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Evaluation of Some Comfort and Mechanical Properties of Knitted Fabrics Made of Different Regenerated Cellulosic Fibres

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Abstract: Knitted fabrics with a wide range of fabric construction varying in fibre type, yarn type is frequently preferred by consumers owing to their high comfort properties. Today new, functional and biodegradable, natural fibre based raw materials are mostly considered for knitted fabrics and clothing designs with a sustainable consumer manner. Collagen peptide added fibres are the recent improved regenerated cellulosic fibres which are known to be providing a skin friendly texture with high thermal and moisture comfort. Within this study, some performance properties such as thermal properties, water vapour permeability, water vapour resistance, air permeability as well as bursting strength of greige and dyed knitted samples made of 100 % Tencel™, Modal, Cupro, Umorfil®, combed cotton and carded cotton yarn were evaluated. ANOVA test was performed for the statistical evaluation of yarn and fabric properties. According to ANOVA results, regenerated cellulosic yarn type of knitted fabrics and the process type (untreated greige fabric or dyed fabric) were generally significant factors on mentioned performance properties of knitted fabrics. The results of experiments also revealed that beside the regenerated cellulosic fibres, new developed collagen peptide added Umorfil® fibre may be used as the raw material of knitted fabrics for sport garments with satisfying comfort results.

Keywords: Collagen peptide fibre, Thermal comfort, Water vapour permeability, Bursting strength

Introduction

Comfort satisfaction and mechanical fabric properties are much more considered today as the consumer awareness for textile garments has increased among the world. Mechanical properties of fabrics such as abrasion, pilling, bursting strength should be evaluated for the fabric durability while comfort properties are directly related with the wearers' sensorial and non-sensorial comfort including many factors such as physical, physiological and psychological.

Non-sensorial comfort can be obtained from test equipments such as Alambeta, sweating guard hot plate and moisture management tester (MMT)…etc. On the other hand, tactile sensations (irritation, sticky, itchy), moisture feelings (wet, sticky, clammy ...etc.) and thermal sensations (cold, warm, hot...etc.) are considered under the group of sensorial evaluations which are obtained from human skin feelings [1].

Raw material is the main factor which directly influences the textile comfort properties. Fibre property and its influence to the comfort property to the garment comes first before the fabric structure. The final purpose of textile product should be known in order to put forward the expected performance properties. For example, a cloth designed for warm climate should have different properties from the designed clothes for cold climate. By the way, it is impossible to combine all required features in a one textile structure even with the best approach of selecting the right raw material.

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Synthetic fibres may be examined under three groups depending on their source of origin; Those fibres may be based on natural polymers, on synthetic polymers or on inorganic substances. Furthermore, the sub group based on natural polymer are divided into two groups where one is cellulose based and the other is protein based materials.

Viscose, Modal, Lyocell, Cupro and acetate fibres are the most common cellulose based fibres [2]. All regenerated cellulosic fibres have the similar chemical composition however they differ in density, molecular mass, degree of polymerization, super molecular arrangement as well crystallinity and orientation [3]. Demands for regenerated cellulosic fibres have been gradually increasing owing to consumer demands for high comfort with the wide range of fabric designs. These fibres are included in the group of high comfort fibres. Viscose fibre is the first commercial regenerated fibre provided from wood pulp. The fibre is absorbing, comfortable and breathable however has the disadvantage of wet strength. This disadvantage of viscose fibre led to development of Modal® fibre [4]. Tencel Lyocell is another durable cellulosic fibre regenerated from eucalyptus wood. The surface of fibres is very smooth, as the fibrils are covered by the fibre skin. The fibrils themselves do not absorb water; water absorption only takes place in the capillaries between the fibrils. Tencel branded Lyocell fibres and Tencel branded Modal fibres may be utilized alone or blended with natural or synthetic fibres [5-7]. Cupro fibre is obtained from wood pulp or cotton linters. The dissolved cellulose solution with copper salts and ammonia is oriented to the coagulation bath where there is a spinneret. Hence the multifilament yarn called Cuprammonium Rayon is obtained.

Another prominent feature of Cupro is its sustainability with solubility in the soil in a short time hence gives less damage to the environment. Cuproammonium rayon yarns and cupro-cotton blended yarns may be used as the raw material of lightweight summer dresses and blouses [4,8].

Many researchers investigated the properties of knitted or woven fabrics made of regenerated cellulosic fibers; In a research, Viscose, Modal and lyocell knitted samples were evaluated in terms of dimensional properties where the samples were knitted with three levels of loop length. The course and wale spacing values of lyocell fabrics were found to be lower compared to those made of viscose and Modal. K_s value of lyocell fabrics was also found to be increasing as the tightness factor increased. It was also concluded that fabrics made of lyocell revealed maximum bursting strength, lower spirality as well as better dimensional properties as compared with other fabrics. The result was attributed to structural characteristics of lyocell fibers [3]. In another study, structural properties of viscose, Modal and lyocell fibers, yarns and their influence of structural characteristics on the knitted fabrics performance such as pilling, bursting strength, some comfort properties and colour efficiency. It was concluded by the authors that pilling tendency was higher for the viscose fibres compared to lyocell and Modal grey fabrics. High fabric bursting strength of lyocell samples was attributed to high tensile strength of lyocell fiber [9]. Bhattacharya and Ajmeri conducted a research where air permeability property of the knitted structures made from viscose and Modal yarns for sportswear was evaluated. Viscose and Modal yarns spun in different counts (Ne 30s, Ne 40s) with the same twist coefficient of α_e=3.3 were knitted to be used as pique fabrics at four different tightness factors. Air permeability result of the samples was found to be directly related with fabric thickness, porosity [10]. Basit *et al*. conducted a research related to comparison of mechanical and thermal comfort properties of Tencel blended with regenerated fibres and cotton woven fabrics. Some mechanical properties such as pilling, tearing strength, abrasion resistance also some comfort properties such as moisture management properties, thermal resistance and air permeability features were evaluated where Tencel blended fabrics revealed better results compared to 100 % cotton fabrics [11].

Apart from the regenerated cellulosic fibres; recently collagen peptide added regenerated cellulosic fibres have been commercially utilized for the sport clothes owing to their high comfort properties beside with their antibacterial contribution. Collagen is known to be constituting the 30 % of total protein in animal body. Meat, skin and fish wastes may be used for the extraction of collagen. One of the appropriate hydrolysis method may be applied for the synthesis of collagen peptides where the short peptide chains occur after the treatment with protease enzymes [12,13]. Some biomedical applications of collagen is indicated in Table 1.

Table 1. Biomedical applications of collagen [14]

Composition	Biomaterial form	Application
Collagen	Gel	Cosmetic skin defects, drug delivery, vitreous replacement, surgery coating of bioprostheses
	Sponge	3D cell culture, wound dressing, hemostatic agent, skin replacement, drug delivery
	Hollow fiber tubing	Cell culture, nerve regeneration
	Sphere	Microcarrier for cell culture, drug delivery
	Membrane	Wound dressing, dialysis tissue regeneration, corneal shields, skin patches
	Rigid form	Bone repair
Collagen+GAG	Membrane	Tissue regeneration, skin patches
Collagen+ hydroxyapatite	Powder sponge	Bond-filling and repairdrug delivery (BMP)

Supramolecular biomaterials are known to be replicating aspects of structural or functional properties of biological signal transduction. Umorfil® a commercial brand is one of the new developed fibre which is a result of supramolecular technology integrating fish cell collagen peptide with textile materials like viscose or filament chips hence creating the bionic functional fibre. Those fibre groups are known to be providing comfort with a skin-friendly nature as well as indicating some antimicrobial features [15].

As mentioned in the above parts, there are many researchers focused on the influence of regenerated cellulosic yarns such as Modal, Tencel, viscose on knitted fabric performance properties. However, there are limited studies regarding to effect of cellulosic yarns on fabric comfort and mechanical performance involving newly developed collagen peptide added cellulosic fibre utilization. Today more and more people are now sensitive skin and suffer from Atopic dermatitis due to environment, air pollution, food...etc. Hence those type of collagen peptide enriched skin care fibres may be a good alternative for the consumers who prefer Bio-tech recycled- polymer containing garments.

In this study, it was aimed to conduct a comparative study related to some comfort performance properties such as thermal comfort, water vapour permeability, water vapour resistance and air permeability properties as well as to one of the mechanical property; bursting strength of single jersey knitted greige and dyed fabrics. Knitted samples were separately produced from those regenerated cellulosic yarns (Tencel™(lyocell), Modal, Cupro yarn) as well as from collagen peptide enriched regenerated cellulosic yarn (Umorfil® yarn) and finally from combed, carded cotton yarn for a comprehensive comparison.

Table 2. Fibre parameters of cotton blends

Fiber type	SCI	Micronaire	UHML	SFI	Strength (gr/tex)	Elongation	Neps (gr)	Rd	(+b)	%RH
Aegean cotton	127	4.11	28.85	10.1	30.50	6.93	354	76.62	8.41	5.38
American cotton	149	4.93	30.22	6.45	34.17	7.28	118	71.66	8.46	7.42

UHML: upper half mean length, SFI: short fibre index, Rd: reflectance degree, %RH: relative humidity.

Experimental

Yarn Spinning

Ne 30/1 Compact yarns made of 100 % Tencel™ (Lyocell), 100 % Modal, 100 % Cupro, 100 % cotton and 100 % Umorfil® fibres were spun separately with twist multiplier of 3.60 (α_e) and twist level of 775 (tpm) on the same K45 compact spinning machine. American cotton batch was utilized in order to produce combed cotton yarn group while Aegean cotton batch was utilized for production of carded cotton yarn.

Processing stages of carded yarn production line was utilized for obtaining 100 % cellulosic compact yarn. Cotton fibres were opened and cleaned in blow room and oriented to carding machine, 1st drawing machine, 2nd drawing machine, roving machine and finally to compact spinning machine respectively. Additional combing process was included in the stages in order to produce combed yarns of American cotton batch. HVI properties of Aegean and USA cotton batch are revealed in Table 2 while physical properties of Modal, Tencel™, Umorfil, Cupro fibres were indicated in Table 3.

Uster Tensorapid 4 test device (Switzerland) was used for yarn tensile measurements with a test speed of 400 m/min while Uster Tester 5 (Switzerland) was used for yarn unevenness and hairiness with a test speed of 500 m/min. 5 bobbins were selected for each yarn sample and five measurements were conducted on each bobbin. All the measurements were subjected under standard test conditions: 65±4 % relative humidity and 20±2 °C temperature.

Table 3. Fibre parameters for regenerated cellulosic fibres

Raw material	Linear density (dtex)	Staple length (mm)
Modal	1.3	38 mm
Tencel™	1.3	
Umorfil®	1.25	
Cupro	1.4	

Fabric Production

Single jersey plain knitted fabrics were separately produced from 100 % Modal, Tencel™, Umorfil®, cupro and cotton compact yarns by using TTM-4 model single plated circular knitting machine with a gauge of 28. After knitting, fabrics to be dyed were pre-treated with sodium hydroxide (NaOH) and H_2O_2 bleaching. The processes were carried out at the maximum temperature of 110 °C for 30 minutes by using non-ionic wetting agent, oil remover and sequestering agent. Later, fabrics were dyed by using pad batch system where reactive dye was impregnated at 60 °C for 45 minutes. Fabric types were then rinsed with acid for the neutralization and soaped at 50 °C for 10 minutes, at 80 °C for 10 minutes, at 70 °C for 10 minutes. Afterwards, fabrics were cold rinsed and air dried.

For the sake of simplicity; fabric samples were classified to greige (untreated) and dyed samples. The fabric weights were measured according to the standard test methods for mass per unit area (gr/m^2) of fabric (ASTM D3776). Experimental design is indicated in Table 4. Conducted tests for thermal comfort properties, water vapor permeability, water vapor resistance, air permeability properties and bursting strength within the study will be mentioned in each related part below. All the tests included in this study were carried out according to TS EN ISO 139 under standard atmospheric conditions (20±2 °C and 65±4 % relative humidity) [16].

Table 4. Experimental design

Fabric code	Utilized yarn type	Linear yarn density	Twist value (turns per meter)	Greige fabric weight (g/m^2)	Dyed fabric weight (g/m^2)	Process type	
						Greige	Dyed
Carded	Carded cotton yarn	Ne 30/1	775	140.70	140.30	No pre-treat-ment or dying	Pre-treatment+ dying
Combed	Combed cotton yarn			143.28	140.32		
Modal	Modal yarn			132.26	141.10		
Tencel™	Tencel™ yarn			133.44	129.34		
Umorfil ®	Umorfil® yarn			126.12	131.12		
Cupro	Cupro yarn			132.64	138.68		

Thermal Comfort Properties

Thermal comfort may be described as a property related to ability of clothing for keeping the body temperature within the required temperature limits and to transfer the sweat from the body to outside. This sense is the state in which the person is satisfied with the temperature or moisture rate. Since knitted fabrics produced from regenerated cellulose and collagen peptide added cellulosic fibres within our study were aimed to be used for sport wearing clothes, thermal comfort properties were considered necessary to be determined by using Alambeta device. Average of three measured results was calculated as the means for determining the means for thermal conductivity (λ), thermal resistance (r), thermal absorptivity (b) at the contact point before and after dying process [17-19]. The definitions of thermal properties mentioned in this part such as thermal conductivity, thermal resistance, thermal absorptivity are briefly summarized below.

Thermal Conductivity (λ)

Thermal conductivity is an intensive property of a material that indicates its ability to conduct heat. The measurement result of thermal conductivity is based on equation (1);

$$\lambda = \frac{Q}{A \cdot \frac{\Delta t}{h}}, \ \mathrm{Wm^{-1}K^{-1}} \quad (1)$$

where, Q is amount of conducted heat, A: area through which the heat is conducted, ΔT: drop of temperature and finally h; fabric thickness (mm).

Thermal Absorptivity

Thermal absorptivity is the objective measurement of the warm-cool feeling of fabrics. This parameter allows assessment of the fabric's character in the aspect of its "cool warm" feeling [19]. The equation (2) displays the calculation of thermal absorptivity

$$b = \sqrt{\lambda \cdot \rho \cdot c}, \ \mathrm{Wm^{-2}s^{1/2}K^{-1}} \quad (2)$$

Thermal Resistance

Thermal resistance is a measure of the body's ability to prevent heat from flowing through it. Under a certain condition of climate, if the thermal resistance of clothing is small, the heat energy will gradually reduce with a sense of coolness [19]. Thermal resistance is connected with fabric thickness by the relationship (3) [20].

$$r = \frac{h}{\lambda}, \ \mathrm{m^2KW^{-1}} \quad (3)$$

r: thermal resistance h: fabric thickness λ: thermal conductivity coefficient.

Water Vapour Permeability

Water vapour permeability should be considered for the knitted fabrics to be used for sports garments since the body requires perspiration when the body temperature increases. Water vapour permeability is the ability of fabric to allow perspiration in water vapour form. A fabric of low moisture vapour permeability is unable to allow sufficient perspiration and this may lead to sweat accumulation in the clothing and hence discomfort [1]. Among this study, relative water vapor permeability and water vapor resistance were measured on 'Permetest' instrument working on similar skin model principle as given by EN ISO 11092.

Air Permeability

Air permeability of the fabrics was determined according to EN ISO 9237 standard using a SDL ATLAS Digital Air Permeability Tester Model M 021A at 20±2 °C and %65±4 % humidity. Measurements were performed by application under 100 Pa air pressure per 38 cm^2 fabric surface. Averages of measurements from 10 different areas of fabrics were calculated [21].

Bursting Strength

Bursting strength of samples was measured by means of SDL ATLAS M229P Pnuburst testing device according to EN ISO 13938-1 standard. 5 repetitions were performed for the average result of fabric bursting strength [22].

Statistical Analysis

One-way ANOVA was performed for determining the effect of yarn raw material on yarn tensile, evenness and hairiness properties. Two-way ANOVA was applied for determining the statistical significance of yarn raw material and process type on fabric properties (thermal properties, water vapour permeability, air permeability, bursting strength). The means were compared with the help of SNK tests. The treatment levels were marked in accordance with the mean values, and levels marked by a different letter (a, b, c, d, e) reveal that they were significantly different. The statistical evaluations were done by using SPSS 23 Statistical software package. In order to obtain correlation coefficient between some yarn and fabric properties also between some fabric and fabric properties. (fabric thickness-thermal resistivity, water vapour permeability-water vapour resistance, fabric weight-air permeability), Pearson correlation analyses were also subjected within the study.

Results and Discussion

Yarn Properties

One-way ANOVA test was performed for analysing the yarn evenness, hairiness and tensile properties of compact yarns at Ne 30/1 yarn count made of different fibres statistically (Table 5). A significant difference of CVm (yarn mass variation), number of thin places (-50 %), thick places (+50 %), neps (200 %), hairiness (H), elongation (%), tenacity values were observed between the compact yarns

Table 5. One-Way ANOVA results

Yarn parameter	Sum of squares	F	Sig (p)
Cv_m	51.077	141.671	0.00*
Thin places (-50 %)	19018.442	11555.509	0.00*
Thick places (+50 %)	111415.975	185.237	0.00*
Neps (+200 %)	316849.767	341.065	0.00*
Hairiness	1.403	4.262	0.02*
Elongation (%)	153.931	3231.591	0.00*
Tenacity (cN/tex)	484.290	868.149	0.00*

*Statistically significant (5 % significance level).

made of different fibres. SNK results (Table 6) also displayed that yarn groups produced from different fibres had different CVm, thin places (-50 %), thick places (+50 %), neps, hairiness, elongation and tenacity at significance level of 0.05. According to SNK results; minimum CVm value was provided from the Modal yarns while maximum CVm value was found in carded cotton yarn. When it comes to number of thin places (-50 %); combed cotton, Modal, Tencel™ and Cupro yarns indicated the lowest number of thin places which were observed under the same subset at significance level of 0.05. Umorfil® yarns indicated the highest number of thin places (-50 %) and carded cotton yarns revealed the highest number of thick places (+50 %). Yarns made of cellulosic fibres revealed lower number of neps compared to combed cotton and carded cotton compact yarns. Cupro yarns indicated the best satisfying level for hairiness while carded cotton yarns revealed the highest hairiness results. Carded yarn elongation (%) was observed to be the lowest while Umorfil® yarn provided the highest elongation (%). And finally Tencel™ yarns indicated the highest yarn tenacity while Umorfil® and Cupro yarns revealed the lowest yarn tenacity which were observed under the same subset at 0.05 significance level.

Fabric Properties

Thermal Properties

Thermal properties of textile fabrics such as thermal resistance, thermal conductivity, and thermal absorptivity are influenced by fabric properties such as structure, density, humidity, material and properties of fibres, type of weave, surface treatment, filling and compressibility, air permeability, surrounding temperature and other factors [23].

Thermal properties of greige and dyed samples made of 100 % cotton, 100 % cellulosic and collagen peptide added regenerated cellulosic fibre were discussed in terms of thermal conductivity (λ), thermal absorptivity (b), thermal resistance (R) values respectively. Additionally, two factor ANOVA test was performed in order to evaluate the effect of yarn type, process type and the interaction of this two factors on above mentioned thermal properties. ANOVA and SNK results (Table 7, Table 8) of thermal properties will be discussed each related section.

Table 7. ANOVA results for thermal properties

Main effect	λ ($W\cdot m^{-1}\cdot K^{-1}$)	b	r (m^2KW^{-1})
Yarn type	0.00*	0.00*	0.00*
Process type	0.00*	0.00*	0.00*
Interaction of yarn type and process type	0.00*	0.00*	0.00*

*Statistically significant (5 % significance level).

Table 8. SNK results for thermal properties

Parameter: yarn type	λ ($W\cdot m^{-1}\cdot K^{-1}$)	b	r (m^2KW^{-1})
Carded	48.35d	151.60a	11.93c
Combed	48.52d	151.40a	11.51ab
Modal	46.95c	160.5b	11.27a
Tencel™	44.18b	163.3b	11.44ab
Umorfil®	41.83a	161.1b	11.26a
Cupro	46.45c	158.10b	11.77bc

Note: The different letters (a, b, c, d) next to the counts indicate that they are significantly different from each other at a significance level of 5 %.

Thermal Conductivity (λ)

Figure 1 indicates the thermal conductivity of greige and

Table 6. SNK results for yarn evenness and tensile properties

	Combed cotton	Carded cotton	Modal	Tencel™	Umorfil®	Cupro
Cv_m	12.03c	14.58d	10.55a	11.31b	11.94c	10.99b
Thin places (-50 %)	0.20a	1.80b	0.0a	0.30a	68.0c	0.0a
Thick places (+50 %)	22.80a	173.2b	7.6a	4.30a	5.0a	13.0a
Neps (+200 %)	50.20b	299.60c	14.0a	16.4a	20.0a	28.0a
Hairiness	5.36abc	5.74c	5.32abc	5.22ab	5.61bc	5.12a
Elongation (%)	5.37b	5.16a	6.20c	9.06d	11.47e	6.41d
Tenacity (cN/tex)	15.93b	17.03c	16.87c	26.59d	15.03a	15.18a

Note: The different letters (a, b, c, d) next to the counts indicate that they are significantly different from each other at a significance level of 5 %.

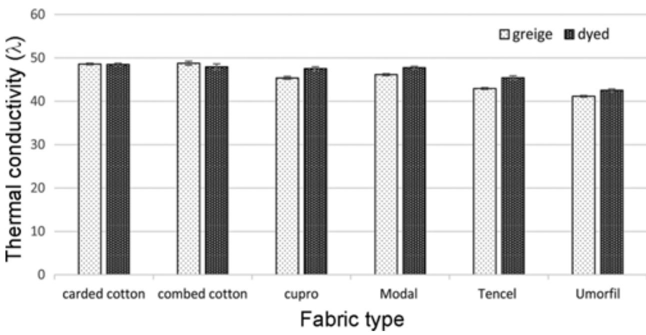

Figure 1. Thermal conductivity of knitted samples.

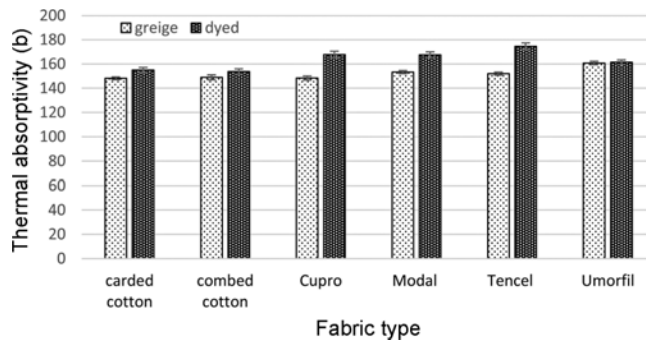

Figure 2. Thermal absorptivity.

dyed fabrics made of cotton and cellulosic fibres. According to Figure 1; dyed fabrics made of cellulosic yarns slightly indicated higher thermal conductivity compared to their greige counterparts. However, a vice versa situation was observed among the samples of 100 % combed cotton yarn where greige samples provided slightly higher thermal conductivity. Among the dyed samples; knitted fabrics made of Modal yarns revealed the highest thermal conductivity compared to other groups while samples made of Umorfil® yarns indicated the lowest thermal conductivity. When it comes to greige samples, highest thermal conductivity was obtained from samples made of 100 % combed yarns while lowest thermal conductivity was observed among those made of 100 % Umorfil® samples. ANOVA results also indicated that yarn type, process type and their interaction were influential factors on thermal conductivity of the samples at significant level of 0.05 (Table 7). SNK results displayed that fabric samples made of different yarns possessed different thermal conductivity. According to SNK results (Table 8), knitted samples made of Umorfil® yarns indicated the lowest thermal conductivity while samples made of combed yarn revealed the highest thermal conductivity at significant level of 0.05. Additionally, thermal conductivity of samples made of cupro and samples made of Modal fibre were observed under the same subset at significance level of 0.05.

Thermal Absorptivity (b)

Thermal absorptivity (b) of knitted samples were revealed with bar graph in Figure 2. According to Figure 2, all dyed samples revealed higher thermal absorptivity compared to their greige counterparts. Among the dyed fabric groups; knitted samples made of Tencel™ yarns indicated the highest thermal absorptivity while knitted samples made of combed yarn revealed the minimum value. When it comes to greige fabric groups; 100 % Umorfil® knitted samples indicated the highest thermal absorption while 100 % Cupro knitted samples revealed the lowest value.

ANOVA test also revealed that yarn type, process type and their interaction were influential factors on thermal absorption at significance level of 0.05 (Table 7). SNK results (Table 8) displayed that knitted samples made of different yarns possessed different thermal absorptivity values b ($W \cdot m^{-2} \cdot s^{1/2} \cdot K^{-1}$). Thermal absorptivity value of knitted samples made of combed and carded yarns were observed under the same subset at significance level of 0.05. Thermal absorptivity of knitted samples made of regenerated cellulosic fibres were also observed under the same subset and higher than the samples made of combed cotton, made of carded cotton at significance level of 0.05.

Thermal Resistance (R)

Thermal resistance is another considerable parameter from the point of view of thermal insulation, and is directly related with fabric structure. Thermal resistance of greige and dyed knitted samples were indicated in Figure 3. According to Figure 3, greige samples indicated higher thermal resistance compared to their dyed counterparts. This result may be attributed with the thermal conductivity results of the knitted samples where greige samples provided lower thermal conductivity compared to dyed samples (Figure 1). According to Figure 3; Among the greige samples; highest thermal resistance was obtained from the samples made of Tencel™ yarns while lowest thermal resistance was found among the samples made of Umorfil® yarn. When the dyed samples were considered; highest thermal resistance was obtained from 100 % carded samples while lowest thermal resistance was found among 100 % Tencel™ samples.

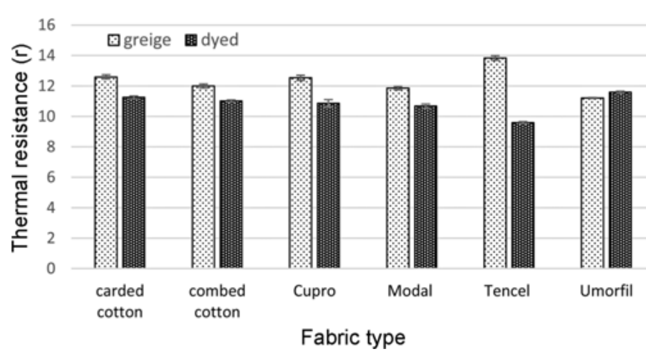

Figure 3. Thermal resistance.

Table 9. Correlation between fabric thickness and thermal resistivity

Parameter	Correlation coefficient
Fabric thickness and thermal resistivity	0.73*

*Correlation is significant at the 0.01 level.

ANOVA results also indicated that yarn type, process type and their interaction were significant factors on thermal resistance of the fabric samples at significance level of 0.05 (Table 7). Additionally, SNK results revealed that samples made of different yarns possessed different thermal resistivity values (Table 8). According to SNK results of thermal resistance; Knitted samples from Umorfil® yarns revealed the lowest value while fabric samples produced from carded cotton yarn indicated the highest thermal resistance value (m^2KW^{-1}). Furthermore, thermal resistivity of samples made from cupro yarn and samples from carded cotton yarn were observed under the same subset at significance level of 0.05.

Fabric thickness is known directly to be influencing thermal resistance. It is generally stated that fabric thickness has a direct relation with the thermal resistance with indicates that thicker fabrics lead to higher thermal resistance for the fabrics. There are some researches which indicate the direct proportion between hairiness and thermal resistance [24]. According to correlation results within our study; fabric thickness results obtained from Alambeta instrument was positively correlated with thermal resistance with the correlation coefficient of 0.73.

Relative Water Vapor Permeability and Water Vapor Resistance

Relative water vapor permeability is defined as the fabric ability permitting water vapor transfer in percentage scale. This parameter should be mostly considered especially for the hot weather clothes where perspiring is maximal. When the stored heat in the body increases because of high evaporative resistance; this situation may result with uncomfortable feeling. Garments with high water vapor permeability enhances moisture evaporation easily after sweating enhancing comfort sense [25,26]. In order to reveal the inverse relation between water vapor permeability and water vapor resistance mentioned in the literature, correlation analysis between these two parameters was also conducted within our study. According to correlation analysis; there is a powerful negative correlation coefficient between water vapor permeability and water vapor resistance (r^2=-0.921).

Figure 4 indicates the water vapor permeability of knitted samples. According to Figure 4, dyed samples made of carded and combed cotton yarn prominently revealed higher water vapor permeability values compared to their greige counterparts. Similar result was observed among the Tencel® dyed samples. However, Cupro, Modal and Umorfil® greige samples indicated slightly higher water vapor permeability compared to their dyed counterparts.

Table 10. Correlation between fabric water vapor permeability and water vapor resistance

Parameter	Correlation coefficient
Fabric water vapor permeability and water vapor resistance	-0.921*

*Correlation is significant at the 0.01 level.

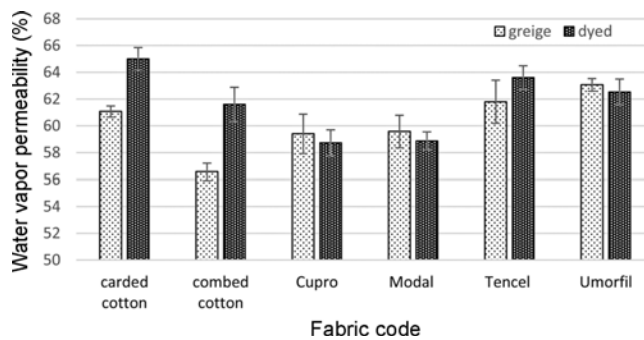

Figure 4. Water vapor permeability.

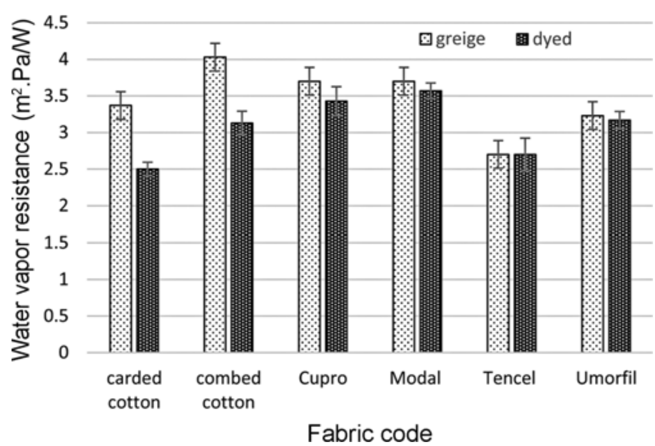

Figure 5. Water vapor resistance.

According to Figure 5; greige samples of each fabric type generally indicated higher water vapor resistance compared to their dyed counterparts. On the other hand, there was not a prominent difference between the water vapor resistance of greige and dyed samples of Tencel™ fabrics. As the greige samples are considered; Fabric groups made of combed cotton yarns indicated the highest water vapor resistance while samples made of Tencel™ yarn revealed the lowest water vapor resistance. On the other hand, samples made of Modal yarns revealed the highest water vapor resistance while samples made of carded yarns indicated the lowest water vapor resistance among the dyed samples.

Additionally, two-way (ANOVA) test was conducted for the investigation of effects of yarn raw material type and process type on water vapor permeability and water vapor

Table 11. ANOVA results for water vapor permeability, water vapor resistance

Main effect	Water vapour permeability	Water vapour resistance
Yarn type	0.02*	0.00*
Process type	0.12	0.01*
Interaction of yarn type and process type	0.32	0.29

*Statistically significant (5 % significance level).

Table 12. SNK results for water vapor permeability and water vapor resistance

Parameter: yarn type	Water vapor permeability	Water vapor resistance
Carded	63.03a	2.93ab
Combed	59.08a	3.58b
Modal	59.21a	3.63b
Tencel	62.70a	2.70 a
Umorfil	62.80a	3.20ab
Cupro	59.06a	3.56b

The different letters next to the counts indicate that they are significantly different from each other at a significance level of 0.05.

resistance properties of fabric samples. According to ANOVA test (Table 11), yarn type was an influential factor while process type and interaction of yarn type and process type were non-significant factors on water vapor permeability properties. When it comes to water vapor resistance, yarn type and process type were influential factors while interaction of yarn type and process type was non-significant on water vapor resistance of the knitted samples. SNK results also revealed that fabrics produced from different yarn raw material type possessed different water vapor resistance. According to SNK results of water vapor permeability, it was observed that water vapor permeability of knitted samples made of different yarn type were observed under the same subset at significance level of 0.05 (Table 12). Regarding to SNK results for water vapor resistance; samples made of Tencel™ yarns indicated the lowest water vapor resistance while samples made of combed cotton yarns indicated the highest water vapor resistance which was observed under the same subset with the knitted samples of Modal yarns. Our result was compatible with Ener and Okur's study where Tencel™ knitted fabrics revealed the lowest water vapor resistance among those made of polyester, cotton, viscose [27].

Air Permeability

The resistance to wind penetration in cold weather can be interpreted from the fabrics' air permeability. Thermal insulation in the cloth is influenced from this wind penetration in cold weather. Air permeability of fabrics is

Table 13. Correlation between fabric air permeability and fabric weight

Parameter	Correlation coefficient
Air permeability and fabric weight	-0.921*

*Correlation is significant at the 0.01 level.

mainly influenced from fabric structural property which is related to fibre and yarn type, linear density, fabric weight...etc. All these parameters have strong effects on porosity of fabric hence on the fabrics' air permeability properties. A correlation analyse was performed in order to reveal the relationship between fabric weight and air permeability properties of the knitted samples within our study. A powerful negative correlation (r^2=-0.78) was also observed between the fabric weight and air permeability properties of knitted samples (Table 13). This result is attributed to fabric weight parameter directly influencing the total porosity hence the air permeability of the knitted samples [28-30].

Air permeability results of samples are indicated in Figure 6. According to Figure 6; Greige samples indicated generally higher air permeability values compared to their dyed counterparts. However, this situation was vice versa in Umorfil® fabrics where dyed samples provided higher air permeability values compared to greige samples. Among the greige samples; samples made of combed compact yarn displayed the minimum air permeability while samples made of Tencel™ yarn revealed the maximum air permeability. This result may be attributed to low yarn hairiness values of Tencel™ (Table 6). Among the dyed samples; Umorfil® samples revealed the maximum air permeability while fabrics made of carded cotton yarn provided the minimum air permeability.

Completely randomized two-factor analysis of variance (ANOVA) test was also conducted in order to investigate the effect of process and yarn type on fabric air permeability

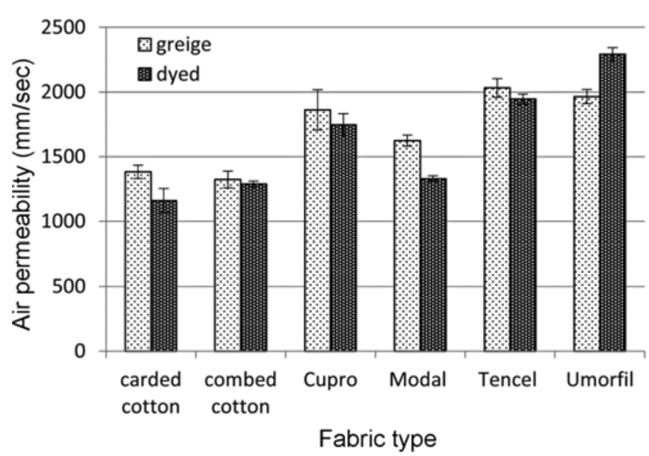

Figure 6. Air permeability properties.

Table 14. ANOVA results for air permeability

Main effect	Air permeability
Yarn type	0.00*
Process type	0.15
Interaction of yarn type and process type	0.00*

*Statistically significant (5 % significance level).

Table 15. SNK results for air permeability

Parameter: yarn type	Air permeability
Carded	1327a
Combed	1331a
Modal	1485b
Tencel	2005d
Umorfil	2096d
Cupro	1818c

The different letters next to the counts indicate that they are significantly different from each other at a significance level of 0.05.

(Table 14). According to ANOVA test, yarn type was a significant factor while process type was non-significant on air permeability properties. Additionally, interaction of yarn type and process type was also significant on air permeability properties. For the comparison of means, SNK results for air permeability were also displayed in Table 15. It is observed that knitted fabrics made of different yarn type possessed different air permeability value at significance level of 0.05. According to SNK test, fabrics made of carded and combed yarn indicated the minimum air permeability which were observed under the same subset while samples made of Umorfil® yarn provided the maximum air permeability.

Bursting strength

Bursting strength of knitted fabrics made of different yarn types are indicated in Figure 7. Among the greige samples; highest bursting strength was obtained from Tencel™ fabrics while lowest value was found among Umorfil samples. This result may be attributed to high fibre and yarn strength of Tencel™ fibre owing to its high crystallinity which reflects in fabric bursting strength. The similar result was provided in Dirgar's study where Tencel fabrics indicated higher bursting strength compared to Modal, viscose and Cupro fabrics [4]. When it comes to dyed fabrics; it is observed that maximum bursting strength was obtained from samples of combed cotton while minimum bursting strength was found among Modal fabrics. It is also observed that except Umorfil® knitted samples, the bursting strength of dyed cellulosic fabrics decreased when compared with their greige counterparts while bursting strength of cotton made samples increased with the dying process. Our

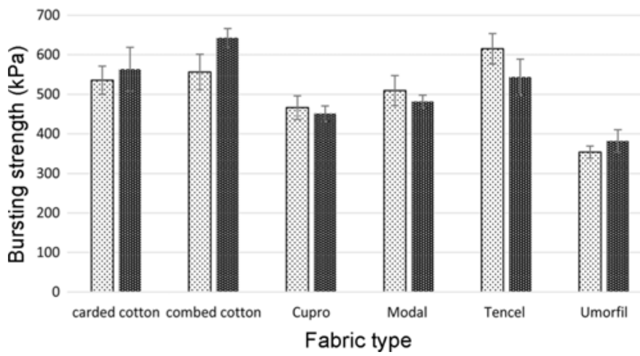

Figure 7. Bursting strength.

Table 16. ANOVA results for bursting strength

Main effect	Air permeability
Yarn type	0.00*
Process type	0.70
Interaction of yarn type and process type	0.00*

*Statistically significant (5 % significance level).

Table 17. SNK results for bursting strength

Parameter: yarn type	Bursting strength
Carded	549.35c
Combed	599.52c
Modal	465.44b
Tencel ™	579.23c
Umorfil ®	367.67a
Cupro	458.66b

The different letters next to the counts indicate that they are significantly different from each other at a significance level of 0.05.

result was consisting with the earlier findings of Kayseri *et al*. where the dyed cellulosic knitted fabrics were found lower compared to their greige counterparts [9].

Additionally, randomized two-factor analysis of variance (ANOVA) test was conducted in order to investigate the yarn type and process type on bursting strength of fabrics. According to ANOVA test; yarn type and the interaction of yarn type and process type were significant factors on bursting strength values. However, process type factor alone was non-significant on bursting strength value of the fabrics. SNK results also possessed that fabrics made of different yarns revealed different bursting strength value. According to SNK results; Knitted samples made of Umorfil® yarn indicated the lowest bursting strength while samples made of combed cotton yarn provided the highest bursting strength where samples made of Tencel™ yarn followed it. Additionally, knitted samples made of Modal and Cupro yarns provided lower bursting strength compared to knitted samples made of carded cotton and Cupro cotton yarn.

Conclusion

This study involves the evaluation of some comfort properties such as thermal property, water vapour permeability, water vapour resistance, air permeability and bursting strength of single jersey knitted fabrics made of different raw material including combed cotton, carded cotton, Cupro, Tencel^{TM,} Modal and Umorfil® yarn As all yarn and fabric production conditions are kept all same, the differences of the fabric performance properties mentioned above were attributed due to the yarn characteristics as well as fabric being exposed to dyeing process or not.

According to one-way ANOVA test conducted for the yarn properties; significant differences were observed among the CVm, thin places (-50 %), thick places (+50 %), neps (200 %), H, elongation (%), tenacity (cN/ tex) values of Ne 30/1 compact yarns made of different fibres. Cupro yarns indicated the best satisfying level for hairiness while carded cotton yarns revealed the maximum hairiness results. Carded yarn elongation (%) was observed to be providing the lowest value while Umorfil® yarn provided the highest elongation value (%). Tencel^{TM} yarns indicated the maximum yarn tenacity.

According to two-way ANOVA test; Thermal properties such as thermal conductivity, thermal absorptivity, thermal resistivity was significantly influenced from yarn type and process type at significant level of 0.05.

Regarding to thermal properties; dyed fabrics made of cellulosic fibres indicated higher thermal conductivity compared to their greige counterparts. Knitted fabrics made of Umorfil® yarns indicated the lowest thermal conductivity while fabrics made of combed yarn revealed the highest thermal conductivity at significant level of 0.05. Considering the thermal absorptivity results; dyed samples indicated higher thermal absorptivity compared to greige samples. Thermal absorptivity of knitted fabrics made of regenerated cellulosic fibres were observed to be under the same subset and higher than the fabrics made of combed cotton, made of carded cotton at significance level of 0.05. This indicates that knitted garments made of cellulosic fibres give cooler feeling compared to cotton garments which will be more satisfying in summer time.

Thermal resistance of the knitted fabrics made of regenerated cellulosic fibres were generally lower compared to those made of cotton yarn. Among the dyed samples, knitted fabrics made of Tencel^{TM} indicated the lowest thermal resistance which allows comfortable wearing for knitting wears made of Tencel^{TM} yarn in hot conditions. Correlation test results between thermal conductivity and thermal resistance of the fabric samples indicated the inverse proportion while the correlation between fabric thickness and thermal resistivity revealed the direct proportion between mentioned parameters prominently. Only yarn type was an influential factor on water permeability of the fabrics while process type and the interaction of process type and yarn type were not significant factors on water permeability of the fabric samples. Yarn type and process type were influential parameters at significance level of 0.05. while interaction of yarn type and process type was a non-significant factor on water vapour resistance of the knitted samples. Fabrics made of Tencel^{TM} yarns indicated the lowest water vapor resistance while samples made of combed cotton yarns indicated the highest water vapor resistance.

A negative correlation was observed between the fabric samples' fabric weight and the air permeability values which was attributed to porosity of fabrics. Process type (fabric being greige or dyed) was not a significant factor while yarn type and interaction of yarn type and process type were significant factors on air permeability properties. According to SNK test, fabrics made of carded and combed yarn indicated the minimum air permeability which were observed under the same subset while samples made of Umorfil® yarn provided the maximum air permeability.

Considering bursting strength under the subset of mechanical properties; yarn type and the interaction of yarn type and process type were significant factors on bursting strength values. However, process type sole was a non-significant factor on bursting strength value of the fabrics. Knitted samples made of Umorfil® yarn indicated the lowest bursting strength while fabrics made of combed cotton yarn provided the highest bursting strength where samples made of Tencel^{TM} yarn followed it.

General results indicate that regarding to final aim of the product, different fibre types may be utilized for the knitted fabrics according to expected properties from the garment. Although the regenerated cellulosic fibre properties and their contribution to the fabric are similar, presence of collagen peptide in the cellulosic fibres may reflect to fabric performance properties in many aspects including comfort and mechanical properties. Considering those fibres' biodegradable, antibacterial and sustainable features, new knitted designs with utilization of yarn blends of collagen peptide added fibres, regenerated cellulosic fibres or natural fibres in sport clothes may be promising for adding up a more sustainable world.

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