# INFLUENCE OF YARN STRUCTURE ON LIQUID TRANSFER PROPERTIES OF PLAIN KNITTED FABRICS

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***ABSTRACT:*** *Liquid transport is one of the most significant comfort-related properties of textile fabrics intended for underwear and sportswear. To meet the wearer's thermophysiological comfort, the textile fabric has to transmit and release sweat away from the skin. The fabric's capability to transmit liquid sweat is affected by various factors, including the structure of the yarn it is made from. Due to the limited results available in the literature regarding the influence of yarn twist on the "liquid permeability" of textile fabrics, this research aimed to investigate the effect of yarn twist on liquid transfer through plain knitted fabrics. Additionally, the influence of moisture content in the fabric on the liquid transport was investigated. Three plain weft knitted fabrics were produced from three cotton yarns differing in twist. These knitted fabrics were subjected to the Malden Mills water distribution test, with some modifications. The liquid transfer properties of the knitted fabrics were evaluated using parameters - water transfer ability and water holding capacity. The results obtained indicated that varying the yarn twists, which directly influence the geometry and distribution of the complex pore system in knitted fabrics, allows for effective design of the liquid transfer properties.*

***Keywords:*** *yarn, twist, knitted fabric, water transfer ability, water holding capacity.*

# UTICAJ STRUKTURE PREĐE NA PRENOS TEČNOSTI KOD GLATKIH PLETENINA

***APSTRAKT:*** *Sposobnost prenosa tečnosti predstavlja jedno od najznačajnijih svojstava komfora tekstilnih materijala namenjenih za izradu rublja i sportske odeće. Kako bi se obezbedio termofiziološki komfor osobi koja nosi određeni odevni predmet, tekstilni materijal treba da omogući nesmetani prenos i oslobađanje znoja sa površine kože. Sposobnost tekstilnog materijala da prenosi tečni znoj uslovljena je nizom faktora uključujući strukturu pređe od koje je materijal proizveden. Kako je u naučnoj literaturi prisutan ograničen broj rezultata koji se odnose na uticaj upredenosti pređe na propustljivost tečnosti kod tekstilnih materijala, cilj ovog istraživanja bio je ispitivanje uticaja upredenosti pređe na prenos tečnosti kroz glatke DL pletenine. Pored toga, ispitivan je uticaj sadržaja vlage u materijalu na sposobnost prenosa tečnosti. Tri različito upredene* *pamučne pređe upotrebljene su za izradu tri glatke DL pletenine. Ove pletenine su podvrgnute Mallden Mills-ovom testu distribucije vode, uz određene modifikacije. Svojstva upravljanja tečnošću ovih pletenina ocenjena su pomoću parametara – sposobnost prenosa tečnosti i sposobnost zadržavanja tečnosti. Dobijeni rezultati su pokazali da se variranjem upredenosti pređe, čime se direktno utiče na geometriju i distribuciju kompleksnog sistema pora u pletenini, omogućuje efikasno projektovanje svojstava upravljanja tečnošću pletenine.*

***Ključne reči:*** *pređa, upredenost, pletenina, sposobnost prenosa vode, sposobnost zadržavanja vode.*

## 1. INTRODUCTION

The ability of the textile material to transfer heat and to allow air and water vapor to pass through is essential for achieving optimal thermal comfort. However, liquid sweat forms on the skin surface during intense physical activities or frequent changes in environmental conditions. If liquid sweat is not promptly removed from the skin surface, it can impair the feeling of comfort. Therefore, the ability of the textile material to transfer liquid and allow the evaporation of sweat becomes the fourth important factor of thermal comfort in dynamic conditions. Previous research has indicated a significant effect of yarn structure and properties on the moisture management ability of plain knitted fabrics [1-5]. Only a few studies address the impact of yarn twist on "liquid permeability" [6-8]. Therefore, in this investigation, an attempt was made to indicate the influence of yarn twist on the liquid transfer properties of plain knitted fabrics. In addition, a step forward has been taken by considering the effect of moisture content in the fabrics on their liquid transfer properties.

## 2. MATERIALS AND METHODS

Three cotton yarns, all having the same linear density 50 tex and different twist levels (490, 590, and 690 t/m), were used to produce three plain weft knitted fabrics. They were produced under controlled conditions on a circular knitting machine and wet relaxed to relax their structure. The characteristics of the weft relaxed plain knitted fabrics are presented in Table 1. These knitted fabrics were subjected to the Malden Mills water distribution test (Polartec® LLC, USA) [9], with some modifications. A square knitted fabric sample was placed on the absorbent side of a filter paper. After 1.5 ml of water was dripped uniformly over the sample surface, and left for 2 min to stabilize, the sample was covered by another filter paper and a piece of Plexiglas, then the paper-sample-paper sandwich was weighted down with a 500 g weight. The weight was removed after 1 minute, and the masses of the partially moistened filter papers were recorded. The difference between the masses of the wet and dry lower filter paper indicated the mass of water absorbed by the paper, or water transferred through the knitted sample. The ratio of the transferred water mass to the total water absorbed by both filter papers indicates the water transfer ability of the fabric. The water holding capacity of the knitted fabrics was calculated by subtracting the total mass of water absorbed by both filter papers from the total mass of water applied to the sample.

**Table 1**: Construction characteristics of the wet relaxed knitted fabrics

| Parameter, unit | | KCo1 | KCo2 | KCo3 |
|---|---|---|---|---|
| Stitch density | Wale, $cm^{-1}$ | 6.9 | 6.8 | 7.1 |
| | Course, $cm^{-1}$ | 12.0 | 12.5 | 12.0 |
| | Surface, $cm^{-2}$ | 82.8 | 85.0 | 85.5 |
| Thickness, mm | | 1.248 | 1.256 | 1.268 |
| Areal density, $g/m^2$ | | 446.2 | 453.0 | 458.4 |
| Bulk density, $g/m^3$ | | 0.358 | 0.361 | 0.362 |
| Porosity, % | | 76.2 | 76.0 | 75.9 |

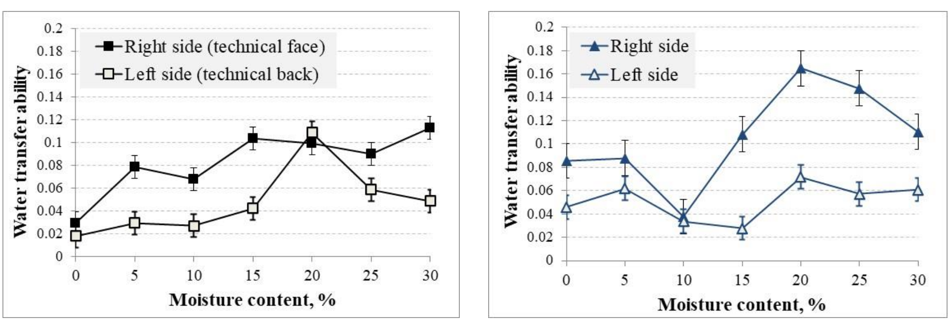
The fabric samples were tested with both the left (technical back) and right (technical face) sides facing up (in contact with water), and the parameters: water transfer ability and water holding capacity were determined for both sides in contact with water.
This study conducted a modified Malden Mills water distribution test while varying the moisture content in the knitted fabrics in 5% increments, starting from 30% down to 0% (ultra-dry state). The various levels of sample wetness were achieved using the moisture analyser (Radwag MA 50.R). The water distribution test was conducted in triplicate on both sides of the fabrics and at each moisture content level.

## 2. RESULTS AND DISCUSSION

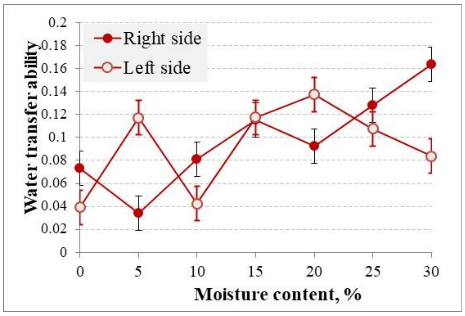
As a result of the different twists of the cotton yarns, the fibre packing density in these yarns is not the same. The lowest fibre packing density is expected for the least twisted cotton yarn, while the highest fibre packing density of the most twisted yarn is anticipated. Data on the structural and geometric characteristics of the plain knitted fabrics produced from differently twisted cotton yarns (Table 1) indicate their almost identical structures. The discrete differences in the stitch density in these three knits are due to the different flexibility of the cotton yarns. The differences in the flexibility of cotton yarns are caused by their different twists. As the twisting intensity increases, the pressure on the fibre layers in the yarn increases, which increases the frictional forces between the fibres and decreases their mobility. As shown in Table 1, the knit made from medium-twisted cotton yarn (KCo2) exhibits a slightly higher course density, whereas the knit made from the highest twisted yarn (KCo3) displays a somewhat higher wale density. As a result, the stitch surface density of these two knits is almost identical, while the stitch surface density of the knit made from the least twisted cotton yarn (KCo1) is slightly lower. The observed differences, although small, indicate certain differences in the loop configuration in these three knits. The order of knits, starting from the one with the highest surface mass (KCo3), to the knit with the lowest surface mass value (KCo1), is in accordance with their surface density (Table 1). The same order of knits is also observed regarding thickness (KCo3>KCo2> KCo1). Considering geometrical properties, knitted fabrics are characterized by the same density and porosity (Table 1).

### 2.1. Water transfer ability

The equilibrium moisture content of the tested knits was 5.3%, 4.9%, and 4.2% for KCo1, KCo2, and KCo3, respectively. The amount of moisture above the equilibrium moisture content will either be absorbed by the fibres or fill the knit pores. Water transfers through a textile fabric transversally and radially in the Malden Mills water distribution test. Initially, water transfers through macropores outward as the liquid spreads along the path of least resistance. After macropores become saturated, they serve as reservoirs for micropores to wick the water [10]. When analysing the results obtained, the hydrophilic nature of cotton fibres should be taken into account, i.e., the increased affinity of cotton fibres for absorbing water. The experimental results are shown in Figure 1. Considering some previous results [3], it can be said that the knitted fabrics tested exhibited a relatively low ability to transfer liquid. This can be explained by the relatively high stitch density of the knitted fabrics, indicating relatively small macropore size. The graph in Figure 1a shows two zones of water transfer ability of KCo1 knit. In the first zone (up to 10% moisture content), a lower liquid transfer capacity is observed with a slight improving trend with an increase in moisture content up to 30%. With more moisture content, except moisture absorbed by the fibres, some liquid partially fills the macropores. The swelling of the fibres, with the partial closure of the macropores, accelerates the transfer of the liquid. The same trend can be noted regardless of which side, the right (technical face) or left (technical back) of KCo1 knit is in contact with water. However, the ability of this knit to liquid transfer is greater in the direction from the face to the back of the knit (right to left). This can be explained by the specifics of plain knitted fabrics in which all loops exhibit a technical back side, while on the technical face side, only the right sides of the loops (loop legs) are on view. A smoother right-side surface of the knit will wet more quickly, allowing for faster liquid transfer through the knit.



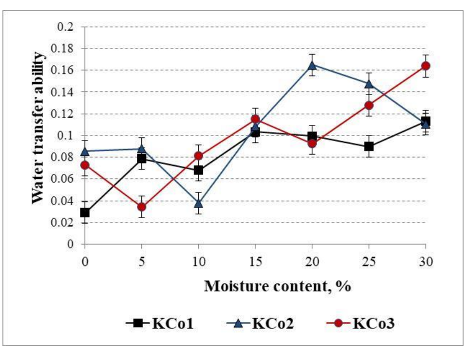

a) b)



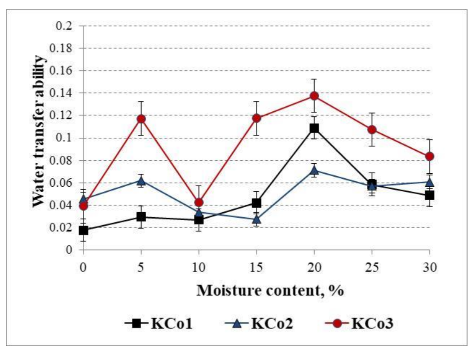

c)

**Figure 1**: Water transfer ability of KCo1 (a), KCo2 (b), and KCo3 (c) knitted fabrics

An enhanced ability to transfer liquid from the face to the back was also observed in the knitted fabric produced from medium-twisted cotton yarn (KCo2), as shown in Figure 1b. Similar to the KCo1 knit, two zones are distinguished in the graphs that illustrate the liquid transfer ability of KCo2 knit, particularly in the right-to-left direction. In the first zone (up to 10% moisture content), a low moisture content in the knit is associated with a lower ability to transfer liquid. With an increase in moisture content, the size of pores is reduced, leading to accelerated filling of the macropores with liquid and faster moisture wicking to the opposite side of the knit. The effect of the direction of liquid transfer is not clearly expressed for KCo3 knitted fabrics, except at the equilibrium moisture content of the knit, when the liquid transfer ability in the left-to-right direction is higher than that of the opposite direction (Figure 1c). As the moisture content increases (above 10%), the difference in the ability of the left and right sides of KCo3 knit to transfer liquid decreases.




a)




b)

**Figure 2**: Comparison of water transfer ability of the knitted fabrics in right-to-left (a) and left-to-right (b) direction

Figure 2a compares the liquid transfer ability of the knitted fabrics in the right-to-left direction. The knitted fabrics exhibit similar liquid transfer capabilities in a lower moisture content range. At a moisture content of 15%, the knitted fabrics are characterized by identical liquid transfer abilities. However, in the zone of higher liquid content (above 20%), the trend of increasing liquid transfer ability (with the moisture content increase) is less pronounced in the KCo1 knit. It is common practice for knitted products that the left side (technical back) is in contact with the skin. Therefore, it is particularly important to compare the liquid transfer ability of the knits from left to right. At equilibrium moisture content in cotton knitted fabrics (about 5%), the KCo3 knit exhibits the highest liquid transfer ability, while the lowest liquid transfer ability is observed in the KCo1 knit (Figure 2b). This can be attributed to some differences in stitch density of the knit (Table 1), which resulted from the different twist of the cotton yarns. The lowest stitch density of KCo1 knit indicates the largest dimensions of macropores, explains their slower filling and, consequently, slower liquid transfer through the knit. At a moisture content of 10%, the previously described difference between knitted fabrics in terms of liquid transfer ability disappears. The excess moisture (above the equilibrium content) is absorbed by the fibres, due to which the capillaries in the yarn are closed. Since the highly twisted cotton yarn has the most densely packed fibres, it is possible that the fibre swelling in this yarn led to excessive narrowing of the capillaries (air channels between the fibres in the yarn), which led to a slowdown in capillary action. With higher moisture content (above 10%), some liquid occupies the macropores (pores between the yarns), so adding liquid in the Malden Mills' test will fill the knit's macropores faster, initiating wicking. In this range, KCo3 knit exhibited the highest water transfer ability.

## 2.2. Water holding capacity

In addition to the absorbed water, liquid can be retained as free liquid in the capillaries or the macropores of the knit. The water holding capacities of the cotton knitted fabrics are presented in Figure 3. Considering KCo1 knit (Figure 3a), the water holding capacity is the same over the whole range of moisture contents (except the equilibrium moisture content when the right side is in contact with liquid), due to the constant number of bonding sites for water molecules. The noted exception requires further investigation. At equilibrium moisture content (4.9%), the water holding capacity of KCo2 knit is the same for both sides (Figure 3b). A similar observation was also noted at higher moisture content (above 25%). In the 5-25% moisture content range, the left side of the knit was characterized by lower water holding capacity. The same trend of water holding was observed in the knit produced from the highest twisted cotton yarn.

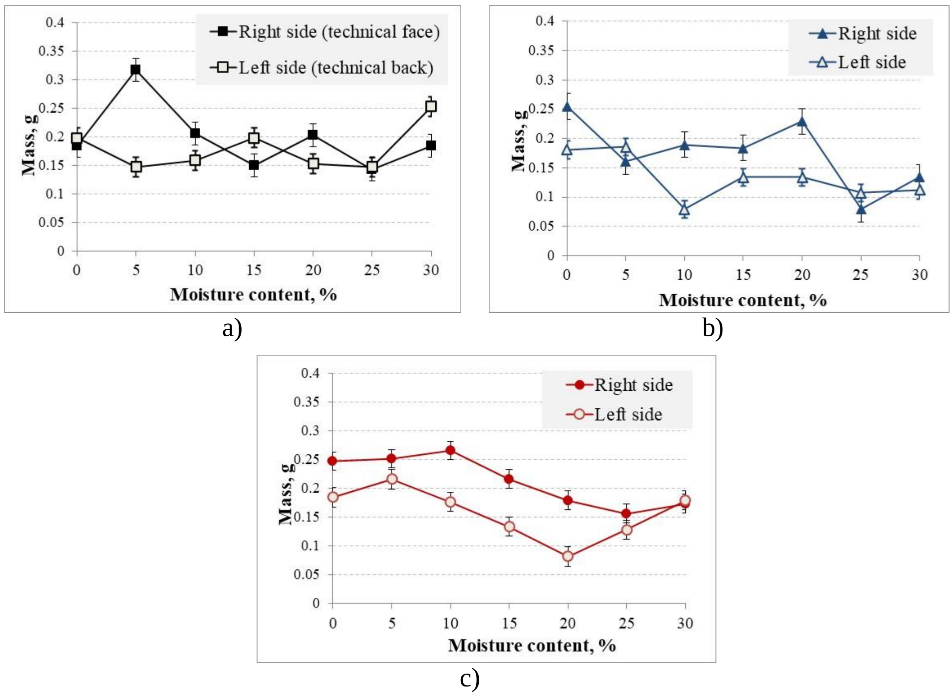



**Figure 3**: Water holding capacity of KCo1 (a), KCo2 (b), and KCo3 (c) knitted fabrics

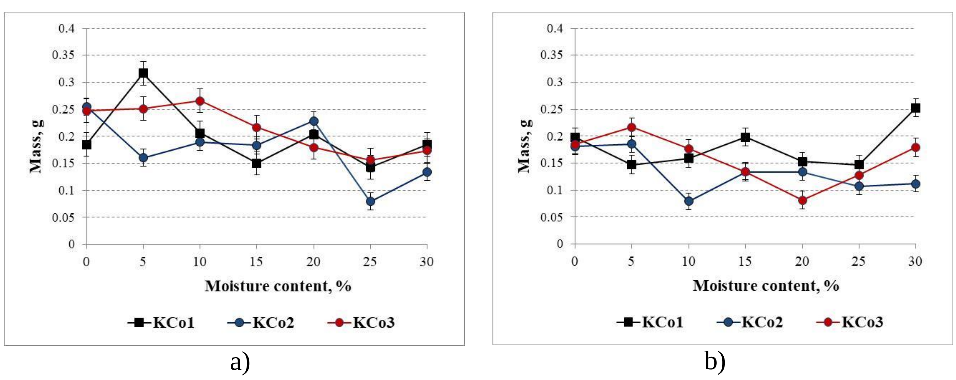



**Figure 4**: Comparison of water holding capacity of the knitted fabrics in right-to-left (a) and left-to-right (b) direction

The graph in Figure 4a compares the water holding capacity of all three knits when liquid is transferred from the face to the back. At the equilibrium moisture content, the knit from the lowest twisted cotton yarn (KCo1) retains the highest amount of liquid, whereas KCo2 knit (from medium twisted yarn) has the least water holding capacity. Since all three knits have the same density (Table 1), they also have the same bonding sites for water molecules. Therefore, a higher amount of retained water in KCo1 knit can be explained by free water in the knit macropores. As evidenced by the stitch surface density of the cotton knitted fabrics (Table 1), KCo1 knit was characterized by somewhat lower surface density, indicating larger macropore size, which are more easily filled with liquid. With increasing moisture content, the water holding capacity is similar for all knitted fabrics.
When the left side of the knit is in contact with water, the water holding capacity is similar for all tested knits, except for the case of a moisture content of 30%, when KCo1 holds the most water in its structure (Figure 4b). Some of the retained water in KCo1 knit comes from free water held in the capillaries and macropores of the fabric. The KCo1 knits have the largest diameter of capillaries (the channels between fibres) due to the lowest twist of the Co1 yarn. Additionally, because of the reduced loop density, the macropore size in this knit is also the largest. As a result, KCo1 knit exhibits the highest water-holding capacity at a humidity level of 30%.

## 3. CONCLUSION

The plain cotton knitted fabrics were produced from various twisted yarns under controlled conditions, and therefore, they were characterized by quite similar construction characteristics, such as thickness and areal density, and almost identical bulk density and porosity. However, they differed from each other in the stitch density, which was caused by the different flexibility of various twisted cotton yarns. Such experimental material made it possible to investigate the impact of yarn twist intensity on the liquid transfer properties of textile fabrics. These properties of plain cotton knitted fabrics were determined by two parameters – water transfer ability and water holding capacity. In addition to yarn twist intensity, the experimental variable was the moisture content of the knits.
Considering the water transfer ability, an increase in the ability to transfer liquid is observed when the moisture content in knitted fabrics is above 10%. In addition, the knitted fabrics made from the lowest and medium twisted cotton yarns exhibited enhanced liquid transfer in the face-to-back (right-to-left) direction. The opposite effect is seen with the knit made from the highest-twisted cotton yarn, as it transfers water faster when the left side is in contact.
Only slight variations in the structural and geometric parameters of plain knits resulted in similar behaviour among all tested knits regarding their ability to transfer liquid. However, this trend changes when the moisture content exceeds 20%, as the increase in liquid transfer ability tends to slow down in knits made from the least twisted yarn. In the back-to-face direction, the knit made from the highest-twisted cotton yarn demonstrated improved liquid transfer ability compared to the other two knits tested.
Since the ability to absorb water is primarily determined by the number of functional groups available to form hydrogen bonds with water molecules, the observed similar water holding capacity of the knitted fabrics can be attributed to their comparable structural

characteristics. Differences in the knits' capillary and macropore geometry, resulting from varying yarn twists, were reflected to some extent in their water-holding capacity at higher moisture levels.

As this study examined three different twist levels of yarns to assess how twist level affects the liquid transfer properties of knitted fabrics, the findings cannot be directly applied to knitted fabrics outside the scope of this research. However, what can be generalized is the fact that varying the yarn twists, thereby directly affecting the geometry and distribution of the complex pore system in the knit, can affect the liquid management properties. Further research will involve yarns with a broader range of twist intensity to establish clear guidelines for effective design.

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