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Study on the Comfort Properties of Knitted Fabrics Produced from Conventional and Sustainable Cotton and Polyester Fibres

Študija udobnosti pletiv, izdelanih iz konvencionalnega in trajnostnega bombaža in poliestrskih vlaken

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Abstract

Recently, the production of organic fibres and the recycling of textile waste have become essential global issues due to the decrease in non-renewable resources and the increase in disposal costs. The aim of this work was to identify changes in the properties of single jersey knitwear produced from conventional and sustainable fibres after 20 washes. The samples were knitted from different conventional and sustainable yarns. The selected conventional fibres were 100% cotton, 50% cotton-50% polyester and 100% polyester, while the sustainable fibres were 100% better cotton, 100% recycled polyester, and 50% organic cotton-50% recycled polyester. Measurements were taken before and after 20 washes according to the relevant standards. It was found that fabric produced from 100% recycled polyester is suitable for active sportswear due to its high air permeability, and resistance to heat and water vapor. In addition, the fabric with 50% organic cotton-50% recycled polyester fibres was more suitable for cold environmental conditions due to its lowest water vapor resistance, good air permeability and high thermal resistance.
Keywords: organic cotton, recycled polyester, sustainable yarn, thermal comfort, comfort properties, knitted fabrics

Izvleček

Proizvodnja organskih vlaken in recikliranje tekstilnih odpadkov sta zaradi zmanjšanja neobnovljivih surovinskih virov in povečanja stroškov deponiranja postali bistveni vprašanji po vsem svetu. Namen te raziskave je bil ugotoviti spremembe v lastnostih enojnih jersey pletiv, izdelanih iz konvencionalnih in trajnostnih vlaken. Vzorci so bili spleteni iz različnih konvencionalnih in trajnostnih prej. Izbrana konvencionalna vlakna so bila 100-odstotni bombaž, 50 % bombaž/50 % poliester in 100-odstotni poliester, medtem ko so bila trajnostna vlakna 100-odstotni boljši bombaž (better cotton™), 100-odstotni recikliran poliester in 50 % organski bombaž/50 % recikliran poliester.

Meritve so bile opravljene pred pranjem in po dvajsetih pranjih v skladu z ustreznimi standardi. Ugotovljeno je bilo, da je pletivo iz 100-odstotnega recikliranega poliestra zaradi visoke zračne prepustnosti, toplotnega upora in upora prehodu vodne pare primerno za oblačila za aktiven šport, pletivo iz 50 % organskega bombaža/50 % recikliranih poliestrskih vlaken pa je bilo zaradi najnižjega upora prehodu vodne pare, dobre zračne prepustnosti in visokega toplotnega upora primernejše za hladne okoljske razmere.
Ključne besede: organski bombaž, recikliran poliester, trajnostna preja, toplotno udobje, udobne lastnosti, pletiva

1 Introduction

Due to population growth, industrialization, rising living standards, and rapidly changing fashion trends, a significant increase in global textile consumption was inevitable. It is estimated that total textile consumption will increase by 3% by 2030 to reach 102 million tonnes [1]. Unfortunately, the use of many hazardous chemicals in garment manufacturing is also increasing [2]. The increasing environmental problems due to the size of the market and the use of chemicals in the production phase, as well as growing awareness, have led to an increasing interest in sustainable production in the textile sector [3, 4].

One of the sustainable alternatives in the textile industry is the use of environmentally friendly fibres, also known as sustainable yarns. They are materials produced from non-toxic, renewable, and biodegradable sources that have a lesser environmental impact than conventional fibres. Organic fibre production and the recycling of textile waste are widely used methods to produce sustainable fibres [5]. Organic cotton produced without chemical fertilizers and pesticides plays an important role in creating a less harmful environment [6]. The Better Cotton Initiative (BCI), which is the subject of this study, is the largest cotton sustainability programme in the world, and teaches farmers crop protection practices, water management and the importance of soil health and biodiversity, and helps them work under these conditions [7]. It is believed that when BCI cotton production increases, the environmental sustainability of the soil improves and fertilizer consumption decreases, which will eventually lead to a reduction in negative environmental impacts. Similarly, the recycling process helps to reduce global warming and air pollution by saving energy and reducing the labour required to produce a new product [8]. The reuse and recycling of textile products could reduce the negative impact on the environment, as it could reduce the production of new textile fibres [9].

When the ecological footprint of products and materials is studied using tools such as life cycle assessment (LCA), it is found that new polyester has a larger ecological footprint compared to recycled polyester [10, 11]. Thanks to recycling, it is possible to keep waste out of landfills, reduce the need for new raw materials, save energy and water, create new jobs and reduce environmental pollution [12]. On the other hand, several researchers have found that the mechanical properties of yarn deteriorate as the percentage of recycled polyester in the blends of virgin and recycled polyester increases. This is particularly true for fine yarns, as the physical and chemical properties deteriorate due to impurities during the reprocessing of recycled polyester fibres [13, 14].

Fibres alone do not have all the necessary physical, aesthetic and serviceability properties required for ideal clothing for various applications [15]. Therefore, the blending of different fibres is a widely used method to achieve desired properties and improve weak points. The cotton-polyester blend is one of the most common blends in the textile and apparel industry. Typically, cotton-polyester blends have higher durability and better care properties than 100% cotton and less pilling, easier spinning and better uniformity than 100% polyester. The use of recycled polyester in blended yarns has opened new avenues for a sustainable future [16].

Telli [17] studied the properties of knitted fabrics made of cotton, polyester and blended yarns made of recycled polyester, and found that fabrics made of 100% polyester had the highest burst strength and the lowest abrasion resistance, followed by blended fabrics made of recycled polyester and cotton. Kurtoğlu [18] compared single jersey fabrics made from 50-50% recycled cotton-polyester and 50% cotton-50% polyester fibres. The study concluded that there was no significant difference between the quality and appearance of recycled and conventional cotton-containing fabrics. However, Utebay [19] found that the strength of yarns made from recycled cotton fibres was lower.

The fibre type, spinning technology, linear density, twist and hairiness of the yarn, as well as the thickness, cover factor, porosity and finish of the fabric, are certain factors that play an essential role in regulating the comfort properties of fabrics [20]. An ideal fabric must have high thermal resistance for protection from cold weather, low water vapor resistance for efficient heat transfer under soft thermal conditions, and fast fluid transport for heat transfer and the elimination of uncomfortable tactile sensations [21]. Celep [22] found that for single jersey fabrics made from a blend of virgin and recycled cotton fibres, thermal conductivity, heat absorbency and air permeability decreased as the percentage of recycled fibres increased, while the thermal resistance increased. Vadicherla and Saravanan [23] studied single jersey fabrics knitted with recycled polyester and cotton blend yarns. They found that the fabric became thicker, heavier and less porous as the percentage of recycled polyester blend and stitch length decreased. As the linear density increased, the fabrics exhibited lower air permeability, lower thermal resistance and higher relative water vapor permeability. Kumar and Raja [24] found that the overall moisture management capacity (OMMC) of socks made from recycled polyester yarns was better and that the water transport capacity was greater than other fabrics. According to another study on socks produced from recycled yarns, it was found that as the percentage of recycled polyester in fibre blends increased, the thermal resistance, air permeability and relative water vapor permeability also increased, while the thermal conductivity value decreased [25].

Several researchers have studied the dimensional and mechanical properties of single jersey fabrics made from organic cotton and recycled polyesters. However, there is a lack of systematic and comparative studies focusing on the thermal comfort properties of fabrics knitted with conventional yarns and sustainable yarns, such as better cotton and recycled polyester. The aim of the present study was to investigate changes in the dimensions and thermal comfort properties of single jersey fabrics knitted from some sustainable fibres and compare them with conventional yarns after 20 washings.

2 Experimental

2.1 Materials

In this study, six different yarns with the same count and twist coefficient were produced from conventional and sustainable fibres using a ring-spinning machine. The fibre types, fibre content in the yarns, fabric codes and yarn properties are given in Table 1.

Table 1: Fibre and yarn properties

Fibre type	Fibre content in the yarn	Fabric code	Yarn count (tex)	Twist coefficient (α_e)
Conventional fibres	100% cotton	C	20/1	3.8
	50% cotton/50% polyester	C-P		
	100% polyester	P		
Sustainable fibres	100% better cotton	BC		
	50% organic cotton/50% recycled polyester	OC-RP		
	100% recycled polyester	RP		

The single jersey fabrics were produced on a Mayer circular knitting machine (gauge 28, diameter 32”) with constant machine settings. The yarn feeding system was set to 14 cm yarn for 50 needles for all samples. The samples were conditioned for dry relaxation for at least 48 hours in an atmosphere with a temperature of 20 °C ± 2 °C and a relative humidity of 65% ± 5%. To observe the effect of repeated washing on fabric properties, the samples were washed 20 times in a household washing machine according to the TS EN ISO 6330:2012 standard. The washing conditions were 50 minutes at 40 °C with 20 g of commercial detergent for each wash cycle. Concerning the uniform distribution of the load in the machine, the total weight of the load was set at 3 kg, and white cotton woven fabric was used as the filling material. After each wash, the samples were hung to dry lengthwise of the fabric and then conditioned for 24 hours under standard atmospheric conditions [26].

2.2 Methods

Measurements were made under standard atmospheric conditions after the fabrics were dry relaxed and repeatedly washed. The codes, symbols, related standards and instruments used in the experiments are listed in Table 2. The properties of the fabrics were measured after both dry relaxed and washed samples following the relevant standards using pre-determined instruments:

$$P = \left[1 - \frac{M/_T}{\rho}\right] \times 100\ (\%) \qquad (1),$$

where P represents the porosity of the fabric (%), M represents the mass per unit area of the fabric (g/cm^2), T represents the thickness of the fabric (cm), and ρ represents the fibre density (g/cm^3). The fibre densities used in equation 1 are as follows: C = 1.53 g/cm^3, P = 1.38 g/cm^3, C-P = 1.45 g/cm^3 = [(0.5 × fibre density of cotton) + (0.5 × fibre density of polyester)]. The other important parameter is the fabric density, which is calculated according to equation 2:

$$\rho = \frac{M}{T} \qquad (2),$$

where ρ represents the fabric density (g/m^3), M represents the mass of the fabric (g/m^2), and T represents the thickness of the fabric (m).

Table 2: Details of test methods

Test	Symbol (unit)	Method	Test device
Courses per unit length	C_{pc} (courses/cm)		counted
Wales per unit length	W_{pc} (wales/cm)		counted
Mass per unit area	M (g/m^2)	TS EN 12127	scale
Thickness	T (mm)	ASTMD 177	TESTEX TF121C
Porosity	P (%)		calculated
Fabric density	ρ (g/m^3)		calculated
Bursting strength	BS (kN/m^2)	ISO 13938-1	James H. Heal tru-burst
Air permeability	AP (mm/s)	TS391 EN ISO 92	MESDAN – Air Tronic
Thermal resistance	R_{ct} (m^{2}K/W)	ISO 11092	SDL Atlas M259B
Water vapor resistance	R_{et} (m^{2}Pa/W)	ISO 11092	SDL Atlas M259B

The Hohenstein Institute [28] developed a classification system, as shown in Table 3, to determine the rating levels of water vapor resistance. The results were evaluated using the SPSS software to test the significance of the fibre types for the fabric properties studied.

Table 3: R_{et} comfort-rating system [28]

Rating	R_{et}	Description
Very good	0–6	Extremely breathable and comfortable at a higher rate of activity
Good	7–13	Very breathable and comfortable at a moderate rate of activity
Satisfactory	14–20	Breathable, but uncomfortable at a higher rate of activity
Unsatisfactory	21–30	Slight breathable, moderate comfort at a low rate of activity
Very unsatisfactory	31+	Not breathable and uncomfortable, with a short tolerance time

3 Results and discussion

The dimensions and thermal comfort characteristics of the dry relaxed fabrics and the washed fabrics are shown in Tables 4 and 5, respectively. In these tables, the mean values are indicated by the letters "a", "b" and "c" (where "a" represents the lowest value and "c" represents the highest value). If the mean values of the different fibre materials do not differ significantly according to statistical analyses, they are marked with the same letter.

Table 4: Dimensional characteristics of the samples after dry relaxation and 20 washes

Fabric code	C_{pc} (course/cm)		W_{pc} (wale/cm)		Mass per unit area (g/m²)		Thickness (mm)		Porosity (%)		Fabric density (kg/m³)	
	D [1)]	W [2)]	D	W	D	W	D	W	D	W	D	W
C	15	15	18	17	141.3 [a)]	140.7 [a)]	0.67 [a)]	0.66 [a)]	86	86	210.9	210.0
C-P	16	16	19	18	147.7 [b)]	148.3 [b)]	0.75 [b)]	0.74 [b)]	86	86	196.9	200.4
P	16	16	18	17	145.7 [b)]	142.0 [a)]	0.81 [c)]	0.79 [b)]	87	87	186.8	184.4
BC	16	15	18	18	140.3 [a)]	138.7 [a)]	0.68 [a)]	0.67 [a)]	86	86	206.3	207.0
OC-RP	16	16	18	17	146.7 [b)]	141.3 [a)]	0.77 [b)]	0.76 [b)]	87	87	190.5	185.9
RP	16	16	18	17	149.0 [b)]	150.0 [b)]	0.85 [c)]	0.83 [c)]	87	87	175.3	180.7

[1)] dry relaxation, [2)] after 20 washes
[a)] the lowest level of mean values according to statistical analyses
[b)] the second level of mean values according to statistical analyses
[c)] the maximum level of mean values according to statistical analyses

Table 5: Thermal comfort characteristics of the samples after dry relaxation and 20 washes

Fabric code	Bursting strength (kN/m²)		Air permeability (mm/s)		Thermal resistance (m²K/W)		Water vapor resistance (m²Pa/W)	
	D [1)]	W [2)]	D	W	D	W	D	W
C	575.4 [a)]	442.2 [a)]	695.1 [a)]	567.8 [a)]	0.019 [a)]	0.017 [a)]	3.17 [c)]	2.74 [a)]
C-P	602.0 [b)]	574.9 [b)]	667.1 [a)]	764.6 [c)]	0.027 [c)]	0.022 [b)]	3.05 [b)]	2.83 [b)]
P	661.5 [b)]	676.1 [c)]	1635.0 **[d)]**	1558.8 **[f)]**	0.027 [c)]	0.031 [c)]	3.06 [b)]	3.47 [c)]
BC	572.1 [a)]	447.7 [a)]	751.6 [b)]	617.4 [b)]	0.025 [b), c)]	0.016 [a)]	3.12 [c)]	2.80 [a)]
OC-RP	629.3 [b)]	599.4 [b)]	717.9 [b)]	897.8 **[d)]**	0.025 [b), c)]	0.022 [b)]	2.83 [a)]	2.88 [b)]
RP	648.9 [b)]	657.0 [c)]	1254.2 [c)]	1206.4 **[e)]**	0.032 **[d)]**	0.033 [c)]	3.19 [c)]	3.48 [c)]

[1)] dry relaxation, [2)] after 20 washes
[a)] the lowest level of mean values according to statistical analyses
[b)] the second level of mean values according to statistical analyses
[c)] the maximum level of mean values according to statistical analyses
[d)] the fourth level of mean values according to the statistical analyses
[e)] the fifth level of mean values according to the statistical analyses
[f)] the maximum level of mean values according to the statistical analyses

3.1 Dimensional characteristics

Statistical analysis showed that the fibre material had no significant effect on the values of course/cm, wale/cm and porosity in dry relaxation and after repeated washings. The results show that as the polyester fibre content increases, the thickness of the samples increases linearly, and there is no significant difference between the thicknesses of the fabrics made from conventional and sustainable fibres (Figure 1). In addition, the fabric mass per unit area of the fabrics made from sustainable fibres shows a similar trend to the fabric thickness. 100% cotton (C) and 100% better cotton (BC) fabrics have the lowest mass per unit area values, while the difference in mass per unit area for fabrics containing polyester is usually negligible. However, when examining fabric density, it was noted that 100% polyester (P) fabrics have minimum values and 100% cotton (C) fabrics have maximum values after dry relaxation and after 20 washes. When investigating the effect of repeated washings on dimensional properties, it was found that there was no significant difference in wale/cm, course/cm, fabric thickness or fabric porosity after 20 washings. In general, the fabric mass values decreased after repeated washing for the different materials. Although it was expected that fabric mass would increase due to shrinkage that may occur in the fabric after washing, the fact that the fabric mass value remained constant and even decreased for some samples after 20 washes suggests that fibre detachment occurs in the fabric.

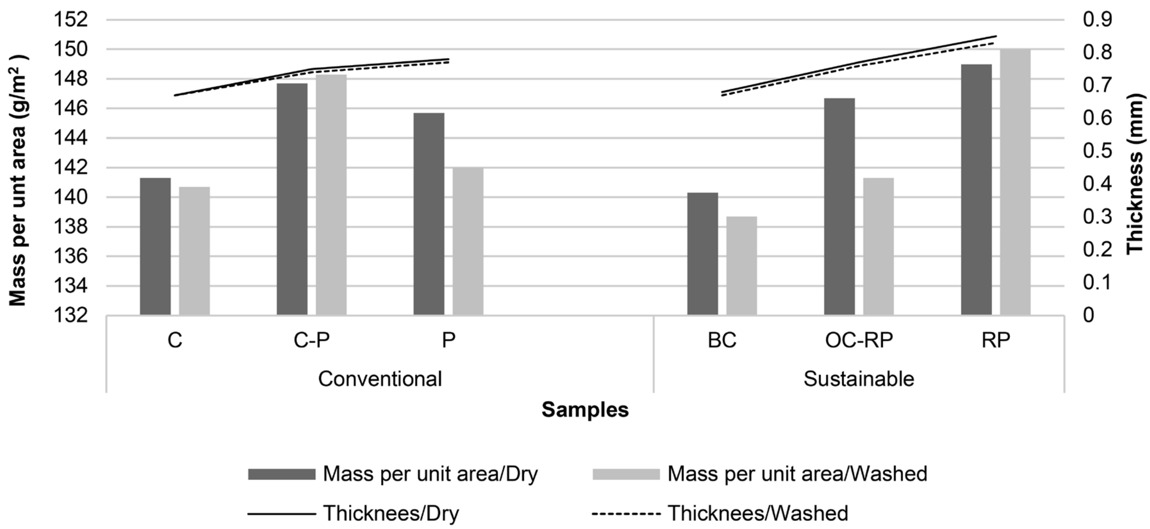

Figure 1: Mass per unit area and fabric thickness values for before and after the washing processes.

3.2 Bursting strength

Bursting strength is a measure of the strength and durability of a fabric, and depends largely on the fabric structure, fibre type, blend ratio and yarn properties [29]. This value is important in certain situations where durability and tensile strength are critical.

Statistical analysis showed that the bursting strength values of the samples with polyester fibres were significantly higher for both relaxation states (Figure 2). As mentioned by previous researchers, this result is related to the high bursting strength value of polyester fibres [30, 31] and the lower mass per unit area and thickness values of these specimens. According to the results, the difference between the bursting strength values of samples containing the same amount of conventional and sustainable fibres was insignificant. On the other hand, 100% polyester (P) and 100% recycled polyester (RP) samples have significantly higher bursting strength than 50% cotton-50% polyester (C-P) samples after the

20 washings. The results show that higher thickness values lead to higher strength values, as mentioned by Herath [32]. However, the bursting strength of recycled polyester specimens is significantly lower than that of conventional polyester specimens in both relaxation states.

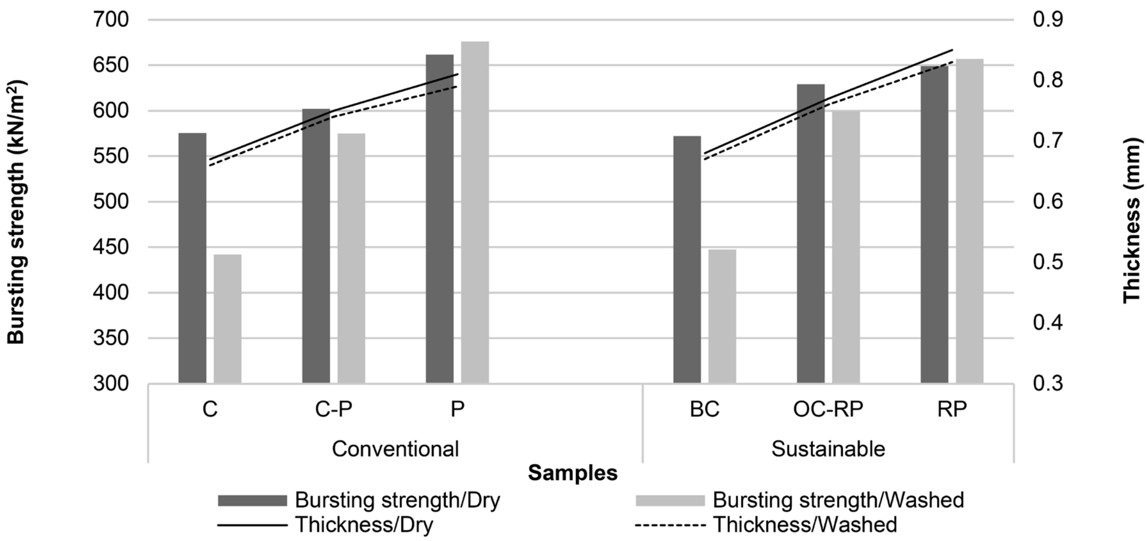

Figure 2: Bursting strength and fabric thickness values for before and after the washing processes

3.3 Air permeability

Garments with good air permeability allow air to pass through the fabric, which improves ventilation and moisture transfer. Higher air permeability is generally preferred to allow better air circulation and cooling during high-intensity activities or in hot climates. However, for colder or windy conditions a balance between air permeability and thermal insulation is required.

When investigating the influence of material type on air permeability, it was found that the 100% polyester (P) and recycled polyester (RP) samples had significantly higher values than the 100% cotton (C) samples in both relaxation states due to their low fabric density and high porosity (Figure 3). The difference in air permeability values of the 100% cotton (C) and 50% cotton-50% polyester (C-P) samples before and after repeated washings is not statistically significant. When comparing the air permeability values of conventional and sustainable fibres, it was found that the 100% better cotton (BC) sample had a higher value than the conventional cotton sample. Similarly, the air permeability value of the 50% organic cotton-50% recycled polyester (OC-RP) sample was higher than that of the 50% cotton-50% polyester (C-P) sample. On the other hand, recycled polyester has lower air permeability than conventional polyester fabric. When the effect of washing was examined, it was observed that the permeability generally decreased after 20 washes, except for the 50% cotton-50% polyester (C-P) and 50% organic cotton-50% recycled polyester (OC-RP) samples.

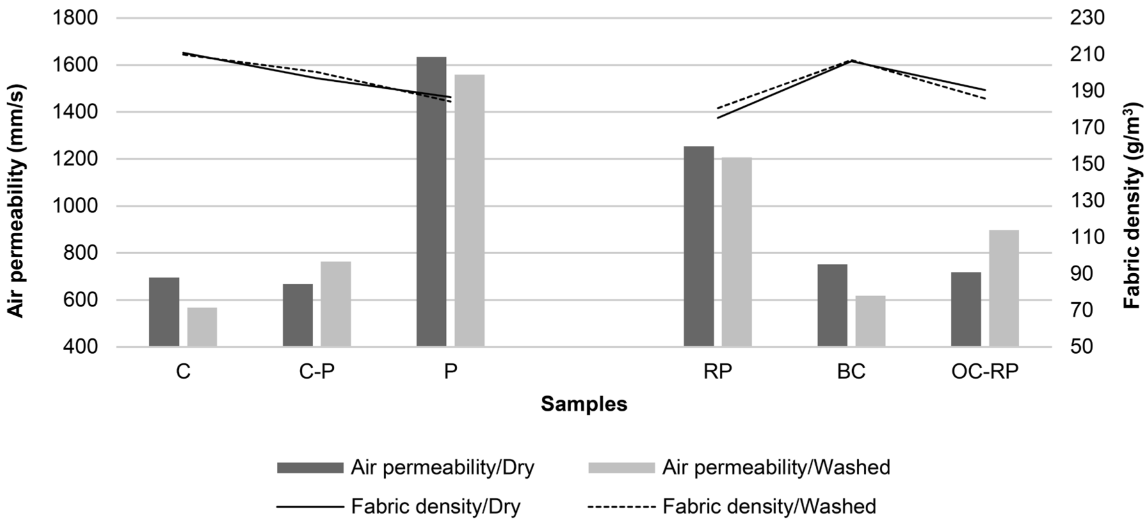

Figure 3: Air permeability and fabric density values for before and after washing processes

3.4 Thermal resistance

The thermal resistance of sportswear refers to the ability of the fabric to insulate and warm the wearer in cold environments or outdoor activities. When investigating the influence of fibre type, it was found that fabrics produced from conventional and sustainable 100% polyester fibres had the highest thermal resistance values before and after washing. The samples knitted from 100% cotton (C) and 100% better cotton (BC) for conventional and sustainable fibres, respectively, had the highest thermal resistance values (Figure 4). This result can be explained by fabric density, which is a function of fabric mass and thickness. 100% recycled polyester (RP) fabrics had the lowest fabric density value before and after the washing process, which can be attributed to the highest thickness values and mass. As found in previous studies [33, 34], fabrics with lower fabric density have higher thermal resistance, which is due to the larger amount of stagnant air in their structure. When comparing conventional and sustainable fibres, it was found that sustainable fibres generally had higher thermal resistance values than conventional fibres. The results indicate that all samples, except the 100% polyester (P) and 100% recycled polyester (RP) samples, showed a decrease in thermal resistance after 20 washes. This is because the fabric density of these samples decreased after repeated washings.

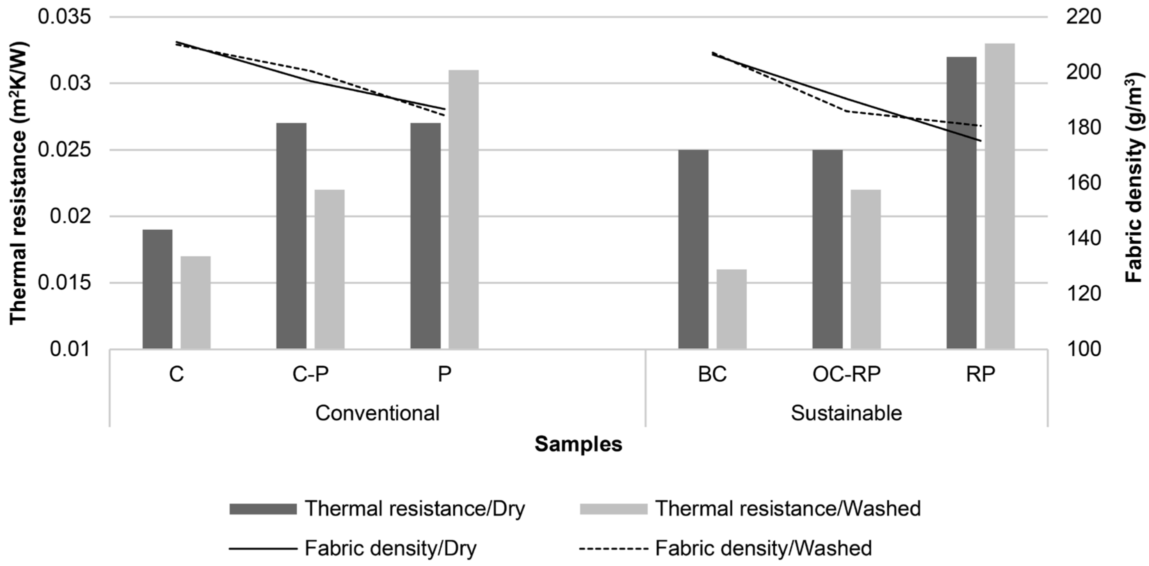

Figure 4: Thermal resistance and fabric density results in dry relaxation and after 20 washings.

3.5 Water vapor resistance

The water vapor resistance of a material is a measure of how reluctant it is to let water vapor through. This value is an important characteristic of sportswear because it affects breathability and the ability to manage moisture during physical activity.

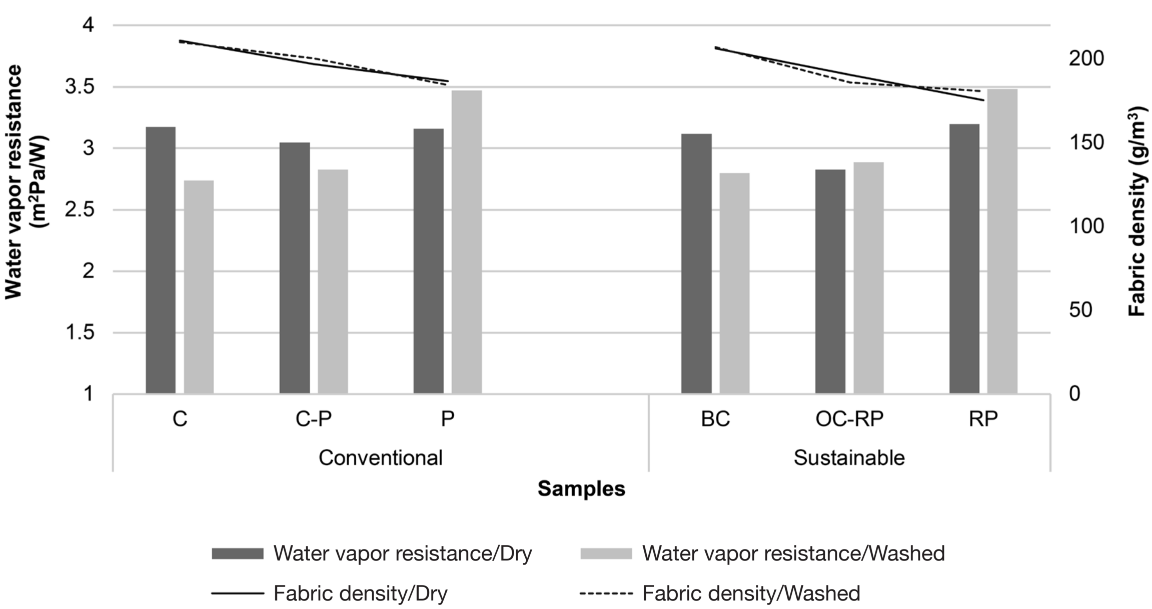

Figure 5: Water vapor resistance and fabric density results in dry relaxation and after 20 washings

The results show that the lowest value for water vapor resistance was found in 50% organic cotton-50% recycled polyester (OC-RP) fabric in dry relaxation situations. However, after 20 washes, the 100% cotton (C) and 100% better cotton (BC) samples had the lowest value, as can be seen in Figure 5. On the other hand, as the polyester content in the fabric structure increased, the water vapor resistance also increased. This value is crucial for sportswear, especially for high-intensity activities such as running or cycling. This is because, when the water vapor resistance of a fabric is high, it prevents the water vapor from evaporating and cooling the skin, so that the stored heat cannot be dissipated from the body. In this case, the wearer does not feel comfortable [35]. Hydrophobic polyester fibres, on the other hand, practically do not absorb moisture but can release it into the atmosphere by diffusion, so that the moisture is transported away from the skin surface and the wearer feels comfortable. According to the Hohenstein Institute classification criterion listed in Table 2, it can be concluded that all the fabric samples developed in this study had "very good" water vapor resistance. In comparisons between dry relaxed samples and samples that were subjected to 20 washes, the water vapor resistance increased for the 100% polyester (P) and 100% recycled polyester (RP) samples by increasing number of washes, as mentioned by Reljic [28]. Considering the difference between the water vapor resistance values of conventional yarns and their sustainable versions, it was found that the samples produced from sustainable fibres had similar water vapor resistance values. This result shows that sustainable and recycled fibres can be used instead of conventional fibres.

4 Conclusion

In this study, the dimensional and thermal comfort properties of single jersey fabrics produced from different conventional and sustainable fibres were measured, compared and statistically evaluated. In this context, fabric samples were produced using 100% cotton, 100% better cotton, 100% polyester and 100% recycled polyester, 50% cotton-50% polyester and 50% organic cotton-50% recycled polyester yarns. As evident from the results, the fabric mass, thickness and thus bursting strength of the 100% cotton and 100% better cotton samples are significantly lower than the samples containing polyester fibre for both relaxation states. in terms of statistical results, it can be concluded that fabric density and fibre type generally have a significant influence on the studied properties of single jersey fabrics. It is evident that, as the fabric density increased, the fabric became heavier, resulting in poorer air permeability, thermal resistance and water vapor resistance. No significant difference was found between the properties of conventional fibres (100% cotton, 100% polyester, and 50% cotton-50% polyester) and sustainable fibres (100% better cotton, 100% recycled polyester, and 50% organic cotton-50% recycled polyester) in terms of dimensions and thermal comfort. It can thus be said that sustainable fibres could be used instead of conventional fibres to protect the environment. Moreover, it was found that fabric produced using 100% polyester and 100% recycled polyester had higher air permeability, thermal resistance and water vapor resistance than the other types of fibres. This indicates that the fabric knitted with 100% recycled polyester fibre is suitable for active sportswear applications. On the other hand, the fabric produced using 50% organic cotton-50% recycled polyester fibres with satisfactory air permeability and thermal resistance and the lowest water vapor resistance values was found to be more suitable for cold environmental conditions. The use of sustainable fibres makes textile products more environmentally friendly. It is therefore recommended to increase the use of sustainable fibres in the textile industry.

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