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Investigation of the Wicking and Drying Behaviour of Polyester Woven Fabrics

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Abstract
This paper investigated the wicking and drying behaviour of polyester woven fabrics. The effects of yarn type, weft density, weave structure, thickness and air permeability were evaluated by the application of vertical wicking, transfer wicking and drying tests. Correlation analysis and two sided independent t-tests of the data obtained from experiments and the evaluations reveal that the texturizing process - the alteration of the arrangement and packing of yarns by changing the weft density and weave type, are influential with respect to the wicking performance. Moreover the drying behaviour is influenced by the thickness of the fabric, air permeability and yarn type used in the fabric.

Key words: *wicking, drying, woven fabrics, weave type, weft density, yarn type.*

Introduction

Clothing comfort has thermo-physiological, sensorial and psychological aspects. Thermophysiological factors include the heat exchange within clothing, air permeability, and the transfer and evaporation of moisture [1].

Liquid on the body surface or inner layer of clothing should be transferred to the outer layer in order to keep the skin dry and to make the liquid evaporate from the outer layer to the environment [2], otherwise it creates a sense of dampness and clamminess and can even reduce body heat, making people tired. Wear comfort is influenced by the ability of the clothing material to transport moisture vapour [3] and to dry quickly, especially when sweating conditions are considered.

The liquid transfer involves two sequential processes: wetting and subsequently wicking [4]. Wetting is defined as the initial behaviour of the fabric when it comes into contact with liquid [5], causing it to reach the spaces of the clothing and capillary pressure is produced [6]. Wicking occurs after the fibres with capillary spaces in between them are wetted by a liquid [7]. Wicking is identified with the ability of maintaining capillary flow [5] as it increases the spreading of the liquid or vapour throughout the fabric by increasing the evaporation of moisture [6], leaving a drying feeling in the end. Drying is another important characteristic of fabric in terms of comfort. The time required for drying is related to the amount of water held originally, which is dependent on the moisture affinity and water holding capacities of the fibre [8].

The liquid transfer mechanism consists of water diffusion and capillary wicking determined by effective capillary pore distribution, pathways and surface tension [9]. Wetting is determined by the surface properties of the fibre and the wetting liquid, whereas wicking is influenced by the arrangement of fibres and yarns in the fabric [7]. The drying rate, on the other hand, is related to the macromolecular structure of fibre [9].

The thermophysiological comfort properties, such as air permeability, water vapour permeability, thermal resistance, wickability, absorbency, the drying rate and water resistance are altered by the fabric construction [10]. Specifically vapour transmission through fabrics is controlled by the fibre, yarn and fabric construction, which mostly determine the thickness and porosity that drives the diffusion process [11]. The fibre length, width, shape and alignment influence the quality of capillary channels in the interfibre spaces and sizes of pores present [12]. Moreover the density and structure of yarns have an influence on the dimensions and structure of inter- and intra- yarn pores, pore sizes and their distribution along the fabrics [12]. The wicking of yarns is determined by the yarn structure, yarn tension, twist, fibre shape, number of fibres in yarns, the fibre configuration, finish and surfactants [13]. Textile characteristics such as the fabric mass, thickness, draping ability, stress-strain behaviour and air permeability are strongly influenced by the fabric texture. The finishing treatment on the fabric surface can change the thickness, creating tribological and antistatic properties as well as the wettability of the fibres [12]. Drying time is found to be related to the fabric porosity and thickness and possibly to fibre hygroscopicity [14]. Nonetheless the drying rate is controlled by the resistance of the air layers to the passage of heat [8]. Therefore the thickness of the fabric and the still air near the surface are influential regarding the drying rate [8].

Nonetheless there are numerous studies in the literature that investigated the relationship between wicking properties and textile characteristics, focusing mostly on knitted materials. For instance, Yanilmaz and Kalaoglu investigated the relationship between different knitted structures with different properties such as the fabric tightness factor, thickness, porosity, loop length and pore size, as well as some thermophysiological comfort properties such as wetting, drying and wicking [3]. They found out that slack fabrics had longer loop lengths with higher porosity values and higher pore sizes; therefore they had higher transfer wicking ratios than the tight structures [3]. The authors added that the water evaporation rate was inversely related to fabric thickness, as the thickness increased the compactness whereas decreased the air space [3]. Prahsarn et al found that moisture transmission through largely open knit fabrics is mostly controlled by fibre, yarn and fabric variables that determine thickness and permeability [11]. Bivainytė and Mikučionienė investigated the influence of the knitting structure, fibre type and yarn properties on the air and water vapour permeability of double layered weft knitted fabrics. They stated that the fibre composition of yarn and knitting structure parameters such as the loop length, area linear filling rate, and pattern have significant influences on the air perme-

Table 1. *Characteristics of fabric samples.*

Fabric code	Weave type	Weft yarn, 111 dtex PES	Warp yarn, 167 dtex PES	Weft density, weft/cm	Warp density, warp/cm	Fabric weight, g/m2	Fabric thickness, mm	Air permeability, l/m2s
TWp26	$\frac{2}{2}$ Warp Ribs	Texturized	Filament	26	64	179.7	0.51	24.93
TWp20				20		165.6	0.52	92.85
TWp18				18		162.1	0.42	77.82
FWp26		Filament		26		156.5	0.34	61.68
FWp20				20		163.9	0.34	36.74
FWp18				18		180.4	0.45	9.51
TWt16	$\frac{2}{2}$ Weft Ribs	Texturized		16		162.7	0.46	363.52
FWt16		Filament				162.7	0.35	98.43
TB16	Ribstop	Texturized				165.2	0.50	218.83
FB16		Filament				161.2	0.36	132.87

ability of double layered weft knitted fabrics. Moreover the main influence on the water vapour permeability was the kind of raw material as well as the wetting and wicking properties of the fibres [1]. Cil et al investigated the effects of fibre composition, yarn count and tightness on the water vapor permeability, wicking abilities and drying behaviors of fabrics. The transfer and longitudinal wicking abilities of the fabrics increased with coarse yarns, whereas the drying rates increased with the usage of finer ones [8]. Ozturk et al investigated the wicking properties of cotton/acrylic rotor yarns and knitted fabrics. They implied that the wicking abilities of yarns and fabrics increased with an increase in acrylic content in the blends and with the use of coarse yarns. Moreover it was claimed that the randomness of the rotor yarn structure had an effect on the wicking behaviour of both yarns and fabrics [5]. Das et al studied the effects of yarn characteristics such as yarn fineness, acrylic proportion and twist level and found that the thermal resistance, air permeability and moisture vapor transmission was improved in cotton/acrylic blended bulk yarns [4, 15].

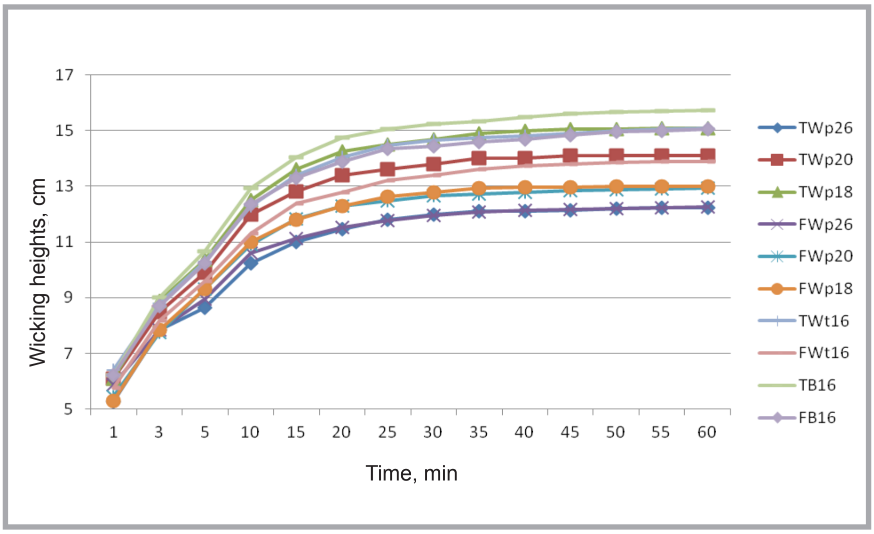


Figure 1. *Vertical wicking curves for warp direction.*

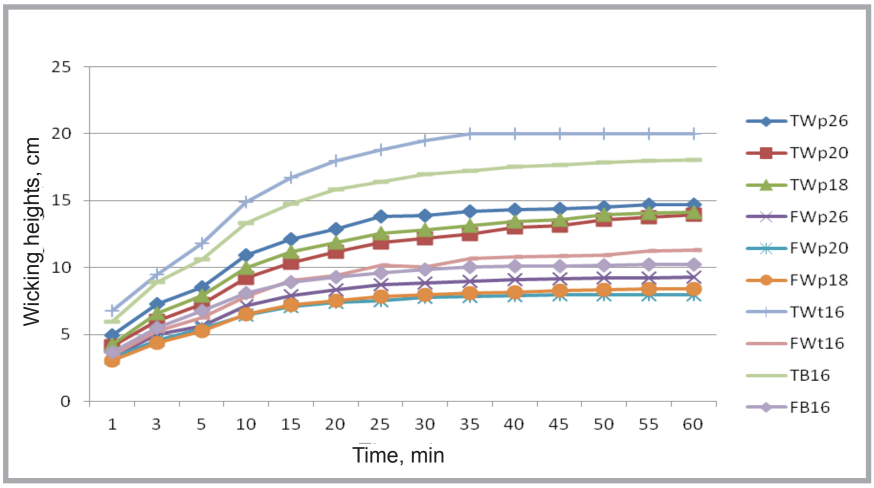


Figure 2. *Vertical wicking curves for weft direction.*

Although wicking properties are important for knitted fabrics, the performance of woven fabrics in terms of moisture transfer has significance considering that work clothes are mostly made of woven fabrics. In this study it was attempted to determine the relationship between the wicking and drying properties of woven fabric and the fabric construction parameters, such as the the texturising of yarns, yarn density and weave type, thickness and air permeability.

Experimental

10 types of samples with different weave types were used for the experiments. All the samples had 166.67 dtex 350 twist/cm filament polyester yarns as warp yarns. The weave type, weft and warp yarn type, warp and weft densities, fabric weight and fabric thickness values for the samples are summarised in ***Table 1***. ***Table 1*** also includes the air permeability values of all the fabric samples, measured according to BS5636 by WIRA Air Permeameter (WIRA Instrumentation, England).

The samples were conditioned and then tested under standard atmospheric conditions 20 ± 2 °C and 65 ± 5% relative humidity.

The vertical wicking test was applied in the warp and weft directions according to the method proposed by Fangueiro et al [9]. Samples were cut along the warp and weft directions within the dimension of (200 × 25 mm). The specimens were suspended in a reservoir of distilled water with their bottom ends immersed vertically at a depth of 3 cm in the water. The wicking heights were measured and recorded at 1, 3, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55 & 60 minutes.

For transfer wicking, established to eliminate the effects of gravity, the test procedure proposed by Zhuang et al [2] was used, with the difference that an external pressure of 15.6 kg/m^2 was applied. Specimens were cut into 7.45 cm diameter circles, wetted and then placed between two dishes. Dry specimens were put on wet specimens and the weight was recorded every 5 minutes, beginning with the time 0 and ending with 30 minutes.

The drying capabilities were measured using the method described by Fangueiro et al [9]. Specimens were cut to the dimension (200 × 200 mm) and wetted until the amount of the water in them was equal to 30% of their weight in dry form. Then weight measurement was made every ten minutes in 90 minutes. Water evaporation curves (WER) were established using ***Equation 1***:

$$WER\% = (w_o - w_i)/(w_o - w_f) \times 100 \quad (1)$$

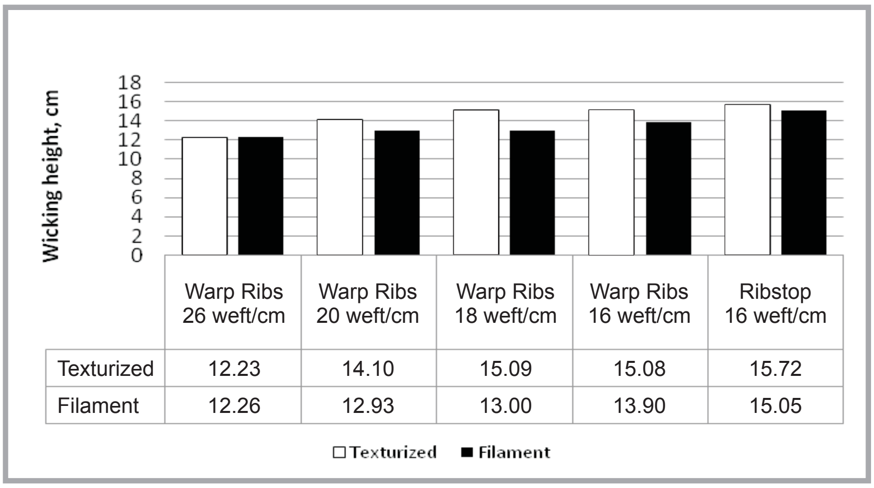
where: w_f: dry weight, w_o: initial weight of water, w_i: weight of water at time t.

After the tests were conducted, evaluations were made and the results subjected to statistical analyses.

Results

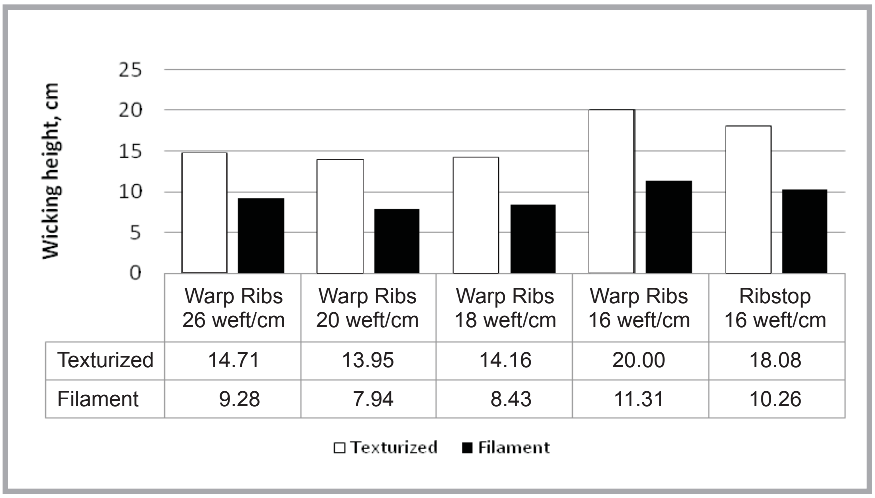
Vertical wicking test results

Figures 1 and ***2*** show vertical wicking test results for the specimens in the warp and weft directions, respectively. It is seen that the vertical wicking height increases with a decreasing slope, which can be explained by Wong [16], indicating that the liquid movement began firstly in the smaller pores, in which the action was faster because of the influence of the capillary action and higher capillary pressure, and then it continued to fill in the larger pores [16] with a decreasing wicking rate. The values become stabilised when the mass of water absorbed in the specimen is balanced with the hydrostatic head of water, as a result of which a quasi-equilibrium state is reached [12].



	Warp Ribs 26 weft/cm	Warp Ribs 20 weft/cm	Warp Ribs 18 weft/cm	Warp Ribs 16 weft/cm	Ribstop 16 weft/cm
Texturized	12.23	14.10	15.09	15.08	15.72
Filament	12.26	12.93	13.00	13.90	15.05

Figure 3. *Comparison of the vertical wicking of fabrics in the warp direction when texturized and filament yarns are used in the weft.*



	Warp Ribs 26 weft/cm	Warp Ribs 20 weft/cm	Warp Ribs 18 weft/cm	Warp Ribs 16 weft/cm	Ribstop 16 weft/cm
Texturized	14.71	13.95	14.16	20.00	18.08
Filament	9.28	7.94	8.43	11.31	10.26

Figure 4. *Comparison of vertical wicking of fabrics in the weft direction when texturized and filament yarns are used in the weft.*

The relationship between the vertical wicking performance and fabric parameters: yarn type, weft density, weave type and air permeability was analysed considering the wicking height of the specimens at the fifteenth minute. Values at the fifteenth minute were taken into account as they corresponded to the values that the specimens show when still continuing to wick but at the same time were close to the steady state.

Figures 3 and ***4*** show the vertical wicking height at the fifteenth minute in the warp and weft directions, respectively. In ***Figures 3*** and ***4***, the specimens made up of texturised yarns show better performance than those made up of filament yarns. Thus the texturising process improved the wicking capabilities.

This result is in parallel with the findings of Ozturk et al, who found out that the bulking process provided more capillary space, thereby increasing the wicking performance [5]. Loops such as floats and arcs in air jet textured yarns lead a less tortuous path for the liquid to travel, causing a higher wicking height [13] as the bulking process enhances the capillary space [4].

The relation between the wicking performance, weft density and weave type was found to be significant, achieving correlation coefficients -0.777 and 0.657 with p values of 0.008 and 0.039, respectively, within a significance interval of 95%. However, no correlation was found in the weft direction with these characteristics due to keeping warp densities the same for all specimens.

Specifically, based on the results which are shown in ***Figure 3***, as the density of weft yarns increased, the wicking height

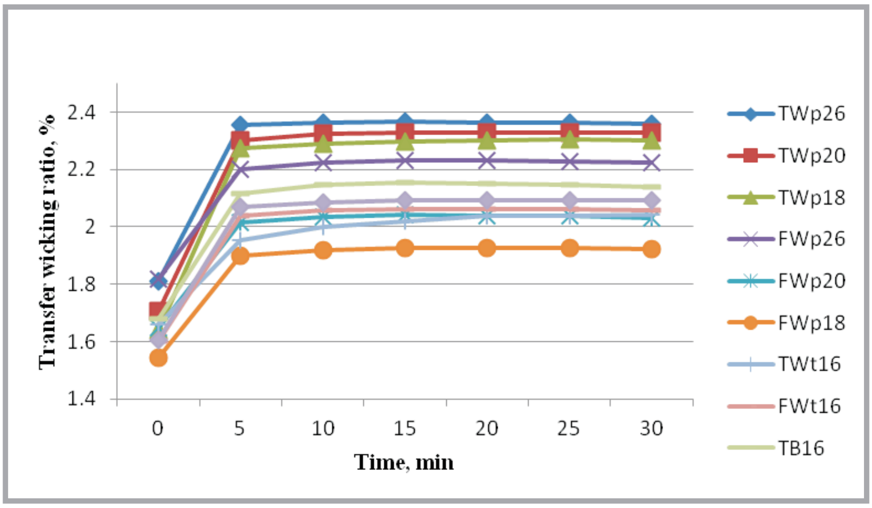
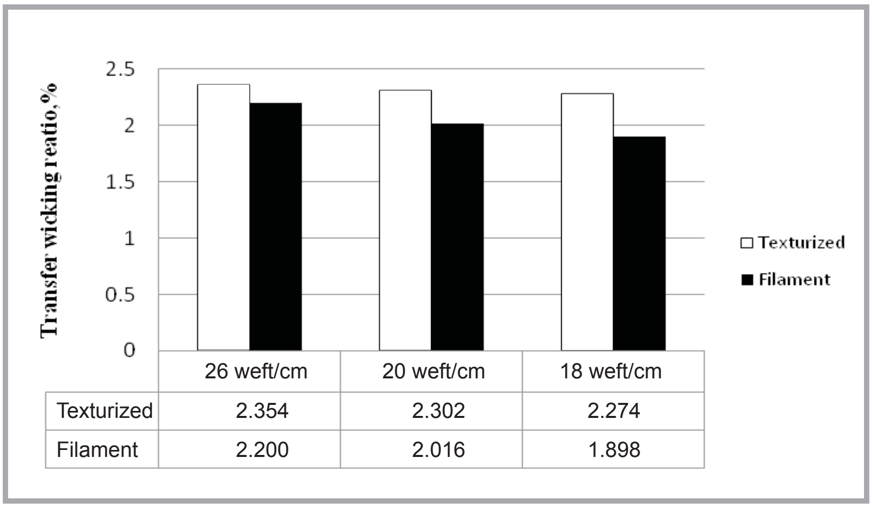


Figure 5. Transfer wicking curves.



	26 weft/cm	20 weft/cm	18 weft/cm
Texturized	2.354	2.302	2.274
Filament	2.200	2.016	1.898

***Figure 6.** Relationship between weft density and transfer wicking at the fifth minute.*

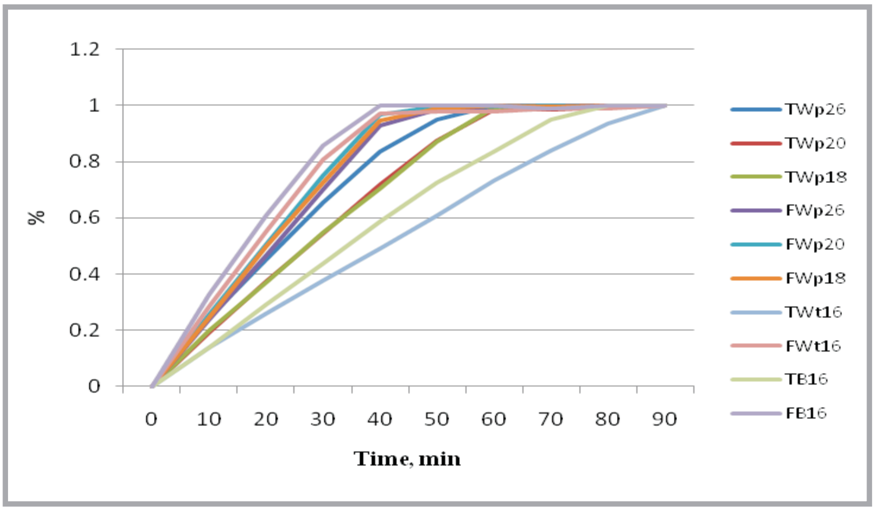


Figure 7. Water evaporation rate curves.

increased, but then decreased with a further increase in weft density for filament yarns, whereas the wicking height decreased as the weft density increased for texturised yarns. Thus, increasing the density of yarns along the wicking direction did not always affect the wicking height positively. The gathering of weft yarns located close to each other may improve moisture diffusivity, but after reaching a certain level, this situation could decrease the volume of pores, leading to a decrease in wicking performance. According to Das et al, the density and geometry of the fabric pores influence the flow pattern both in the intersices and downstream, with the moisture diffusivity of the textile material decreasing with an increase in the fibre volume fraction and flatness of the fibre cross section [4].

In the case of weave type, the following wicking heights were found at the fifteenth minute, ranked in descending order: ribstop > warp ribs > weft ribs for texturised yarns, and ribstop > weft ribs > warp ribs for filament yarns, when the specimens with close weft densities were compared, as shown in ***Figure 3***. Weave type has the capability of changing the alignment and arrangement of yarns within the fabric, therefore it may cause weft yarns to come together in a convenient arrangement to improve capillary action, providing suitable waviness depth because, according to Calvimontes et al, the waviness depth and spreading rate are proportional to each other [17]. However, the number of weave types that were taken into account within this research was not sufficient to say how important the influence of weave type on the vertical wicking height is. In order to find out the direction and significance of the relationship, the cross sectional appearance of weave structures should be investigated with different weave structures at different weft densities.

The air permeability values of the specimens were found to be highly correlated with the vertical wicking performance. The correlation coefficients between the air permeability and vertical wicking height at the fifteenth minute were found to be 0.826 with a p-value of 0.03 in the weft direction; 0.671 and 0.034 in the warp direction within a significant interval of 95%, implying the influence of the pores on the wicking characteristics of the fabrics, because air permeability, determining the ability of air flow through the fabric, is mainly affected by the pore characteristics of fabrics [1], such as the shape and value of pores and inter yarn channels, which are dependent on the fabric [10].

Transfer wicking test results

Figure 5 shows the transfer wicking curves. The wicking values are more linear than the vertical wicking curves; but the time needed for reaching the equilibrium state is shorter. Even after a short time of 5 minutes, wicking reaches a state of equilibrium, therefore transfer wicking values at the fifth minute were selected for evaluations and analyses.

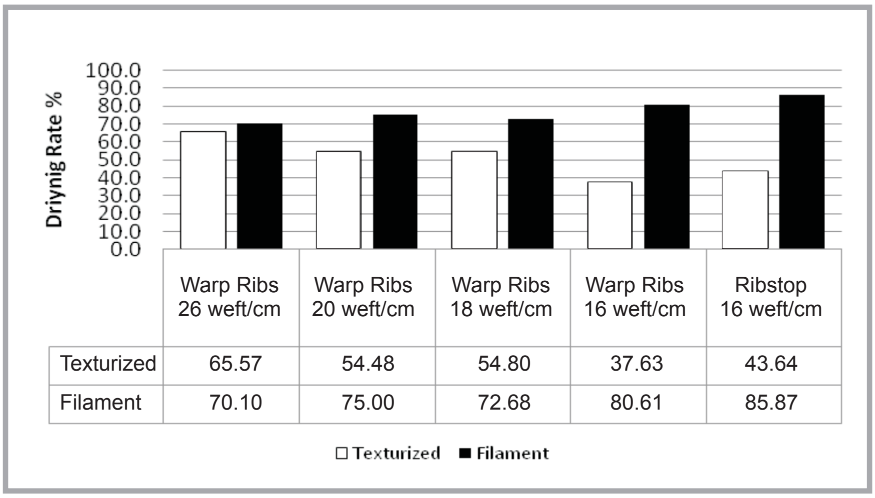
No significant relation was found between the transfer wicking performance and weave type or air permeability. Besides, the influence of the weft yarn type was not observed within the transfer wicking performance; the influence of the weft density was highlighted instead, as seen in **Figure 6**. This result was also stated by Duru and Candan, who noted that irrespective of the fibre type, slack samples tended to give higher transfer wicking values [19].

The relationship with the transfer wicking performance at the fifth minute was found to be in correlation with the weft density, with a pearson coefficient of -0.642 and p-value of 0.046 within a significance interval of 95%. As the weft density increased, the volume of pores may have been reduced, worsing the transfer wicking performance. In fact, according to the literature, the amount of water wicked from one layer to another is due to the pore sizes and their volumes in the transfer wicking test [2, 20].

Drying test results

Figure 7 shows the drying behaviour of the fabric with water evaporation rate curves. It is seen that all the moisture in the fabrics evaporated in 90 minutes, whereas the rate of drying differs from sample to sample.

The drying rates were calculated considering the drying amount at the thirtieth minute and the relationship between the weft yarn type and drying rate is analysed in ***Figure 8*** since all samples were very close to the state of being completely dry and this time interval was sufficiently large enough to show the drying rate of the specimens. The fabrics made up of filament yarns showed better performance than those made up of texturised yarns, as seen from ***Figure 8.*** The independent t-test results implied that the relation between the drying rate and weft yarn type was statistically significant, achieving a value of 0.002 within a significance interval of 95%.



	Warp Ribs 26 weft/cm	Warp Ribs 20 weft/cm	Warp Ribs 18 weft/cm	Warp Ribs 16 weft/cm	Ribstop 16 weft/cm
Texturized	65.57	54.48	54.80	37.63	43.64
Filament	70.10	75.00	72.68	80.61	85.87

Figure 8. *Relationship between drying rate and weft yarn type.*

It was found that the specimens made up of filament yarns dried faster than those made up of texturised yarns, which can be explained by the bulky structures of texturised yarns, giving porosity to the fabric. According to Prahsarn, water vapour transport is independent of the fibre hygroscopicity, whereas the drying time is a function of fabric porosity, thickness and, possibly, fibre hygroscopicity [14].

Based on the statistical analysis, the samples with different weave types and densities did not show any significant difference for the drying rate. However, the drying rate was evaluated to be statistically correlated with the air permeability, with a correlation coefficient of -0.669 and p-value of 0.035 in a significance interval of 95%. Besides this, the relation between the drying rate and thickness was found to be significant according to the Pearson correlation test within a 95% significance interval, with a coefficient of -0.677 and p-value of 0.032.

These results are in parallel with the literature, which states that the drying time is positively correlated with the fabric thickness and mass of water in the fabric [18], and that water vapour diffusion is directly proportional to air permeability, with diffusivity decreasing with an increase in fabric thickness but increasing with an increase in porosity [4].

Conclusion

The study discussed the effect of yarn and fabric characteristics on the wicking and drying behaviour of polyester woven fabrics. The results showed that the texturising process and air permeability had an impact on the vertical wicking and drying characteristics, whereas weft density influenced the vertical wicking and transfer wicking performance. Finally it was found out that the weave type had an influence on only the vertical wicking performance, while thickness only affected the drying characteristics. Thus different parameters were found to be influential for different types of wicking activities and drying capabilities. The capillary space and arrangement of these spaces has a high impact on the vertical performance, whereas pore sizes are more influential with respect to transfer wicking performance. The drying rate on the other hand is influenced by the diffusivity and capillary spaces.

Nonetheless, if the way and degree of the influence of different types of weaves are to be investigated, more weave types should be analysed with further investigation of the intersection of yarns in fabrics.

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