



EFFECTS OF WASHING ON BENDING PROPERTIES OF COTTON MILANO RIB FABRIC

Scientific paper
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ABSTRACT: This study investigates the effects of washing on the bending properties of cotton Milano rib fabric, along with associated dimensional and structural changes. The results showed that washing causes ~5.4% shrinkage in both directions, increases stitch density, while stitch length remains unchanged. Fabric mass and thickness increase, resulting in a denser structure. The bending properties showed that the fabric exhibits statistically increased drape coefficient, with a higher number of nodes, as well as higher bending stiffness in both directions, despite a decrease in bending modulus. These results demonstrate the complex impact of washing on the structural and mechanical performance of knitted fabric.

Keywords: cotton Milano rib, washing, drape coefficient, bending stiffness, bending modulus.

UTICAJ PRANJA NA SVOJSTAVA SAVIJANJA PAMUČNE MILANO REBRASTE PLETENINE

APSTRAKT: Ova studija ispituje uticaj pranja na svojstva savijanja pamučne Milano rebraste pletenine, zajedno sa povezanim dimenzionalnim i strukturnim promenama. Dobijeni rezultati su pokazali da pranje uzrokuje skupljanje od ~5.4% u oba pravca, povećava gustinu pletenine, dok dužina pređe u petlji ostaje nepromenjena. Masa i debljina pletenine se povećava, što rezultira gušćom strukturom. Rezultati svojstava savijanja pletenina nakon pranja pokazali su statistički značajano povećanje koeficijenta drapiranja, sa većim brojem nabora, kao i veću krutost savijanja u oba pravca, uprkos smanjenju modula savijanja. Ovi rezultati pokazuju složen uticaj pranja na strukturne i mehaničke performanse pletenine.

Ključne reči: pamučna Milano rebrasta pletenina, pranje, koeficijent drapiranja, krutost savijanja, moduo savijanja.



1. INTRODUCTION

Knitted fabrics are highly valued for their comfort, stretchability, and versatility, making them ideal for a wide range of clothing and technical applications [1]. Their performance is primarily governed by the interaction between knit structure and yarn properties, with structural variations playing a key role in determining mechanical and functional behavior [2]. Through appropriate knit structures, it is possible to enhance dimensional stability, mechanical performance, and aesthetic qualities.

Garment appearance and fit depend on both mechanical properties (tensile, bending, and shear) and structural characteristics such as mass per unit area, thickness, and stitch density [3], [4]. Among these, bending behavior is particularly significant, as it directly influences fabric flexibility, drape, and overall performance [5]. It is affected by multiple factors, including fiber composition, yarn characteristics, fabric density, knit structure, and finishing treatments [6][8].

Bending stiffness is a key parameter governing drape behavior: fabrics with low stiffness exhibit smooth, fluid drape, whereas stiffer fabrics form more defined, structured folds. Since drape reflects the mechanical response of a fabric to its own weight, bending properties play a dominant role in determining the garment's appearance. Previous studies confirm that knit structure significantly affects bending behavior, with more open structures generally exhibiting greater flexibility than compact configurations [9], [10].

In this context, the bending stiffness of 1×1 rib and half Milano rib fabrics, produced from various cotton/PET blends, is strongly influenced by fabric structure, direction, and finishing [11]. Stiffness is consistently lower in the course direction than in the wale direction, and higher on the technical face than on the back side, reflecting the anisotropic nature of knitted fabrics. The 1×1 rib fabrics exhibit lower bending stiffness compared to the half Milano rib fabrics due to their more open and elastic loop configuration. Furthermore, all applied treatments (dyeing, softening with Aquasoft® SI hydrophilic softener, and Polygiene VO-600 antibacterial finish) reduce bending stiffness relative to untreated fabrics, indicating improved flexibility and enhanced fabric handle.

The purpose of this investigation is to evaluate the effect of washing on the bending behaviour of cotton Milano rib knitted fabric, together with the associated dimensional and structural changes, in order to better understand how washing influences fabric stability, density, and mechanical performance.

2. MATERIALS AND METHODS

2.1. Materials

In this study, knitted fabric was produced using a commercially available cotton yarn (19 × 2 tex). The yarn exhibited an experimentally determined linear density of 37.8 ± 0.4 tex, a twist of 266 ± 20 turns/m, a breaking force of 516 ± 35 cN, a tenacity of 13.65 cN/tex, and a breaking elongation of $3.6 \pm 0.6\%$ [12].

Knitting was performed on a CMS 340.6L double-needle flat V-bed knitting machine (Stoll, Germany), E12 gauge, with 863 needles per needle bed and four knitting systems.

To ensure consistent fabric quality, all relevant machine settings – such as stitch cam position, yarn feeding tension, and take-down adjustments – were maintained unchanged throughout the process. For this study, the Milano rib structure (Figure 1) was chosen.

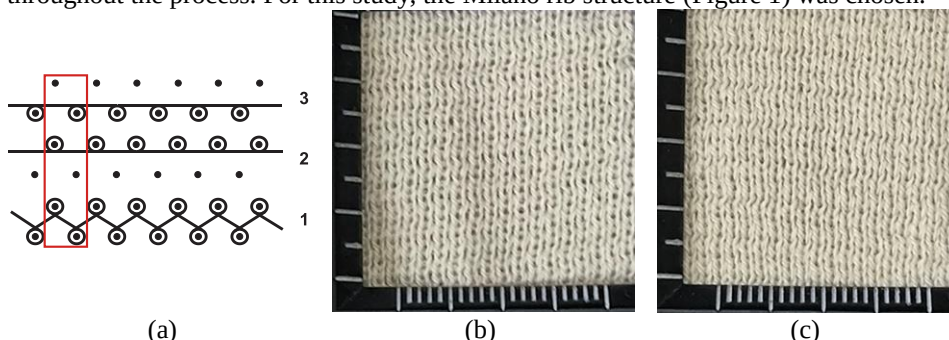


Figure 1: Milano rib structure: a) graphical notation, photos b) before washing, and c) after washing with a measuring ruler (X-axis in mm, Y-axis in inches)

The Milano rib knit structure is produced using three cam systems (Figure 1a). In the first system, knit loops are formed on needles of both needle beds (1x1 rib), while in the second system, knit loops are created only on the needles of the back needle bed (plain), and in the third system, the knit loops are formed on the needles of the front needle bed (plain). As a result, the technical face and back of the fabric are identical (Figures 1b and 1c). Two courses on the face correspond to two courses on the back.

2.2. Methods

Determination of the dimensional changes of the knitted fabric caused by washing

The dimensional changes (DC, %) of the knitted fabric after a one washing cycle were assessed by calculating the percentage variation in the wale and course directions. After knitting, the samples were conditioned by laying them flat for several days under standard atmospheric conditions to relax residual stresses induced during knitting. Following this dry relaxation period (dry relaxed state – DR), the samples were washed in accordance with ISO 6330:2023. After washing, the fabric was again laid flat under minimal tension and conditioned for at least 24 hours under standard atmospheric conditions (wash or wet relaxed state – WR). The mean percentage of dimensional change – expressed as shrinkage („–“) or expansion („+“) – in both the wale and course directions was then calculated using the methodology described in the literature [12].

Determination of the structural characteristics of the knitted fabric

The structural characteristics of the knitted fabric, before and after washing, were evaluated by determining the number of wales (WPC, loops/cm), the number of courses (CPC, loops/cm) per centimeter, and fabric stitch density (S , loops/cm²). Furthermore, stitch length was measured for the 1x1 rib stitches (l_1 , mm), plain stitches (l_2 , mm), and expressed as the average stitch length (l_a , mm). The fabric mass per unit area or weight (W , g/m²) and thickness (T , mm) were also determined. The structural characteristics of the cotton Milano

rib fabric were determined in accordance with the methodology described in the literature [12].

Determination of the bending properties of the knitted fabric

The bending properties of cotton Milano rib knitted fabric were evaluated using the drape coefficient, number of nodes, bending stiffness, and bending modulus before and after washing.

The disc method was used to determine the drape coefficient (K_d , %) using an apparatus designed at the Department of Textile Engineering, Faculty of Technology and Metallurgy, University of Belgrade. In the test, a circular sample of knitted fabric (with a diameter (D) of 20 cm) is held concentrically between two smaller horizontal discs (with a diameter (d) of 8 cm) and is allowed to drape into nodes under its own weight. A light is shone from underneath the specimen, and the shadow that the fabric casts is traced onto a piece of paper the same size as the undeformed fabric specimen. To measure the areas involved, the mass of a paper disk whose dimensions are equal to the dimensions of the undeformed sample (m_{Ad} , g), the mass of a paper disk whose dimensions are equal to the dimensions of the horizontal discs ($m_{Ad'}$, g), and the mass of paper corresponding to the area of the sample projected shadow (m_{As} , g) are cut away and weighed [13]-[15]. The drape coefficient (K_d , %), which characterizes the drapeability of the investigated knitted fabric in all structural directions, is calculated according to the following equation:

$$K_d = \frac{m_{As} - m_{Ad}}{m_{Ad} - m_{Ad'}} \cdot 100 \quad (1)$$

The drape coefficient is the mean value of six measurements.

The cantilever method [13], [16] was used to determine the bending stiffness and bending modulus of the investigated knitted fabric. The method consisted of fixing a tested specimen measuring 16 x 3 cm at its central part, so that it would fall freely to both sides under the influence of its own weight. The magnitude of the absolute deflection (f) was read separately for each free end of the fabric, and then the bending of the tape (f_{sr}) was determined as the arithmetic mean value of the deflection of both ends (f_1) and (f_2). The relative deflection (f_o) was calculated by the equation $f_o = f_{sr}/l$, where l is the length of the hanging-down ends of the test stripe (cm), determined by the equation:

$$l = \frac{L-2}{2} \quad (2)$$

where L is the length of the test stripe (in this case, it is 16 cm).

The size of relative deflection (f_o) is not allowed to be greater than 0.65, and the size of average deflection (f_{sr}) is not less than 1 cm. If at 16 cm long test stripe these conditions are not satisfied, the length of the stripe is reduced by 1 cm and relative as well as average deflection are determined again. The procedure of reducing the length of the test stripe is repeated as long as it is needed to obtain the values of (f_o) and (f_{sr}), which will satisfy the mentioned limited conditions.



Bending stiffness (B , $\text{N} \cdot \text{m}^2$) was calculated according to the equation:

$$B = \frac{m \cdot l^3}{A} \quad (3)$$

where m is the weight per unit length ($\text{N} \cdot \text{m}^{-1}$) of the test stripe, l is the hanging length (m) of the test stripe, which was determined according to equation (2), and A is the dimensionless value, in dependence on relative deflection (f_o) given in the literature [13], [16].

Bending modulus (E , $\text{N} \cdot \text{m}^{-2}$) was calculated through the value of bending stiffness (B) using the equation [13]:

$$E = \frac{B}{I_x} \quad (4)$$

where B is the bending stiffness ($\text{N} \cdot \text{m}^2$), which was determined according to equation (3), and I_x (m^4) is the principal moment of inertia given by the following equation [13]:

$$I_x = \frac{b \cdot T^3}{12} \quad (5)$$

where b is the sample width (3 cm, i.e., 0.03 m), and T is the fabric thickness (m) determined under the pressure of 9.96 kPa. The results for bending stiffness and bending modulus presented a mean of five measurements of knitted fabric in both directions (in the wale and course directions).

Statistical analysis

The statistical analysis used the Student t -test [17] for the dependent samples, which was calculated using the equation:

$$t = \frac{\bar{d}}{\frac{\sigma_d}{\sqrt{n}}} \quad (6)$$

where $\bar{d}$ is the sample mean value of the differences of determining characteristic before and after washing, σ_d is the sample standard deviation of the differences, while n is the sample size.

3. RESULTS AND DISCUSSION

3.1. Dimensional changes of the knitted fabric

As mentioned in the Methods section, the dimensional changes were measured after one washing cycle in both directions (wale and course), and the results are presented in Tab 1. The analyzed dimensional changes of the cotton Milano rib fabric after washing show shrinkage in both the wale and course directions, indicating isotropic dimensional behavior as previously reported [12]. The shrinkage of Milano rib fabric in both the wale and course directions is similar (5.28% and 5.61%, respectively) due to the structure of the Milano rib,

which features courses of plain stitches created on the opposite needle bed by the second and third systems of the knitting machine. However, the variability in dimensional change is notably large in both directions, as reflected by large coefficients of variation. This indicates non-uniform shrinkage behavior, with slightly greater dispersion observed in the wale direction. Overall, although shrinkage occurs in both directions with similar mean values, the fabric demonstrates inconsistent dimensional stability, particularly in the wale direction.

Table 1: Final measurements (*FM*) and shrinkage (*DC*) of the Milano rib fabric after washing

Parameter	In the wale direction			In the course direction		
	mean	<i>SD</i>	<i>CV</i> , %	mean	<i>SD</i>	<i>CV</i> , %
<i>FM</i> , mm	189.44	5.13	2.71	188.78	4.71	2.50
<i>DC</i> , %	5.28	2.56	48.56	5.61	2.36	41.98

FM – final measurement, *DC* – shrinkage, *SD* – standard deviation, *CV* – coefficient of variation

3.2. Structural characteristics of the knitted fabric

Structural characteristics of the Milano rib structure in dry relaxed (*DR*) and washed (*WR*) states are presented in Table 2.

Table 2: Structural characteristics of the Milano rib structure in dry relaxed (*DR*) and washed (*WR*) states [12]

Structural characteristics	<i>DR</i>			<i>WR</i>		
	mean	<i>SD</i>	<i>CV</i> , %	mean	<i>SD</i>	<i>CV</i> , %
<i>WPC</i> , loops/cm	13.81	0.02	0.16	14.76	0.22	1.48
<i>CPC</i> , loops/cm	10.56	0.10	0.91	10.72	0.11	0.76
<i>S</i> , loops/cm ²	145.87	1.11	0.76	158.24	3.63	2.30
<i>l</i> ₁ , mm	4.96	0.04	0.89	4.93	0.04	0.65
<i>l</i> ₂ , mm	4.86	0.03	0.59	4.85	0.04	0.86
<i>l</i> _a , mm	4.91	0.03	0.65	4.89	0.04	0.84
<i>W</i> , g/m ²	261.28	11.18	4.28	302.14	3.87	1.28
<i>T</i> , mm	1.25	0.01	1.07	1.33	0.05	3.43

WPC – the number of wales per centimeter, *CPC* – the number of courses per centimeter, *S* – stitch density, *l*₁ – stitch length for a 1x1 rib stitch, *l*₂ – stitch length for a plain stitch, *l*_a – average stitch length, *W* – weight, *T* – thickness, *SD* – standard deviation, *CV* – coefficient of variation

The presented results (Table 2) show clear differences between the dry relaxed (*DR*) and wash relaxed (*WR*) states, indicating structural rearrangement of the knitted fabric after washing. The number of wales per centimeter (*WPC*) rises from 13.81 to 14.76 loops/cm, representing an increase of approximately 6.8%, while the number of courses per centimeter (*CPC*) increases slightly from 10.56 to 10.72 loops/cm (1.5%). Consequently,



stitch density (S) increases from 145.87 to 158.24 loops/cm², representing an 8.5% increase, indicating overall fabric compaction.

In contrast, the stitch length remains largely unchanged after washing. For the 1x1 rib stitch, the stitch length (l_i) slightly decreases from 4.96 mm to 4.93 mm, representing a 0.6% decrease. Meanwhile, the stitch length of the plain stitch (l_2) remains nearly unchanged (0.1%). As a result, the average stitch length (l_a) remains unchanged (0.4%), reflecting the stabilizing effect of the plain stitch on the overall trend.

Fabric weight (W), or mass per unit area, increases from 261.28 g/m² to 302.14 g/m² (15.7%), while thickness (T) rises from 1.25 mm to 1.33 mm (6.4%), indicating a denser, bulkier structure. This trend can be explained by the increasing number of wales per centimeter and the resulting increase in fabric stitch density, with a slight decrease in stitch length.

Overall, washing increases fabric stitch density, weight, and thickness, accompanied by slight reductions in stitch length, thereby confirming fabric shrinkage and structural consolidation after wet relaxation.

Statistical analysis using a t -test for dependent samples (Table 3) confirms the results obtained for the structural characteristics of the cotton Milano rib fabric.

Table 3: Statistical results of the structural characteristics of cotton Milano rib knitted fabric determined by using the t -test for dependent samples [12]

t value	Values of parameter t based on washing for the tested parameters ($df=n-1=4$ for WPC , CPC , S , W , T) ($df=n-1=9$ for l_a)					
	WPC	CPC	S	l_a	W	T
$t_{DR/WR}$	-8.73(***)	-4.00(*)	-8.88(***)	1.55(/)	-9.63(***)	-3.78(*)
WPC – the number of wales per centimeter, CPC – the number of course per centimeter, S – fabric stitch density, l_a – average stitch length, W – weight, T – thickness, DR – dry relaxed state, WR – wash relaxed state, (*) – 0.05 level of significance, (***) – 0.001 level of significance, (/) – no statistically significant difference, df – degrees of freedom, n – sample size						

3.3. Bending properties of the knitted fabric

As previously mentioned, the bending behavior of the cotton Milano rib knitted fabric studied was assessed using the drape coefficient, number of nodes, bending stiffness, and bending modulus.

Top view of the real drape image and drape profile for the cotton Milano rib knitted fabric in dry relaxed and wash relaxed states are presented in Figure 2.

The results for the drape coefficient (K_d), the number of nodes (N), the bending stiffness (B), and bending modulus (E) values of the cotton Milano rib knitted fabric, measured in dry relaxed (DR) and wash relaxed (WR) states, are shown in Table 4.

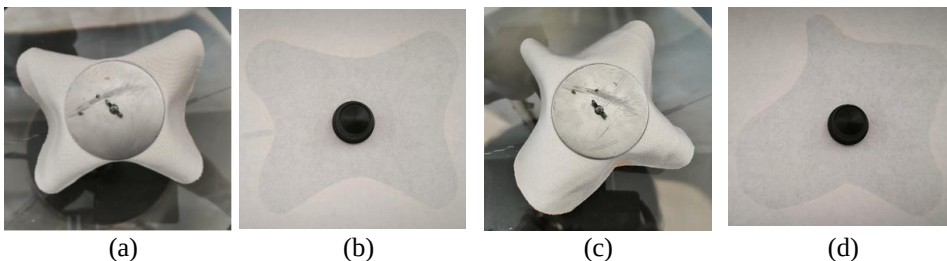


Figure 2: Top view of the real drape image and drape profile for the cotton Milano rib knitted fabric in dry relaxed (a, b), and wash relaxed states (c, d)

Table 4: The results of the bending properties of the cotton Milano rib fabric

Fabric state	Parameter	Value of the tested parameter					
		K_d	N	B_{wales}	$B_{courses}$	E_{wales}	$E_{courses}$
DR	mean	40.66	3.83	$4.85 \cdot 10^{-7}$	$1.21 \cdot 10^{-7}$	99177.95	24808.61
	SD	1.85	0.41	$5.69 \cdot 10^{-8}$	$3.98 \cdot 10^{-8}$	11626.73	8136.35
	CV, %	4.55	10.65	11.72	32.80	11.72	32.80
WR	mean	45.04	4.00	$5.58 \cdot 10^{-7}$	$1.29 \cdot 10^{-7}$	94492.10	21884.12
	SD	2.06	0.00	$1.91 \cdot 10^{-7}$	$4.59 \cdot 10^{-8}$	32294.98	7771.92
	CV, %	4.57	0.00	34.18	35.51	34.18	35.51

K_d – drape coefficient, N – the number of nodes, B – bending stiffness, E – bending modulus, DR – dry relaxed state, WR – wash relaxed state, SD – standard deviation, CV – coefficient of variation

The results indicate that washing affects the bending properties of the cotton Milano rib fabric. The drape coefficient (K_d) rises from 40.66 in the dry relaxed state (DR) to 45.04 in the wash relaxed state (WR), an increase of 10.8%, showing that the fabric becomes stiffer and less drapable after washing. This change is also reflected in the drape image and profile (Figure 2), as well as in the number of nodes (N) measured in the dry relaxed (DR) and wash relaxed (WR) states (Table 4), suggesting certain structural alterations on the fabric surface following washing.

Bending stiffness (B) increases in both wale and course directions after washing, from $4.85 \cdot 10^{-7}$ to $5.58 \cdot 10^{-7}$ (by 15.1%) in wale direction and from $1.21 \cdot 10^{-7}$ to $1.29 \cdot 10^{-7}$ (by 6.6%) in course direction, although high variability is observed ($CV > 34\%$), reflecting non-uniform changes in fabric behavior. In contrast, the bending modulus (E) decreases slightly after washing – from 99,177.95 to 94,492.10 (by 4.8%) in wale direction and from 24808.61 to 21884.12 (by 11.8%) in course direction – indicating that while localized stiffness may increase, the fabric overall becomes somewhat more flexible in bending.

Statistical results of the bending properties of cotton Milano rib knitted fabric determined by using the t -test for dependent samples are presented in Table 5. Statistical analysis using a t -test showed that washing statistically significantly increased only the drape coefficient.



Table 5: Statistical results of the bending properties of cotton Milano rib knitted fabric determined by using the *t*-test for dependent samples

<i>t</i> value	Values of parameter <i>t</i> based on washing ($df=n-1=5$ for K_d and N) ($df=n-1=4$ for B and E)					
	K_d	N	B_{wales}	$B_{courses}$	E_{wales}	$E_{courses}$
$t_{DR/WR}$	-4.10(**)	-1.00(/)	-0.90(/)	-0.25(/)	0.34(/)	0.50(/)
K_d – drape coefficient, N – the number of nodes, B – bending stiffness, E – bending modulus, DR – dry relaxed state, WR – wash relaxed state, (**) – 0.01 level of significance, (/) – no statistically significant difference, df – degrees of freedom, n – sample size						

Overall, washing results in a slightly stiffer fabric, with minor structural changes, highlighting the complex impact of washing on fabric performance.

4. CONCLUSIONS

Investigation of the effects of washing on the bending properties of cotton Milano rib fabric revealed that washing induces notable dimensional and mechanical changes. The fabric exhibits shrinkage in both wale and course directions (~5.4%). Structural rearrangements are evident, with increases in the stitch density, while stitch length remains largely unchanged, helping stabilize the fabric structure. Fabric weight and thickness increase by 15.7% and 6.4%, resulting in a denser, slightly bulkier fabric. Mechanically, the fabric becomes stiffer and less drapable: the drape coefficient rises by 10.8%, bending stiffness increases by 15.1% in the wale direction and by 6.6% in the course direction, while the bending modulus decreases. These results demonstrate that washing produces subtle yet significant modifications in both dimensional and bending properties, highlighting the complex impact of washing on fabric performance and stability.

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