(REFEREED RESEARCH)

THE INVESTIGATION OF THERMAL COMFORT, MOISTURE MANAGEMENT AND HANDLE PROPERTIES OF KNITTED FABRICS MADE OF VARIOUS FIBRES

FARKLI LİFLERDEN ÜRETİLMİŞ ÖRME KUMAŞLARIN ISIL KONFOR, NEM İLETİMİ VE TUTUM ÖZELLİKLERİNİN İNCELENMESİ

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ABSTRACT

Textile industry continuously searches for new raw materials in order to accomplish the consumers´ demands. Nowadays active lifestyle has created a rapidly increasing market for a wide range of textile products having good comfort and handle properties. For this aim, this research comparatively investigated thermal comfort, moisture management and handle properties of fabrics produced with relatively new fibres to contribute the studies related with this area. In the experimental part of the study, 90% Cotton / 10% Seacell, 90% Cotton / 10% Silver, 100% Cotton, 100% Bamboo and 100% Soybean yarns were used. Knitted fabrics were produced with these yarns and thermal comfort, moisture management and handle properties of fabrics were examined. According to test results it was concluded that Soybean fabric gave the best thermal comfort and moisture management properties where Cotton/Silver and Bamboo gave the smoothest feeling.

Key Words: Thermal comfort, Moisture management, Handle, Knitted fabric.

ÖZET

Tekstil endüstrisi müşteri taleplerini karşılamak için sürekli olarak yeni hammaddeler araştırmaktadır. Günümüzde aktif yaşam tarzına uygun iyi konfor ve tutum özelliklerine sahip olan ürünlere olan talep hızla artmaktadır. Bu amaçla, çalışmada klasik liflere kıyasla yeni sayılabilecek liflerden üretilen kumaşların konfor, nem iletimi ve tutum özelliklerini karşılaştırmalı olarak inceleyerek bu alanda yapılan çalışmalara katkı sağlamayı amaçlamaktadır. Çalışmanın deneysel kısmında, %90 Pamuk / %10 Seacell, %90 Pamuk / %10 Gümüş, %100 Pamuk, %100 Bambu ve %100 Soya iplikleri kullanılmıştır. Bu ipliklerden üretilen süprem örgü kumaşların ısı konfor, nem yönetim kabiliyetleri ve tutum özellikleri incelenmiştir. Termal konfor özellikleri için Alambeta ve Permetest cihazları, nem yönetim özellikleri için MMT cihazı ve tutum özellikleri için ise dairesel eğilme ve FrictorQ cihazları kullanılmıştır. Test sonuçları, soyadan üretilen kumaşların en iyi termal konfor ve nem yönetim özelliklerine sahip olduğunu, pamuk/gümüş ve Bambu kumaşların ise diğer kumaşlarla karşılaştırıldığında en pürüzsüz yüzey hissi verdiğini ortaya koymuştur.

Anahtar Kelimeler: Termal konfor, Nem yönetimi, Tutum, Örme kumaş.

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1. INTRODUCTION

The ideal fabric should have good thermal, moisture management and handle properties. Garments can give this effect when people both have freedom of motion and can regulate or help their thermoregulation system (1).

Many studies have been done about the thermal comfort properties of fabrics. Cimilli et. al (2) investigated the comfort properties of socks made from new fibres, such as modal, micro modal, bamboo, soybean, and chitosan. They concluded that the fibre type, together with regain and fabric properties such as thickness, appears to affect some comfort-related properties of the fabrics like thermal conductivity, air permeability, wicking, drying, water vapour permeability. Marmaralı et. al. (3) observed air permeability, thermal resistance and thermal absorbtivity properties of fabrics produced with different blended ratios Co/Soybean, Co/Seacell. It is observed that the comfort parameters are affected from blend ratios of fibers significantly. Seacell fibres have lower air permeability and 50/50 % Co/Seacell fabrics provide cooler feeling at the initial touch.Wu et. al (4) investigated the thermal-wet comfort of t-shirts made of ten kinds of hygroscopic fibres, such as cotton, wool, lyocell, modal, soybean, bamboo and their blends. According to test results, the thermal-wet comfort varied due to the fibre types which mainly influence the heat and moisture transfer during exercise, natural hygroscopic fibre, cotton and wool are much damper and more thermal than others. Chidambaram et. al. (5) investigated the thermal comfort properties of single jersey knitted fabric structures made from cotton, regenerated bamboo and cotton-bamboo blended yarns. According to test results, the water vapour permeability and air permeability of the fabrics were observed to increase with increase in bamboo fibre content. Frydrychet. al. (6) claimed that the type of raw materials influences some fabric properties characterising their thermal and utility comfort. Cotton yarns have better thermal properties but worse air permeability than tencel yarns.

The moisture transmitting property of fabric is a key factor that both affect textile and clothing comfort decides handling quality of clothing. According to previous researches, raw material type, yarn properties such as; number and twist and fabric properties mainly affect the moisture management properties of fabrics (7, 8).

Handle is another important parameter which affects the end products appearance. Handle affected by various parameters such as; raw material, yarn properties and fabric properties etc. (9).

This study aims to examine the thermal comfort, moisture management and handle properties of fabrics made from new generation fibres such as; silver, seacell, bamboo and soybean. In order to compare the new generation fibres with conventional fibre, it is also included the fabrics produced with cotton fibres in the study.

2. MATERIAL AND METHOD

In this study, 90%Cotton/ 10%Seacell, 90%Cotton/ 10%Silver, 100% Cotton, 100%Bamboo and 100%Soybean yarns were taken into consideration. The details regarding to the fibre properties were given in Table 1.

Cotton/Silver, Cotton/Seacell, Bamboo and Cotton ring spun yarns were supplied from Boyteks Textile Mill, Soybean ring spun yarns were supplied from Hayteks sales office. Yarn count, diameter and hairiness values were measured with Uster Tester 5. Twist coefficient were determined with Zweigle D315 twist tester. Both tests were carried with 10 repeats for each yarn type. Measured yarn properties were given in Table 2.

Single jersey fabrics were produced at the same knitting settings (i.e. same tightness) with the “Mesdan Lab Knitter” machine. Technical properties of knitting machine were summarized in Table 3.

Porosity of the fabrics was calculated according to the definitions given in the literature (10,11). Volume porosity (P) evaluation is based on the definition of hydraulic pore for the filtration purposes and it is defined in below;

$$P = 1 - \frac{Volume \quad \text{cov}ered \quad by \quad yarns}{Total \quad volume} \qquad (1)$$

By determining the course (c) per cm, wale (w) per cm, thickness (t), yarn diameter (d_y) and loop length (l), the yarn volume and total volume can be calculated as follows

$$Yarn\ volume = \frac{\pi d_y^2 2l}{4} = \frac{\pi d_y^2}{2} \qquad (2)$$

$$Total\ volume = \frac{1}{c}\frac{1}{w}t = \frac{t}{cw} \qquad (3)$$

All tests were performed after the fabrics were kept in standard atmospheric conditions for 24 hours (65±5 % relative humidity, 20±2ºC). In the analysis of the test results, ANOVA method was used with SPSS statistical pocket program at 0.05 significance level.

Table 1. Fibre properties

	Cotton	Silver	Seacell	Bamboo	Soybean
Fibre fineness (dtex)	1.73	2.5	1.7	1.33	1.5
Fibre length (mm)	28.6	38	38	38	38

Table 2. Measured yarn properties

	90% Cotton/ 10% Silver	90% Cotton/ 10% Seacell	100% Cotton	100% Bamboo	100% Soybean
Yarn count (Ne)	29.1	29.9	28.5	28.5	31.6
Yarn twist coefficient (α_e)	3.71	3.70	3.73	3.73	3.71
Yarn diameter (mm)	0.216	0.230	0.257	0.222	0.216
Yarn hairiness (H)	4.34	6.75	7.59	5.52	4.79

Table 3. Technical properties of knitting machine

Number of needle	220
Diameter (inch)	3 ¾
Gauge	48
Knitting type	Single jersey
Yarn tension	38
Production speed	225 turns/m

2.2.1. Thermal Comfort Properties

Thermal conductivity, thermal resistance and thermal absorptivity properties of fabrics were measured with Alambeta; relative water vapor permeability was measured on Permetest instrument working on similar skin model principle as given by the ISO 11092. Alambeta and Permetest instruments were manufactured by the SENSORA Company from CzechRepublic. Air permeability was measured according to the TS 391 EN ISO 9237 using tester FX3300. All measurements were repeated three times.

Thermal conductivity is defined as the measure of conducted heat pass though unit thickness under 1°C temperature difference. Thermal conductivity measurement is based on the equation given below:

$$\lambda = \frac{Q\sigma}{\Delta T} \quad \text{(W/mK)} \qquad (4)$$

where λ is the thermal conductivity, Q is the amount of conducted heat (W/m K), σ is the thickness (mm) and ΔT is the heat difference (K).

The thermal resistance of a fabric is a measure of a temperature difference by which a material resists to a heat flow and is determined by dividing the fabric thickness to thermal conductivity values. The equation of thermal resistance is given below:

$$R = \frac{\sigma}{\lambda} \qquad (5)$$

where R is the thermal resistance, σ is the thickness and λ is the thermal conductivity.

Thermal absorptivity (b) is defined as sudden heat flow occurs when two materials with different temperatures contact to each other and it is calculated according to the following equation:

$$b = \sqrt{\rho \lambda c} \quad \text{(Ws}^{1/2}\text{/m}^2\text{K)} \qquad (6)$$

where ρ is the density (kg/m^3), λ is the thermal conductivity (W/mK), c is the specific heat (J/kg K).

The relative water vapour permeability and air permeability properties were also investigated, since they are important factors in determining the comfort level of a fabric. The relative water vapour permeability is defined as the rate of water vapour transmission through a material. Air permeability is the rate of air flow passing perpendicularly through a known area under a prescribed air pressure differential between two surfaces of a material.

Moisture transport properties of fabrics were measured with SDL-ATLAS Moisture Management Tester (MMT). MMT is an instrument used to test the liquid moisture management capabilities of textiles such as knitted and woven fabrics dynamically per AATCC Test Method 195. This instrument consists of upper and lowers concentric moisture sensors. The fabric sample is placed between the two sensors. MMT is designed to sense, measure and record the liquid moisture transport behavior in multiple directions.

A series of indexes are defined and calculated to characterize liquid moisture management performance of the test sample by using moisture management tester, such as wetting time, absorption rate, maximum wetted radius, spreading speed for both top and bottom surfaces of fabrics and overall moisture management capacity (OMMC).

Wetting time is the time period in which the top and bottom surfaces of the fabric just start to get wetted after the test commences. Maximum wetted radius is defined as the maximum wetted ring radii at the top and bottom surfaces and spreading speed is the accumulative spreading speed (mm/sec) from the centre to the maximum wetted radius.

Overall moisture management capacity (OMMC) is an index to indicate the overall ability of the fabric to manage the transport of liquid moisture and is calculated with moisture absorption rate of the bottom side, one-way liquid transport capacity and spreading/drying rate of the bottom side. The larger the OMMC is the higher the overall moisture management ability of the fabric. OMMC values are compared with the grading scale given by the manufacturing company (0-0.2: very poor, 0.2-0.4: poor, 0.4-0.6: good, 0.6-0.8: very good, >0.8: excellent). (12)

2.2.2. Handle Properties

The fabric hand related to the concept of comfort, style, and appearance is one of the most important properties of the textile end products. In this study, various handle properties such as circular bending rigidity, friction coefficient of fabrics were examined into to determine the effect of material types used in the fabric production. Subjective handle test was also carried out and statistically analysed.

Five specimens in the dimensions of 20 × 10 cm were prepared for the measurement of bending rigidity in multiaxial directions. Circular bending rigidity tester, developed according to ASTM D 4032 (13), was used for this purpose. In this method, the force which is generated while pushing a fabric specimen through a ring is measured and read from the digital indicator.

Friction coefficient tests of the fabrics were carried out by using FrictorQ instrument developed by Minho University, Portugal. Kinematic friction coefficient of the samples ($\mu_{kinetic}$) and the graphic showing the variation of the friction values during 20 sec were supplied from the instrument. For each product, the average of the friction coefficient values was calculated. The lower the kinematic friction coefficient means the smoother and more even product.

Moreover the subjective fabric handle evaluation tests were also performed by ten panelists who were textile engineer in order to compare the results of objective test measurements. The panelists were allowed to see the fabrics without knowing the fabric type. A grading scale from 1 to 5, in which 1 meant hard and 5 meant soft, was used in the subjective evaluation of the fabrics.

3. RESULTS AND DISCUSSION

According to test results, the physical properties of the fabrics were given in Table 4.

3.1. Thermal Comfort Properties

Test results and statistical analysis results of thermal comfort properties, water vapour permeability and air permeability tests were given in Table 5 and Table 6, respectively.

Table 4. Physical properties of fabrics

Yarn type	Weight (g/m²)	Stitch Density (loops/cm²)	Porosity (%)
90% Cotton/10% Silver	93.28	238	54.34
90% Cotton/10% Seacell	87.24	208	56.67
100% Cotton	88.04	221	44.80
100% Bamboo	83.24	192	58.41
100% Soybean	73.31	204	64.76

Table 5. Thermal comfort and air permeability results

Fabric property	90% Cotton / 10% Silver	90% Cotton/ 10% Seacell	100% Cotton	100% Bamboo	100% Soybean
Thermal conductivity (W/m K)	0.049	0.046	0.047	0.042	0.043
Thermal resistance (m²K/W)	0.015	0.016	0.016	0.016	0.018
Thermal absorptivity (Ws½ / m²K)	127.76	118.83	118.00	133.83	119.10
Thickness (mm)	0.734	0.750	0.778	0.679	0.755
Relative watervapourpermeability(%)	52.83	55.83	53.03	59.96	54.36
Air permeability (l/m²sec)	1625	1558	1228	1926	1882

Table 6. Statistical test results of thermal comfort and air permeability properties

	Sum of squares	F	Sig
Thermal conductivity (W/m K)	0.00011	57.51	0.000*
Thermal resistance (m²K/W)	1.102496e-005	14.54	0.000*
Thermal absorptivity (Ws½ / m²K)	589.109	6.71	0.007*
Relative watervapourpermeability(%)	102.336	4.58	0.023*
Air permeability (l/m²sec)	3169808	30.89	0.000*

**Statistically significant*

The difference between fabric types was found statistically significant for thermal comfort and air permeability properties observed in this study.

3.1.1. Thermal Properties

The highest thermal conductivity results were achieved for Cotton/Silver fabrics, while bamboo and soybean fabrics have the lowest value (Figure 1).

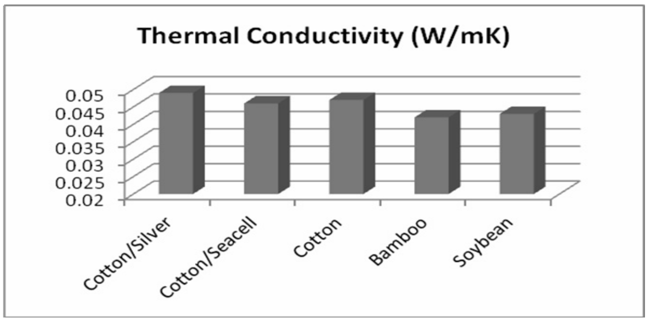

Figure 1. Thermal conductivity values of samples

There was not any significant difference between Cotton/Seacell and cotton fabrics statistically. As it is known from the literature, cotton fibre is a good conductor of heat and draws heat away from the skin to keep the body cool, making it comfortable to wear (2). Thus the test results proved that the cotton and blended cotton fabrics had higher conductivity than bamboo and soybean fabrics. Furthermore the usage of silver fibre in cotton fabrics increased the conductivity properties of fabrics.

Soybean fabric had the highest thermal resistance which was also in agreement with the results of previous study (2), whereas the lowest result for this property was determined for Cotton/Silver fabric. It was expected that thermal resistance results of bamboo and soybean fabrics should have been similar. However, bamboo had lower thermal resistance value than soybean, due to lower fabric thickness consequence of lower yarn diameter and fibre fineness values.

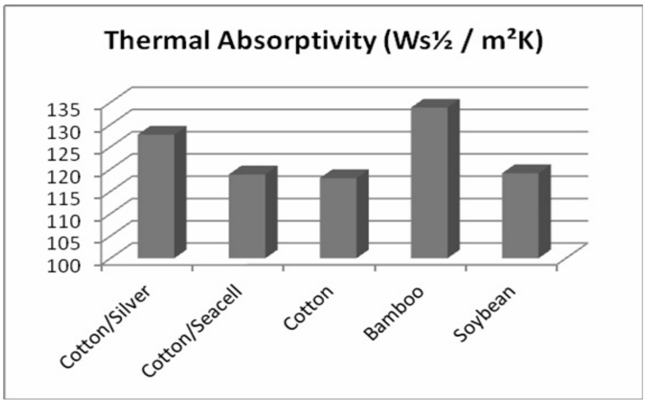

Figure 2. Thermal absorptivity values of samples

The highest thermal absorptivity values (Figure 2) were determined for Cotton/Silver and bamboo fabrics and three remaining fabric types had similar absorptivity values statistically. The reason of higher thermal absorptivity result is related to higher thermal conductivity value of Cotton/Silver fabrics. In the case of bamboo fabrics, even though its thermal conductivity is low, higher thermal absorptivity values could be explained with the lower fibre fineness. Lower fibre fineness causes lower porosity with less air involved within, leading to higher thermal absorptivity and feel cooler.

Thermal absorptivity allows assessment of the fabric's character in the aspect of its 'cool warm' feeling. Fabrics with a low value of thermal absorption give us a ''warm'' feeling (14).Hence, due to having lower thermal absorptivity values of Cotton/Seacell, cotton and soybean fabrics, they give us warmer feeling than Cotton/Silver and bamboo fabrics.

3.1.2. Water Vapour Permeability

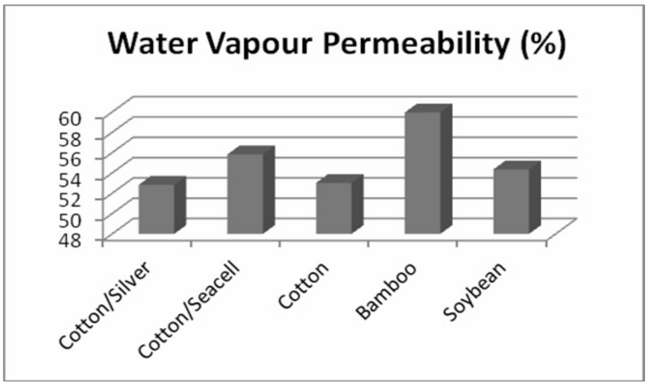

Figure 3. Water vapour permeability results

According to the Permetest results (Figure 3), bamboo fabric had the highest relative water vapour permeability values due to highest air permeability, lowest fibre fineness and fabric thickness properties. Furthermore, bamboo fibres can absorb and evaporate moisture instantly, since they have uncountable lumen distribution on the cross-section (15). Cotton/Silver, Cotton/Seacell, cotton and soybean had similar water vapour permeability values statistically.

3.1.3. Air Permeability

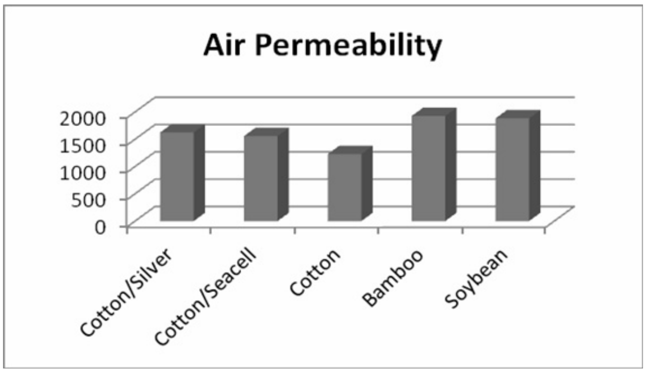

Figure 4. Air permeability results

Air permeability results (Figure 4) indicated that fibre type influenced the air permeability of fabrics, bamboo and soybean fabrics had the highest air permeability results. Cotton/Silver and Cotton/Seacell fabrics had the second highest air permeability values. According to SPSS correlation analysis, the correlation coefficient between porosity and air permeability was found statistically significant and calculated as 0.905 at 0.05 significance level. Thus, with the increase of porosity, air permeability increases.

3.1.4. Moisture Management Properties

MMT results of the fabrics and statistical analysis results were given in Table 7 and Table 8, respectively. However, it was not possible to test Cotton/Silver fabrics with MMT due to the metallic component it contained.

Table 7. MMT results of fabrics

Fabric property		90% Cotton/ 10% Silver	90% Cotton/ 10% Seacell	100% Cotton	100% Bamboo	100% Soybean
Top	Wetting Time (sec)	-	3.0260	3.0523	3.039	2.3073
	Absorption Rate (%/sec)	-	48.3582	45.7029	50.2441	54.0247
	Max Wetted Radius (mm)	-	21.67	20.00	20	30.00
	Spreading Speed (mm/sec)	-	4.4116	4.3223	3.229	7.3175
Bottom	Wetting Time (sec)	-	3.0780	3.3440	3.313	2.3330
	Absorption Rate (%/sec)	-	42.0637	41.1456	49.2792	47.9246
	Max Wetted Radius (mm)	-	21.67	25.00	25	30.00
	Spreading Speed (mm/sec)	-	4.3228	4.2133	3.079	7.3975
OMMC		-	0.3865	0.4115	0.2840	0.4389
Moisture management category		-	Poor	Good	Poor	Good

Table 8. Statistical test results of MMT properties

Fabric property		Sum of squares	F	Sig
Top	Top Wetting Time (sec)	1.169	10.073	0.006*
	Top Absorption Rate (%/sec)	109.686	0.717	0.572
	Top Max Wetted Radius (mm)	206.250	33.000	0.000*
	Top Spreading Speed (mm/sec)	24.788	88.580	0.000*
Bottom	Bottom Wetting Time (sec)	1.903	24.018	0.000*
	Bottom Absorption Rate (%/sec)	143.399	2.721	0.124
	Bottom Max Wetted Radius (mm)	116.667	2.333	0.150
	Bottom Spreading Speed (mm/sec)	27.759	23.876	0.000*
OMMC		0.031	9.716	0.007*

**Statistically significant*

According to statistical analysis, it was observed that the differences between fabric types were found statistically significant for all measured properties except absorption rate and bottom max wetted radius. It was also observed that spreading speed and maximum wetted radius decrease while the wetting time of the fabrics increases.

Wetting time of the bottom surfaces was calculated higher than the top surfaces for all the fabrics as expected. The lowest wetting time was achieved for soybean fabrics, where there was not any statistically significant difference between Cotton/Seacell, cotton and bamboo fabrics.

According to Table 8, the top absorption rates of the fabrics are generally higher than bottom surfaces. However, top and bottom absorption rates of bamboo fabric were calculated similar. This indicates that bamboo fibres could pass the sweat from inner surface to outer surface of the fabric.

Highest wetted radius was achieved for soybean fabrics, where there was not any statistically significant difference between Cotton/Seacell, cotton and bamboo fabrics. According to test results, it was also observed that fibre type had significant effect on spreading speed. Thus, highest spreading speed was found for soybean fabrics. Next came Cotton/Seacell and cotton fabrics and finally, bamboo had the lowest spreading speed for both top and bottom fabric surfaces.

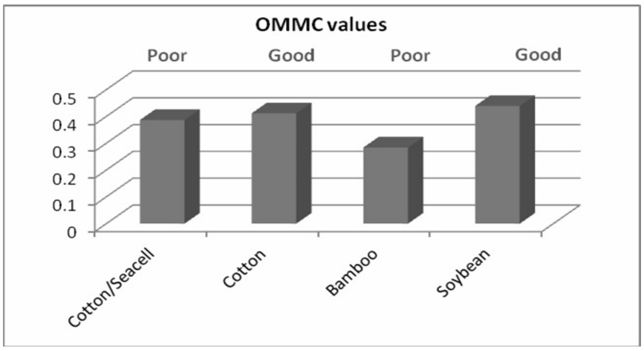

Figure 5.OMMC values of the fabrics

According to the test results (Figure 5), the lowest OMMC value was calculated for bamboo fabrics which indicated that bamboo fabrics had poor moisture management ability when compared with others. Soybean and cotton fabrics had similar moisture management ability and slightly better than Cotton/Seacell fabric.

3.2. Handle Properties

Results of handle properties and statistical analysis results regarding to these tests were displayed in Table 9 and Table 10, respectively.

Statistical analysis showed that fibre type had no effect on circular bending rigidity of fabrics, since there was no significant difference between bending rigidity values of all fabric types. The other handle property analysed was friction coefficient where statistically significant difference between fabric types was found. According to test results, lower friction coefficient values were determined for Cotton/Silver and bamboo fabrics comparing with the others. No statistically significant difference was found between friction coefficient values of Cotton/Seacell, cotton and soybean fabrics pair wised. Thus, it can be concluded that Cotton/Silver and bamboo gives smoother felling when compared to Cotton/Seacell, cotton and soybean fabrics.

Subjective assessment treats fabric hand as a psychological reaction obtained from the sense of touch (16). In this study it was aimed to test the softest of the fabric types with subjective assessment test. The test results indicated that bamboo was chosen as the softest fabric among others. On the other hand, Cotton/Silver and soybean fabrics had the roughest felling.

Cotton/Silver fabrics showed the lowest friction coefficient among the samples, but the subjective assessment resulted in the roughest feeling. The reason of reduction in fabric friction for Cotton/Silver fabrics in the study may be due to the low yarn hairiness of Cotton/Silver yarns. However, some hairiness is also required for yarns to produce good handle and comfort properties (17). As Cotton/Silver had the lowest yarn hairiness results among others, it was chosen as the roughest fabric in subjective assessment tests.

Table 9. Results of handle properties of fabrics

Fabric property	90% Cotton/ 10% Silver	90% Cotton/ 10%Seacell	100% Cotton	100% Bamboo	100% Soybean
Circular bending rigidity (N)	0.81	0.77	0.86	0.76	0.82
Friction coefficient ($\mu_{kinetic}$)	0.3295	0.3474	0.3460	0.3348	0.3580
Subjective handle evaluation value	2.1	3.5	3.5	3.9	2.3

Table 10. Statistical test results of handle properties

Fabric property	Sum of squares	F	Sig.
Circular bending rigidity (N)	0.0326	2.117	0.116
Friction coefficient ($\mu_{kinetic}$)	0.0025	4.27	0.012*
Subjective handle evaluation value	25.5	11.65	0.000*

**Statistically significant*

4. CONCLUSION

The aim of the study was to contribute the studies related with comfort, moisture management and handle properties of relatively new fibres of the market. For this purpose, Co/Seacell, Co/Silver, Bamboo and Soybean yarns were selected as raw materials in the study. In order to compare the new generation fibres with conventional, fabrics produced with cotton fibres also included in the study.

According to test results, silver fibre improves the thermal comfort properties of cotton fabrics. Co/Silver fabrics have higher conductivity and lower thermal resistance which makes it more comfortable to wear. Although adding of 10% Seacell fibres to cotton fibres did not affect the thermal comfort and handle properties of fabrics.

Bamboo and soybean have highest water vapour and air permeability compared to other fibre types observed in this study. Beside good air permeability properties bamboo was chosen as the smoothest, softest and provide the coolest feeling at the initial touch among other fibre types observed in this study. However, bamboo fabric had 'poor' moisture management ability.

Even though soybean fabric did not show good handle characteristics; liquid moisture management performance of this fabric type was found better than the others, since soybean fabric absorbed liquid faster and more than other investigated materials. It was observed that fibre type had significant effect on moisture management ability of fabrics. Thus, the highest OMMC value was achieved for soybean fabrics.

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