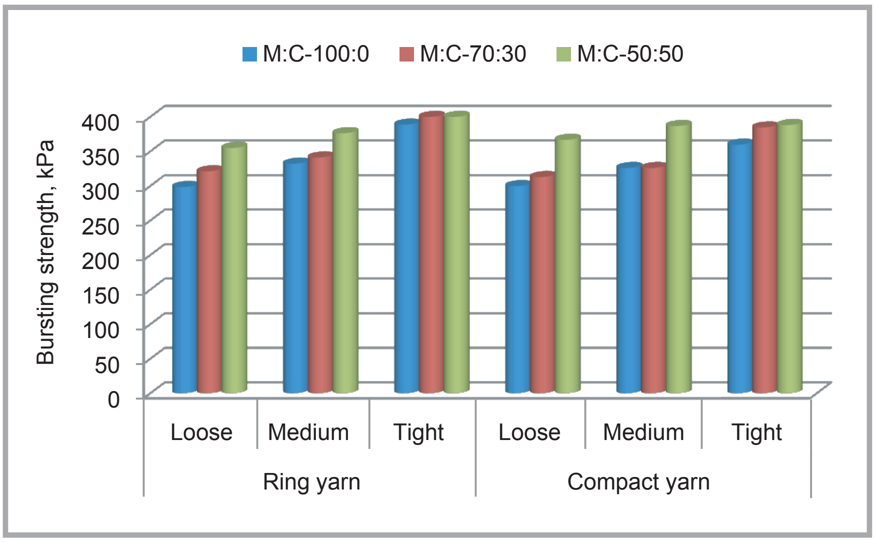

Figure 4. *Influence of fibre blend, yarn type and loop length on bursting strength.*

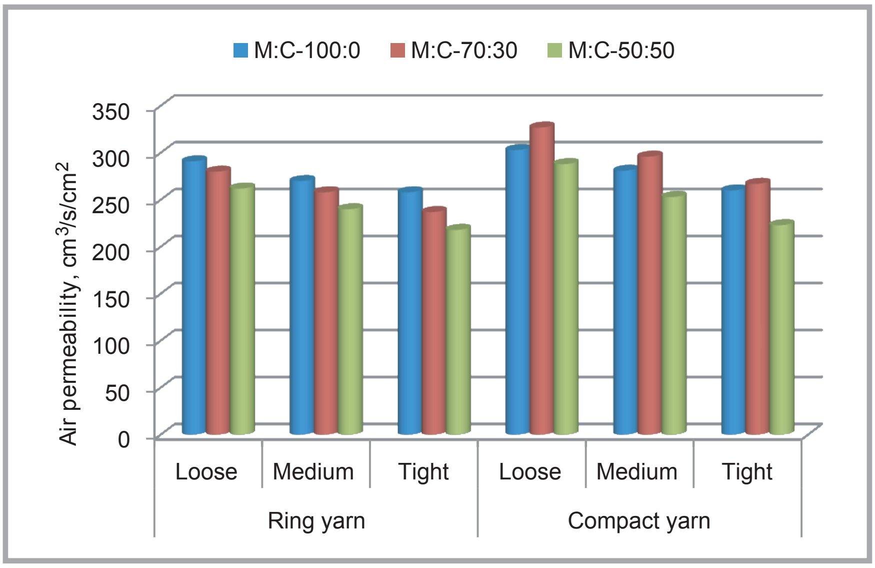

Figure 5. *Influence of fibre blend, yarn type and loop length on air permeability.*

show the same trend. Furthermore, the loop length has a negative influence on the bursting strength of fabric obtained from all types of blended yarns.

Moreover, knitted fabric produced from ring yarn is observed to have slightly higher bursting strength than compact yarn, even though its tenacity values are lower than those of compact yarn. This trend is also due to the influence of the higher fabric thickness and weight per unit area of ring yarn knitted fabric.

Air-permeability

The average air-permeability values of all eighteen fabric samples are shown in ***Figure 5***. The main factors influencing the air-permeability of knitted fabrics are fabric thickness and yarn hairiness. The air-permeability of knitted fabric made from ring yarn decreases as the proportion of cotton content increases in the blend from 100% modal to 50:50 MC. This trend is due to the increase in fabric thickness as the cotton proportion increases in the blend mix from 100% modal yarn to 50:50 MC yarns. Also, the difference in yarn hairiness between 100% modal and 70:30 MC yarn is less compared to compact yarn. Hence, in this case fabric thickness has played a major role in the air permeability of fabric, and the influence of yarn hairiness on fabric air-permeability is not vital. Unlike ring yarn, in the case of knitted fabric made from compact yarn, as the proportion of cotton content increases in the MC blend, the air permeability values initially increase and then decrease. Knitted fabric obtained from 70:30 MC yarn shows the maximum air-permeability value, while 50:50 MC blend yarn fabric shows the minimum. Knitted fabric obtained from 70:30 MC blend yarn has slightly higher thickness than 100% modal yarn fabric; however, the former exhibits maximum air-permeability since its yarn hairiness value is much lower than that of latter. The difference in yarn hairiness is wide enough to influence the air-permeability of the fabric. The reason for the minimum air permeability value of knitted fabric made from 50:50 MC blended yarn is due to higher values of thickness, mass per unit area and yarn hairiness when compared to the other two samples.

Furthermore, the air-permeability of knitted fabrics made from compact MC blended yarn is better than for ones made of ring yarn due to the lower fabric thickness and yarn hairiness. Also, as expected an increase in loop length increases the air-permeability characteristics of knitted fabric for all types of MC blended yarns considered.

ANOVA analysis

F_{actual} values calculated by performing ANOVA analysis for both air-permeability and bursting strength results of samples with respect to three different MC blend ratios (same loop length) are shown in ***Table 6***. It is observed that the F_{actual} value is greater than the $F_{critical}$ one (3.35), and also P > 0 for all samples. Hence, the MC blend ratio has a significant influence on the air-permeability and bursting strength of knitted fabrics.

Table 6. *F_{actual} value calculated through ANOVA.*

Properties	Compact yarn			Ring yarn		
	3.4 mm	3.1 mm	2.8 mm	3.4 mm	3.1 mm	2.8 mm
Air permeability	20.93	31.10	23.22	15.87	12.83	25.29
Bursting strength	153.42	76.5	13.88	75.34	31.30	78.62

Conclusions

An experimental work was carried out to examine the impact of blended yarn made with various blend ratios of modal and cotton fibres on single jersey knitted fabric properties. The test results and ANOVA analysis reveal that the MC blend ratio has a significant impact on single jersey fabric properties. It is found that the influence of fabric thickness on the bursting and air-permeability properties of single jersey knitted fabrics made from MC blend yarn is vital. The trend shows that an increase in the cotton ratio in the blend increases fabric thickness, which leads to a significant improvement in bursting strength for both ring and compact yarn fabric. But the addition of cotton in MC blended ring yarn leads to a reduction in knitted fabric air-permeability due to the decrease in fabric thickness. Whereas the addition of cotton in MC blended compact yarn increases air-permeability to a certain extent (M:C – 70:30), which shows maximum air-permeability due to less yarn hairiness and medium fabric thickness. Furthermore, an increase in the cotton proportion in MC blended yarn decreases the air-permeability characteristics of knitted fabric samples due to the increase in fabric thickness. Moreover, analysis reveals that knitted fabric samples obtained from ring yarn exhibit higher bursting strength than compact yarn fabric. This may be due to the higher diameter of ring yarn, which produced knitted fabric with higher thickness than compact yarn fabric. Air permeability is observed to be higher for compact yarn fabric due to the lower fabric thickness and yarn hairiness than those of fabric from ring yarn. Moreover, an increase in loop length leads to a reduction in loop density, which results in a reduction in the bursting strength and an increase in the air-permeability of knitted fabric, and vice versa, in both ring and compact yarn fabrics.

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