EFFECT OF RIB SET-OUT REPEAT AND NEEDLE INACTIVITY ON STRUCTURAL AND STRETCH BEHAVIOR OF FLAX-CONTAINING DOUBLE-KNITTED FABRICS

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This study investigates the structural and stretch properties of five variants of double-knit fabrics made from 29 × 2 tex flax-containing (50% PAN, 27% viscose, and 23% flax) yarn in comparison with a half Milano rib structure. These fabrics are knitted with alternating rib set-out and plain courses. The effect of 1–3 inactive needles (X) in the rib-set out repeat on the back bed of a 10-gauge flat-bed knitting machine was assessed, while plain stitch was knitted on the front bed of the knitting machine. The results showed that lengthwise dimensional changes were greater than widthwise changes, with the most notable effects occurring after the first washing cycle. Adding inactive needles reduced lengthwise shrinkage, balanced widthwise changes, and enhanced overall dimensional stability. Increasing the number of inactive needles reduced the number of wales and courses, resulting in lower stitch density, while stitch length remained at a similar level, and fabric thickness and weight decreased, indicating controlled adjustment of fabric compactness. Stretch analysis showed that elastic deformation dominates, with delayed and residual deformations playing secondary roles. Fabrics with inactive needles exhibited reduced lengthwise deformation, but reduced widthwise stability, highlighting the importance of the rib-set out repeat. These findings offer practical guidance for optimizing double-knit fabric structure, dimensional stability, and stretch performance in various knitted fabric applications.

Keywords: flax, double-knit, miss (float) stitches, rib set-out repeat, inactive needle, shrinkage, stretch properties

INTRODUCTION

Growing environmental awareness and the increasing demand for eco-friendly textiles have accelerated the search for suitable material solutions.[1,2] One promising approach involves using natural fibers, either alone or in combination with other natural or synthetic fibers, to achieve improved performance. Among these, flax attracted considerable attention due to its biodegradability, moisture absorption, comfort, and relatively low environmental footprint during cultivation.[3-5] However, its inherent limitations – such as low elasticity, structural rigidity, and processing challenges – restrict its broader application, particularly in knitted fabrics that require high flexibility and dimensional stability. To address these limitations, flax is commonly blended with cotton or synthetic fibers, with flax contents in the range 20–30% identified as optimal for both yarn spinning and fabric properties.[6-12]

The structural and mechanical behavior of knitted fabrics is strongly influenced by both yarn properties and fabric structure. In flax-containing, fiber composition significantly affects key properties such as structural characteristics, dimensional stability after washing, non-creasing performance, air permeability, and stretch properties of Swiss piqué fabrics.[13,14] Fabrics produced from pure flax yarns, which exhibit high torsional stiffness and low flexibility, typically demonstrate low widthwise elasticity and high residual deformation. In contrast, blending flax with cotton or polyacrylonitrile (PAN) reduces stiffness and enhances flexibility, resulting in more stable loop structures and improved elastic behavior.

Previous studies have shown that flax-based plain knitted fabrics characterized by higher stitch density, weight, thickness, and moisture content, along with lower porosity, exhibit distinct electrical and mechanical behaviors. These include reduced resistivity and compressibility, as well as increased dielectric permeability, conductivity, and compressive resilience.[15-17] Nevertheless, their structural integrity may deteriorate under pilling, as repeated abrasion affects resistance and key structural characteristics.[18]

Fabric performance can be further tailored by combining different knit structures.[19] The integration of single- and double-knit structures enables the development of fabrics with diverse dimensional and mechanical properties.[20-23] For instance, miss-knit structures have been shown to enhance dimensional stability compared to knit structures with knit loops.[24-26] In single-jersey cotton fabrics, variations in knit loop types (knit, tuck, and float) significantly influence drape behavior, widthwise extensibility, shrinkage, thickness, areal density, and low-stress mechanical properties.[27] Similarly, single and double float stitch repeats play an important role in defining the structure of cotton/flax double-faced knitted fabrics.[28-30] In double-weft cotton/flax fabrics, the presence of miss stitches significantly affects dimensional stability and stretch: lengthwise shrinkage (15–25%) typically exceeds widthwise shrinkage, while a higher proportion of miss stitches reduces widthwise shrinkage and stretch due to float positioning. Fabrics with the same proportion of miss stitches display similar structural and deformation behavior.

A comparable effect is observed in relation to rib set-out repeat configuration in double-knitted fabrics. In wool/PAN blends (60% wool, 40% PAN), an increase in the number of inactive needles leads to greater lengthwise shrinkage and reduced widthwise shrinkage, with repeated washing cycles having minimal effect.[31] In cotton/flax double-knitted fabrics (25 × 2tex × 2), increasing the number of inactive needles results in higher shrinkage, stitch density, thickness, and weight. While lengthwise deformation remains largely unaffected, widthwise stretch is strongly dependent on the proportion of inactive needles. Fabrics with identical proportions of inactive needles (50%) show minimal differences, aiding the prediction of dimensional stability and performance.[21] Additionally, structural variations such as the double-stitch structure influence shielding properties; for instance, half Milano rib fabrics have demonstrated superior performance.[32]

Dimensional stability and stretch properties of knitted fabrics are governed by multiple interacting factors, including yarn type and characteristics, knit structure, relaxation, and drying conditions. Hydrophilic yarns, such as cotton, silk, and viscose, exhibit the most significant dimensional changes upon initial wetting, followed by further, though less significant, changes during subsequent wetting.[33] Fiber blending and yarn composition also significantly influence dimensional changes in cotton and cotton/polyester weft-knitted fabrics.[34]

In this context, this study investigates flax-containing double-weft knitted fabrics (50% PAN, 27% viscose, 23% flax) constructed through alternating rib set-out and plain courses, using a half Milano rib structure as reference. A controlled number of inactive needles, ranging from 1 to 3, was set on the back bed of the knitting machine, while the front bed of the knitting machine formed a plain stitch. By varying the rib set-out repeat, this research establishes the relationship between stitch configuration, selective needle inactivity, and key performance parameters, including structural characteristics, dimensional stability, and stretch behavior. The findings provide new insights into the combined influence of rib set-out repeat and needle inactivity on structural and stretch properties of fabrics, offering practical guidance for optimizing knitted fabric performance. Ultimately, this research supports the development of high-quality and versatile knitted textiles that balance comfort, aesthetics, and performance.

EXPERIMENTAL

Materials

This research analyzes the half Milano rib structure (variant I) and five variants of double-faced weft knit structures (variants II–VI) (Table 1).

The repeat at the height (R_h) of each variant includes a combination of two courses: rib set-outs in the 1st yarn feeder and plain in the 2nd. The rib set-outs are created by selectively deactivating needles only on the back bed of a flat V-bed knitting machine, with the number of inactive needles ranging from 1 to 3. The plain knit structure is produced on the front bed of the knitting machine.

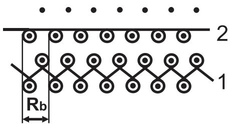
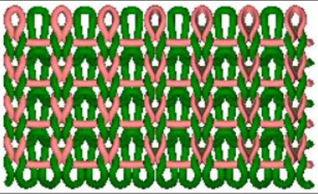
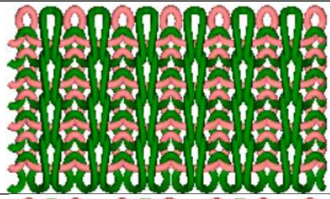
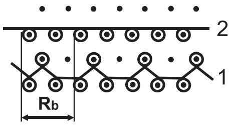
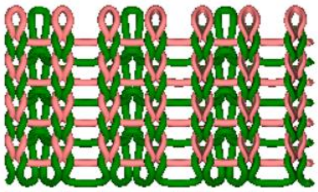
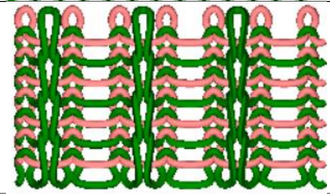
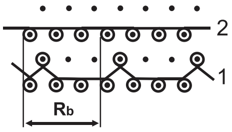
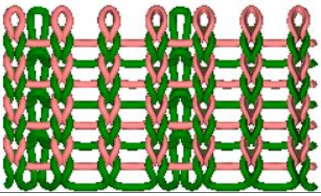
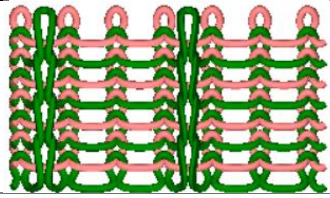
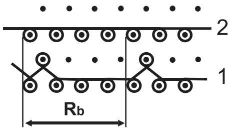
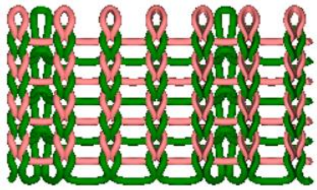
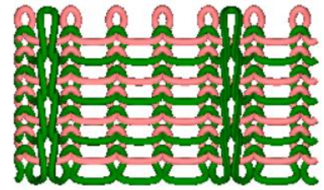
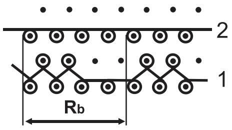
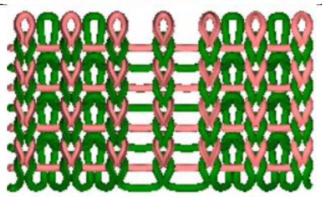
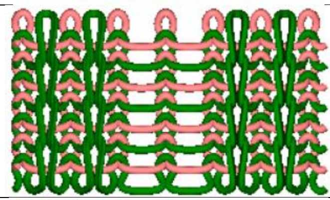
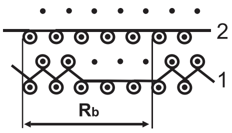
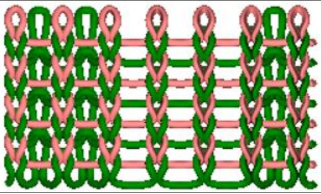
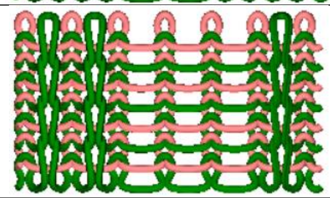
The percentage of inactive needles within the rib set-out repeat at the width (X) in % on the back bed of the flat V-bed knitting machine was calculated using the following formula:

$$X = \frac{n}{m+n} \cdot 100 \qquad (1)$$

where n – inactive needles within the rib set-out repeat at the width of the back bed of the knitting machine, m – active needles within the rib set-out repeat at the width of the front and back beds of the knitting machine.

All the samples were produced using a 10-gauge flat V-bed knitting machine with a yarn composed of 29 x 2 tex flax-containing fibers (50% PAN, 27% viscose, and 23% flax). Throughout the knitting process, key parameters such as stitch cam settings (3.5 mm), yarn tension (10.8 cN), and fabric take-downs (17 cN/wale) were kept constant. Before knitting, the yarn was coated with 0.5% wax.[35]

Table 1
Graphical notations and visual illustrations of the knitted fabrics

V	X, %	Graphical notation	Visual illustration of the side view of the structure	
			Technical face	Technical back
I	0			
II	25			
III	33.3			
IV	37.5			
V	25.0			
VI	30			

V – fabric variants, X - the percentage of inactive needles within the rib set-out repeat on the back bed of the flat knitting machine, R_b - the repeat at the width; green colour – rib course; coral colour – plain course

As shown in Table 1, the technical face of the knitted structures includes two courses: plain and rib, which are knitted using needles on the front bed of the knitting machine. The technical back consists of only one course, formed by rib loops from the back bed of the knitting machine. The technical back of all fabric variants consists of extended rib loops knitted on the back needle bed of the knitting machine. The technical face of all knitted fabrics has rib loops knitted on the front bed in the first yarn feeder of the machine, with plain loops knitted on the same bed in the second yarn feeder.

Methods

Dimensional changes after washing

After knitting, all the fabrics were conditioned according to ISO 139:2005.[36] The knitted fabrics were subsequently washed in a washing machine, comprising four cycles. Following each cycle, they were laid flat under standard atmospheric conditions for at least 24 hours. The washing process complied with ISO 6330:2021.[37] Results represent a mean of six measurements per sample.

The lengthwise (DC_l) and widthwise (DC_w) dimensional changes in knitted fabrics were measured according to ISO 5077:2007.[38]

The dimensional change (DC) in the knitted fabrics in % was calculated using the formula:

$$DC = \frac{FM - OM}{OM} \cdot 100. \quad (2)$$

where FM – final measurement in mm, OM – original measurement in mm before first washing (OM = 200 mm).

Structural characteristics

All structural characteristics of the double-faced knit fabrics were measured after washing.

The number of wales (WPC) and courses (CPC) per centimeter on both the technical front (WPC_f, CPC_f) and back (WPC_b, CPC_b) were measured according to EN 14971:2006[39] and GOST 8846-87[40] standards. Measurements were taken over a 10 cm span and calculated to per one centimeter. For variants 2–6, wale counts were taken over a longer span to cover the full repeat at the width (R_b). Results reflect the mean obtained from ten distinct locations per sample and side.

Based on the number of wales and courses, the fabric stitch density was calculated only for the technical back (SD_b) in loops per square centimeter:

$$SD_b = WPC_b \cdot CPC_b \quad (3)$$

The structure on the technical face of the knitted fabrics is irregular, caused by the different loop shapes of plain and rib loops, and the fabric stitch density (SD_f) could not be calculated.

The stitch length in the knitted fabric was measured for each stitch (rib and plain) and calculated as the average yarn length per stitch, following the EN 14970:2006[41] and GOST 8846-87[40] standards. Measurements were taken over an area covering 50 wales for plain and 50 × 2 needles for rib stitch. The results represent the mean of ten measurements for both the rib stitch length (l_1) and plain stitch length (l_2) in mm. Based on the stitch length per stitch, the average stitch length (l_a) in mm was calculated using the formula:

$$l_a = \frac{l_1 + l_2}{2} \quad (4)$$

The weight (GSM) in grams per square meter was measured according to EN 12127:1997.[42] Results reflect the mean of five measurements for each fabric variant.

The fabric thickness (t) in mm was determined according to ISO 5084:1996[43] using a thickness gauge SM-124 device at a pressure of 2.5 N/cm^2 (25 kPa) with a test surface area of 1 cm^2. Results represent the mean of ten different locations for each sample.

Stretch characteristics

The characteristics of stretch in knitted fabrics, including full, elastic, delayed, and residual deformations, and their respective contributions, were assessed according to the GOST 8847-85 standard test method.[44] A "rack" relaxometer was used to perform a "loading–unloading–rest" cycle. The process involved applying a steady load of 6 N for 60 minutes, then unloading and allowing a 120-minute rest. Fabric samples, each 50 mm wide and 200 mm long, were initially clamped at a distance of 100 mm (L_o). Results are the mean of five samples for each direction.

The stretch characteristics were calculated using the following equations:

– full deformation (E) in %:

$$E = \frac{L_1 - L_0}{L_0} \cdot 100 \quad (5)$$

where L_0 – the initial length of the specimen in mm (L_0 = 100 mm), L_1 – the length of the specimen after 60 min of loading in mm;

– elastic deformation (E_1) in %:

$$E_1 = \frac{L_1 - L_2}{L_0} \cdot 100 \quad (6)$$

where L_2 – the length of the specimen just after unloading in mm;

– delayed deformation (E_2) in %:

$$E_2 = \frac{L_2 - L_3}{L_0} \cdot 100 \quad (7)$$

where L_3 – the length of the specimen after resting in mm;

– residual deformation (E_3) in %:

$$E_3 = \frac{L_3 - L_0}{L_0} \cdot 100 \quad (8)$$

Following the calculation of deformation values, the contribution of each component to the full deformation (E_1/E, E_2/E, E_3/E) was determined, thereby enabling the evaluation of the fabric's elasticity.

Statistical analysis

For the statistical analysis of the results, the Student t-test was used for the independent sample according to the following equation:

$$t = \frac{|\overline{x_1} - \overline{x_2}|}{\sqrt{\frac{\sigma_1^2 \cdot (n_1 - 1) + \sigma_2^2 \cdot (n_2 - 1)}{n_1 + n_2 - 2} \cdot \frac{n_1 + n_2}{n_1 \cdot n_2}}} \quad (9)$$

where $\bar{x}_1$ and $\bar{x}_2$ the samples' mean values of the determined characteristic, σ_1 and σ_2 the sample's standard deviation of the determined characteristic, n_1 and n_2 are their corresponding sample sizes ($n_1 = n_2$), while n is the sample size (n = 10 for the number of wales WPC and courses CPC, the length of yarn (the rib stitch length l_1 and plain stitch length l_2), the fabric thickness t; n = 6 for dimensional change DC and n = 5 for the weight GSM, stretch characteristics – E, E_1, E_2 and E_3).

RESULTS AND DISCUSSION

Dimensional changes after washing

The lengthwise (DC_l) and widthwise (DS_w) dimensional changes in knitted fabrics after four washings (WR1-WR4) are presented in Table 2.

The dimensional changes of the investigated knitted fabrics (variants II-VI) exhibit isotropic behavior, characterized by concurrent shrinkage in both the lengthwise and widthwise directions. This trend is consistent with observations reported for Swiss double piqué knitted fabrics made from PAN/flax blends and pure flax yarn.[13] Notably, the incorporation of viscose into the flax-containing yarn did not alter this overall trend.

The relationship between the dimensional changes after washing cycles of knitted fabrics and the percentage of inactive needles in the rib set-out repeat (X) is presented in Figure 1.

The lengthwise dimensional change of the knitted fabrics after the first washing cycle exhibits a nonlinear trend, with a coefficient of determination (R^2) below 0.5. In contrast, after the second, third, and fourth washing cycles, the relationship becomes distinctly linear, indicating stabilization of the shrinkage behavior (Fig. 1a). The widthwise dimensional changes in knitted fabrics depend on the number of inactive needles in the rib set-out repeat at the width (X) and follow a linear trend after all four cycles (Fig. 1b).

The half Milano rib (variant I) shrinks in length and exhibits fluctuating width across the four washing cycles, as mentioned in previous research.[22] Lengthwise dimensional changes (DC_l) are notably greater than widthwise (DC_w), which can be explained by the knitting process when the fabric stretches in length (Table 2, Fig. 1). While washing, the loops in the knitted fabrics tried to change in size and shape. Also, the received result showed that the most significant dimensional changes in knitted fabrics in both directions were after the first washing cycle, as mentioned in the findings.[13,21,22,31]

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Table 2
Dimensional changes of the knitted fabrics after washing

Fabric variants	X, %	Dimensional change after washing, %							
		Lengthwise DC_l				Widthwise DC_w			
		WR1	WR2	WR3	WR4	WR1	WR2	WR3	WR4
I	0	-22.3±0.9	-25.5±1.6	-25.6±0.6	-26.4±0.7	0.5±4.5	1.8±2.8	1.3±1.4	-0.1±1.9
II	25.0	-22.3±2.0	-19.5±1.1	-21.2±1.9	-21.4±1.9	-7.7±2.6	-9.8±3.8	-8.7±4.4	-9.2±4.8
III	33.3	-17.5±1.7	-17.5±1.0	-19.9±1.3	-21.2±0.8	-10.6±1.2	-11.1±2.0	-10.8±3.1	-11.6±2.7
IV	37.5	-18.9±2.0	-20.2±1.5	-20.3±1.4	-21.0±1.8	-10.1±2.0	-9.2±1.4	10.4±1.2	-10.3±1.2
V	25.0	-22.4±1.6	-24.0±2.0	-25.5±1.3	-25.8±1.4	-5.0±3.2	-4.4±3.3	-3.0±1.0	-3.4±1.5
VI	30.0	-18.2±1.8	-20.7±2.3	-19.3±3.4	-18.5±1.9	-10.3±1.5	-11.7±2.0	-7.8±3.0	-7.8±2.6

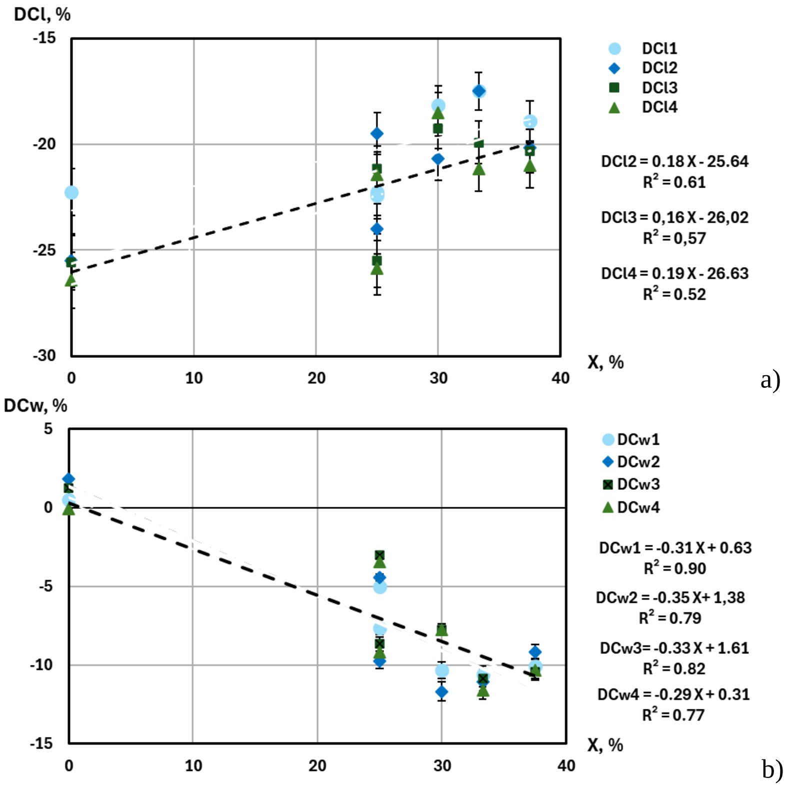


Figure 1: Relationship between the dimensional changes after washing cycles of knitted fabrics and the percentage of inactive needles in the rib set-out repeat (X): a) lengthwise (DC_l), b) widthwise (DC_w)

Table 3
Statistical results for determining dimensional changes after washing for independent samples using the t–test

Tested parameter	Number of washings	Values of parameter *t* regarding the dimensional changes after washing ($df=n_1+n_2-2=10$)				
		$t_{I/II}$	$t_{I/III}$	$t_{I/IV}$	$t_{I/V}$	$t_{I/VI}$
DC_l	WR1	0.0(/)	6.0(***)	3.8(**)	0.2(/)	4.9(***)
	WR2	7.6(***)	10.3(***)	6.0(***)	1.4(/)	4.2(**)
	WR3	5.5(***)	9.8(***)	8.8(***)	0.1(/)	4.6(**)
	WR4	6.1(***)	12.5(***)	6.9(***)	0.9(/)	9.7(***)
DC_w	WR1	3.9(**)	5.9(***)	5.3(***)	2.5(*)	5.7(***)
	WR2	6.1(***)	9.3(***)	8.7(***)	3.6(**)	9.7(***)
	WR3	5.3(***)	8.9(***)	15.8(***)	6.2(***)	6.7(***)
	WR4	4.3(**)	8.5(***)	11.0(***)	3.3(**)	5.9(***)

Legend: I, II, III, IV, V, VI – fabric variant; (*) 0.05 level of significance; (**) 0.01 level of significance; (***) 0.001 level of significance; df – degree of freedom, (/) no statistically significant difference

The analysis of lengthwise dimensional changes (DC_l) across knitted fabric variants I–VI shows that shrinkage decreases with increasing percentage of inactive needles (X), whereas widthwise dimensional changes (DC_w) show the opposite trend. These findings confirm that introducing inactive needles into the rib set-out repeat affects dimensional changes and can improve overall dimensional stability, balancing shrinkage in both directions.

The statistical results for determining the dimensional changes after washing for independent samples using the t–test are presented in Table 3. The statistical analysis using the t-test (Table 3) revealed significant differences in the widthwise dimensional changes (DC_w) across all fabric variants (II-VI), with a significance level of 0.001. Additionally, there was a significant difference in the lengthwise dimensional changes (DC_l), at the 0.001 significance level. In contrast, no statistically significant difference was observed for knitted fabric variants II and V after the first wash, which can be explained by the lower level of inactive needles in the rib set-out repeat (X=25%). Based on these results, the repeat width (R_b) has a greater influence on the lengthwise and widthwise dimensional changes of the investigated knitted fabrics than the half Milano rib (variant I).

Structural characteristics

The number of wales per centimeter (WPC) and courses per centimeter (CPC), stitch density (SD), stitch length (l_1, l_2, l_a), fabric thickness (t), and weight (GSM) are regarded as essential structural parameters, as they predominantly influence fabric performance during use and washing. Variations in fabric structures affect the structural parameters of the knitted fabrics.[19,21-23] The measured structural characteristics of the examined knitted fabrics following washing are presented in Table 4.

Number of wales per centimeter (WPC_b)

A comparative analysis of the number of wales per centimeter (WPC_b) on the technical backside of fabric variants II–VI, in relation to the half Milano rib structure (variant I), shows a significant decrease as the percentage of inactive needles in the rib set-out repeat (X) increases. These decreases range from 39.3% to 75.5% (Fig. 2).

In the half Milano rib structure (variant I), the back side is composed of closely arranged, extended rib loops that contribute to a higher wale density. In contrast, the introduction of inactive needles in variants II–VI disrupts this regularity, decreasing the number of vertical loops formed and thereby significantly reducing wale density. This confirms that needle activity plays an essential role in determining the longitudinal compactness of knitted fabric structures, as mentioned in the findings.[21,22] Additionally, yarn stiffness – particularly in flax-containing yarns – further influences this behavior by limiting loop deformation and reducing structural adaptability.[13,1314] As the percentage of inactive needles within the rib set-out repeat at width (X) increased, both the wales per centimeter on the technical back of the knitted fabrics (WPC_b) showed an apparent linear decline (Table 4, Fig. 2). Increasing the percentage of inactive needles in the rib set-out repeat (X) up to 37.5% directly decreased WPC_b by 67.7%.

Table 4
Post-wash structural characteristics of the knitted fabrics

Fabric variants	X, %	WPC_b, loops/cm	CPC_b, loops/cm	SD_b, loops/cm^2	l_1, mm	l_2, mm	l_a, mm	t, mm	GSM, g/m^2
I	0	4.55±0.11	5.51±0.12	25.07±0.83	7.53±0.04	6.36±0.03	6.94±0.03	1.70±0.07	414±15
II	25.0	2.76±0.05	4.88±0.08	13.47±0.34	7.51±0.04	6.33±0.05	6.92±0.01	1.49±0.09	372±26
III	33.3	1.86±0.05	4.78±0.08	8.89±0.26	7.53±0.05	6.31±0.07	6.92±0.04	1.34±0.09	400±51
IV	37.5	1.47±0.05	4.78±0.08	7.03±0.30	7.46±0.04	6.53±0.04	6.99±0.02	1.44±0.06	360±16
V	25.0	1.73±0.05	5.19±0.07	8.98±0.29	7.62±0.06	6.31±0.06	6.96±0.06	1.57±0.08	444±37
VI	30.0	1.16±0.05	4.80±0.08	5.57±0.27	6.00±0.03	6.43±0.07	6.21±0.04	1.43±0.08	404±34

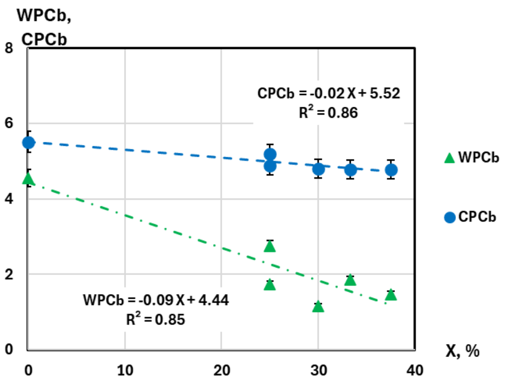


Figure 2: Relationship between WPC_b and CPC_b and the percentage of inactive needles in the rib set-out repeat (X)

Number of courses per centimeter (CPC_b)

The number of courses per centimeter (CPC_b) on the back side of fabric variants II–VI also decreased relative to the half Milano rib structure, as the number of wales per centimeter (WPC_b) (Fig. 2, Table 4).

However, this reduction (ranging from 5.8% to 12.3%) was less pronounced than that observed in WPC_b. This decrease can be attributed to the yarn redistribution that occurs when inactive needles are introduced, specifically, the formation of longer rib loops on the back side. These longer loops occupy more vertical space, slightly reducing the number of horizontal courses without dramatically altering the overall course formation process. Thus, while needle inactivity affects both wale and course densities, its impact on CPC_b is relatively moderate, as mentioned in the findings.[21,22]

As the percentage of inactive needles within the rib set-out repeat at width (X) increased, the courses per centimeter on the technical back of the knitted fabrics (CPC_b) exhibited an evident linear decline, as did WPC_b (Table 4, Fig. 2). Raising the percentage of inactive needles in the rib set-out repeat (X) to 37.5% resulted in a 13.2% reduction in CPC_b. The percentage of inactive needles in rib set-outs affected yarn redistribution between rib loops knitted on different needle beds of the knitting machine. The rib loops on the back side became longer than those on the face side, which explained a five times less impactful decrease than the one caused by WPC_b.

Stitch density (SD_b)

The relationship between the stitch density on the technical back side of the knitted fabrics (SD_b) and the percentage of inactive needles in the rib set-out repeat (X) is shown in Figure 3.

Variations in WPC_b and CPC_b underscore the significant impact of needle activity on the structural properties of knitted fabrics. As needle inactivity increased (variants II-VI), the overall stitch density on the back side of fabrics (SD_b) also declined significantly, with reductions ranging from 46.3% to 77.8% compared to the half Milano rib structure (variant I). This decline reflects the cumulative effect of the reduced number of wales and courses on the fabric's compactness. Moreover, as the percentage of inactive needles within the rib set-out repeat (X) increased, the stitch density exhibited a nearly linear downward trend, reaching a maximum reduction of 77.8% (Fig. 3). These findings emphasize the direct correlation between the percentage of inactive needles and the resulting fabric stitch density.

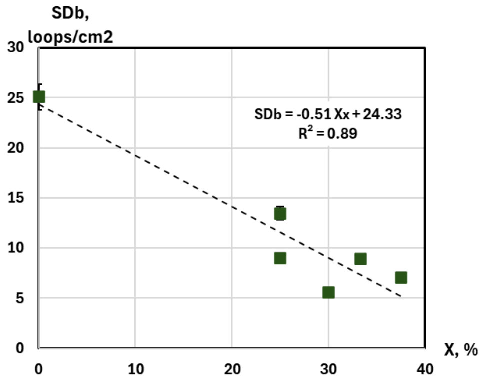


Figure 3: Relationship between the stitch density (SD_b) and the percentage of inactive needles in the rib set-out repeat (X)

Stitch length

The stitch length of the knitted fabrics, including rib stitch length (l_1), plain stitch length (l_2), and average stitch length (l_a), remained largely consistent across the fabric variants (~2-3%), except for variant VI (Table 4). This stability can be attributed to the methodology used for measuring the stitch length. The deviation observed in the rib stitch length of variant VI is likely a result of the specific rib set-out configuration used in this sample, namely, the 5×2 rib structure.

Fabric thickness (t)

The thickness (t) of the investigated knitted fabrics is strongly influenced by the rib set-out variants (Table 4). This can be explained by the structural changes introduced by inactive needles: as their percentage in rib set-outs increases up to 37.5%, fabric thickness decreases linearly by 15.3% (Fig. 4). The reduction is primarily due to a lower number of wales on the back side of the fabric (WPC_b) and the increased presence of areas composed only of knit loops on the face side (rib and plain knit loops), which have inherently smaller thickness (t') (Fig. 5). Thus, variations in rib set-out and the distribution of inactive needles provide a controllable mechanism for adjusting fabric thickness by modifying loop composition and density throughout the fabric structure.

A comparison of the fabric variants II–VI's thickness (t) with the half Milano rib structure (variant I) reveals a significant reduction as the percentage of inactive needles in the rib set-out repeat (X) rises. These reductions range from 7.9% to 21.1%.

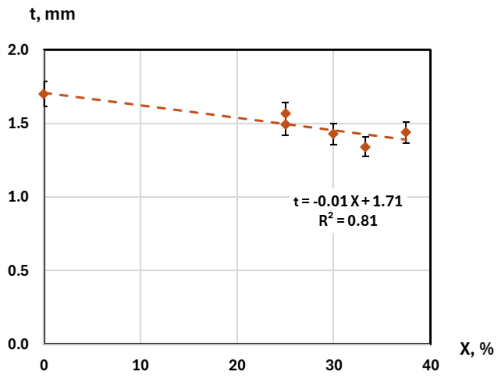
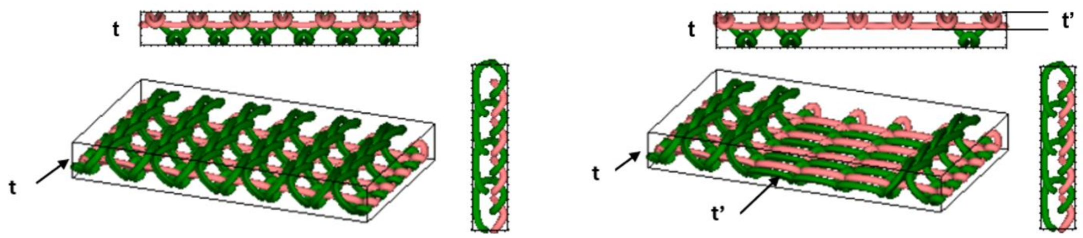


Figure 4: Relationship between the thickness of knitted fabrics (t) and the percentage of inactive needles in the rib set-out repeat (X)



a) b)

Figure 5: Visual illustrations of the knitted fabric: a) variant I, b) variant VI

Table 5

Statistical results for the determination of structural characteristics for independent samples using the t–test

Tested parameter	Values of the parameter *t* regarding the structural characteristics (df=n_1+n_2-2=18 for the WPC_b, CPC_b, l_1, l_2, t; df=n_1+n_2-2=8 for the GSM)				
	$t_{I/II}$	$t_{I/III}$	$t_{I/IV}$	$t_{I/V}$	$t_{I/VI}$
WPC_b	59.7(***)	89.7(***)	102.7(***)	94.0(***)	113.0(***)
CPC_b	15.8(***)	18.3(***)	18.3(***)	8.0(***)	17.8(***)
l_1	2.0(/)	0.5(/)	7.0(***)	4.5(***)	153.0(***)
l_2	3.0(**)	2.5(*)	17.0(***)	2.5(*)	3.5(**)
t	7.0(***)	12.0(***)	8.7(***)	4.3(***)	9.0(***)
GSM	3.1(**)	0.6(/)	5.5(***)	1.7(/)	0.6(/)

Legend: I, II, III, IV, V, VI – fabric variant; (*) 0.05 level of significance; (**) 0.01 level of significance; (***) 0.001 level of significance; df – degree of freedom, (/) no statistically significant difference

Weight (GSM)

Table 4 shows that increasing the percentage of inactive needles (X) to 37.5% results in a 13.0% decrease in the weight of knitted fabrics (GSM) due to reduced stitch density. The relationship between fabric weight and the percentage of inactive needles in the rib set-out repeat is nonlinear.

The statistical results for the determination of the number of wales and courses of the knitted fabrics for the technical back (WPC_b and CPC_b, respectively), the rib stitch length (l_1), plain stitch length (l_2), and the weight (GSM) for independent samples using the t–test are presented in Table 5.

A statistical t-test analysis (Table 5) revealed a significant difference in the number of wales (WPC_b) and courses (CPC_b) for the technical back of the knitted fabrics between variant I and variants II-VI, with a p-value of 0.001. The same trend is observed in the thickness (t) of the investigated fabrics. The structural characteristics of fabric variant VI, which has the highest percentage of inactive needles

(37.5%), showed significant differences compared to those of the half Milano rib structure (variant I). In contrast, a less significant difference was observed for plain stitch length (l_2) and weight of the knitted fabrics (GSM).

Stretch characteristics

Tables 6 and 7, and Figure 6 show the stretch characteristics of knitted fabrics in both directions (lengthwise and widthwise) after four washings. Equations (5-8) are used to calculate the values of full deformation (E) and its components – elastic (E_1), delayed (E_2), and residual (E_3) – as well as their parts (E_1/E, E_2/E, E_3/E).

The stretch properties vary based on the type of the knit structure and the yarn's stretch characteristics.[21] When knitted fabrics are subjected to tensile loading, structural elements such as loops and float loops experience stress and elongation along the direction of the applied force. The overall stretchability of the fabric is primarily governed by the redistribution of yarn within specific loop segments, including the loop head, sinker loop, and loop legs. This redistribution mechanism is further affected by the presence and length of float loops, which are directly dependent on the number of inactive needles incorporated in the knitting process. Consequently, variations in loop geometry and float loop configuration play a critical role in determining the mechanical response and extensibility of knitted fabrics under load.

In addition, fiber composition can play a significant role in determining deformation behavior. Fabrics produced from pure flax yarns, characterized by high stiffness and limited elastic recovery, typically exhibit more pronounced and less recoverable dimensional changes.[13,14] This behavior is associated with restricted loop mobility and limited capacity for elastic relaxation within the fabric structure. In contrast, PAN/flax blended yarns provide improved flexibility and resilience due to the presence of polyacrylonitrile (PAN) fibers, which contribute to improved loop recovery and reduced residual deformation after loading.

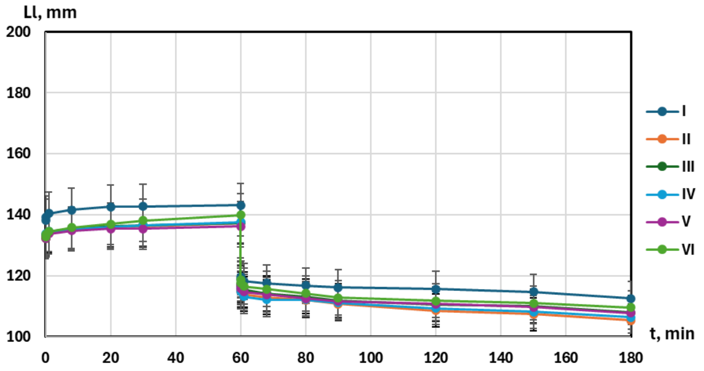
The lengthwise stretch characteristics of the fabric variants II-VI, such as full (E), elastic (E_1), and residual (E_3) deformations, are lower than those of the half Milano rib structure (Fig. 6a). Only the delayed deformation (E_2) is higher than that of the half Milano rib structure. This can be explained by the influence of the number of float loops or the number of inactive needles (X) on the redistribution of yarns during loading in the length direction.

Table 6
Lengthwise stretch characteristics of knitted fabrics after washing

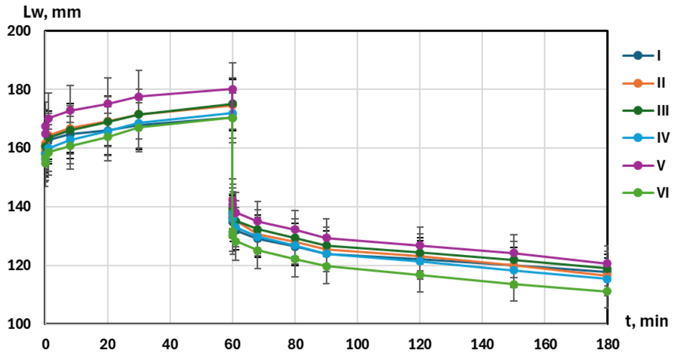
Fabric variants	X, %	Full, elastic, delayed, and residual deformations and their components						
		E	E_1	E_2	E_3	E_1/E	E_2/E	E_3/E
I	0	43.2±1.1	23.4±1.5	7.2±0.8	12.6±1.8	0.54	0.17	0.29
II	25.0	37.4±4.0	22.0±4.8	10.0±2.8	5.4±1.8	0.59	0.27	0.14
III	33.3	37.4±1.1	20.0±1.9	9.4±0.9	8.0±1.6	0.53	0.25	0.21
IV	37.5	37.6±2.3	21.8±1.1	9.4±1.5	6.4±1.7	0.58	0.25	0.17
V	25.0	37.2±1.3	20.4±2.2	9.0±0.7	7.8±1.9	0.55	0.24	0.21
VI	30.0	40.0±1.6	21.4±1.7	9.0±1.7	9.6±1.1	0.54	0.23	0.24

Table 7
Widthwise stretch characteristics of knitted fabrics after washing

Fabric variants	X, %	Full, elastic, delayed, and residual deformations and their components						
		E	E_1	E_2	E_3	E_1/E	E_2/E	E_3/E
I	0	70.4±3.4	34.2±3.2	18.4±0.9	17.8±3.2	0.49	0.26	0.25
II	25.0	74.6±5.9	37.6±3.2	20.4±1.5	16.6±3.0	0.50	0.27	0.22
III	33.3	75.2±3.8	35.8±4.4	20.4±1.1	19.0±1.6	0.48	0.27	0.25
IV	37.5	72.0±3.2	34.4±1.8	22.2±1.3	15.4±2.5	0.48	0.31	0.21
V	25.0	80.2±2.9	37.8±1.1	21.8±2.3	20.6±2.3	0.47	0.27	0.26
VI	30.0	70.4±4.7	39.0±2.9	20.2±0.8	11.1±2.8	0.55	0.29	0.16



a)



b)

Figure 6: Length changes in specimens during the 'loading-unloading-resting' cycle for knitted fabrics: a) lengthwise (L_l), b) widthwise (L_w)

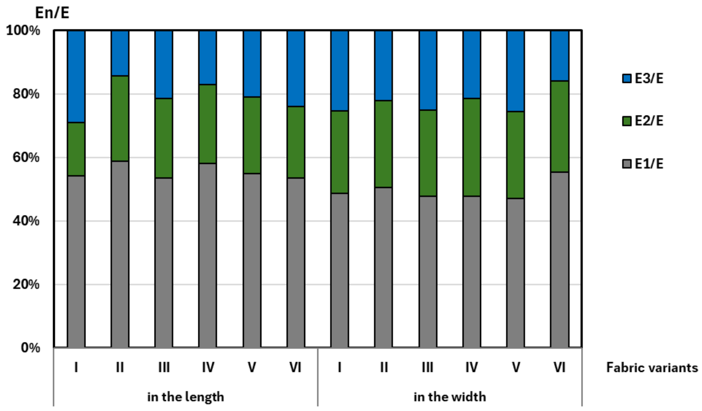


Figure 7: Lengthwise and widthwise full deformation contributors of the knitted fabrics

The widthwise stretch characteristics of fabric variants II-VI show the opposite trend to that of the lengthwise stretch. Full (E), elastic (E_1), and delayed (E_2) deformations were higher than those of the half Milano rib structure (Fig. 6b). Only residual deformation (E_3) behaves differently from the half Milano rib structure. This can be explained by the influence of the number of float loops or the number of inactive needles on the redistribution of yarns during loading in the width direction.

The lengthwise and widthwise full deformation contributions are presented in Figure 7.

Elastic deformation (E_1) results from the realignment of stress within the loops and alterations in their shape immediately following fabric unloading. Research findings indicate that elastic deformation constitutes the most significant contribution (E_1/E) to full deformation in both directions. The values range from 0.54 to 0.59 for lengthwise stretching and from 0.47 to 0.55 for widthwise stretching (Tables 6 and 7, Fig. 7). The double-knitted fabrics analyzed show reduced width stability, which should be considered in related applications.

Delayed deformation (E_2) causes gradual changes in fabric dimensions and shape during use. Its contribution to full deformation (E_2/E) across all knitted fabric variants shows slight differences, ranging from 0.17 to 0.27 lengthwise and 0.26 to 0.31 widthwise (Tables 6 and 7, Fig. 7). This trend is consistent with previous research findings.[45,22]

The residual deformation (E_3) impacts the overall performance and quality of the fabric. The contribution to full deformation of the fabrics studied (Fig. 7) lengthwise ranges from 0.14 to 0.29 (Table 6), and widthwise from 0.16 to 0.25 (Table 7). The lengthwise contribution to full deformation in knit fabrics with inactive needles is less than that of a half Milano rib structure.

A statistical analysis using t-tests (Table 8) showed a significant difference only in lengthwise full (E_1) and residual deformation (E_3), with levels of 0.001, 001, and 0.05, and less influence on widthwise full (E), elastic (E_1), and residual (E_3) deformations. Based on the results, the number of inactive needles (X) has a greater impact on lengthwise full and residual deformations than on widthwise deformations.

Table 8
Statistical results for the determination of stretch characteristics for independent samples using the t–test

Tested parameter		Values of parameter *t* regarding the stretch characteristics (df=n_1+n_2-2=8)				
		$t_{I/II}$	$t_{I/III}$	$t_{I/IV}$	$t_{I/V}$	$t_{I/VI}$
Lengthwise	E	3.2(*)	8.3(***)	4.9(**)	7.9(***)	3.7(*)
	E_1	0.6(/)	3.2(*)	1.9(/)	2.5(*)	2.0(/)
	E_2	2.1(/)	4.1(**)	2.9(*)	3.8(**)	2.1(/)
	E_3	6.3(***)	4.3(**)	6.5(***)	4.1(**)	3.2(*)
Widthwise	E	1.4(/)	2.1(/)	0.8(/)	5.0(**)	0.0(/)
	E_1	1.7(/)	0.7(/)	0.1(/)	2.4(*)	2.5(*)
	E_2	2.6(*)	3.1(*)	5.4(***)	3.1(*)	3.3(*)
	E_3	0.6(/)	0.8(/)	1.3(/)	1.6(/)	3.5(**)

Legend: I, II, III, IV, V, VI – fabric variant; (*) 0.05 level of significance; (**) 0.01 level of significance; (***) 0.001 level of significance; df – degree of freedom, (/) no statistically significant difference

CONCLUSION

This study provides insights into the structural and stretch characteristics of six variants of the double weft-knitted fabrics produced from 29 × 2 tex PAN/viscose/flax yarn, constructed by alternating two courses: rib set-out and plain. The research specifically examined the influence of varying the number of inactive (X) needles on the back bed of a 10-gauge flat-bed knitting machine, with values ranging from 1 to 3. The findings highlight how fabric variants, particularly the proportion of inactive needles on the back bed (X), affect the fabric's dimensional stability over four washing cycles, its structural properties post-washing, and its stretch behavior relative to a half Milano rib structure.

The analysis of the results led to the findings below.

- Lengthwise dimensional changes in knitted fabrics are greater than widthwise, with the most significant changes occurring after the first washing cycle, emphasizing the substantial impact of initial washing on fabric stability. In summary, incorporating inactive needles into the rib set-out repeat reduces lengthwise shrinkage, balances widthwise dimensional change, and thereby enhances the overall dimensional stability of knitted fabrics.
- Increasing the percentage of inactive needles in the rib set-out repeat causes a nearly linear decline in the number of wales and courses, and fabric stitch densities, highlighting needle activity as a key determinant of knitted fabric compactness.
- The stitch length of knitted fabrics remained stable across most variants, while fabric thickness and weight consistently decreased with higher percentages of inactive needles in the rib set-out. These results demonstrate that introducing inactive needles provides a controlled way to adjust fabric density and thickness without substantially affecting stitch length, offering a practical tool for optimizing knitted fabric properties.
- The study confirms that the incorporation of inactive needles and resulting float loops significantly influences the stretch behavior of double-knitted fabrics. Elastic deformation (E_1) is the dominant component of full deformation in both directions, while delayed (E_2) and residual (E_3) deformations play secondary roles. Overall, fabrics with inactive needles exhibit reduced lengthwise deformation, but reduced width stability, indicating that loop geometry and float configuration are key factors governing the mechanical response and should be carefully considered in design and application.

In conclusion, the analysis underscores the significant impact of rib set-out repeats on key performance aspects of knitted fabrics, including dimensional changes, weight, and deformation behavior. These results offer practical guidance for designers and manufacturers to optimize fabric structures, enhancing dimensional stability and stretch performance, and tailoring materials to meet the requirements of diverse applications.

REFERENCES

[1] Textile Exchange, https://textileexchange.org/knowledge-center/reports/materials-market-report-2024/, Accessed July 17, 2025

[2] A. Gojic and N. Bukhonka, in *Procs. ICPAE 2023*, Zrenjanin, August 24-26, 2023, pp. 95-100

[3] R. M. Kozlowski and M. Mackiewicz-Talarczyk, "Handbook of Natural Fibres: Processing and Applications", edited by R. M. Kozlowski and M. Mackiewicz-Talarczyk, 2nd ed., Woodhead Publishing, Cambridge, England, 2012

[4] J. Müssig, "Industrial Applications of Natural Fibres: Structure, Properties and Technical Applications", Wiley, 2010, https://doi.org/10.1002/9780470660324

[5] B. Güler, F. Demirci, A. Oruç and A. Kaya, *Eur. J. Res. Develop.*, **3**, 1 (2023), https://doi.org/10.56038/ejrnd.v3i4.301

[6] E. Adomaviciute, J. Baltusnikaite-Guzaitiene, V. Jonaitiene and S. Stanys, *Fibres Text. East. Eur.*, **23**, 45 (2015), https://doi.org/10.5604/12303666

[7] L. N. Chen, F. R. Kong and R. C. Xu, *Adv. Mater. Res. AMR*, **627**, 33 (2012), https://doi.org/10.4028/www.scientific.net/amr.627.33

[8] J. Harwood, P. McCormick, D. Walrom and R. Bonadei, *Ind. Crop. Prod.*, **27**, 22 (2008), https://doi.org/10.1016/j.indcrop.2007.06.004

[9] M. F. M. Ghowdhury and M. N. Islam, *Heliyon*, **8**, e10161 (2022), https://dx.doi.org/10.2139/ssrn.4107463

[10] I. V. Goudar and S. D. Kulloli, *Pharm. Innov. J.*, **9**, 378 (2020)

[11] A. Sevkan and H. Kadoglu, *J. Text. Apparel*, **22**, 218 (2012)

[12] A. F. Bogdan, *PhD Thesis*, De Montfort University, United Kingdom, 2008

[13] N. P. Bukhonka, *J. Eng. Fibers Fabrics*, **18**, (2023), https://doi.org/10.1177/15589250231181701

[14] N. Bukhonka, *Cellulose Chem. Technol.*, **59**, 601 (2025), https://doi.org/10.35812/CelluloseChemTechnol.2025.59.53

[15] K. A. Asanovic, M. M. Kostic, T. V. Mihailovic, N. Bukhonka and S. B. Miletic, in *Procs. International Conference Contemporary Trend and Innovations in Textile Industry*, September 15-16, 2022, pp. 99-108

[16] K. A. Asanovic, M. M. Kostic, T. V. Mihailovic, I. Cvejetic, N. Bukhonka *et al.*, in *Procs. 13th International Scientific-Professional Conference "Textile Science and Economy"*, October 21, 2022, pp. 65-70, https://doi.org/10.1177/15589250231181701

[17] K. A. Asanovic, T. V. Mihailovic, N. Bukhonka, I. Cvijetic, M. Reljic *et al.*, *Cellulose Chem. Technol.*, **56**, 419 (2025), https://doi.org/10.35812/CelluloseChemTechnol.2025.59.37

[18] K. Asanovic, N. Bukhonka, T. Mihailovic, I. Cvejetic, M. Reljic *et al.*, in *Procs. VI International Conference Contemporary Trends and Innovations in the Textile Industry*, September 14-15, 2023, pp. 116-124

[19] F. A. Moiseenko and N. P. Bukhonka, "Fundamentals of the Structure and Computer Design of the Knitted Fabrics", edited by F. A. Moiseenko and N. P. Bukhonka, Kyiv, Center for Educational Literature, 2004 (in Ukrainian)

[20] A. Kurbak and T. Alpyildiz, *Text. Res. J.*, **79**, 495 (2009), https://doi.org/10.1177/0040517508096217

[21] N. P. Bukhonka and O. P. Kyzymchuk, *J. Eng. Fibers Fabr.*, **18**, 1 (2023), https://doi.org/10.1177/15589250231210954

[22] N. P. Bukhonka and O. P. Kyzymchuk, *J. Eng. Fibers Fabr.*, **19**, 1 (2024), https://doi.org/10.1177/15589250241255099

[23] N. P. Bukhonka, A. Vukadinovic and A. O. Kyzymchuk, *AATCC J. Res.*, **13**, 1 (2026), https://doi.org/10.1177/24723444261435018

[24] R. Sathyam, C. Prakash, S. K. Kubera, R. Rathinamoorthy, K. V. Kumar *et al.*, *J. Test. Eval.*, **50**, 20210257 (2022), https://doi.org/10.1520/JTE20210257

[25] A. Assefa and N. Govindan, *J. Eng. Fibers Fabr.*, **15**, (2020), https://doi.org/10.1177/1558925020928532

[26] M. S. Choi and S. P. Ashdown, *Text. Res. J.*, **70**, 1033 (2000), https://doi.org/10.1177/00405175000700120

[27] A. Assefa and N. Govindan, *J. Eng. Fibers Fabr.*, **15**, 1 (2020), https://doi.org/10.1177/1558925020928532

[28] N. P. Bukhonka and J. P. Stupaka, *Visnik KNUTD*, **6**, 112 (2007)

[29] N. P. Bukhonka and J. P. Stupaka, *Visnik Hmeljnickog Nacionalnog Universiteta*, **3**, 191 (2008)

[30] N. P. Bukhonka, in *Procs. 44th Congress of IFKT*, September 21-26, 2008

[31] N. Bukhonka, *AATCC J. Res.*, **11**, 241 (2024), https://doi.org/10.1177/24723444241237314

[32] V. Tunakova, M. Tunak, V. Bajzik, L. Ocheretna, S. Arabuli S *et al.*, *J. Eng. Fibers Fabr.*, **15**, 1 (2020), https://doi.org/10.1177/1558925020925397

[33] D. L. Munden, *J. Text. Inst.*, **51**, 200 (1960), https://doi.org/10.1080/19447016008664427
[34] L. Onal and C. Candan, *Text. Res. J.*, **73**, 187 (2003), https://doi.org/10.1177/004051750307300301
[35] I. I. Shalov and L. A. Kudrjavin, "Basics of Designing Knitwear Production with CAD Elements", edited by I. I. Shalov and L. A. Kudrjavin, 2nd ed., Moscow, Legprombitizdat, 1989 (in Russian)
[36] ISO 139:2005 Textiles - Standard atmospheres for conditioning and testing
[37] ISO 6330:2021 Textiles - Domestic washing and drying procedures for textile testing
[38] ISO 5077:2007 Textiles - Determination of dimensional change in washing and drying
[39] EN 14971:2006 Textiles - Knitted fabrics - Determination of number of stitches per unit length and unit area
[40] GOST 8846-87 Knitted fabrics and garments. Methods for determination of linear dimensions. distortion. number of courses and wales and yarn length in the loop (updated 01.01.2021)
[41] EN 14970:2006 Textiles - Knitted fabrics - Determination of stitch length and yarn linear density in weft knitted fabrics
[42] EN 12127:1997 Textiles - Fabrics - Determination of mass per unit area using small samples
[43] ISO 5084:1996 Textiles - Determination of thickness of textiles and textile products
[44] GOST 8847-85: Knitted fabrics – Methods for the determination of breaking characteristics and extensibility under loads less than breaking loads, updated 01.01.2023
[45] J. Sang, M. Lee and M.-J. Park, *Fashion Textiles*, **2**, 22 (2015), https://doi.org/10.1186/s40691-015-0047-4