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RESEARCH ARTICLE

Moisture management and antimicrobial performance of collagen peptide enriched knitted fabrics

Ali Serkan Soydan[a], Gizem Karakan Günaydin[b], Haluk Ergezer[c] and Sema Palamutcu[a]

[a]Textiles Engineering Department, Faculty of Engineering, Pamukkale University, Denizli, Turkey; [b]Fashion & Design Programme, Pamukkale University Buldan Vocational School, Denizli, Turkey; [c]Food Engineering Department, Faculty of Engineering, Pamukkale University, Denizli, Turkey

ABSTRACT

Knitted fabrics made of natural, synthetic and regenerated fibres are presented to the final consumers at different fabric constructions. Reason to select different fibre types, fibre blends, and knitting constructions utilisation is to optimize consumer demands of comfort, functionality, fashion and price. Continuous fibre improving studies are one driving factor behind the fabric and clothing design possibilities. Collagen peptide added fibres are one recent fibre type in the regenerated cellulosic fibre family. Collagen peptide addition to the regenerated cellulosic fibre has been reported to improve fibre properties of moisture management, thermoregulation, anti-static, ultraviolet protection, biodegradable properties which make the fibre preferable material for active wear clothes. This study involves with the influence of new fibre type addition on moisture management, antimicrobial, and air permeability properties of the plated knitted fabric structures. Within this work; one plain knitted fabric is knitted using 100% collagen peptide added regenerated cellulosic yarn and polyamide yarn grounded six different plated knitted fabrics were studied. Moisture management transport (MMT) properties, antimicrobial properties (against *Escherichia coli*, *Staphylococcus aureus* and *Candida albicans*) and air permeability properties of those knitted samples were evaluated comparatively. Gathered results are statistically evaluated using one-way Anova test; it was determined that there was a significant difference on MMT and air permeability properties of knitted samples at significance level of 0.05. Additionally, presence of collagen peptide added fibre exhibits considerable level of antimicrobial effect against included microorganisms. The results of the experimental work represent an initial phase towards a better understanding of the influence of different fibre blended yarn utilization on plated knitted fabrics which would be appropriate for active wear cloth manufacturing.

Abbreivations: *E. coli*: *Escherichia coli*; *S. aureus*: *Staphylococcus aureus*; *C. albicans*: *Candida albicans*; MMT: Moisture management transport; OMMC: Overall moisture management control; AOTI: Accumulative one-way transport index; MWR: Maximum wetted radius; SPW: Sterile physiological water

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KEYWORDS
Plated knitted fabric; collagen peptide fibre; moisture management; antibacterial; antifungal

1. Introduction

There has been an increasing demand for the knitted fabrics which provide outstanding comfort qualities. Different knitting patterns with different developed fibres may be preferred by the consumers based on their comfort and visual appearance requirements. Comfort is a complex term which includes sensorial and non-sensorial measurements. Non-sensorial comfort parameters are measureable parameters by using laboratory equipment of Alambeta, sweating guard hot plate and Moisture Management Tester (MMT); whereas sensorial evaluations can be obtained *via* human skin feelings of tactile sensations, moisture sensations and thermal sensations (Song, 2011).

A garment fabric is expected to meet three required thermal properties high thermal resistance for cold interphases, low water vapor resistance for heat transfer under warm climate conditions and fast moisture transfer for preventing the wet feeling disturbance in high degree conditions (Tao, 2001). A high comfort cloth should also provide to have some additional properties such as easy adaptation to body movements, easy drying, lightness, durability, easy caring (Mikučioniene & Milašiene, 2013).

Moisture management is about sweat transportation mechanism from skin surface and its evaporation to atmosphere beside fabric weight control mechanism with prevention of moisture increase on textile surface (Onofrei et al., 2011; Ramkumar et al., 2007) . Surficial contact of liquids with a textile material can be explained with surface wetting, liquid transfer into fibre groups, adsorption or diffusion mechanisms of liquid through the fibre bundle (Kissa, 1996; Sharabaty et al., 2008).

Today functional knitted structures are preferred in the next to skin clothing where moisture of body sweat is expected to transferred and released to out of fabric surface reducing the humidity over the body. Moisture management concept in the clothing is commonly used for special clothing of sportswear, work-wear and inner-wear for its dry feeling and minimised

CONTACT Sema Palamutcu spalamut@pau.edu.tr Textile Engineering Department, Faculty of Engineering, Pamukkale University, Denizli, Turkey.

liquid collection on body surface in case of sweating (Y. Jhanji et al., 2015a; Patnaik et al., 2006).

Active wear cloth fabrics are specially designed fabrics where comfort properties such as thermal comfort, moisture management properties and air permeability are highly required. Plated knitted fabric constructions are one appropriate knitting type that may be used for the manufacturing of active wear sport clothes with its purposely improved high moisture transfer properties. Those fabrics are designed using engineering approach during the designation of fibre and yarn content front and back sides of the fabric (Karthik et al., 2018). Generally, it is observed that a simple double side structure has inner face made of synthetic fibre yarn which is hydrophobic and has good capillarity; and has outer face manufactured with hydrophilic yarn (Khan et al., 2018). Plated knitting structures made of different fibres may be a good solution for both absorbing the sweat liquid from body surface and transfer it to fabric inner surface which accelerates the drying performance.

Early studies related to comfort properties of knitted fabrics are summarized below;

Prakash and Ramakrishnan (2013) concluded that thermal conductivity of fabrics decreased with the increase in the proportion of bamboo fibre. On the other hand, water vapor permeability and air permeability of the fabrics were observed to be increased with the increase in bamboo fibre (Prakash & Ramakrishnan, 2013).

Uzumcu et al. (2019) conducted a study where mulberry silk/combed cotton blended yarns were produced by using siro and ring spinning systems in three different yarn counts. Knitted fabrics were evaluated in terms of comfort properties. Authors concluded that increment of silk content in the blend and the usage of siro spinning system instead of ring spinning system provided more satisfying results in terms of comfort properties (Uzumcu et al., 2019).

Onofrei et al. made a research related to thermal and moisture management analyse of sportswear fabrics made of two types of yarns (Coolmax® and Outlast®) with thermo regulation effect. According to results it was concluded that thermal properties, diffusion ability, air and water vapor permeability were influenced by both raw material type and knitted structure parameters. Outlast® fabrics were found more suitable for the warmer climate sportswear due to low thermal resistance, high thermal conductivity, high thermal absorptivity, high air permeability while Coolmax® based structures were found as the best choice for colder weather (Onofrei et al., 2011).

Fabric air permeability, wicking, moisture management, thermal and water vapor resistances of two knitted structures composed of tuck and float combinations with six raw materials were assessed in Öner and Okur's study (2015). According to test results; it was observed that polyester fabrics and cotton/Coolmax fabrics provided better moisture transport properties., and high air permeability and low water vapor resistance were obtained in viscose and Tencel LF fabrics with tuck stitches (Öner & Okur, 2015).

Khan et al. studied single jersey, plated jersey and hybrid plated jersey knitted fabric samples to evaluate their liquid moisture management properties of wetting time, maximum wetted radius, absorption rate, one-way transportation capability and overall moisture management control (OMMC). It was observed that plated jersey and hybrid plaited jersey structures had better moisture management properties compared to single jersey knitted structures. However, air permeability of single jersey knitted fabrics was observed to be better than the other knitted structures (Khan et al., 2018).

Yamini Jhanji et al. studied comfort properties of plated knitted fabrics with varying fibre type. Plated fabrics with nylon in the next to skin layer were found as a satisfying choice for warm conditions as these fabrics indicated high thermal absorptivity as well as were permeable to air passage and moisture vapor. It was also concluded within the study that fabrics with low linear density were found as suitable in warm conditions owing to higher thermal resistance with low air permeability, moisture vapor transmission rate (Yamini Jhanji et al., 2015b). Thermophysiological comfort properties of polyester elastane-plated fabrics were studied by Manshahia and Das (2014) where polyester filament shape factor, elastane linear density and fabric loop length were selected as the variables. Thermal and evaporative resistances and most of the moisture transmission properties were found to be influencing from the mentioned variables (Manshahia & Das, 2014).

Özdil et al. investigated the thermal properties of 1×1 rib fabrics made of different yarn properties in terms of thermal resistance, thermal absorptivity and thermal conductivity, and water vapor permeability. It was emphasized that yarn features of yarn count, yarn twist and combing process have significant influence on thermal comfort properties of 1×1 rib knitted fabrics. Thermal resistance values decreased with the increase of yarn count and yarn twist (Özdil et al., 2007).

Selection of right fiber or fiber blend type for sport garments is a big phenomenon since such fabrics' long time contacts with the skin may cause to skin infections. Current literature indicates that less bacterial growth was observed on Tencel™ fibres which were attributed to its unique high water absorption capacity. It was emphasized that bacterial growth was 10 times lower compared to cotton owing to its very good water absorption in combination with its smooth surface (Firgo et al., 2006; Männer et al., 2004; Teufel & Redl, 2006).

Apart from early researches, selection of collagen peptide based raw material as the component fibre of active wear fabric yarns might be useful due to its inherited features such as antimicrobial efficiency, and wound healing accelerating property beside its sustainable characteristic. Collagen is the most abundant animal protein, accounting for almost 30% of total protein in animal body. This fibrous protein plays an important role for providing the biological and structural integrity of extracellular matrix of the tissues in the body. In fishes, collagen is usually extracted out of meat, skin, fins, scale, and fish wastes. The extracted fish collagen can be purified for use in cosmetics, medical, sports, and nutrition, etc. Those collagen peptides have been discovered as one of the alternative antimicrobial sources as the potential health risks of synthetic antimicrobials have increased (Felician et al., 2018). Researchers have reported that almost all fish peptides have antibacterial or bacteriostatic functions

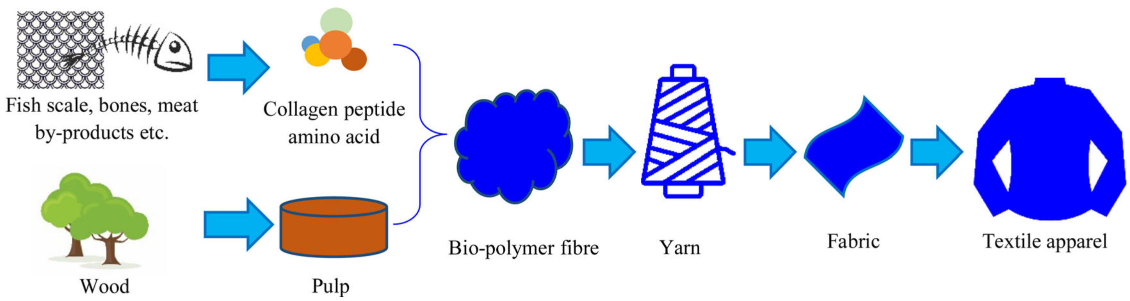

Figure 1. Collagen peptide added regenerated cellulosic fibre production and its conversion from fibre to apparel.

Table 1. Physical properties of Umorfil®, some natural and regenerated fibres (Umorfil® Beuty Fiber® Intro 20170609, n.d.).

Fibre Property	Umorfil® (1.25/38 mm)	Rayon	Wool	Tencel™ (1.3/38 mm)	Cotton
Tenacity (g/d)	2.75	2.5	1.6	3.3	4
Elongation (%)	20-25	10-20	25-35	13-15	6-10
Moisture Regain (%)	16-18	11-13	14-18	8-11	7.5
UV Resistance	Good	Poor	Fair	Fair	Poor

Table 2. Spun yarn types and their structural properties.

Yarn type	Yarn Count (Ne)	CVm	Thin places (-50%)	Thick places (+50%)	Hairiness	Neps (+200%)	Tenacity (cN/tex)	Elongation (%)
100% Umorfil®	30/1	10.89	0.16	2.93	4.37	6.31	19.35	13.33
35%Umorfil® 65% Tencel™	40/1	13.06	17	18	5.36	49	20.38	7.31
50% Umorfil® 50% viscose	30/1	11.01	171	18	5.34	32	17.18	11.83
50% Umorfil® 50% cotton	30/1	11.03	0	15	5.22	25	15.99	5.63
15% cotton 85% Tencel™	40/1	13.95	132.37	55	4.19	41	16.91	4.23
35% Umorfil® 65% Tencel™	80/1	16.67	167	116	3.73	114	19.96	5.96

against several gram-negative and -positive strains (Najafian & Babji, 2012; Rajanbabu & Chen, 2011).

Umorfil® is Taiwan based commercial textile fiber brand which is 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. Collagen peptide added regenerated cellulosic fibre production and its conversion from fibre to apparel are schematically displayed in Figure 1. Those kind of fibres may be blended to any desired staple or filament fibre in order to produce special yarns at any linear density.

Physical properties of a collagen peptide added regenerated cellulosic fibre - Umorfil® fibre is given in Table 1 with some other fibres.

As mentioned in the above parts there are many researchers focused on the influence of fibre, yarn and fabric structure parameters on the comfort properties of single and double jersey knitted fabrics however the number of studies related to evaluation of some comfort and antimicrobial properties of plated knitted structures made of different fibres containing collagen peptides are limited. This study aimed to contribute to the literature with the evaluation of moisture management, air permeability, and antimicrobial efficiency properties of plated knitted fabrics made of newly developed collagen peptide added regenerated cellulosic fibre-Umorfil® and its blend with cotton, viscose, Tencel™ (commercial brand) staple yarns, and polyamide filament yarn. https://www.umorfil.com/products.html

Within the study, 100% Umorfil® plain knitted and plated knitted fabrics with altering polyamide and Umorfil® blended yarns of different linear density on upper side of fabric and 100% polyamide (210 deniers, 136 filament) filament yarn on lower side of layers have been knitted on laboratory sized circular knitting machine. Plated sample fabrics are used to research influence of collagen peptide presence in the fabric structure on the moisture management properties, air permeability property of sample fabrics, and antimicrobial property for preventing bacterial and fungal infections.

2. Material and method

This study evaluates the influence of textile production parameters on moisture management, air permeability and antimicrobial properties of active wear clothing fabric. Details about yarn spinning, fabric production as well as the testing methods with the statistical analyses are given below respectively.

2.1. Yarn structural properties

100% Umorfil® and Umorfil® blends of Tencel™, viscose and cotton fibres were processed in compact spinning line. The yarn properties of evenness and tensile properties were given in Table 2. Tensile properties of the yarns were evaluated on Uster Tensorapid 4 while yarn unevenness and hairiness measurements were performed on Uster Tester 5 testing machine. Five cops were chosen for the efficient assessment of each yarn sample and five measurements were completed from each cops. All the measurements were conducted under standard test conditions according to ISO 139:2005 standard (ISO, E. N., 2005). Leica Dm 750p brand

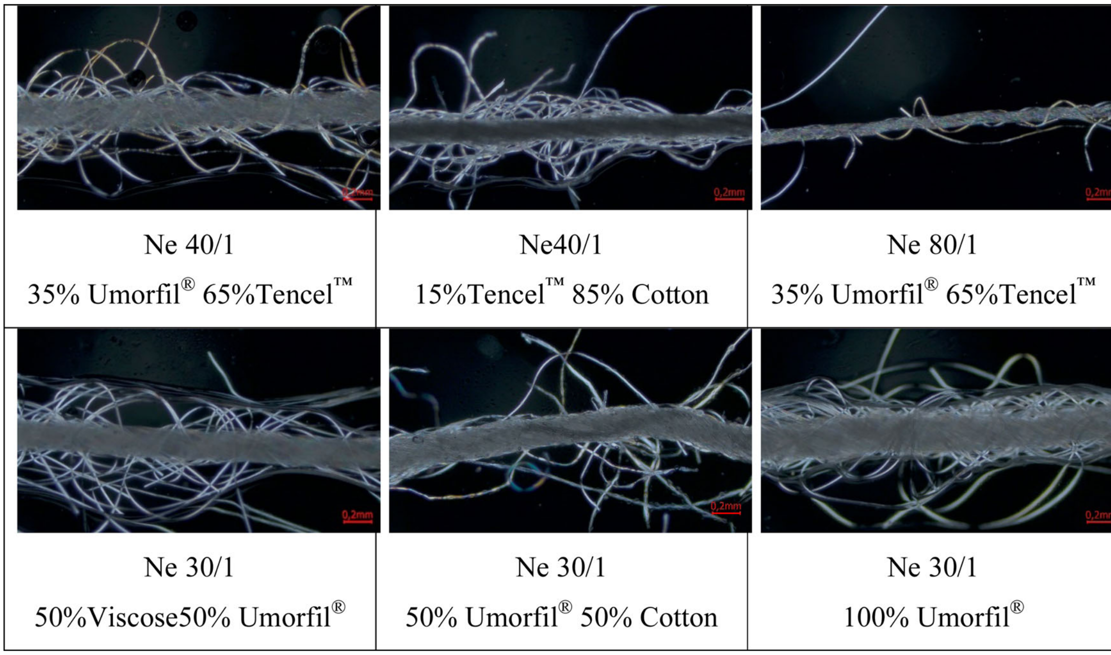

Figure 2. Microscope images of the yarns (magnification of 4x).

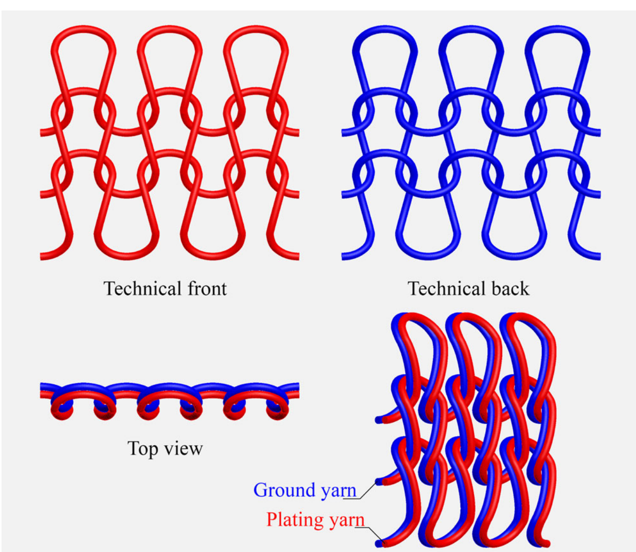

Figure 3. Plated knitting fabric construction (*drawn by using Autodesk® Inventor® Professional 2020 educational version*).

polarized microscope was utilized for obtaining yarn images. Magnification of 40× optical was applied with LED illumination (Figure 2).

2.2. Fabric production

Knitted surfaces were manufactured on a laboratory sized circular knitting machine as plated design using several combinations of Umorfil®, Tencel™, viscose, cotton fibre spun and polyamide filament yarn types. Six different plated and one 100% Umorfil® plain knitted fabrics (without plating yarn) were produced with the gauge of '18' on Faycon CKM 01 S model circular knitting machine. After knitting process, fabrics were exposed to soft washing at 30°, then conditioned for 24 h in standard atmospheric conditions before the conducted tests (ISO, E. N., 2005). Schematic diagrams of plated knitted fabrics are revealed in Figure 3.

Constructional properties of plated knitted fabric samples are revealed in Table 3.

Since the plated knitted fabrics were planned to be used for active wear sports garments which requires breathability

Table 3. Fibre composition and yarn linear densities of plated knitted fabrics samples.

Fabric code	Ground yarn composition	Ground yarn linear density (tex)	**Plating yarn composition**	Plating yarn linear density (tex)	Plating + Ground yarn linear density (tex)	Fabric weight (gr/m^2)
F1	%100 Polyamide	23	15% cotton 85% Tencel™	15	38	141
F2	%100 Polyamide	23	35% Umorfil® 65% Tencel™	8	31	113
F3	%100 Polyamide	23	35% Umorfil® 65% Tencel™	15	38	148
F4	%100 Polyamide	23	50% Umorfil® 50% viscose	20	43	166
F5	%100 Polyamide	23	50% Umorfil® 50% cotton	20	43	172
F6	%100 Polyamide	23	100% Umorfil®	20	43	175
F7	%100 Umorfil®	20	–	–	42	84

and moisture management, air permeability and moisture management transport tests were conducted respectively. In addition to some comfort properties; antimicrobial activity of the Umorfil® blended plated knitted samples were also evaluated. Prior to moisture management, air permeability and antimicrobial tests, all samples were conditioned for 24 h in standard atmospheric conditions according to ISO 139:2005 standard (ISO, E. N., 2005). Mentioned tests conducted within the study are described below alongside the related standards.

2.3. Moisture management evaluation

Moisture Management Tester (MMT, SDL Atlas) was used to measure moisture management properties of fabrics based on the AATCC 195-2009 standard (American Association of Textile Chemists & Colourists, 2009). The device evaluates the moisture management in many aspects considering the fabric's top and bottom sides (Hu et al., 2005; Li et al., 2002). Schematic diagram of MMT is revealed in Figure 4.

Test sequence; fabric sample was placed horizontally between concentric pins of top plate and bottom plate on MMT equipment. Liquid, that simulates sweat droplet, was dropped through the sweat gland on to the upper face test fabric. Upper face of the fabric where the liquid was dropped is supposed to be the fabric side which contacts to the skin (SDL Atlas, n.d.). The changes in electrical resistance among the pins were measured and recorded as the solution moved through and across test samples. The results were expressed in terms of the wetting time (s), absorption rate (%/s), spreading speed (mm/min) and maximum wetted radius for top and bottom surfaces (mm), accumulative one-way transport index (AOTI), and overall moisture management capability (OMMC). The terms along with their definitions are given below: Additionally, Table 4 reveals the grading of moisture management terms indices where the indices are graded and converted from value to grades of five levels: 1 – Poor, 2 – Fair, 3 – Good, 4 – Very good, 5 – Excellent.

Wetting Time (sec) defines wetting time of the test fabric for both top and bottom sides in seconds after the test is started.

Absorption rate (%/sec) defines the average speed of liquid moisture absorption for both top and bottom sides of the specimen during the liquid dropping interval.

Maximum wetted radius (MWR_{top}, MWR_{bottom}) defines the maximum wetted ring radius for both top and bottom sides, respectively, where the slopes of water content become greater than Tan 15° .

Spreading Speed defines the cumulative wetting spreading speed (mm/sec) between the centre of the specimen where

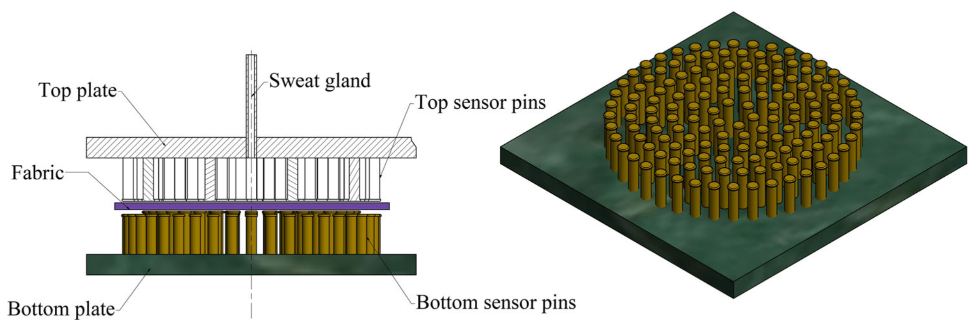

Figure 4. Schematic drawing of MMT Test Equipment (*drawn by using Autodesk® Inventor® Professional 2020 educational version*).

Table 4. Grading of MMT indices (Özkan & Kaplangiray, 2015).

Index		Grade 1	2	3	4	5
Wetting time	Top	≥120	20-119	5-19	3-5	<3
		No wetting	Slow	Medium	Fast	Very Fast
	Bottom	≥120	20-119	5-19	3-5	<3
		No wetting	Slow	Medium	Fast	Very Fast
Absorption rate	Top	0-10	10-30	30-50	50-100	>100
		Very slow	Slow	Medium	Fast	Very Fast
	Bottom	0-10	10-30	30-50	50-100	>100
		Very slow	Slow	Medium	Fast	Very Fast
Max. wetted radius	Top	0-7	7-12	12-17	17-22	>22
		No wetting	Small	Medium	Large	Very large
	Bottom	0-7	7-12	12-17	17-22	>22
		No wetting	Small	Medium	Large	Very large
Spreading speed	Top	0-1	1-2	2-3	3-4	>4
		Very slow	Slow	Medium	Fast	Very Fast
	Bottom	0-1	1-2	2-3	3-4	>4
		Very slow	Slow	Medium	Fast	Very Fast
AOTI	Top	<-50	−50 to 100	100-200	200-400	>400
		Poor	Fair	Good	Very good	Excellent
OMMC	Bottom	0.0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	>0.8
		Poor	Fair	Good	Very good	Excellent

*Accumulative one-way transport index (AOTI).
**One-way liquid transport capacity (OMMC).

the liquid is dropped and the maximum wetted radius. If it is assumed that the ring is wetted in time period of t_i, ($i = 1,2,3,4,5,6$); the liquid spreading speed from the ring of ***i-1*** to ring ***i*** is calculated as shown in Equation (1); Here '*R*' is defined as the diameter of the ring. Cumulative Spreading Speed (*SS*) is calculated as shown in Equation (2) where *N* is the maximum number of wet ring; (Hu et al., 2005).

$$S_i = \frac{\Delta R_i}{t_i} = \frac{R}{t_i - t_{i-1}} \tag{1}$$

$$SS = \sum_{i=1}^{N} S_i = \sum_{i=1}^{N} \frac{R}{t_i - t_{i-1}} \tag{2}$$

Accumulative one-way transport index (AOTI) defines division of the area difference between the maximum wet radius in the top and the maximum wet radius in the bottom to the test time.

Overall moisture management capacity (OMMC) is an index revealing the fabric ability of liquid moisture transport management. This index consists three aspects of performance; moisture absorption rate of bottom side (*BAR*), one-way liquid transport capacity (*OWTC*), and spreading/drying rate of the bottom side (SS_b) which is maximum spreading speed. The larger the *OMMC* is the higher overall moisture management ability of the fabric. The overall moisture management capacity (*OMMC*) is defined as:

$$OMMC = 0.25BAR + 0.5\ OWTC + 0.25SS_b \tag{3}$$

2.4. Air permeability

Air permeability property of the knitted samples was measured based on EN ISO 9237 standard using a SDL Atlas Digital Air Permeability Tester Model M 021 A at standard atmospheric conditions according to ISO 139:2005 standard (ISO - ISO 9237, n.d.; ISO, E. N., 2005). Test is conducted under 100 Pa air pressure per 20 cm^2 fabric surface. Results were determined as average of ten different fabric measurements and were expressed as 'mm/sec' (ISO, E. N., 1995).

2.5. Antimicrobial test

Within the study; antimicrobial efficiency of the fabrics was evaluated according to shake flask test method (ASTM E2149-13a, 2001). Gram-positive bacteria *Staphylococcus aureus* (ATCC® 6538™) and gram-negative *Escherichia coli* (ATCC® 35218™) and a strain of yeast as *Candida albicans* (ATCC® 10231™) were used as the test micro-organisms since they are the major causes of cross contamination in hospitals (Orhan et al., 2009). *Staphylococcus aureus* (*S. aureus*) is responsible for severe skin infection while *Escherichia coli* (*E. coli*) is bacteria frequently encountered in interdigital and genital infections. *Candida albicans* (*C. albicans*) is responsible for a widely encountered itching skin infection with yeasts especially in skin folds. These fungal infections are associated with warm, moist, and occlusive conditions, e.g. under the armpits, under the breasts, as well as in the genital and anal regions (Hipler et al., 2006).

After preparation and incubation of test inoculums, diluted solutions of microorganisms were obtained where consecutive dilutions were repeated by taking 1 ml of previous solution and mixing with 9 ml of sterile physiological water (SPW). As the bacterial concentration was diluted to 1.5×10^5 CFU/ml, sterilized textile samples (3×3 cm) were added to each flask and shaken vigorously for 1 h at 37 C° in shaking incubator. Diluted solutions of 1 ml are taken from these flasks and then they were poured onto the petri dishes. Then nutrition agar [PCA (Plate Count Agar) for *S. aureus* and *E. coli;* PDA (Potato Dextrose Agar) for *C. albicans*] was also added to those petri dishes. Finally, incubation of petri dishes was conducted at 37 C° in conventional incubator for *S. aureus* and *E. coli;* at 25 C° in conventional incubator *for C. albicans*. Afterwards, viable colonies of bacteria (*S. aureus* and *E. coli*) were determined after 24 h, viable colonies of yeast (*C. albicans*) were determined after 72 h. All stages were followed for the test flasks being shaken for 24 h at 37 C° in shaking incubator.

The reduction in number of microorganism was calculated with following Equation (4):

$$Reduction\ rate\ \left(\%\right) = \left[(B - A)/B\right] \times 100 \tag{4}$$

where *A* is number of microorganism recovered from inoculated test flasks incubated over the desired shaking period (24 h). *B* is the number of microorganism recovered from test flasks immediately after 1 h shaking.

2.6. Statistical analyses

In order to analyse the influence of knitted fabric type on fabric moisture management and air permeability properties, randomised one-factor analysis of variance (One-Way Anova) test was used. The means of measured results were compared by SNK tests. The value of the significance level $\alpha = 0.05$ was selected on all statistically evaluations. The treatment levels on SNK tests were marked in accordance with the mean values, and marked by letters (a, b, c, d, e) indicating their significant differences. All statistical work was conducted using the SPSS 23.0 statistical software package.

3. Results and discussion

3.1. Moisture management properties

The moisture management performances of all sample fabrics were evaluated in terms of wetting time (sec), absorption rates (%/sec), maximum wetted radius (mm), spreading speed (mm/sec) for top and bottom surfaces, accumulative one-way transport index (*AOTI*) and overall moisture management capacity (*OMMC*). Measured findings of each MMT test term values are statistically evaluated (one way Anova test) to understand their significance level for each sample fabric (Table 5). As it is revealed in Table 4, test term of MMT measurement results are found significantly important except Max wetted radius (top) value (0.43).

Detailed test results for each test term of MMT are given in bar graphs, and SNK tests were performed respectively in order to evaluate the significant influence of fabric type on fabrics' moisture management properties and compare the means of those properties. Discussion of Anova and SNK results for each terms will be mentioned within each related sections.

3.1.1. Wetting time (sec)

Wetting time after the liquid has been applied was evaluated for all fabric samples in Figure 5, where wetting time of the fabrics' top and bottom surfaces fluctuates between 2 sec. and 8.5 sec. Maximum top wetting time was observed among F1 coded plated knitted fabrics where the ground yarn was selected as 100% polyamide and plating yarn was selected as 15% cotton 85% Tencel™ yarns. Minimum top wetting time was observed among F4 coded plated knitted fabrics with the ground yarn of 100% polyamide and 50% Umorfil® 50% viscose plating yarn. When the bottom wetting time is considered; F5 coded plated knitted fabrics with the ground yarn of 100% polyamide and 50% Umorfil® 50% cotton plating yarn indicated the highest bottom wetting time while F7 coded fabric made of 100% Umorfil® fibres revealed the minimum value.

As a general evaluation it can be concluded that a fabric with higher top wetting time compared to bottom wetting time such as F7 plain knitted fabric reveals that fabric will stay dry during sweating and quick liquid transport to bottom face without high moisture accumulation (Y. Jhanji et al., 2015a). However, F2, F3, F4, F5 and F6 coded fabrics exhibit moisture accumulation on top face and poor liquid transfer on bottom face.

As it is shown on Table 6 that there was a significant effect of fabric type on top wetting time and on bottom wetting time of fabric surfaces ($p < 0.05$). SNK test is run to explain the influence of fabric constructional properties on wetting time measurement test. Results revealed that fabrics having different fibre blend ratio possessed statistically different top wetting time and bottom wetting time at significant level of 0.05. Considering the top wetting time; maximum value was observed on the F1 coded fabric while minimum value was found on the F6 coded fabric.

It is also observed that top wetting time for F2, F5, and F7 coded fabrics were determined under the same subset at significance level of 0.05. When it comes to bottom wetting time, F7 coded plain knitted fabric made of 100% Umorfil® which tends to provide higher wicking away from the body revealed the lowest bottom wetting time while F5 coded plated fabric made of 100% polyamide ground yarn and 50% Umorfil® and 50% cotton fibre provided the highest bottom wetting time.

3.1.2. Maximum wetted radius

Figure 6 displays the maximum wetted radius for the top and bottom surfaces of the plain and plated fabrics made of

Table 5. Anova Results for each term of MMT.

Main effect	wetting time (top)	wetting time (bottom)	Max wetted radius (top)	Max wetted radius (bottom)	Absorption rate (top)	Absorption rate (bottom)	Spreading speed (top)	Spreading speed (bottom)	Accumulative one-Way transport Index	Overall moisture management Capacity
Fabric type	0.00*	0.00*	0.43	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*

*Statistically important according to $\alpha = 0.05$.

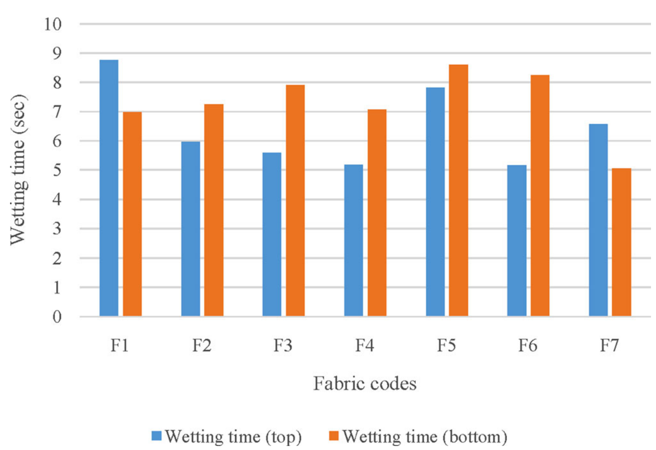

Figure 5. Wetting time (sec).

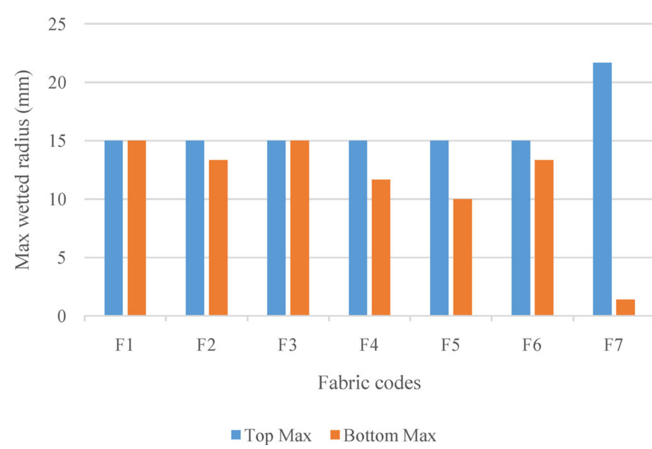

Figure 6. Max wetted radius.

Table 6. SNK Results of the wetting time (sec).

Parameter	Fabric type F1	F2	F3	F4	F5	F6	F7
WTT	8.75c	5.96 bc	5.59 abc	5.18 abc	7.81 bc	5.15 a	6.56 bc
WTB	6.96 ab	7.25 ab	7.90 b	7.06 ab	8.59 b	8.25 b	5.06 a

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

different fibre blend. According to Figure 6, max wetted radius for top surfaces were found same as '15mm' for all samples. When it comes to max wetted radius for bottom surfaces it is observed that the highest radius was observed among F7 coded fabric made of 100% Umorfil® while minimum radius was observed among the F5 coded samples.

One-way Anova test was run to evaluate the significant effect on wetted radius for the top and bottom surfaces of knitted surfaces. According to Table 5, fabric type was an influential factor on bottom max wetted radius while it was a non-significant factor on top max wetted radius at significant level of 0.05, that SNK analyses for top max wetted radius was not conducted. SNK results also indicated that knitted plated samples made of different fibre blends of Umorfil® revealed different max wetted radius for bottom surface at significant level of 0.05 (Table 7). The highest bottom wetted radius value was observed among F7 coded fabrics made of 100% Umorfil® while the lowest value was gathered among F5 coded plated samples of 50% Umorfil® 50% cotton plating yarn.

3.1.3. Absorption rate

The absorption rate values of samples for both top and bottom face of the samples are shown in Figure 7, where maximum top and bottom absorption rate (%/sec) was obtained among F5 coded fabrics while minimum top and bottom absorption rate (%/sec) was found among the F7 coded fabrics respectively. There was a general trend for plain and plated knitted fabrics for providing higher top absorption rate (%/sec) compared to their bottom absorption rate (%). However, F5, coded fabrics provided higher bottom absorption ratio compared to top absorption rate which indicates that there is liquid diffusion from the next-to-wet surface to the opposite face of the fabric sample. It means the liquid is accumulated on the bottom face of the fabric. High bottom absorption rate of F5 coded fabrics may be due to the high moisture absorptivity of cotton and Umorfil® fibre utilized together in plating yarn.

When the 100% Umorfil® plain knitted fabric is considered it is also understood that bottom absorption rate is higher than top absorption rate. This would promote liquid transfer to bottom face by capillary wicking mechanism and provide dry feeling by consumer.

According to Anova results, fabric type was an influential factor on top absorption rate and on bottom absorption rate (%/sec) at significance level of 0.05 (Table 5). SNK results also indicated that plated knitted fabrics made of different fibre blends possessed statistically different top and bottom absorption rate (%/sec) (Table 8). Considering the top absorption rate (%/sec); Minimum value was obtained among F7 coded 100% Umorfil® fabrics while maximum value was obtained among F5 coded plated fabrics made of 100% polyamide ground yarn and 50% Umorfil® 50% cotton plating yarn. Additionally, F1, F2, F3, F4, F6 coded

Table 7. SNK results of bottom max wetted radius (mm).

	Fabric type						
Parameter	F1	F2	F3	F4	F5	F6	F7
Bottom Max Wetted Radius (mm)	15.0 c	13.33 b	15.0 c	11.66 b	10.0 a	13.33 b	21.66 d

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%.

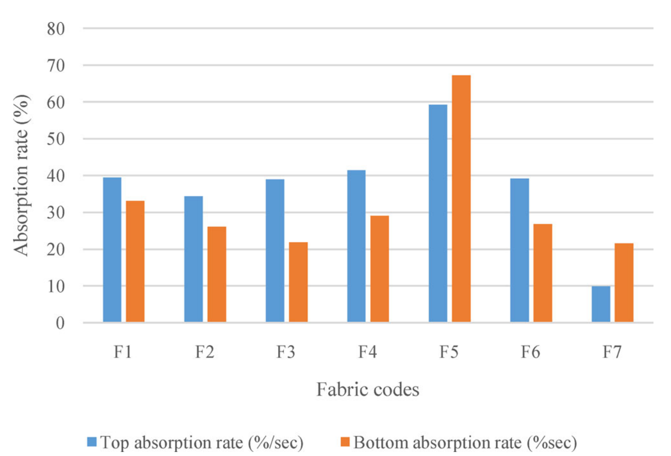

Figure 7. Absorption rate (%/sec).

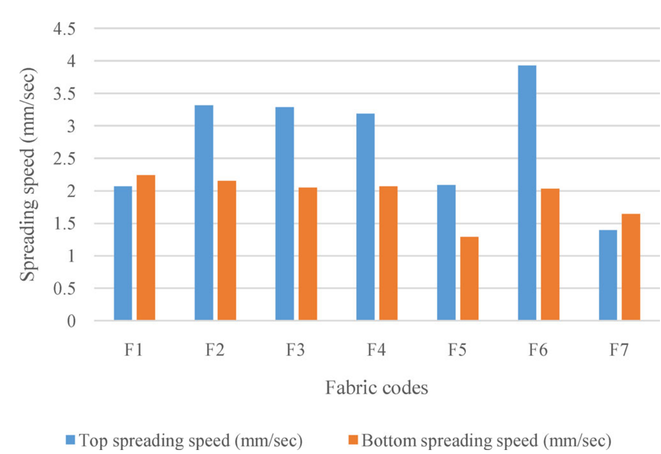

Figure 8. Spreading speed (mm/sec).

Table 8. SNK results of fabrics' absorption rate.

	Fabric type						
Parameter	F1	F2	F3	F4	F5	F6	F7
Absorption rate (top)	39.51 bc	34.39 bc	39.00 bc	41.45 bc	59.21 c	39.16 bc	9.90 a
Absorption rate (bottom)	33.10 abcd	26.17 abc	21.92 ab	29.09 abcd	67.22 e	26.83 abc	21.55 ab

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

Table 9. SNK results of spreading speed for top and bottom surfaces.

	Fabric type						
Parameter	F1	F2	F3	F4	F5	F6	F7
Top spreading speed (mm/sec)	2.06 a	3.31 ab	3.28 ab	3.18 ab	2.08 a	3.92 ab	1.39 a
Bottom spreading speed (mm/sec)	2.24 ab	2.15 ab	2.05 ab	2.06 ab	1.29 a	2.03 ab	1.64 ab

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

fabrics revealed the same top absorption rate at significance level of 0.05. When it comes to bottom absorption rate (%/sec), F7 coded 100% Umorfil® plain knitted fabrics revealed the minimum absorption rate while F5 coded plated fabrics provided the highest absorption rate as 67.22%/sec which is accepted as very fast level according to Table 4. Additionally, F1 and F4 coded fabrics also F2 and F6 coded fabrics statistically indicated the same bottom absorption rate at significance level of 0.05. F3 and F7 coded fabrics were also determined under the same subset at significance level of 0.05 (Table 8).

3.1.4. Spreading speed

Spreading speed (mm/sec) values of the fabrics are revealed in Figure 8. According to Figure 8; Maximum top spreading speed was obtained among F6 coded fabrics while minimum top spreading speed was obtained among F7 coded fabrics made of 100% Umorfil® fibre. When the bottom spreading speed is considered; minimum value was belonging to F5 coded fabrics made of 50% cotton 50% Umorfil® ground yarn while maximum value was obtained among F1 coded fabrics made of 15% cotton 85% Tencel™ ground yarn. F2, F3 and F4 and F6 coded fabrics which have higher top spreading speed (mm/sec) compared to bottom spreading speed seem to be enhancing low accumulative one-way transport index.

Another prominent result about Figure 8 is higher bottom spreading speed of F7 coded 100% Umorfil® fabrics compared to top spreading speed which may indicate a satisfying moisture management existence in the fabric. Higher the bottom spreading speed of the fabric, greater the evaporation from the bottom layer and less time the fabric dries. In other words, inner side of the plain knitted fabric made of 100% Umorfil® yarn transferred water to the outer side by capillary forces and transferred water is absorbed by the outer side.

In order to evaluate the fabric type on top spreading speed and on bottom spreading speed, One Way-Anova was performed (Table 5). It was observed that fabric type was a significant factor on top spreading speed and on bottom spreading speed. SNK results also indicated that plain and plated knitted samples possessed statistically different top spreading and bottom spreading speeds at 95% confidence interval.

Regarding to SNK results in Table 9; Minimum top spreading speed was belonging to F7 coded 100% Umorfil® plain knitted fabrics whilst maximum top spreading speed was belonging to F6 coded plated samples made of 100% polyamide plating yarn and 100% Umorfil® ground yarn. F2, F3, F4 and F6 coded plated samples were observed under the same subset at significance level of 0.05.

Considering the bottom spreading speed of the samples; minimum value was obtained among F5 coded plated fabrics where 100% polyamide ground yarn and 50% Umorfil® 50% cotton plating yarn were used. The highest bottom spreading speed was observed among F1 coded plated fabrics with 85% Tencel™ 15% cotton ground yarn. Additionally, bottom spreading speed of F1, F2, F3, F4, F6 plated knitted and F7 coded plain knitted fabrics were observed under the same subset at significance level of 0.05. As a general evaluation top spreading speed values of the samples were between 2-3 level which means a medium speed while bottom spreading speed values of the samples were between 1-2 which indicates a slow speed according to grading of MMT indices in Table 4.

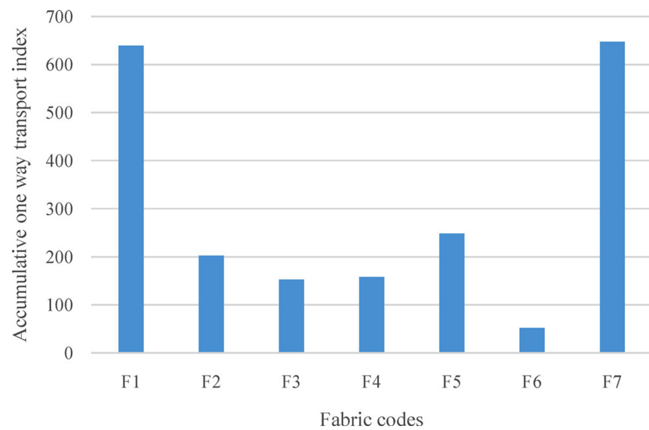

Figure 9. Accumulative one-way transport index.

3.1.5. Accumulative one-way transport index (AOTI)

Accumulative one-way transport index defines easiness of moisture transfer from fabric conducting face to the other face. Figure 9 exhibits the AOTI of 7 knitted samples.

According to Figure 9, F7 coded plain knitted fabric made of 100% Umorfil® yarn displays the highest accumulative one-way transport index while F6 coded plated fabrics made of 100% polyamide ground yarn and 100% Umorfil® plating yarn indicates the lowest accumulative one-way transport index. The highest accumulative one-way transport index value of 100% Umorfil® plain knitted fabric may be probably due to the implementation of capillary action of Umorfil® fibre which helps the sweat to transport from the human skin to outer layer. When the spreading speed and absorption rate results are associated with the accumulative one-way transport index it is observed that F7 coded sample made of 100% Umorfil® fibre has higher bottom absorption rate and spreading speed compared to top results which shows the ability of liquid transfer from top to the bottom layer (Figures 7 and 8).

One-way Anova test was performed in order to evaluate the effect of fabric type on accumulative one-way transport index. According to Anova tests; there was a significant effect of fabric type on accumulative one-way transport

Table 10. SNK results of accumulative one-way transport index.

	Fabric type						
Parameter	F1	F2	F3	F4	F5	F6	F7
Accumulative one way transport index	639.60 d	202.22 bc	152.31 ab	158.07 ab	248.77 bc	51.75 a	647.45 d

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%.

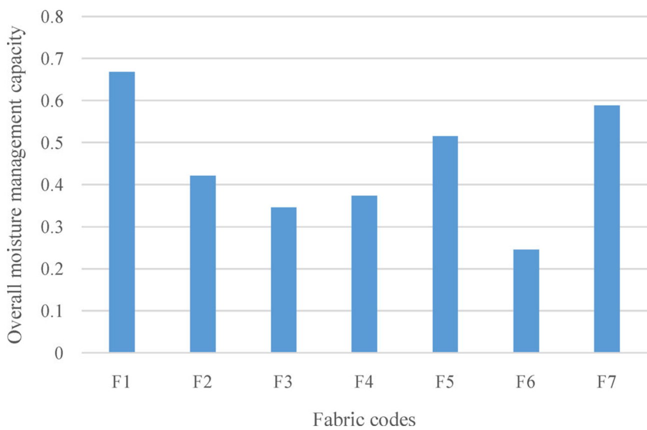

Figure 10. Overall moisture management capacity.

index of samples at significant level of 0.05. Additionally, SNK results were evaluated in order to compare the means of accumulative one –Way transport index of samples. SNK results displayed that knitted samples with different plating yarn and plain knitted fabric enhanced different accumulative one-way transport index at significance level of 0.05. According to SNK results in Table 10, maximum accumulative one-way transport index was obtained among F7 coded fabrics which were observed under the same subset with F1 coded fabrics at significance level of 0.05.

On the other hand, minimum accumulative one-way transport index was found among the F6 coded fabrics. Additionally, F2 and F5 coded fabrics were observed under the same subset at significance level of 0.05.

3.1.6. Overall moisture management capacity (OMMC)

Overall moisture management capacities of fabrics are revealed in Figure 10. OMMC results fluctuate between 0.2 and 0.8.

According to Figure 10; the highest OMMC was obtained among F1 coded plated fabrics with 15% cotton and 85%Tencel™ ground yarn whereas lowest value was found in F6 coded samples made of 100% polyamide ground yarn and 100% Umorfil® plating yarn. There is not a prominent trend of OMMC results with the amount of Umorfil® (% in gram) within the produced samples.

Anova results indicated that fabric type was a significant factor on OMMC of plain and plated knitted fabrics at significant level of 0.05. SNK results (Table 11) also indicated that different fabric types made of different plating yarn possessed different overall moisture management capacity at significant level of 0.05. According to SNK results, F1 coded samples with 15% cotton and 85% Tencel™ revealed the highest OMMC as 0.66. This means very good level for OMMC is provided by F1 coded samples according to Table 4.

3.1.6.1. Pearson correlation coefficient between different moisture management indices. Pearson correlation coefficient was conducted in order to observe the pairwise relationship of the distinct top and bottom face moisture management indices. Pearson correlation coefficient was determined by bivariate correlation test and the results are shown in Table 12.

It was determined that AOTI and OMMC which determine the overall moisture management ability of textiles

Table 11. SNK results of overall moisture management capacity.

	Fabric type						
Parameter	F1	F2	F3	F4	F5	F6	F7
Overall moisture management capacities	0.66 e	0.42 bc	0.34 b	0.37 b	0.51 cd	0.24 a	0.58 de

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

Table 12. Pearson correlation coefficient of different moisture management indices.

	Top wetting time	Bottom wetting time	Top absorption rate	Bottom absorption rate	Top maximum wetting radius	Bottom maximum wetting radius	Top spreading speed	Bottom spreading speed	AOTI	OMMC
Top wetting time	1	−0.070	0.20	0.54	0.042	−0.04	−0.72	−0.25	0.71	0.879**
Bottom wetting time	−0.07	1	0.896**	0.52	−0.	0.70	0.58	−0.07	−0.735	−0.52
Top absorption rate	0.201	0.896**	1	0.748	−0.838*	0.619	0.308	−0.177	−0.517	−0.208
Bottom absorption rate	0.541	0.52	0.748	1	−0.29	0.00	−0.30	−0.70	−0.05	0.255
Top maximum wetting radius	0.042	−0.848*	−0.838*	−0.297	1	−0.927**	−0.660	−0.367	0.633	0.411
Bottom maximum wetting radius	−0.041	0.701	0.61	0.00	−0.927**	1	0.675	0.621	−0.495	−0.366
Top spreading speed	−0.72	0.58	0.30	−0.3	−0.66	0.675	1	0.52	−0.87**	−0.90**
Bottom spreading speed	−0.25	−0.07	−0.17	−0.774	−0.36	0.621	0.528	1	−0.09	−0.21
AOTI	0.712	−0.73	−0.51	−0.05	0.63	−0.49	−0.87**	−0.09	1	0.928
OMMC	0.879**	−0.52	−0.20	0.25	0.41	−0.36	−0.90	−0213	0.928	1

Note: AOTI: accumulative one-way transport index; OMMC: overall moisture management capacity.
*Correlation significant at 0.05 level.
**Correlation significant at 0.01 level.

were positively and linearly related to each other at coefficient of 0.928.

Both AOTI and OMMC were positively and linearly related to top wetting time and bottom spreading speed, however, negative correlation of the two indices with top absorption rate are also observed (−0.51, −0.20). As it was declared within the early literature high top absorption rate reveals the liquid absorption and inhibition of liquid transfer to the bottom layer (Y. Jhanji et al., 2015a). It is also observed that there is a positive and linear relationship between top wetting time and AOTI, OMMC which indicates that the longer time the top surface gets wet, better one-way liquid transfer to the bottom layer would be provided.

3.2. Air permeability properties

For determining the comfort properties of fabrics, air permeability has great influence on transportation of the moisture from body to environment. Figure 11 indicates the air permeability properties of knitted samples

According to Figure 11, maximum air permeability was obtained among F7 coded 100% Umorfil® fabrics where F6 coded fabrics with 100% Umorfil® plating yarn followed it. Fabric samples of F1, F2, F3, F4 and F5 seem to have similar air permeability values although they are made of different plating yarn. Minimum air permeability was found among the F5 coded plated fabrics with 100% polyamide ground yarn and 50% cotton and 50% Umorfil® plating yarn.

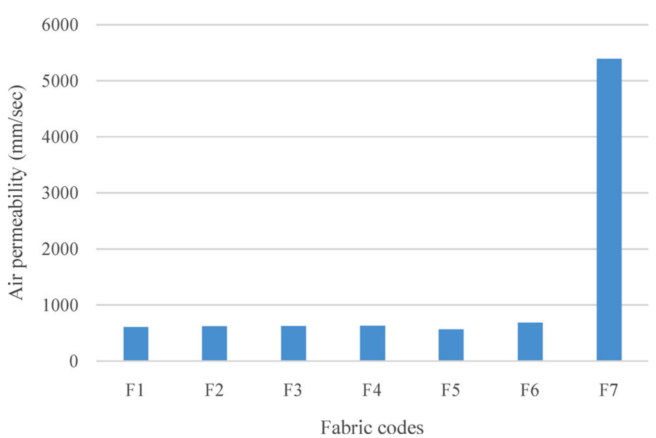

Figure 11. Air permeability properties of the fabrics, (mm/sec).

Table 13. Anova results for air permeability.

Anova test results for fabrics' air permeability			
	df	F	Sig (p)
Air permeability	12	37.19	0.00*

*Statistically important according to $\alpha = 0.05$.

In order to investigate the effect of fabric type on air permeability properties of the fabrics, randomized one way Anova test was conducted (Table 13). It was observed that there was a significant effect of fabric type on air permeability properties of knitted samples. Knitted samples made of different fabric type also indicated different air permeability at significance level of 0.05 according to SNK tests (Table 14). Minimum air permeability was found in F5 coded plated samples made of 50% Umorfil® 50% cotton ground yarn which were observed under the same subset with F1, F2, F3 and F4 coded fabric samples. Maximum air permeability was obtained among F7 coded plain knitted fabric made of 100% Umorfil® yarn. The prominent air permeability difference between the plated samples and the plain knitted sample might be due to the low fabric weight parameter of the fabrics which directly affects the porosity.

3.3. Antimicrobial properties

According to the medical literature, the materials which contains appropriate amount of collagen peptide and multi kinds of amino acids, may provide some antimicrobial properties. Hence the produced knitted samples containing Umorfil® and Umorfil® blended yarns were conducted to antimicrobial tests in order to evaluate their resistance against *E. coli*, *S. aureus* and against *C. albicans*. Figure 12 indicates antimicrobial activity of knitted samples revealing the amount of Umorfil® fibre percent in total weight. As it is observed Umorfil® containing fabrics indicated high antibacterial activity especially against *S. aureus*.

Considering the antibacterial activity against gram positive bacteria; there is a prominent reduction of *S. aureus* with the increment of the amount of Umorfil® within the fabric (% gram/total gram within the fabric). The highest antimicrobial efficiency against *S. aureus* was observed among the F2, F3 coded fabrics (~83%) while there was also a prominent reduction of *S. aureus* (>65%) independently of total Umorfil® amount in the fabrics. It may be summarized that Umorfil® utilization has much more influence on *S. aureus* microorganisms compared to gram negative *E. coli*.

Considering the antibacterial activity against gram negative; except F3 sample, reduction of *E. coli* has increased depending on Umorfil® amount (% gram/total gram within the fabric) within the fabric.

When the antifungal activity against *C. albicans* is evaluated, most satisfying antifungal activities is especially observed when the amount of Umorfil® is above %20 within the fabric weight. F4 and F5 coded fabrics were observed to be indicating satisfying results. Additionally, except F3 coded fabrics, prominent antifungal activity was also observed among the other samples.

Table 14. SNK results of air permeability.

	Fabric type						
Parameter	F1	F2	F3	F4	F5	F6	F7
Air permeability	613.60a	621.60a	621.90a	628.10a	566.30a	685.10b	5383.90c

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

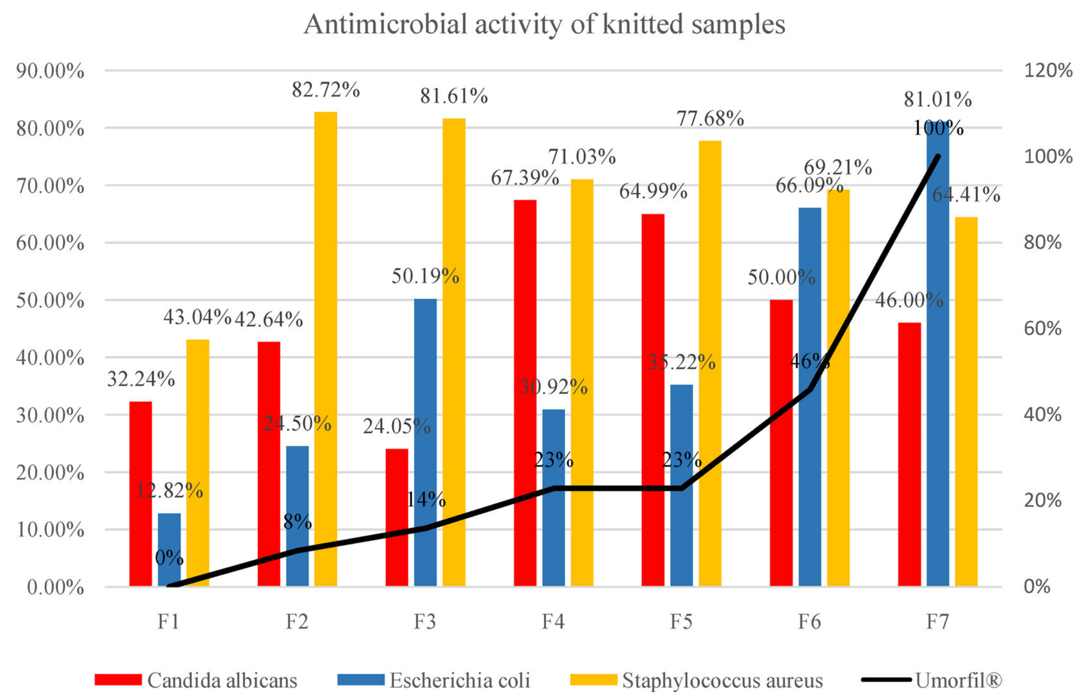

Figure 12. Antimicrobial activity of knitted samples.

Fibre content of F1 sample is polyamide, cotton and Tencel™, there are not any collaged peptide added fibre presence in the fabric construction. However, when antibacterial and antifungal tests are conducted, it has seen that there is some inhibition against *E. coli* (%12,82), *S. aureus* (%43,04), and against *C. albicans* (%32,24) microorganisms. These findings may be attributed to presence of high Tencel™ content in the fabric. Water absorption capacity of Tencel™ fibre is higher comparing to the other spun fibre types in the fabric contents. Therefore high water absorption of the fibre from the media, causes water deficiency for the living bacteria and fungi on fibre surface (Firgo et al., 2006; Männer et al., 2004; Teufel & Redl, 2006).

As a general conclusion, although any material alone is not expected to exhibit superior antimicrobial property, optimum antimicrobial effect for each three microorganism types was observed among F6 fabrics of the samples contending the highest amount of collagen peptide added fibres. On the other hand, it may be emphasized that F4 and F5 coded samples revealed satisfying antimicrobial activity especially against *S. aureus* and *C. albicans*.

4. Conclusion

This study aimed to investigate the effect of fibre content on knitted fabric types which are designed to be used for active wear clothes. Study is focused on moisture management, air permeability and antibacterial properties of the seven different fabrics; one is plain knitted construction, knitted with a collagen peptide added regenerated cellulosic fibre yarn; and the other six are knitted as plated knitted construction with a ground yarn of % 100 polyamide filament yarn and plating yarn types of cotton, viscone, Tencel™, and Umorfil® blends.

On the basis of the results obtained in this investigation it may be stated that most of the moisture management indices except maximum wetted radius for top surface were significantly influenced from fabric type at significant level of 0.05. F7 coded plain knitted fabric made of 100% collagen peptide based fibre indicated higher top wetting time compared to bottom wetting time which indicates an active wear sport cloth made of those fabric will stay dry during sweating.

SNK results indicated that knitted plated samples made of different fibre blends of Umorfil® revealed different max wetted radius for bottom surface at significant level of 0.05. The highest bottom max wetted radius value was observed among F7 coded fabrics made of 100% Umorfil® while the lowest value was determined among F5 coded plated samples made of 50%Umorfil® 50%cotton plating yarn.

Regarding to absorption rate (%) values of the samples, F5 coded plated knitted sample with 50% Umorfil® −50% cotton yarn and F7 coded 100% Umorfil® plain knitted sample provided a more comparable situation where bottom absorption rates (%) were higher than top absorption rates (%) promoting the liquid transfer. This sample has also higher bottom spreading speed than top spreading speed which indicates capillary forces transferred water from inner side to the outer side.

Considering the accumulative one-way transport index, maximum value was obtained on 100% Umorfil® plain knitted fabric (F7) which were observed under the same subset with F1 coded plated fabrics at significance level of 0.05. According to grading of MMT indices, F1 and F7 coded fabrics revealed an excellent grade of accumulative one-way transport index according to Table 4. Accumulative transport index results of F1 and F7 coded fabrics were also consisted with their moisture management capacity.

According to Pearson correlation coefficient between different moisture management indices of the samples, both AOTI and OMMC were positively and linearly related to top wetting time and bottom spreading speed, however, negative correlation of two indices with top absorption rate are also observed.

The air permeability of plated fabrics made of Umorfil® fibre blends with varying ratio (%) were generally observed under the same subset. However, there was a prominent air permeability difference between the plated samples and the plain knitted sample of 100% Umorfil® fibre which might be attributed to fabric weight parameter difference of fabrics considering the porosity factor.

When it comes antimicrobial properties, collagen peptide containing fabrics were generally more satisfying against *S. aureus*. Additionally, the amount of collagen peptide added fibre increases (% gram/total gram within the fabric), the antibacterial activity of the knitted samples against *E. coli* is also increased. It can be stated that satisfying antimicrobial activities against bacteria and fungi were especially observed when the amount of collagen peptide is above %20 within the fabric weight. It can also be emphasized that presence of Tencel™ fibre in the fabric structure provides some level of antibacterial and antifungal efficiency.

When the moisture management, air permeability properties are considered beside with their antimicrobial properties, F5 coded samples made of 100% polyamide ground yarn-50%cotton 50% Umorfil® plating yarn appear to be the optimum choice for the active wear consumers.

As a general conclusion, knitted fabrics of supreme and plated supreme structures made of new collagen peptide added fibres with varying ratios may be utilized for next to skin application such as active wear clothes, where good moisture management, air permeability, and antimicrobial properties are highly desired. Gathered results show that engineered design approach on yarn type, fibre blend, and knitted fabric structure selection are important issues to design expected performance properties of the final product. Presence of collagen peptide added fibre, regenerated cellulosic fibre or natural fibre in the yarn content and utilisation of polyamide yarn as ground yarn on plated knitted structure exhibit different moisture management property, antimicrobial efficiency, and air permeability levels of fabric types which would be privileged product of socks, outdoor sport clothing, military clothing, or any active wear clothing with an reasonable and affordable price for specific customer expectations.

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Disclosure statement

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