TEKSTİL VE MÜHENDİS

(Journal of Textiles and Engineer)

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BİSİKLET SPORU GİYSİLERİNDE KULLANILAN ÖRME KUMAŞLARIN GİYİM KONFORU ÖZELLİKLERİNİN İNCELENMESİ

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Online Erişime Açıldığı Tarih (Available online):31 Aralık 2023 (31 December 2023)

Bu makaleye atıf yapmak için (To cite this article):

Özlem KURTOĞLU NECEF, Ziynet ÖNDOĞAN (2023): Investigating The Clothing Comfort Properties Of Knitted Fabrics Used In Cycling Sportswear, Tekstil ve Mühendis, 30: 132, 272- 280.

For online version of the article: https://doi.org/10.7216/teksmuh.1296297

TMMOB Tekstil Mühendisleri Odası
UCTEA Chamber of Textile Engineers
Tekstil ve Mühendis
Journal of Textiles and Engineer

Yıl (Year) : 2023/4
Cilt (Vol) : 30
Sayı (No) : 132

Araştırma Makalesi / Research Article

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Gönderilme Tarihi / Received: 12.05.2023
Kabul Tarihi / Accepted: 10.12.2023

ABSTRACT: In this research, it was aim to investigate the clothing comfort properties of knitted fabrics intended for summer cycling sportswear. Five different fiber types and five different knitted structures commonly used in cycling sportwear were selected and totally 25 fabrics were manufactured by using a seamless circular knitting machine namely Santoni SM8-TOP2V in a controlled manner. To assess the impact of material type and knitted structures on clothing comfort properties, mass per unit area, thickness, air permeability, thermal conductivity, thermal resistance, overall moisture management capability and relative vapour permeability tests were conducted. The statistical significance of variations in the obtained results was evaluated using the analysis of variance (ANOVA) method. In conclusion, the most suitable material and knitted structure have been recommended for summer upper body cycling clothing.

***Keywords*:** Sportswear, Clothing comfort, cycling sportswear, knitted fabric.

BİSİKLET SPORU GİYSİLERİNDE KULLANILAN ÖRME KUMAŞLARIN GİYİM KONFORU ÖZELLİKLERİNİN İNCELENMESİ

ÖZ: Bu araştırmada, yaz mevsiminde kullanılan bisiklet spor giysileri için örülmüş kumaşların giyim konfor özelliklerinin araştırılması amaçlanmıştır. Bisiklet sporcu giysilerinde yaygın olarak kullanılan beş farklı lif türü ve beş farklı örgü yapısı seçilmiş ve toplamda 25 kumaş, kontrollü bir şekilde Santoni SM8-TOP2V dairesel örme makinesi kullanılarak üretilmiştir. Malzeme tipi ve örgü yapısının giyim konforu üzerindeki etkisini değerlendirmek için kumaşlara gramaj, kalınlık, hava geçirgenliği, termal iletkenlik, termal direnç, nem yönetimi yeteneği ve bağıl su buharı geçirgenliği testleri uygulanmıştır. Elde edilen sonuçlar, varyans analizi (ANOVA) yöntemi kullanılarak değerlendirilmiştir. Araştırma sonucunda, sıcak iklim koşullarında kullanılacak bisiklet sporcu giysileri için uygun malzeme tipi ve örgü yapısı önerilmiştir.

Anahtar Kelimeler: Spor giyim, giyim konforu, bisikletçi giysileri, örme kumaş.

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DOI: *https://doi.org/10.7216/teksmuh.1296297* *www.tekstilvemuhendis.org.tr*

1. INTRODUCTION

The increasing interest sports has resulted in a rise in the worldwide sales of sportswear within recent years, hence apparel manufacturers and researchers have directed their attention this domain [1,2]. Sportswear has become increasing important for all people, as they anticipate higher expections for sports clothing to fulfill specific functions [3]. In the case of cycling, a highly popular sport globally, the clothing comfort of athletes assumes great importance. The movements of athletes generate a significiant amount of heat during activity. This sport exhibits multiple attributes, such as intensive energy consumption, a high sweating rate, and a higher level of extremity training. Therefore, cycling clothes needs to perform not only functional but also provide optimal comfort during wear [1,2,4]. Several articles were focused on the clothing comfort in the relation to type of fiber, yarn variables, knitted structure. Özkan and Meriç were investigated the thermophysological comfort features of different polyester knitted fabrics used in cycling sportswear. They were stated that warp knitted raschel fabric demonstrated greater suitability for cycling apparel used in summer. A survey was carried out with a cycling team to determine their expectations from clothes. Based on the feedback, five weft knitted and one warp knitted fabric which have different yarn counts and composition were chosen. The authors conducted the comfort tests and they were stated that %100 pes 75/36 denier trilobal cross-section warp knit raschel fabric was most convenient for summer cycling apparel [5]. Suganthi et al. focused the thermal comfort features of knitted fabrics made from modal, texturized polypropylene and micro-denier polyester yarns. Eleven fabrics were knitted in single jersey, plated and bi-layer structures. Objective and subjective evaluation of the fabrics were carried out. The results indicated that bi-layer knitted fabric with polypropylene as the inner and modal as the outer is suitable for volleyball sportswear [3]. Fan and Tsang investigated the influence of clothing's thermal characteristics on the comfort of wearers during sports activities. They utilized a thermal manikin to evaluate the thermal insulation, moisture vapour resistance, and moisture accumulation of five tracksuits. They found that the clothing comfort values after exercising were associated with the moisture vapour resistance of clothing and percentage of moisture accumulation within clothing, as measured by sweating manikin [6]. Wang et al. aim to investigate the impact of fabric structure and materials on fabric performance and produced 12 kinds of jacquard fabrics using polyester and DRYARN. Performance tests, such as air permeability and thermal resistance, were conducted on the fabrics and the results were statistically analyzed. Based on these findings, they designed professional ski underwear by using zone optimization [7]. Kun and Yanzhen analyzed the characteristics of the structural design of cycling clothes, and choose the functional fabrics, the design requirements of the pattern and the color. They concluded their study by offering the future development prospects of cycling clothing in China [8]. Taştan Özkan and Kaplangiray investigated the effect of loop length on thermal and moisture transmission properties of mesh knitted fabrics. They produced six types of fabrics with two different loop lengths in mesh and mesh rib structures. They declared that if the yarn gets finer and loop length increases, the air permeability values increases while overall moisture management capacity and thermal absorptivity values decreases [9]. Öner aimed to investigate the impact of fibers types on mechanical and thermal comfort properties of knitted fabrics. In this context, the author selected several fibers, namely cotton, flax, viscose, modal, bamboo, tencel, zein, polyester and polyamide 6.0. and produced in single jersey knitted fabrics from these fibers. The results emphasized that the type of fiber plays a crucial role in determining the mechanical and thermal comfort features of knitted fabrics [10]. Several studies have examined the influence of fiber types, yarn properties, and knitted fabric structures on clothing comfort. However, it has been observed that there are limited studies in the literature investigate the impact of fiber types on the comfort of cycling sportswear. Moreover, there are very few studies about the cocona® fiber, which is used in this study. Cocona® fiber is a type of synthetic textile fiber that used in sportswear such as cycling jerseys for athletes. Cocona® fabric, made from coconut shells, is widely used in sportswear due to its lightweight, excellent moisture management properties, which helps to regulate the body temperature of athletes within an ideal range during intense physical activity [11,12].

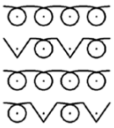
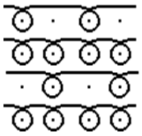
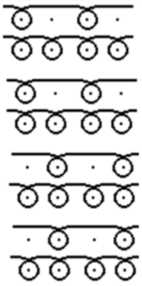
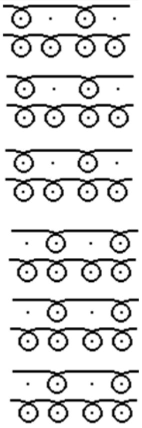
The objective of this study was to investigate the clothing comfort properties of knitted fabrics used in summer cycling sportswear. In this context, 5 different fiber types and 5 different knitted structures commonly used for cycling apparel were selected. Fabrics were manufactured on Santoni SM8-TOP2V by using seamless technology and clothing comfort performance properties were analysed. Seamless circular knitting technology was used due to its significant role in the sportswear production and its capability to offer limitless design possibilities [13]. This technology allows for the creation of continuous knitted fabric in a tubular form, and providing significant benefits to the wearers [14,15].

2. MATERIALS and METHODS

2.1. Materials

In this paper, five different fibers commonly used in cycling sportswear were selected. The fabrics were produced in five different knitted structures on a seamless circular knitting machine, namely Santoni SM8-TOP2V with a gauge (E) of 28, with the same constant machine settings. The fabrics structures were determined as the most preffered knitting structures for cycling sportswear, and single jersey, pique, jacquard 1x1, jacquard 2x2, jacquard 3x3 were knitted by using plating technique. The needle diagrams for these knitted structures were given in Table 1.

Table 1. The needle diagram of the knitted structures of the fabrics.

Fabric Structure	Single Jersey	Pique	Jacquard 1X1	Jacquard 2x2	Jacquard 3x3
Needle Diagram					

Different yarns were used on the surface and interior sides of the fabrics during production process. Poliamid multiflament yarn was choosen as the outside yarn, which is in contact with the environment, for all fabric structures. Polyester (83D/72f), polyamide (78D/68f), polypropylene (78D/50f), coolmax® (75D/72f) and cocona® (75D/48f) with the yarn counts as close to each other as possible were selected for inner side of the garment in contact with the wearer's skin. Totally twenty-five knitted fabric samples were manufactured and systemactically coded as between S1- S25.

This research focussed on examining the influence of inner material and knitted structures on the clothing comfort properties of fabrics. Therefore, the dyeing and finishing processes were kept constant for all fabrics. All the fabric samples were dyed in a garment dye machine with the suitable dyestuffs. Afterward, they were washed with a nonionic detergent at 40°C for 20 minutes followed by tumble drying for 30 minutes.

2.2. Methods

The fabric samples were conditioned at 65% ± 4% relative humidity and 20 °C ± 2 °C temperature for at least 24 h under the standard atmosphere conditions according to EN ISO 139:2005 [16]. Afterwards, the tests namely mass per unit area, thickness, air permeability, thermal resistance, thermal conductivity, overall moisture management capacity (OMMC) were conducted. The testing instruments and corresponding standards were referenced in Table 2.

The air permeability values were measured with a 100 Pa air pressure difference and 20 cm2 testing area. The results represent the average of ten random measurements taken from various regions of the fabric. To measure the thermal conductivity, thermal resistance and fabric thickness using Alambeta testing instrument, three repetitions were performed. Moisture management properties were tested by cutting square samples in 80 mm × 80 mm dimensions, and the average of five repetitions was evaluated. The PERMETEST Sensora instrument, simulates the human skin, was utilized to measure the relative water vapour permeability.

Table 2. The tests, testing instrument and corresponding standards

Fabric Tests	Testing Instrument	Related Standard
Course and wale density	-	CSN EN 14971:2006
Loop length	H.A.T.R.A device	EN 14970:2006
Air permeability	Textest FX 3300	TS 391 EN ISO 9237 [17].
Thickness Thermal conductivity Thermal resistance	Alambeta	ISO 8301
OMMC	MMT	AATCC 195-2009 [18].
Relative water Vapour Permeability	Permetest	TS EN ISO 11092 [19].

2.2.1. Statistical Evaluation

The analysis of variance (ANOVA) method was used to assess the statistical significance of the variations, utilizing PASW18 statistical analysis package program. In order to deduce the significance of the parameters, namely inner material type and knitted structure, the p values were evaluated at the confidence level of 95%. Following that, multiple comparison tests (post-hoc tests) were conducted to analyze any differences among the parameters. Initially, Levene's homogeneity test, with a 95% confidence interval, was applied to assess whether the variances exhibited a homogeneous structure or not. If a homogeneous variance was detected, the Student-Newman-Keuls (SNK) post hoc test was conducted to examine the variations between the means. If a heterogeneous variance was detected, the Tamhane's T2 test was applied.

3. RESULTS and DISCUSSIONS

The tests were conducted to investigate the effects of knitted structure and inner side material on the clothing comfort properties of fabric samples. The obtained average values of mass per unit area, thickness, air permeability, thermal resistance, thermal conductivity, overall moisture management capacity and relative water vapour permeability were presented in Table 3.

Detailed evaluation of the loop structure was perfomed to obtain a better explanation of the relationship between the loop length and the comfort test results (Table 4).

Table 3. Test results of fabric samples

Inner material	Knitted structure	Cpc	Wpc	Stitch density (stitch/cm^2)	Mass per unit area (g/m^2)	Thickness (mm)	Air permeability (l/m^{2}s)	Thermal conductivity (W/m K)	Thermal resistance (m^{2}K/W)	OMMC (-)	Relative water vapour permeability
PES	Jersey	19	25	475	178,6	0,79	342	0,048	0,017	0,4853	49,6
	Pique	18	18	324	163,6	0,61	367	0,051	0,012	0,4263	52,8
	Jac. 1x1	18	19	342	147,6	0,77	630	0,045	0,017	0,3836	53,6
	Jac. 2x2	20	19	380	143	0,83	632	0,045	0,018	0,3843	54,8
	Jac. 3x3	19	19	361	144,9	0,8	642	0,044	0,018	0,4101	56,7
PA	Jersey	18	25	450	158,5	0,83	227	0,053	0,015	0,3918	52,4
	Pique	21	20	420	150,1	0,71	272	0,057	0,012	0,3347	53,5
	Jac. 1x1	18	19	342	132,4	0,79	430	0,051	0,016	0,333	55
	Jac. 2x2	18	19	342	136,9	0,83	406	0,051	0,016	0,3276	58
	Jac. 3x3	18	19	342	137,2	0,83	443	0,051	0,016	0,3351	58,3
PP	Jersey	17	24	408	144,1	0,83	350	0,054	0,015	0,7269	49,6
	Pique	18	19	342	125,9	0,69	421	0,055	0,013	0,7165	51,4
	Jac. 1x1	18	19	342	111,7	0,78	725	0,052	0,015	0,429	52,2
	Jac. 2x2	18	19	342	110,4	0,81	728	0,052	0,015	0,4527	53,7
	Jac. 3x3	18	19	342	110,6	0,85	730	0,052	0,017	0,4817	54,8
Coolmax®	Jersey	18	26	468	163	0,81	420	0,056	0,015	0,8308	47,4
	Pique	18	19	342	149,1	0,71	417	0,058	0,012	0,8212	48,8
	Jac. 1x1	18	20	360	133,6	0,81	605	0,052	0,016	0,641	50,7
	Jac. 2x2	18	21	378	137,2	0,88	619	0,051	0,017	0,6761	51,5
	Jac. 3x3	18	21	378	135,4	0,89	658	0,052	0,017	0,6784	53
Cocona®	Jersey	19	25	475	131,7	0,76	438	0,052	0,015	0,7119	53
	Pique	19	17	323	115,4	0,65	430	0,053	0,012	0,7345	58
	Jac. 1x1	21	19	399	88,7	0,75	716	0,046	0,016	0,4055	60,1
	Jac. 2x2	20	19	380	94,8	0,83	720	0,046	0,018	0,5705	62,8
	Jac. 3x3	20	19	380	97,3	0,83	731	0,046	0,018	0,6019	62,9

Table 4. The loop length values of each sample

Knitted Structure	Loop Structure		Loop Length (mm) / Inner Material				
			PES	PA	PP	Coolmax®	Cocona®
Jersey		Knit loops	2,21	2,17	2,22	2,26	2,29
Pique		Knit loops	2,30	2,20	2,40	2,50	2,60
		Tuck loops	1,40	1,40	1,40	1,41	1,50
Jac. 1x1		Knit loops	2,30	2,26	2,36	2,38	2,50
		Miss loops	2,34	2,30	2,41	2,40	2,58
Jac. 2x2		Knit loops	2,32	2,30	2,42	2,40	2,50
		Miss loops	2,38	2,35	2,50	2,42	2,60
Jac. 3x3		Knit loops	2,50	2,40	2,56	2,60	2,54
		Miss loops	2,58	2,50	2,60	2,68	2,63

To get a better understanding, additional statistical analysis such as multiple comparison tests were performed in order to investigate the effect of knitting structure and interior side material on clothing comfort properties and to determine differences between the samples.

3.1 Air Permeability

Air permeability is the measure of air flow through the fabric due to a pressure difference. It is playing an important role in determining the fabric's breathability and permeability, and mostly affected by the fabric's porosity in addition to its thickness. [10, 20].

Figure 1 illustrates that fabrics with jacquard knitted structures exhibited higher air permeability values compared to other fabrics. This can be explained by the relationship between loop length values and air permeability values. Due to the miss loop based structure in jacquard fabrics, their loop lengths were higher than the other fabrics (Table 4). This observation aligns with the insights from the study by Taştan Özkan and Kaplangiray [9], which demonstrated that an increase in loop length correlates with higher air permeability values. Furthermore, Tamhane's T2 test results revealed that the differences in knitted structures significantly affect air permeability features. Jacquard fabrics exhibited greater values, and statistically, there was no significant difference among them. Due to the tuck loops, pique fabric had lower loop length values and therefore exhibited lower air permeability values compared to jacquard structures. There was no statistically significant difference between pique and jersey fabrics.

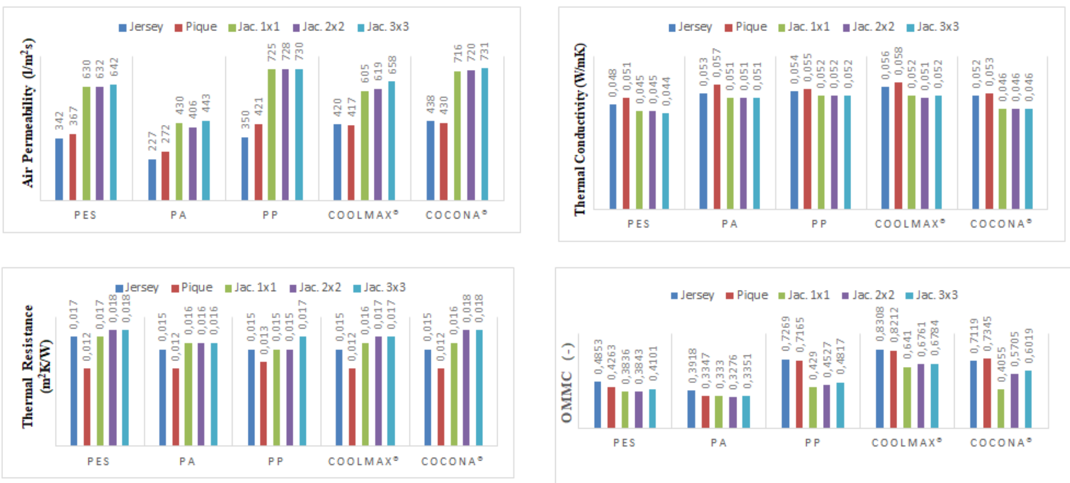


Figure 1. The results of air permeability, thermal resistance, thermal conductivity and overall moisture management capacity tests average values.

As stated in the literature, the air flow principle states that the flow of air will be less in thicker fabric and more in thinner fabric [3]. Supporting this argument, in this study, the jacquard fabrics with lighter weights presented higher air permeability features. To evaluate the influence of inner yarn material type on air permeability properties, Tamhane's T2 tests were conducted. As illustrated in Table 5, the results revealed that the air permeability values of polyamide fabrics were lower than the others and exhibited significant differences. To explain this situation, the thickness value of fabrics was first evaluated. However, there was no significant difference in thickness values among the fiber types. This observation may be caused due to the yarn counts. While polyamide fibers contain 68 filaments, polypropylene had 50 filaments at the same denier. Therefore, it could be said that the air permeability values were lower in polyamide fabrics due to the reduced voids. On the other hand, cocona® and coolmax® fabrics demonstrated the highest air permeability values, with no statistically significant difference observed among cocona®, coolmax® and polypropilen fabrics.

It is a fact that the fabrics with high air permeability values are choosen for summer cycling clothes. This emphasizes the important role of breathability in the fabric; therefore, the jacquard knitting structures come to forefront to be preffered for these clothes.

3.2 Thermal Conductivity

The thermal transfer features are important for ensuring the thermal comfort. Extensive thermal conduction facilitates the transfer of heat generated by the human body through the fabric to the outside environment. This property is expected in summer and sportswear [21].

In the terms of the thermal conductivitiy property, the results of the SNK test analysis (Table 6) indicated that both pique and single jersey fabrics exhibited high thermal conductivity values, and there was no significant difference observed between these fabric samples. On the other hand, jacquard fabric structures had lower thermal conductivity values, although there was no statistical significant difference observed between the jacquard knitted structures.

Table 5. Effects of inner material type on air permeability Tamhane's T2 test analysis results.

Inner type material (I)	Inner type material (J)	The difference between means (I-J)	Standard Error	p.	95% Confidence ınterval	
					Lower bound	Upper bound
PES	PA	166.760	23.624	0.000	98.83	234.69
	PP	-68.200	31.349	0.278	-158.07	21.67
	COCONA®	-21.540	24.920	0.993	-93.03	49.95
	COOLMAX®	-84.760	28.425	0.036	-166.17	-3.35
PA	PES	-166.760	23.624	0.000	-234.69	-98.83
	PP	-234.960	27.431	0.000	-314.10	-155.82
	COCONA®	-188,300	19,766	0,000	-244,95	-131,65
	COOLMAX®	-251.520	24.035	0.000	-320.65	-182.39
PP	PES	68.200	31.349	0.278	-21.67	158.07
	PA	234.960	27.431	0.000	155.82	314.10
	COCONA®	46.660	28.554	0.674	-35.49	128.81
	COOLMAX®	-16.560	31.659	1.000	-107.30	74.18
COCONA®	PES	21,540	24,920	0,993	-49,95	93,03
	PA	188,300	19,766	0,000	131,65	244,95
	PP	-46,660	28,554	0,674	-128,81	35,49
	COOLMAX®	-63,220	25,309	0,134	-135,85	9,41
COOLMAX®	PES	84,760	28,425	0,036	3,35	166,17
	PA	251,520	24,035	0,000	182,39	320,65
	PP	16.560	31.659	1.000	-74.18	107.30
	COCONA®	63.220	25.309	0.134	-9.41	135.85

Table 6. Effects of knitted structure on Thermal Conductivity SNK post hoc test analysis results

Knitted structures	N	Subsets	
		1	2
Jacquard 3x3	15	0,049	
Jacquard 2x2	15	0,049	
Jacquard 1x1	15	0,049	
Pique	15		0,053
Single jersey	15		0,055
p.		**0,933**	**0,050**

The analysis conducted using Tamhane's T2 test demonstrated that the fabrics made from coolmax® and polyester materials had lower thermal conductuvity values compared to the other fabrics, with a significant difference observed between the remaining fabrics. However, there was no significant difference was found between the thermal conductivity values of polyester and coolmax® fabrics. The thermal conductivity values of polypropylene, cocona® and polyamide fabrics were higher than the other fabrics, but no significant difference was observed among these three fabrics.

3.3 Thermal Resistance

Thermal resistance, which plays an important role in assessing the thermal insulation of clothing, is closely associated with the thickness of the fabric [22]. Regarding the influence of knitted structure on thermal resistance values, the results of the Tamhane's T2 test indicated that single jersey fabrics had the lowest thermal resistance values. Pique and jacquard 1x1 fabrics' thermal resistance values did not differ significantly in statistical terms. However, the thermal resistance values of jacquard 2x2 and jacquard 3x3 knitted structures were not statisitically significant and were higher compared to the other structures. Karthikeyan et al. (2016) stated that there is a negative correlation between thermal conductivity and thermal resistance, indicating that as thermal conductivity values decrease, there is an increase in thermal resistance values [23]. Supporting this paper, the thickness values of single jersey fabrics were found to be lower compared to jacquard fabrics. An increase in fabric thickness leads to an increase in the amount of stagnant air within the fabric. Due to its high thermal insulation properties, stagnant air exhibits more resistance to heat transfer. Consequently, this results in higher thermal resistance values and lower thermal conductivity values. As seen in Table 1, the thermal resistance values of fabrics knitted from polyester and coolmax® yarns were higher compared to the other materials. However, upon examining the results of the variance analysis, it was observed that the difference between the thermal resistance values of inner material types is not statistically significant.

3.4 Moisture Management Capability

MMT equipment measures various parametres associated with the fabric moisture management properties and OMMC is one of these parameters [24]. As illustrated in Table 1, the presented results demonstrate the overall (liquid) moisture management capability (OMMC) values of the fabrics. The value of the OMMC parameter is in the range of 0 to 1 with a higher OMMC value indicating a greater capacity to effectively manage liquid moisture [1, 25]. The five-grade indices represent the following levels: (1) poor, (2) fair, (3) good, (4) very good, and (5) excellent (Table 7) [26]. Based on the results, it can be stated that the OMMC values of single jersey and pique fabrics exhibited higher values compared to the jacquard fabrics. However, it is noted that no statistically significant difference was observed among the knitted structures of the fabrics.

Evaluating the influence of the inner side material on moisture management properties, Tamhane's T2 statistical tests (Table 7) were carried out. The findings showed that polyamide fabrics had the lowest OMMC values (poor grades) followed by polyester fabrics. The differences in OMMC values between polypropylene and coolmax® fabrics were statistically insignificant. Coolmax® single jersey and pique fabrics had the highest OMMC values and showed excellent grades. Fabrics knitted from cocona® yarns were observed to have another highest OMMC values (very good-excellent grades), ranking after coolmax® and polypropylene yarns. Based on the OMMC evaluation scale, fabrics knitted from polypropylene, coolmax®, and cocona® yarns demonstrated excellent liquid management performance.

It is stated that coolmax® fibers have the highest OMMC values due to their channeled cross-section structure, which provides capillary effect. This enables the fabric to absorb the liquid from the body more fastly and efficiently. Furthermore, cocona® fibers exhibited high OMMC values due to the activation of carbon particles during contact with water, which incereases the surface area of fabric and provide an increase its OMMC values.

During cycling sports activity, athletes sweat instensly; therefore, it is crucial for liquid water (perspiration) need to escape from the human body in order to keep the body dry. The liquid moisture transfer capability on fabric selection plays a significiant role to ensure optimal comfort for wearers. In this paper, it was stated that cocona® and coolmax® material types exhibited the best capability to manage liquid moisture.

3.5 Relative Water Vapour Permeability

The relative water permeability of a fabric is indicating the ability of its capacity to transmit water vapour. The human body regulates its temperature by producing sweat and allowing it to evaporate, during periods of high activity. The sweat in its vapour state, permeates through the fabric's thickness via macro pores by yarns and through the micro-pores within the fiber's organization in the structure of yarns [28, 29].

Table 7. MMT grading scale for OMMC values [5,27].

Index / Grade	1	2	3	4	5
OMMC	0-0.19 Very Poor	0.2-0.39 Poor	0.4-0.59 Good	0.6-0.8 Very Good	>0.8 Excellent

It was observed that knitted structure had an impact on the relative water vapour permeability. Jacquard 3x3 fabrics exhibited the highest values, and all the jacquard fabrics displayed high values. However, there was no statistically significiant difference between them. Single jersey and pique fabrics demonstrated similar results, and there was no statistically significant difference between them.

Table 8. Effects of knitted structure on relative water vapour permeability SNK test analysis results

Knitted structures	**N**	**Subsets**		
		1	**2**	**3**
Pique	15	50,393		
Single jersey	15	52,893	52,893	
Jacquard 1x1	15		54,327	54,327
Jacquard 2x2	15			56,160
Jacquard 3x3	15			57,147
p.		**0,057**	**0,271**	**0,081**

The influence of material type on relative water vapour permeability reveals that coolmax® material, with their channeled structure, exhibited higher values, and there was a statistically significant difference between them and other fabrics. Polyamid material followed coolmax®. The difference between polypropylene and polyester materials was not statistically significant. On the other hand, cocona® material have the lowest relative water vapour permeability values.

4. CONCLUSION

In this paper, it was aimed to examine the clothing comfort properties of 25 knitted fabrics used in summer cycling sportswear. In this context, 5 different fiber types (polyester, polyamid, cocona®, polipropilen, coolmax® and 5 different knitted structures (single jersey, pique, jacquard 1x1, jacquard 2x2, jacquard 3x3) commonly used for cycling apparel, were selected and the fabrics were manufactured using seamless technology. Since the fabrics have two faces with different materials, it was focused on investigating the impact of the inner material and knitted structure on the clothing comfort properties of the fabrics. To assess the clothing comfort features, mass per unit area, air permeability, thermal conductivity, thermal resistance, relative water vapour permeability, and overall moisture management capacity tests were conducted. Regarding the test results obtained, the influence of inner material type and knitted structures on the clothing comfort features were statistically analyzed and discussed. It was also found that material types and knitted structures significantly impacted the clothing comfort properties of the knitted fabrics.

As summer cycling races, which often involve long periods of physical exertion under hot weather condtions, the clothing comfort properties plays a vital role. Athletes experience intense perspiration with high sweat rates, and it becomes essential for the body to effectively dissipate this perspiration in vapour form. To ensure optimal comfort in this sport, factors such as having lightweight, high air permeability, great thermal conductivity, low thermal resistance, high relative water vapour, and high OMMC values become forefront.

It can be concluded that to ensure clothing comfort in this sport for summer, the single jersey knitting structure is a suitable choice for the main body fabric in such products due to its lightweight, high thermal conductivity values, and lower thermal resistance compared to other fabrics. Jacquard fabrics are also good choise for heavy sweating areas such as underarms, as they exhibit high air permeability and demonstrate good liquid moisture management values. Considering the material type, besides coolmax®, cocona® fiber is a new popular material in sportswear and is highly recommended for summer cycling clothing owing to its high air permeability and excellent liquid moisture management values, as indicated by test results. There are many studies in the literature about the clothing comfort features of knitted fabrics, but limited researches have explored on seamless cycling sportswear. Additionally, there are almost very few studies on cocona® fiber, which is a new fiber in sportswear. Investigating the potential usage of cocona fiber in cycling apparel, among the other fibers, enhances the academic value of this study. Consequently, this study presents a distinctive and original contribution by diverging from existing researchs.

ACKNOWLEDGEMENTS

The authors would like to thank Memteks Textile for supporting this research by knitting the fabrics.

REFERENCES

1. Teyeme, Y., Malengier, B., Tesfaye, T., Vasile, S., Van Langenhove, L. (2020), "Comparative analysis of thermophysiological comfort-related properties of elastic knitted fabrics for cycling sportswear." Materials, 13(18), 4024.
2. Özkan, E. T., Meric, B. (2015), "Thermophysiological comfort properties of different knitted fabrics used in cycling clothes." Textile Research Journal, 85(1), 62-70.
3. Suganthi, T., Senthilkumar, P., Dipika, V. (2017), "Thermal comfort properties of a bi-layer knitted fabric structure for volleyball sportswear." Fibres & Textiles in Eastern Europe, 25, 1(121): 75-80.
4. Liu, K., Kamalha, E., Wang, J., Agrawal, T. K. (2016), "Optimization design of cycling clothes' patterns based on digital clothing pressures." Fibers and Polymers, 17, 1522-1529.
5. Özkan, E. T., Kaplangiray, B. M. (2019), "Investigating thermophysiological comfort properties of polyester knitted fabrics." Journal of Textile Engineering & Fashion Technology, 5(1), 50-56.
6. Fan, J., Tsang, H. W. (2008), "Effect of clothing thermal properties on the thermal comfort sensation during active sports." Textile Research Journal, *78*(2), 111-118.
7. Wang, J., Zhang, B., Yao, X., Shen, J., Yuan, L., Pan, T., Li, Y. (2022), "Single-sided Jacquard knit fabric development and seamless ski underwear zoning design based on body mapping sportswear." Autex Research Journal, DOI 10.2478/aut-2022-0033.

8. Kun, Z., Yanzhen, W. (2015), "Research on bicycle riding clothes." Science Research, 3(5), 252-255.
9. Özkan Taştan, E., Kaplangiray, B., (2020), "Effect of loop length on thermal comfort properties of mesh knitted fabrics.", Tekstil ve Mühendis, 27(120), 243-251.
10. Öner, E., (2019), "Mechanical and thermal properties of knitted fabrics produced from various fiber types", Fibers and Polymers, 20(11), 2416-2425.
11. Chakroun, M. G., Benltoufa, S., Ghith, A., Fayala, F. (2023), "Investigating the Wear Comfort Properties of Knitted Fabrics Made with a Novel Biodegradable Polyester Yarn." Fibers and Polymers, 1-8.
12. Suparna, M. G., Rinsey Antony, V. A. (2016), "Eco-friendly textiles. International Journal of Science Technology and Management, *5*(11), 67-73.
13. Sterman, Y., Almog, E. (2022), "A Computational Design Tool for Gradual Transition of Knit Structures in Seamless Circular Knitting", Computer-Aided Design, 146, 103214.
14. Kanakaraj, P., Ramachandran, R. (2021), "Evolution of Weft Knitted Fabric Design: Seamless Knitwear Production Technology." Review of International Geographical Education Online, 11(7).
15. Nawaz, N., Nayak, R. (2015), Seamless garments. In *Garment manufacturing technology* (pp. 373-383). Woodhead Publishing. ISBN 978-1-78242-232-7
16. EN ISO 139:2005. Textiles - Standard Atmospheres for Conditioning and Testing.
17. EN ISO 9237:1995. Textiles - Determination of the Permeability of Fabrics to Air, International Organization for Standardization, 1995.
18. AATCC 195-2009. Liquid Moisture Management Properties of Textile Fabrics, American Association of Textile Chemists and Colorists (AATCC), 2009.
19. EN 31092 ISO 11092. Measurement of Thermal and Water-vapour Resistance under Steady-state Conditions.
20. Ertekin, G., Oğlakçıoğlu, N., Marmaralı, A., (2018), "Pamuk/Elastan Örme Kumaşların Mukavemet ve Isıl Konfor Özellikleri", Cilt: 25: 110, 146-153.
21. Yang, Y., Yu, X., Chen, L., Zhang, P. (2021), "Effect of knitting structure and yarn composition on thermal comfort properties of bi-layer knitted fabrics." Textile Research Journal, 91(1-2), 3-17.
22. Isler, M., Tama Birkocak, D., Abreu, M. J. (2021). The influence of starch desizing on thermal properties of traditional fabrics in Anatolia. Handloom Sustainability and Culture: Entrepreneurship, Culture and Luxury, 197-219.
23. Karthikeyan, G., Nalankilli, G., Shanmugasundaram, O. L., Prakash, C. (2016), "Thermal comfort properties of bamboo tencel knitted fabrics." International Journal of Clothing Science and Technology, vol. 28 No. 4, pp. 420-428.
24. Öner, E., Okur, A. (2015), "Thermophysiological comfort properties of selected knitted fabrics and design of T-shirts", The Journal of The Textile Institute, 106(12), 1403-1414.
25. Matusiak, M., Sukhbat, O. (2023), "Influence of Stretching on Liquid Transport in Knitted Fabrics." Materials, 16(5), 2126.
26. Jhanji, Y., Gupta, D., Kothari, V. K. (2015), "Moisture management properties of plated knit structures with varying fiber types." The Journal of the Textile Institute, 106(6), 663-673.
27. Supuren, G., Oglakcioglu, N., Ozdil, N., Marmarali, A. (2011), "Moisture management and thermal absorptivity properties of double-face knitted fabrics", Textile Research Journal, 81(13), 1320-1330.
28. Chakroun, M. G., Benltoufa, S., Ghith, A., Fayala, F. (2023)., "Investigating the Wear Comfort Properties of Knitted Fabrics Made with a Novel Biodegradable Polyester Yarn." Fibers and Polymers, *24*(1), 321-328.
29. Ertekin, G. (2017), "Analysis of thermo-physiological comfort and moisture management properties of flat knitted spacer fabrics." Textile and Apparel, 27(3), 241-250.