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Assessing Water-Related Comfort Performance of Knitted Fabrics made of Rayon Microfibers and Lyocell Fibers for Intimate Wear

Sena Cimilli Duru, İkilem Göcek

Istanbul Technical University, Faculty of Textile Technologies and Design, Department of Textile Engineering, 34437, Gumussuyu-Beyoglu, Istanbul, Turkey

Corresponding Author: İkilem Göcek, goceki@itu.edu.tr

ABSTRACT

Comfort properties of knitted fabrics used for intimate wear is an important matter to be dealt with. Hence, the comfort issue of the knitted fabrics made of micro-rayon and lyocell fibers were examined in the current study after they were separately treated with the antibacterial and wicking finishes. Moreover, the effect of spandex was investigated. The fabric samples were analyzed in terms of vertical wicking capacity, transfer wicking, water vapor permeability and drying rate. According to the results, spandex incorporation and process history were found to be influential on the vertical wicking capacity of the fabric samples whereas, spandex incorporation was found as the main affecting parameter for the transfer wicking. Moreover, fiber type and spandex incorporation were both found to have significant effects on the water vapor permeability of the fabric samples. The best fabric option from its alternatives for intimate wear was chosen by the hybrid AHP-TOPSIS approach.

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1. INTRODUCTION

Intimate wear is the most important clothing layer since it acts as human's second skin. It requires the comfort issue to be maintained perpetually than that of outerwear due to the contact to the skin directly [1]. Comfort for intimate wear is multidimensional and can be examined with regard to several aspects such as sensorial, thermal, motion, aesthetical and hygienic all of which are interrelated. Intimate wear is an inner layer worn between the skin and the outerwear allowing perspiration, transmission of body heat and excessive wetness from the skin to the atmosphere for staying dry. Therefore, its thermal comfort in terms of moisture management is very important. Transferring moisture from the clothing to the environment through diffusion, wicking, sorption and evaporation is regulated by the thickness of the fabric, tightness of the fabric construction and hygroscopicity of the fiber kind. Since the wet skin is much more easily irritated than the dry skin, specific care should be taken to provide better skin comfort [1, 2]. As the intimate wear contacts the skin directly, its hygienic comfort becomes also an important issue. If satisfactory hygiene is not provided, health problems (prophylaxis and infections) and the incidence of bacteria and fungi propagation, as a result of which malodor formation and decomposition of textiles due to microbial corrosion can readily occur. Therefore, the antimicrobial finishing consisting of the antimicrobial agents can be used for the protection of the human skin health [1, 3-13].

Wearing intimate clothes consisting of irritating or allergic substances can induce skin reaction so that the tactile comfort which can be defined as the tactile sensations of softness and smoothness becomes the most important issue (Yu, 2011). A pleasing sensation of feeling soft and smooth on the skin is required to be achieved in intimate wear since it is worn directly in contact with the skin. The fabrics made of rayon microfibers and lyocell fibers wrap the body

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with a touch of lightness and soft feeling twice as cotton. Because of their smooth structures, the fabrics made of these fibers become particularly silky and gentle on the skin preventing skin irritations, which makes them a perfect choice for the intimate wear [14]. However, there is a limited number of studies regarding the comfort properties of the knitted fabrics consisting of rayon microfibers and lyocell fibers [1, 2, 15, 16]. Therefore, in this study, some water-related comfort properties of the seamless fabrics for intimate wear made of lyocell fibers and rayon microfibers such as vertical wicking capacity, transfer wicking, water vapor permeability and drying rate were investigated. For outwear garments, drape and silhouette should be acquired. On the other hand, the intimate wear, which is a stretch garment in contact with the skin requires particular fabric tension resulting in a certain degree of fitting by the help of spandex to provide the wearer with a sense of support and security [1, 2]. Thus, spandex was used in the fabric structure to investigate its effect on comfort. Additionally, even though hygiene and dry feel are the unignorable factors for the intimate wear to feel comfortable, there are lack of studies taking the antibacterial efficacy and wicking finishing treatment of the fabrics made of lyocell fibers and rayon microfibers into consideration [17-20]. For that reason, antibacterial and wicking finishes were applied on the fabrics and their effects on the water-related comfort were examined.

2. MATERIAL AND METHOD

2.1 Material

The fabric samples were produced on an E28 13'' Merz Mbs seamless knitting machine with identical machine settings. The purpose of selecting the seamless knitting technology was that it is a common technique for the production of intimate wear as well as functional knits. Half of the fabric samples was knitted only with the main yarns, while the remaining part was produced with both the main yarns and spandex (Lycra®, 100% spandex multifilament fibers by Lycra Company) with the help of the plaiting technique. By doing so, the effect of spandex on the water-related comfort properties of the seamless samples was investigated. In the production, Ne 50/1 yarns made of cellulosic fibers, micro rayon (MicroModal® by Lenzing Ag) and lyocell were used as the main yarns while 33 dtex spandex fibers were utilized as the plaiting yarn.

Since micro rayon and lyocell are regenerated cellulosic fibers they do not have any natural color as cotton has. Therefore, they do not need bleaching however; as a pretreatment, mild scouring helps decontamination of fabric samples from spin finish, dirt and dust existing sticked over the surface of the fibers. Because of this, initially, fabric samples were separately washed with water by using ECE detergent in a conventional washing machine at 60°C for 30 min. to remove industrial contaminations remaining in the fabric structure. Then, in order to be rinsed, all of them were separately washed five times in succession with water without utilizing any detergent in a conventional washing machine at 60°C for 15 min. Finally, they were flat-dried at ambient temperature under atmospheric conditions. After the fabric samples were decontaminated from industrial residuals, dyeing process was conducted on all of the fabric samples under identical conditions in ATC-DYE HT01F lab-type exhaust dyeing machine using black reactive dye (SETAZOL Black MMS), salt and soda ash at 60°C for 60 min with a liquor ratio of 1:10. In a conventional washing machine, the dyed fabric samples were washed off with water utilizing ECE detergent at 60°C for 15 min. and rinsed with water at 60°C for 15 min. without using any detergent.

Afterwards, one third of the samples, a control group were not treated with any finishing applications, while the rest of them were treated with the wicking (one third of the samples) or antibacterial finishing applications (one third of the samples). The wicking finish (Ultraphil® PA by Huntsman Textile Effects) was applied at 400°C for 20 minutes however; (Ultrafresh Silpure® FBR by Thomson Research Associates) was used at 600°C for 30 minutes as an antibacterial finish. The factors chosen for the full-factorial experimental study were "fiber type" including lyocell and micro rayon as levels, "spandex content" including with and without spandex as levels and "process history" including none, wicking and antibacterial as levels. Properties of the seamless samples are shown in Table 1. The samples were coded such that the first letter shows the fibre type (L-Lyocell, M-Micro rayon), the second letter refers to the spandex (W-Without spandex, S-With spandex), and finally the last one stands for the process history (N-None, A- Antibacterial, W- Wicking).

2.2 Method

Water vapor permeability (WVP), fabric weight and fabric thickness were tested in accordance with the standards ASTM E96/E96M-16, TS EN 12127 and TS 7128 EN ISO 5084, respectively. The overall porosity defined as the ratio of the open space to the total volume of the porous material was calculated from the measured thickness and the weight per unit area values according to the equations previously reported [21]. The moisture regain of the samples were obtained according to ASTM D2495-07 standard using the "wet" and "dry" weights. The test regarding the measurement of the transfer wicking (TW) was based on Zhuang et. al.'s method with a modification in the method that the pressure applied was kept constant at 15.6 kg/m^2 [22]. According to the method, samples were prepared as 74.5 mm diameter circles. The sample to be wetted out was dipped in distilled water and then, drained with a drying paper for the removal of excess water. Dry fabric sample was put over the wet fabric sample. For the samples placed horizontally, a 74.5 mm diameter dish was put over the top

Table 1. The properties of the seamless samples

			Weight (g/m^2)	Thickness (mm)	Stitch Density (loops/cm^2)	Porosity (%)	Moisture Regain (R)
Micro rayon	Without spandex	MWN	92.5	0.428	144	85.78	8.6
		MWA	89.8	0.426	153	86.13	9.6
		MWW	92.2	0.466	153	86.98	10.0
	With spandex	MSN	395.0	1.249	189	79.19	9.9
		MSA	378.4	1.212	189	79.46	10.3
		MSW	376.7	1.289	198	80.77	10.0
Lyocell	Without spandex	LWN	85.0	0.476	153	86.26	8.3
		LWA	83.3	0.407	153	84.26	9.9
		LWW	78.4	0.446	180	86.48	10.0
	With spandex	LSN	344.8	1.250	198	78.78	8.8
		LSA	315.9	1.178	216	79.37	9.1
		LSW	338.6	1.257	216	79.28	9.6

layer however; the vertically placed samples were put in between two 74.5 mm diameter dishes. After that, external pressure was applied and water was allowed to be transferred for a specific time period. Later on, dry fabric sample was weighed to determine the amount of water transferred from the wet sample. For repetitions of the tests, the fabric sample water was transferred to was dried to its initial state and wet fabric sample was dipped in distilled water. To conduct the tests at the same conditions, weights of the dry and wet fabric samples were initially determined. Each sample was tested for 5, 10, 15, 20, 25, and 30 min. For testing the vertical wicking capacity (VWC), DIN 53924 standard was used. The drying rates (DR) of the fabric samples were determined according to the Coplan and Fourt methods [23, 24]. According to the method, the fabric was cut into 8 cm x 16 cm samples and weighed. The samples were wet-out upon immersion in distilled water for 1 h. They were taken out of water and held suspended in a vertical position for 15 s. Each side of the samples were subsequently held placed flat on drying paper for 2 min to be drained for the removal of excess water. Each of the samples were weighed following the procedure and the values were considered as the maximum water content of the samples for simple drainage. Later on, the samples were hung on a drying rack to be dried in the laboratory under standard atmospheric conditions (65%±2% R.H. and 20°±2 °C). Weights were measured at one hour intervals during the course of drying process to determine the moisture regain as a percentage. The samples were considered as dry at 1% moisture regain and the time corresponding to the duration of the process in which the samples became dry was considered as the drying time. All of the tests were conducted three times. The statistical evaluation of the data obtained from the experimental work was performed using the Minitab 17 and SPSS 18 package programs. The factors were considered to be significant at a level of 95%.

Additionally, the multi-criteria decision approach was utilized for the selection of the best option from the existing alternatives examined in this study. Multi criteria decision making is a branch of Operations Research (OR) which deals with the selection problems under the presence of finite number of decision criteria and alternatives [25]. TOPSIS, a type of multi-criteria method is based on a simple and intuitive concept enabling consistent and systematic criteria based on the selection of the best alternative with the shortest distance from the ideal solution and the furthest distance from the negative ideal solution [25-27]. The ideal solution is regarded as the maximal benefits solution, which includes taking the best value of the alternative however, the negative ideal solution is treated as the minimal benefits solution which is composed of all the worst value of the alternatives and the alternatives are ranked according to the relative closeness to the ideal solutions. AHP is a powerful and flexible multi-criteria decision-making tool structuring a complicated decision problem hierarchically at several different levels, where both the qualitative and quantitative aspects need to be considered [27]. TOPSIS is a more efficient method for handling the tangible attributes and no limit exists in terms of the number of the criteria or alternatives [25]. Therefore, the combination of AHP and TOPSIS can be used for the determination of the liquid transfer properties of garments. In the case of the hybid AHP-TOPSIS method, the pair-wise comparison method of AHP is combined with the other steps of TOPSIS and the procedure of the hybrid AHP-TOPSIS method is explained elsewhere [25-27].

3. RESULTS AND DISCUSSION

3.1 Vertical Wicking Capacity

As can be seen from Figure 1i, MWA samples gave the highest wicking capacity values whilst LSN samples yielded the lowest ones. All the VWC results (Figure 1i) of full-factorial trials were statistically analyzed using the Minitab® package program. It is known that a high R2 value close to 1.0000 with a low standard deviation is the representative of a good statistical model. According to the Minitab analysis, process history was the most effective factor among those studied, which was followed by spandex incorporation to the fabric structure with an R2 value of 0.7500 and a standard deviation of 5.86, respectively. However, two-way interaction effect between these parameters did not exist.

As can be seen from Figure 1iia, the VWC values of the fabric samples made of rayon microfibers without spandex were slightly higher than those of the ones made of lyocell. When a fabric is immersed into a liquid, water enters the space in between the fibers in the yarns and in between the yarns in the fabric [28]. It is reported that the water transport is suppressed as the number of fibers in the yarn decreases [29, 30]. Therefore, based on the literature survey, it is suggested that the higher number of fibers in the micro rayon yarns may be the reason of the higher wicking capacity values. However, after the incorporation of spandex to the fabric, the fabric samples made of both of these fibers performed almost the same and their wicking capacity decreased to approximately the same level. The flow of the liquid through the textiles is caused by the fiber–liquid molecular attraction at the surface of the fiber, which is mainly determined by the surface tension and effective capillary pathways and pore distribution [31, 32]. As stated in a study, the amount of water taken up by a fibrous material is dependent on the porosity of the material such that as the porosity increases, water entrapment by the pores increases accordingly [33]. Hence, the decrease in the porosity of the structure having spandex contributed to a decrease in the wicking capacity of the fabric samples made of both rayon microfibers and lyocell fibers. Furthermore, the utilization of spandex may cause some problems by reducing the thermophysiological wear comfort since spandex is non hygroscopic, however, hydrophobic. Therefore, it is hard for spandex to absorb moisture in its structure and also it cannot be wettable by liquid sweat [2]. The paired t-test supported this result that spandex became an important parameter on the wicking capacity of the sample (t(36)=2.903 p=.006).

As can be seen from Figure 1iib, both of the finishing treatments improved the wicking capacity values of the fabric samples made of lyocell fibers and rayon microfibers which gave the similar tendency meaning that the antibacterial finishing treatment was much more effective on the wicking capacity values than the wicking finishing treatment. Moreover, at the beginning, although the wicking capacity values of the lyocell fabric samples were lower than the micromodal fabric samples, after the finishing applications, they increased to nearly the same level. In other words, these antibacterial or wicking finishing treatments can provide better water-related comfort by removing excessive liquid from the body. With the finishing applications, surface characteristics of cellulosic fibers are expected to change, i.e. the fiber surface becomes rougher and some cracks and damages are

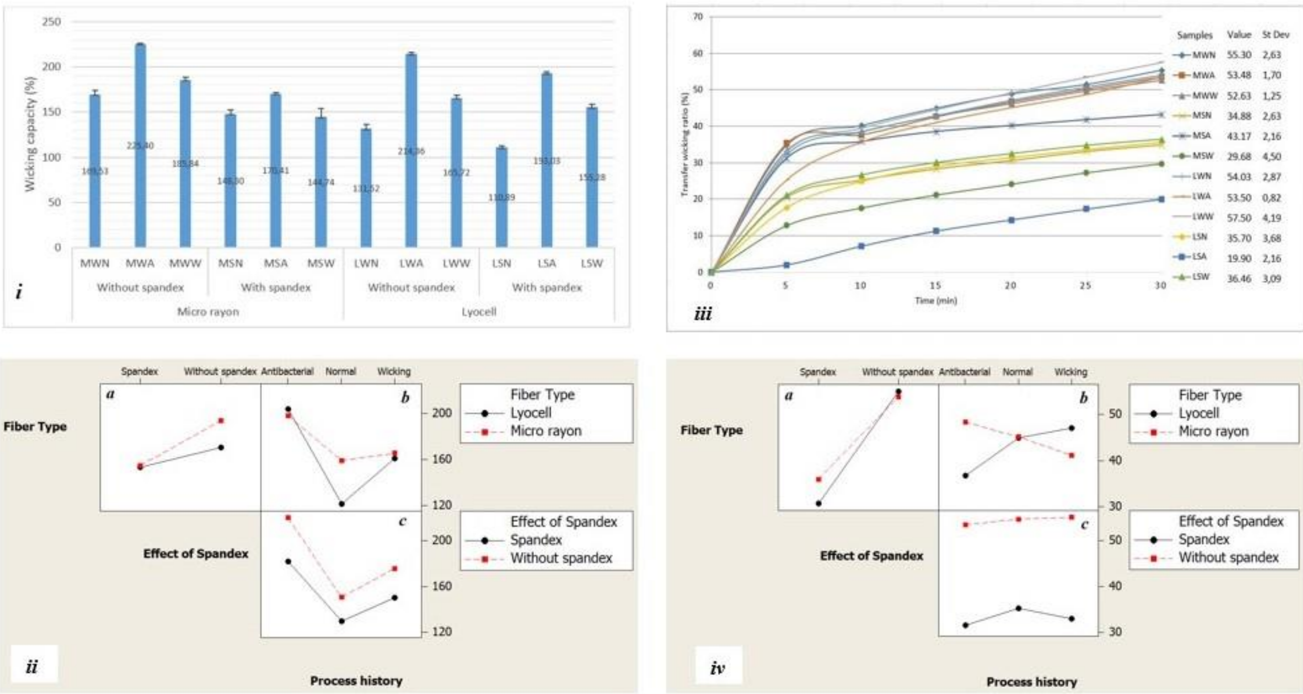

Figure 1. Wicking properties of the fabric samples i) VWC ii) Interaction plot for VWC iii) TW ratios versus time iv) Interaction plot for TW

observed on the surface, which might be caused due to the highly acidic padding bath in the application [34]. Presence of the crosslinkers in the finishing bath decreases acidity which leads to cracks caused by the damage of the cellulosic fibers through the acid hydrolysis of glycosidic linkages [34]. These possible cracks and damages on the surface of the lyocell fibers and rayon microfibers may have created some kind of capillary effect leading to the increase in the wicking capacity values. According to the independent t-test, the finishing treatments influenced the wicking capacity values of the fabric samples ($t(36)=-4.616$ $p=.000$) and also the ANOVA evaluation implied that the wicking capacity values of the fabric samples differed for the three conditions ($F(2,33)=27.274$ $p=.000$).

In addition to this, considering the process history, the wicking capacity of the fabric samples with spandex was lower than that of the ones without spandex for the three different conditions (Figure 1iic). Both of the finishing treatments enhanced the wicking capacity values of the fabric samples with and without spandex with the same trend. However, the antibacterial finishing treatment was observed to be much more influential on the wicking capacity values than the wicking finishing treatment.

3.2 Transfer Wicking

In the first minutes of the test, the TW had a steep increase for all the samples and then became more gradual. Also, as seen from Figure 1iii, among all of the fabric samples, LWW fabric sample had the highest TW ratio, while the LSA one gave the lowest value for the same period. According to the Minitab ® package program results, the presence of spandex in the fabric samples was the main effecting parameter on the TW ratios of the investigated fabric samples with an R2 value of 0.7806 and a standard deviation of 5.23, respectively.

The TW ratios of the samples made of rayon microfibers and lyocell fibers without spandex were almost the same. After the incorporation of spandex to the fabric structure (Figure 1iva), the TW ratios of the samples for both of the fiber types decreased. However, the effect of spandex was found to be slightly more influential on the lyocell ones. Moreover, the difference in the TW ratios of the fiber samples were not statistically significant according to the paired t-test ($t(36)=1.498$ $p=.6$). The reason of the decrease in the TW ratios of the samples after utilizing spandex may be the fabric samples with spandex initially held less water due to not only the hydrophobic structure of spandex but also the reduction of both the amount of pores and pore sizes of the fabric where water fills in, and thus, less amount of water was transferred which is compatible with the literature survey [2, 22, 35]. Also the paired t-test results suggested that spandex was a highly significant factor on the TW ratios of the seamless samples made of not only lyocell fiber but also rayon microfiber (95 % significant level lyocell $t(18)= 11.872$ $p=.000$ and micro rayon $t(18)=8.782$ $p=.000$).

When it comes to the interaction between the fiber type and process history (Figure 1ivb), it was observed that the finishing treatments applied influenced the fabric samples made of lyocell fiber and rayon microfiber differently; such that for the lyocell fabric samples, the TW ratio slightly increased with the wicking finishing treatment, while it slightly decreased with the antibacterial finishing treatment. However, for the fabric samples made of rayon microfibers, the TW ratio slightly increased with the antibacterial finishing treatment, while it slightly decreased with the wicking finishing treatment. According to the literature, porosity and thickness of a fabric are the factors that mainly influence the TW ratio [1, 22, 36, 37]. Fabric thickness and porosity values of the samples with and without any finishing treatments were approximately same hence, no significant difference was expected to occur between the TW ratios of the lyocell and micro-modal fabric samples with and without finishing treatments. Moreover, the independent t-test also implied that the decrease of the TW ratios of the fabric samples were not significant ($t(36)=0.391$ $p=.698$) and the ANOVA statistical evaluation showed there was no significant difference between the TW ratios of the samples for the three cases of the process history ($F(2,33)=0.123$ $p=.885$). On the other hand, these incidents of slight decrease or increase in the TW ratios of the fabric samples with the wicking or antibacterial finishing treatments might be attributed to the cracks thereby, some level of roughness and porosity, occuring on the fiber surface due to the acidic medium in the finishing applications [34, 38]. Since silver particles in antibacterial finishing solution can be incorporated to the fiber structure by the help of the polymer inside the antibacterial finishing receipt because of the bonding mechanism of the finishing agent of the antibacterial finish application on the fiber surface, the surface of the fibers may have been coated effectively and to a high degree with nano-scaled silver particles [39]. Therefore, it may also be attributed to the change in the contact angle of the surface which might have happened by the nanoscaled surface roughness on the fibers. Finally, the interaction plot given for the process history and spandex presence (Figure 1ivc) demonstrated that the TW ratio of the fabric samples with spandex was lower than that of the ones without spandex for the three cases i.e. non-treated, antibacterial and wicking finishes applied. The fabric samples without spandex were more hydrophilic compared to the ones consisting of spandex, because of this, antibacterial and wicking finishes were incorporated more to the structure of these fabric samples leading to some level of increase in the TW. Since thickness and porosity values were approximately same, as expected, the finishing applications did not change TW ratio of the fabric samples without spandex while they slightly decreased TW ratio of the ones incorporated with spandex.

3.3 Water Vapor Permeability

Relative WVP is the rate of water vapor transmission through a material and from Figure 2i, it is apparent that the fabric sample MWN had the highest WVP value, while LSW exhibited the lowest value. The Minitab® program was used to statistically analyze the data in Figure 2i. It was found that when only single effects were considered, the effect of spandex was the most effective factor among those studied in terms of their effects on the resultant WVP values of the fabric samples. Fiber type and process history followed it respectively. Fiber type* spandex incorporation was the two-way deterministic effect (R2=0.9831 and σ=5.14).

Water vapor transfer is the ability of a fabric to transfer perspiration in the form of moisture vapor through its structure and it is measured by the amount of water vapor passing through a square meter of a fabric per day. WVP depends on the construction characteristics of yarns as well as fibers and fabric structure. Thickness and surface characteristics are the other affecting parameters on the WVP of fabrics [33, 40]. As can be seen from Table 1, the mean thickness and porosity values of the fabric samples made of lyocell fibers and rayon microfibers were almost the same. However, since the fiber fineness of the rayon microfiber was smaller than that of the lyocell one, the amount of the free air spaces between the fibers and the yarns for water vapor to flow were higher for the fabric samples made of rayon microfibers without spandex than that of the lyocell ones without spandex. Thus, the WVP values of the fabric samples made of rayon microfibers without spandex were higher as presented in Figure 2iia. Also, the paired t-test showed a significant difference between the vapor permeability values of the fabric samples made of lyocell fibers and rayon microfibers (t(36)=1.876 p=.047). On the other hand, the fabric samples made of both of these fibers performed similarly with the addition of spandex to the production, which resulted in a steep decrease of the WVP values. The decrease was much more effective for the fabric samples made of rayon microfibers; after the spandex incorporation, WVP of the micro rayon and lyocell fabric samples became nearly the same. Both the thickness and porosity of textiles have strong effect on water-vapor diffusion or breathability [29, 35]. When the effect of spandex was considered, the fabric samples produced with spandex fibers were found to have less porous structure and higher thickness as can be seen in Table 1. It was reported that to some extent, the fabric thickness determines WVP with a thicker path facing higher frictional forces during the vapor passage through the fabric [40, 41]. Also, when free spaces in the fabric structure increase, this provides easy passage for water vapor transfer hence, higher moisture transfer occurs through fabric [40, 41]. Because of these reasons, the WVP values of the fabric samples were higher when spandex was not utilized in the production (Figure 2iia). Also, the paired t-test showed that the WVP values of the fabric samples having spandex decreased irrespective of the process history and the fiber type (t(36)=11.514 p=.000).

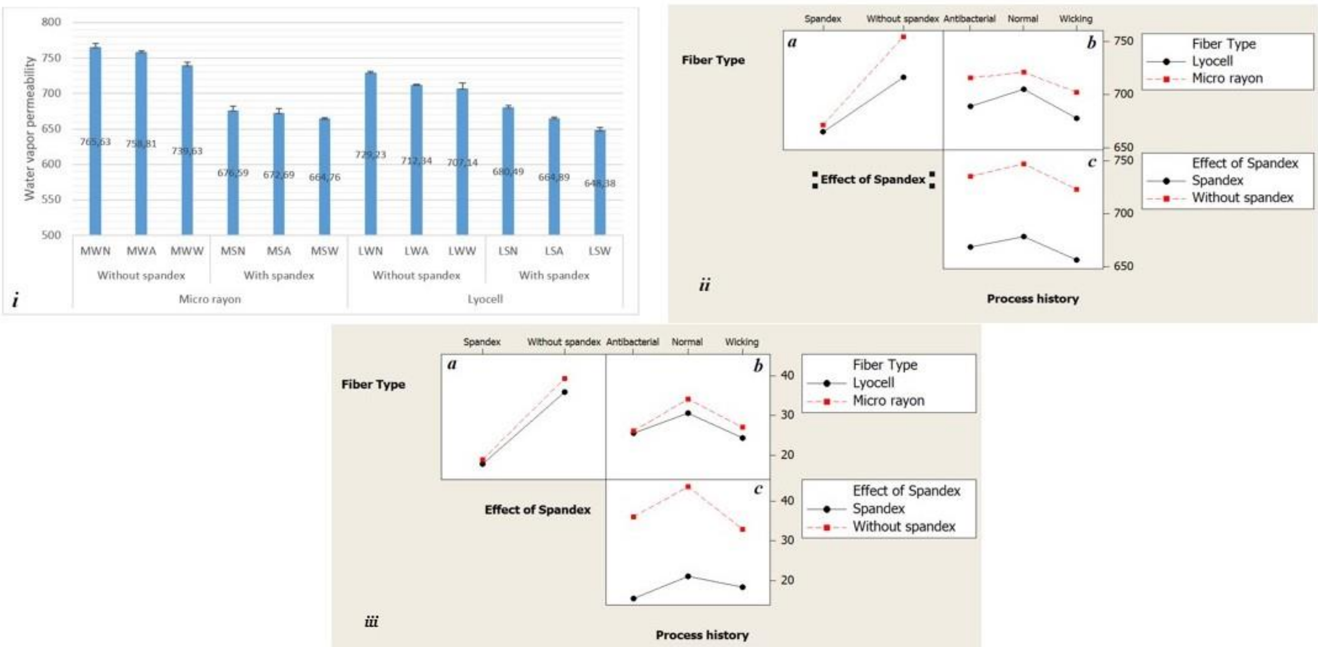

Figure 2. WVP and DRs of the fabric samples i) WVP ii) Interaction plot for MVTR iii) Interaction plot for DR

For the fabrics with higher WVP values, it is easier for water vapor to pass through the fabric to the environment resulting in drier skin thereby, improving water-related comfort. According to the results in Figure 2iib, it was found that the lycocell fabric samples had lower WVP values for the three cases of the process history compared to the micro rayon ones and the finishing treatments slightly reduced the WVP of lyocell and micro rayon fabric samples. Cracks obtained due to the acidic medium in the finishing applications alter the surface characteristics of fibers creating fiber-like structures on the fiber surface, which block the space in between the fibers and as well as the yarns in the fabric structure leading to a decrease in the WVP of fabrics [34, 38]. However, according to the statistical analysis, this reduction was not significant ($t(36)=1.257$ $p=.217$). The ANOVA evaluation showed that there was no significant difference between the WVP values of these three cases of process history irrespective of the fiber type and the spandex incorporation ($F(2,33)=1.085$ $p=.349$). In addition to this, considering the interaction between the process history and the spandex incorporation (Figure 2iic), the WVP of the fabric samples with spandex was lower than that of the ones without spandex for all the cases of treatments due to less porosity in the fabric structure and higher fabric thickness values (Table 1). Moreover, with both of the finishing applications, the WVP of the fabric samples with or without spandex both slightly decreased.

Differently from all of the above findings, the moisture regain, hence the fabric humidity, is an important phenomenon in WVP of fabrics. Thus, in the study, the effect of moisture regain on WVP was also investigated. At the condition of less than or equal to 23% of moisture regain, the major mechanism of moisture transport can be identified as diffusion in fabrics [42]. Moisture regain of all the fabrics of the study were found below 11%. Therefore, in our study, moisture transport mainly took place through the diffusion of water vapor into the fibers leading to fiber swell. As water vapor diffuses in the fiber structure, besides swelling, fiber gets closer to its saturity which reduces the water vapor transfer rate. On the other hand, micro modal and lyocell are hydrophilic fibers which can easily retain water molecules due to their cellulosic structures, so that they can swell resulting in reduction in the porosity of fabrics [40, 43]. All of these mean that as the water vapor transport into the fiber structure (moisture regain) via diffusion increases, fibers get saturated with water. They swell more and end up with a decrease in the fabric porosity. These result in lower fabric water vapor permeability. Therefore, the highest water vapor transfer rate of the hydrophilic fabrics can be also explained by the lowest moisture regain as it was demonstrated in the literature [16].

3.3 Drying Rate

The DRs of the fabric samples were investigated and the results were summarized in Table 2. As can be seen from the table, the MWN samples gave the highest DR whilst the MSA and LSA samples performed the worst ones. The results obtained from the statistical analysis performed by the Minitab® program showed that the spandex incorporation was the main affecting parameter with an R2 value of 0.9298 on the DRs of the investigated fabric samples.

Table 2. Drying properties of samples

		Fabric code	**Dry fabric weight (g)**	**Initial wet-out fabric weight (g)**	**Initial water amount (g)**	**Drying rate, g/h/m^2**	**Drying time, h**	**Standard deviation of drying rate**
Micro rayon	Without spandex	MWN	1,313	6,902	5,589	46,67	4,23	1,70
		MWA	1,293	6,798	5,505	36,90	3,39	2,62
		MWW	1,302	6,575	5,273	34,27	3,29	3,84
	Spandex	MSN	5,234	6,931	1,697	21,58	7,52	1,25
		MSA	5,298	6,583	1,285	15,14	7,42	3,09
		MSW	5,443	6,947	1,504	19,67	7,99	1,25
Lyocell	Without spandex	LWN	1,173	6,43	5,257	40,83	3,93	0,82
		LWA	1,25	6,034	4,784	35,33	3,74	2,62
		LWW	1,182	5,852	4,67	31,66	3,43	4,50
	Spandex	LSN	4,895	6,433	1,538	20,40	7,89	1,70
		LSA	4,72	6,141	1,421	15,84	6,68	2,62
		LSW	4,87	6,37	1,5	16,91	6,73	2,16

The interaction plot presented in Figure 2iiia showed that the fabric samples made of rayon microfibers and lyocell fibers with spandex had almost the same DR values however, for the case without spandex incorporation, the micro rayon fabric samples had slightly higher DRs than the lyocell ones. Since DR is defined as the rate of initial wet weight to drying time per unit area of fabric, the DR would be higher when the fabric dries quickly after absorbing high amount of water. As can be seen from Table 2, the DRs of the micro rayon seamless samples without spandex incorporation were higher although they had higher initial water amount. Therefore, it can be concluded that the fabric samples made of rayon microfibers had slightly higher DRs than the ones made of lyocell fibers due to the higher surface area to volume ratio of rayon microfibers and hence higher water evaporation rate. But the paired t-test conducted between the DRs of these fibers showed that the difference was not so meaningful ($t(36)=0.545$ $p=.590$). The data given in Table 2 and Figure 2iiia demonstrated that the spandex incorporation was an important and influential parameter on the drying properties of the fabric samples; such that the DRs of the fabric samples having spandex were seriously lower for both the micro rayon and lyocell seamless samples. Total volume of liquid a material can hold is positively correlated with its thickness [44]. As it is commonly known that the increase in the thickness of a fabric causes higher water absorption [23, 24, 44-46]. In this study, as given in Table 1, the fabric samples having spandex fibers were thicker than those made of only main yarn such as lyocell fiber and rayon microfiber. However, by the incorporation of spandex into the fabric structure, while the thickness increased, the initial water amount did not increase due to both the lower water absorption capability of spandex and the lower porosity as well as the alteration in the interconnectivity of the pores in the fabric structure. According to the results of this study, as a factor, the porosity was more dominant than the fabric thickness. On the other hand, according to the literature, fabric drying-time mainly depends on the amount of liquid it initially takes up into its structure such that lower the initial amount of liquid in the fabric structure higher the DR [16]. Contrarily, although the fabric samples with spandex had lower initial water amount, they had lower DRs. Moreover, in the literature it was also reported that higher VW ability and higher moisture permeability are other factors that increase the DRs of fabrics [16, 22-24, 44, 46]. Therefore, since the VWC and the WVP of the fabric samples with spandex incorporation were both lower than the ones without spandex incorporation, the DR of the fabric samples with spandex incorporation was lower. According to the results of this study, as a factor, the VWC and the WVP were more dominant than the initial water amount in the fabric structure. The t-test supported this result that the effect of spandex on the DRs of the fabric samples was significant at 95% confidence level ($t(36)=-17.771$ $p=.000$).

When the effect of process history was evaluated, after the seamless samples were treated with either antibacterial or wicking finishes, the tendency was similar for both fiber types that the DRs of the seamless samples decreased (Figure 2iiib). If crosslinking ratio is increased, crystallinity of the fibers may be decreased resulting in higher water absorbency. In between the cellulose chains inside the fiber structure, crosslinking may cause voids to which water molecules can easily penetrate. However, if effective three dimensional polymer network cannot be created by crosslinking, this might result in lower water absorbency. When the crosslinking density is increased, more three dimensional polymer network occurs causing the water absorbency to increase, however, if the crosslinking density gets too high, at that time the space in between the polymer chains gets really low causing a decrease in the water absorbency. This means that optimum crosslinking should be obtained for high water absorbency values. Therefore, numerous voids, free spaces and capillaries caused by the crosslinking obtained after these finishing applications can constitute new paths for water to penetrate inside [47-49]. With both of the finishing applications, the water absorbency values of the fabric samples were found to get lower. This may be caused by the highly cross-linked structure of the cellulosic fibers obtained after the finishing applications resulting in a denser structure. Also, this result was supported with the independent t-test that the difference between the untreated and the treated fabric samples was statistically significant ($t(36)=2.961$ $p=.0343$). On the other hand, although, as aforementioned, the initial amount of water in the fabric structure decreased for all of the fabric samples after both of the finishing applications compared to the ones without finishing treatments, their DRs were found to slightly decrease. However, according to the ANOVA evaluation, the DRs of the fabric samples did not vary with the different finishing treatments and the fabric samples behaved in the same manner ($F(2,33)=0.457$ $p=.657$). When it comes to the interaction between the process history and the spandex incorporation to the fabric structure, the DRs of the fabric samples decreased after both of the finishing treatments however, the effect was much more prominent for the ones without spandex (Figure 2iiic). Moreover, the fabric samples without spandex were found to have higher DRs than the ones with spandex for the three cases of the process history.

3.5. Hybrid AHP-TOPSIS Approach

The analytic hierarchy process was employed to find out the relative weights of four decision criteria in terms of their relative importance for the liquid characteristics of the seamless knitted fabrics. The DR, VWC, TW and WVP are the parameters that are important and effective on the liquid transfer characteristics of the fabrics. Therefore, they were taken as criteria and the normalized weights were calculated. The pair-wise comparison matrix of the four decision criteria in terms of their importance level can be seen in Table 3.

Casual and leisure wear apparels are less likely to become soaked with sweat and do not need to dry so rapidly. Consequently, the drying time is less significant for the comfort of the casual and leisure clothing. However, it is not the case for the intimate wear.

For the measurement of the consistency of the judgement, the original matrix is multiplied by the weight vector to acquire the product. λmax was obtained as 4.25073. Since the value of CR is below 0.1 in Equation (1), the comparison matrix remains coherent.

After the identification of the positive (A+) and the negative ideal solutions (A-), the separation of each alternative from the ideal solution was calculated. The relative closeness of the alternatives (Rj) to the ideal solution (Aj) was defined in terms of A+. Based on the closeness of the coefficient to the ideal solution (Rj value), the ranking of the preference order of all the alternatives in descending order is displayed in Table 4. With reference to Table 4, the MWA fabric samples appeared to be the best alternatives whereas the MSW fabric samples were the ones which gave the worst performance.

Table 3. Pair-wise comparison matrix of criteria with the objective and codes

	Transfer Wicking	Wicking Capacity	Drying Rates	Water Vapor Permeability	Normalized Weights	Codes
Transfer wicking	1	1	3	1/3	0.222	C1
Wicking capacity	1	1	3	1/3	0.222	C2
Drying rates	1/3	1/3	1	1/7	0.112	C3
Water vapor permeability	3	3	7	1	0.444	C4

$$CI = \frac{4.25073 - \mathbf{4}}{4 - \mathbf{1}} = 0.08359\mathbf{1} \qquad CR = \frac{CI}{RCI} = \frac{0.08359\mathbf{1}}{\mathbf{0.9}} = 0.092879 < 0.\mathbf{1} \qquad \text{(Equation 1)}$$

Table 4. Preference order for the samples

Reference order				
Fabrics	**Pos Ideal (d+)**	**Pos Ideal (d-)**	**Relative Closeness (Rj)**	**Rank**
MWA	0.01	0.07	0.85	1
LWA	0.02	0.07	0.79	2
MWN	0.02	0.07	0.76	3
MWW	0.02	0.06	0.74	4
LWW	0.03	0.06	0.67	5
LWN	0.04	0.06	0.61	6
MSA	0.05	0.04	0.45	7
LSW	0.06	0.03	0.34	8
MSN	0.05	0.03	0.33	9
LSA	0.07	0.03	0.32	10
LSN	0.06	0.02	0.28	11
MSW	0.06	0.02	0.24	12

4. CONCLUSION

According to the results of the study, spandex incorporation to the fabric structure and the process history were all proven to be effective on the VWC values of the seamless samples. For the TW, while the spandex incorporation to the fabric structure was found as the main affecting parameter, the fiber type and process history were both exhibited to have no significant effect. The process history was shown to have no significant effect, whereas the fiber type and spandex incorporation to the fabric structure were found to have significant effects on the WVP. When the DR was considered, according to the findings, both the fiber type and process history had no significant effect, while spandex was the main affecting parameter. While the MWA fabric was the best choice, MSW was the worst according to the AHP-TOPSIS approach. In the futurework, assessment of water-related comfort of the knitted fabrics will be conducted after employing both of the finishing agents simultaneously, as both hygiene and dry feel are very important for comfort of intimate wear. Moreover, fabrics made of synthetic-based and natural-based fibers will be compared with each other in terms of their water-related comfort properties after simultaneous application of these finishes, since it is assumed that the effect of finishing agents will be realized more clearly on the comfort of the fabrics made of the fibers from different origin than similar origin.

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