THE IMPACT OF TYPE RELAXATIONS ON THE STRUCTURAL CHARACTERISTICS AND DIMENSIONAL STABILITY OF HALF MILANO RIB COTTON KNITTED FABRICS

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This study aimed to investigate the effects of washing and ironing on the dimensions of cotton yarn and the structural characteristics in half Milano rib knitted fabrics made from this yarn. The primary objective was to understand the impact of different relaxation methods on the dimensional stability of both yarn and fabric, as well as on the structural properties of the resulting fabric. Specifically, the study looked at the effects of three distinct relaxation methods: dry relaxation over ten days, five cycles of ironing, and ten rounds of washing. The study found that dry relaxation had minimal effects on the structural characteristics of the knitted fabrics. On the other hand, washing significantly impacted the fabric's structural properties. The study aimed to compare dimensional changes in yarn and knitted fabrics. The results indicated similarities, particularly in the lengthwise shrinkage observed in fabrics and yarn during the initial five ironing cycles. However, after two washes, distinct dimensional changes became apparent. The experiment highlights the dimensional changes in yarn and fabrics, which exhibit similarities, particularly in lengthwise shrinkage, and become more pronounced with repeated washings. These research findings provide valuable insights into identifying optimal relaxation methods to achieve dimensional stability in cotton yarn and knitted fabrics.

Keywords: yarn; knit fabrics; structural characteristics; dimensional stability; relaxation

Introduction

Different factors, such as mechanical loads, moisture, and heat, can cause deformations like stretching, bending, and changes in linear dimensions during clothing production. These changes can affect the appearance of the clothing and sometimes make it unusable. Therefore, it is important to consider the ability of knitwear to change linear dimensions under the influence of moisture and heat. It is also important to consider the factors that affect the stability of the shape of knitwear during the design stage.

Using cotton yarn and knitted fabrics in commercial garments can be challenging due to their properties, such as shrinking when exposed to moisture and laundering. This often leads to customer dissatisfaction. The yarn used in fabric formation is consistently under stress during knitting. The knit structure is subjected to tensions from various sources like input yarn tension and take-down tension, which leads to fabric distortion compared to its naturally relaxed state. Once the fabric is removed from the knitting machine, it starts to relax and overcome these stresses. Even without yarn shrinkage, knitted fabrics change in length and width, indicating a change in loop shape and loop length [1, 2].

The structural characteristics and dimensional stability of cotton weft-knitted fabrics have been studied extensively, particularly with different knit structures and types of yarn. Early investigations focused on factors such as yarn type and its characteristics [3-10], knit structure and its characteristics [11, 24], loop length [15], knitting machine parameters [3], and type of relaxation [17-20], which affect the dimensional properties of knitted fabrics. The studies examined various knit structures such as plain, 1x1 rib, half Milano and Milano rib, miss and tuck stitches, and their combinations.

The knit structure of a fabric is widely recognized as an important determinant of its overall characteristics, encompassing dimensional stability, stretch properties, and other properties. As such, a comprehensive understanding of the intricacies of knit structure is essential to developing high-quality fabrics. Specific parameters of a knit structure, including loop length, loop shape, and yarn type, can significantly impact fabric properties [1, 2]. The knit structure of a fabric is important in determining its flexibility, relaxation rate, and yarn orientation within loops. These factors

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collectively influence the fabric's behavior and performance. The specific arrangement and type of stitches used in different knit structures can have a significant impact on the final properties of the fabric. Stitches like knit, miss, and tuck can create varying fabric properties, leading to differences in their performance and behavior [3, 12, 21]. To produce a fabric that is of high quality and appropriate for its intended purpose, it is important to carefully consider the primary characteristics of each knit structure. By selecting the most suitable structure, one can ensure that the fabric has the desired properties and is fit for purpose [22-25]. Selecting the suitable knit structure for cotton knitted fabrics is of utmost importance in effectively enhancing the desirable fabric properties such as smoothness of the surface, air permeability, heat transmittance, and hydrophilicity [26].

When creating a new knitted fabric structure that combines single and double-knit, the ratio of the two structures and the number and layout of stitch courses in the height repeat should be considered. These factors significantly influence the fabric's structural characteristics and end-use properties [3, 12]. The ratio of the length of yarn in the plain and rib courses in half Milano rib and Milano knit fabrics is an important factor in achieving a stress-free structure [27]. The structural properties of weft double-knitted fabrics are contingent on the width of repeat of the miss knit stitches based on plain and rib knit structures [22, 28]. The width of repeat of the miss knit stitches based on plain and 1x1 rib knitted fabrics produced from a blended cotton/flax (70% cotton, 30% flax) yarn of 25x2tex x2 influences the structural parameters but not the dimensional stability when washed [29, 30].

The dimensional stability of knitted fabrics depends on the type of yarn used. The dimensional and mechanical properties of cotton fabrics knitted in single jersey, single lacoste, and double pique depend significantly on the length of yarn used and the type of knit structure used [31]. The dimensional, pilling, and abrasion properties of plain, double pique (lacoste), and two-thread fleece knitted fabrics made from the cotton ring and open-end spun cotton/polyester yarns are influenced by the type of knit structure and yarn used [32]. To achieve the desired thermo-physiological comfort properties in knitted fabrics made from cotton and cotton/elastane yarns, it is crucial to carefully consider the type of yarn used [33].

The greatest impact on linear dimensions is caused by wet heat treatments, especially during washing and soaking. The first wash has resulted in the most significant dimensional changes for knitted fabrics [34]. Miss loop stitches can improve a fabric's dimensional stability compared to those with only knit stitches. Wet treatments modify the loop structure, with thread and fiber structure changes playing a secondary role. Longer thread loops increase lengthwise shrinkage and decrease widthwise shrinkage. The loop shape and stitch length are the main factors affecting the dimensional properties of cotton knitted fabrics [35]. The dimensional properties of plain knitted fabrics are significantly influenced by the laundering process and the amount of fabric used. It's important to keep this in mind when caring for your knitted clothes to ensure they maintain their shape and size over time [17-20]. The dimensional changes of pique double knitted fabrics after washing are determined by their structural parameters [36]. The study conclusively demonstrates that the dimensional stability of knitted fabrics is solely determined by the raw materials used [37].

The lengthwise dimensional change of 1x1 rib knitted fabrics is directly influenced by the length of the yarn loop, particularly when made from cotton yarns of varying counts (26 Ne, 28 Ne, and 36 Ne) [38]. The dimensional stability of single jersey, 1x1 rib, and interlock knitted fabrics is unequivocally attributed to the loop configuration in each relaxation state, rather than any changes in yarn length [39]. The number of washing treatments is crucial in determining the dimensional stability of knitted fabrics from cotton/flax blended yarn [40]. To ensure the dimensional stability of 100% cotton honeycombed pique knit fabric, it is important to consider resin finishing [41].

This investigation provides insights into the structural properties and dimensional stability of half Milano rib weft-knitted fabrics made from 72 tex cotton yarn. The study also investigates the dimensional change of cotton yarn during two types of relaxation to gain insights into the dimensional change of knitted fabrics. Cotton fabric is widely used in clothing production for the spring-summer season due to its numerous positive characteristics. This study aims to enhance the quality of cotton clothing by investigating the impact of washing and ironing on the structural characteristics and dimensional stability of half Milano knit fabric. The results are anticipated to offer valuable insights into the impact of washing and ironing on fabric properties, providing valuable information for the creation of comfortable apparel.

Material and methods

Yarn

To achieve an optimal outcome, it's important to take into account the physical and mechanical characteristics of the yarn, including its smoothness, breaking elongation, and strength. These properties are important during the knitting process on machines and during the use of the final product. The yarn is subjected to various forces during processing and use, which can cause it to break. Therefore, the breaking force and elongation indicators measure the yarn's ability to withstand tensile loads without breaking [3].

The research used 72 tex pure cotton yarn. The main characteristics of this yarn are presented in Table 1, providing a comprehensive overview of its properties.

To achieve optimal knitting results, treating the yarn with wax before commencing the knitting process is crucial. In this project, the yarn was treated with wax to ensure the best possible outcome.

Table 1. The main characteristics of the cotton yarn

Characteristics of the yarn	Value
Materials of yarn (%)	100% cotton
Nominal linear density T_n (tex)	72
Experimental linear density T_e (tex)	68± 0,77
Twist	Z
Tenacity P_u (cN/tex)	7.6±0.18
Breaking elongation E (%)	2.38±0.20
Time of breaking t_p (s)	12.9±1.05

Determination of the dimensional and mechanical properties of the yarn

The following parameters were measured after being subjected to a standard atmosphere, as per ISO 139:2005 [42]:

- Experimental linear density (T_e) was measured as per ISO 2060:2012 [43]. These results are based on an average of twenty measurements.
- Strength (breaking force and tenacity (P_u)), as well as breaking elongation (E) and time of breaking (t_p), were measured as per ISO 2062:2012 [44] and ISO 6939:1988 [45]. The following results are based on an average of fifty measurements.

Determination of dimensional change of the yarn

The yarn samples were conditioned by ISO 139:2005 [42]. Subsequently, the samples underwent two distinct relaxation techniques, namely ironing relaxation (IR) and washing relaxation (WashR):

- Ironing relaxation (IR): The yarn samples underwent ironing at 180 °C, with five ironing cycles (K). A relaxation period of one day was observed between each ironing under standard atmospheric conditions to relax according to ISO 139:2005 [42]. After every ironing, measurements were conducted to assess potential changes in dimensions in length according to formula (1).
- Wash relaxation (WashR): After being left to dry for one day, the yarn samples were washed using a cotton program at 40 °C in a fully automatic washing machine. An efficient wetting agent of 3 g/L was added during the wash. After each washing and drying cycle, the yarn was placed on a flat surface with minimal stress, under a controlled atmosphere for at least 24 hours, per ISO 6330:2021 [46]. This process was repeated for 10 washing and drying cycles (K). After every wash, measurements were taken to determine any changes in dimensions in length according to formula (1).

The calculation of dimensional change (DC) in %, whether it is shrinkage (-) or expansion (+) is determined as follows (1):

$$\text{Dimensional change} = 100 \cdot \frac{\text{final measurement} - \text{original measurement}}{\text{original measurement}} \quad \text{........(1)}$$

where: the final measurement (FM) is a measurement taken after relaxation in mm, the original measurement (OM) was 100 mm for yarn.

To conduct these tests, yarn samples were prepared with a total length of 10 meters, with marked samples of 100 mm in length ("original measurement") with a total of 10 measurements per sample. This allowed for multiple samples to be taken during each relaxation technique, ensuring the results would be accurate and reliable. Overall, five total yarn samples were used for these tests.

Knit fabrics

Double weft knitted fabrics were produced on a 10-gauge flat bed-knitting machine. Throughout the sample production, the main knitting parameters, such as the position of the machine stitch cam, yarn input tension, and knitted fabric take-downs, remained unchanged. The stitch cams of both cam systems were set up at the same depth, and their optimal levels were adjusted to produce knits with a loop module of σ=21. This value of the loop module is commonly used in commercially produced fabrics.

Figure 1 presents a graphical representation, knitting notation, and visual illustrations of half Milano rib knit structure.

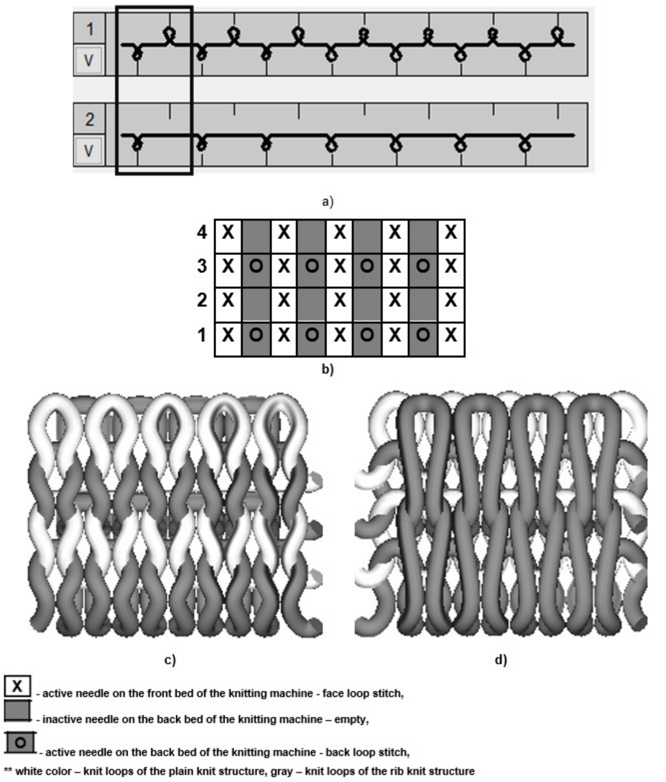

Figure 1. Graphical representation (a), knitting notation (b), and visual illustrations for the technical face (c) and back (d) of half Milano rib structure

The half Milano rib knit structure is created using two types of stitches made on two knitting machine cam systems. These two types of stitches repeat vertically R_h: 1x1 rib and plain. The first cam system creates 1x1 rib stitches, the second cam system creates plain stitches on the front needle bed of the knitting machine. Half Milano rib knitted fabrics have a different structure on the technical face and back. The technical face comprises knit loops of the 1x1 rib stitch and plain (Figure 1, c). On the other hand, the technical back of the half Milano rib knitted fabrics is composed of knit loops of the 1x1 rib (Figure 1, d).

Determination of structural characteristics of the knitted fabrics

The structural characteristics of the knitted fabrics were measured by the following parameters:

- The number of wales (WPC) and courses (CPC) per centimeter were determined according to EN 14971:2006 [47]. Measurements were taken for the technical back (WPC_b, CPC_b). The results represent an average of ten measurements of the number of wales and courses of a fabric sample per 10 centimeters and are then calculated as a value per centimeter. The number of wales and courses for the technical face (WPC_f, CPC_f) in loops/cm could not be measured due to the irregularity of the structure caused by the plain stitches.
- The length of yarn of the one loop (l) in mm – determined as an average of ten unrowed courses for each stitch in the knit structures repeated at height R_h (double stitch – l_1 and singe stitch – l_2) according to the EN 14970:2006 [48].
- The weight (W_s) in the g/m² was determined as an average from the mass of five samples, each having an area of 200 cm² according to EN 12127:1997 [49].
- The fabric thickness (t) in millimeters is calculated based on measurements taken at ten different locations on each sample, following ISO 5084:1996 standards [50].

After measurements the following parameters were calculated:

- The average length of yarn of one loop (l_a) in mm was determined using the formula (2):

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

where: l_a – the average length of yarn of one loop (mm), l_1 – the length of yarn of the one loop of double stitch (mm), l_2 – the length of yarn of the one loop of the single stitch (mm).

- The fabric stitch density for the technical back (Sb) in loops/cm² calculated according to the equations (3):

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

where: WPC_b and CPC_b are the number of wales per centimeter and the number of courses per centimeter for the technical back (loops/cm), respectively.

The fabric stitch density for the technical face (S_f) in loops/cm² could not be accurately calculated due to the irregularity of the structure caused by the plain stitches.

Determination of dimensional change of the knitted fabrics

Knitted fabrics need to maintain their dimensional stability, which is affected by residual stresses that yarns may retain during knitting. The post-production relaxation process is critical to alleviating these stresses and can be done through dry or wet processing. This allows the fabric to regain its intended size and shape, which is essential to ensure its structural characteristics are not compromised. Therefore, relaxation plays a crucial role in determining the properties of knitted fabrics. After being knitted, the fabric samples underwent a series of relaxation types to reduce the stress caused during the process:

- Dry relaxation (DR): After knitting, the knitted samples were laid flat for 10 days under standard atmospheric conditions to relax according to ISO 139:2005 [42]. The dimensional changes were measured after 1st (DR1) and 10th (DR10) days of dry relaxation.
- Ironing relaxation (IR): After drying, the fabric samples underwent ironing at 180 °C, with five ironings (K). A relaxation period of one day was between each ironing under standard atmospheric conditions to relax according to ISO 139:2005 [42]. The dimensional changes were calculated after each ironing.
- Wash relaxation (WR): After being left to dry for one day, the fabric samples were washed using a cotton program at 40 °C in a fully automatic washing machine. An efficient wetting agent of 3 g/L was added during the wash. After each washing and drying cycle, the fabrics were placed on a flat surface with minimal stress under a controlled atmosphere for at least 24 hours, per ISO 6330:2021 [46] This process was repeated for 10 washing and drying cycles (K). After every cycle, measurements were done.

The dimensional change DC of the knitted fabrics in the length and width is calculated using the formula (1). Ten measurements were done for each direction of the knitted fabrics (lengthwise and widthwise), and the mean value was used as dimensional change. The original measurement (OM) was 200 mm for knitted fabrics.

Results and discussion

Dimensional changes in the yarn

As mentioned in the “Materials and Methods” section the yarn samples were subjected to a series of relaxation techniques to reduce the stress accumulated during the manufacturing process. The primary objective of these techniques was to investigate the effect of ironing (IR) and washing (WR) treatments and their number (K) on the dimensional changes of the yarn (DC).

Table 2 shows the final measurement (FM) of the cotton yarn and calculated dimensional change (DC) after undergoing one-day and ten-day relaxation, five ironing (IR), and ten washing (WR) cycles. To calculate the dimensional change (DC) of the cotton yarn in length, use formula (1). The yarn's shrinkage after dry relaxation is approximately 2.1%, and it is not dependent on the number of days of relaxation, as shown in Table 2. The graphical representation depicted in Figure 2 represents the correlation between the number of yarn ironing and washing cycles (K) and the resultant dimensional change after ironing DC (IR) and washing DC (WR).

Table 2. The final measurements (FM) and dimensional changes (DC) of the cotton yarn after dry relaxation (DR), ironing (IR) and washing (WR)

The number of days or cycles (K)	TYPE OF RELAXATİON					
	dry (DR)		ironing (IR)		washing (WR)	
	FM, mm	DC, %	FM, mm	DC, %	FM, mm	DC, %
1	97.9±0.33	-2.1	96.2±0.67	-3.8	95.8±0.83	-4.2
2	-	-	94.9±0.78	-5.1	95.1±0.60	-4.9
3	-	-	95.7±0.50	-4.3	95.1±0.33	-4.9
4	-	-	94.4±0.53	-5.6	94.4±0.53	-5.6
5	-	-	93.9±0.78	-6.1	93.8±0.44	-6.2
6	-	-	-	-	93.7±0.50	-6.3
7	-	-	-	-	93.7±0.52	-6.3
8	-	-	-	-	93.7±0.54	-6.3
9	-	-	-	-	93.7±0.51	-6.3
10	97.8±0.44	-2.2	-	-	93.7±0.53	-6.3

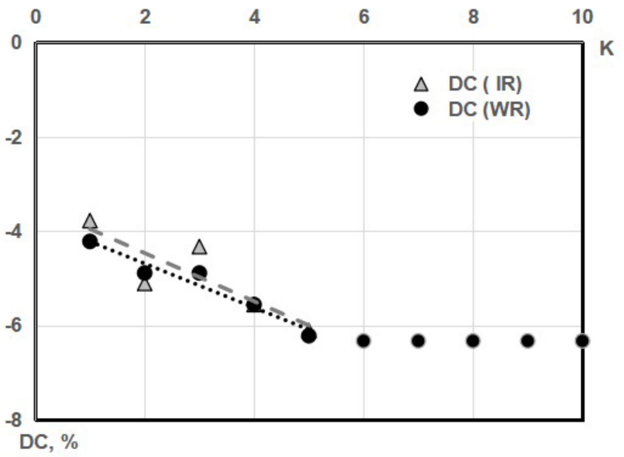

Figure 2. The relation between the dimensional change of yarn after ironing DC (IR) and washing DC (WR) and the number of cycles K

Based on the findings presented in Figure 2, it can be concluded that the shrinkage of the yarn after ironing DC (IR) and washing DC (WR) cycles is comparable during the first five cycles. The level of shrinkage after five ironing cycles ranges from -3.8% to -6.1%, while the shrinkage after the first five washing cycles ranges from -4.2% to -6.3%. The dependence of dimensional changes (DC) after ironing and washing on the number of the ironing and washing cycles (K) can be presented with a coefficient of determination R^2=0.94 as follows:

$$\mathrm{DC} = -0.47 \cdot \mathrm{K} - 3.76 \qquad (4)$$

where K – the number of ironing and washing cycles.

The research also indicates that the most significant dimensional changes occur in the yarn after the 4-5 washes. Thus, it is essential to consider these findings while designing and producing knitted fabrics.

The structural characteristics of the knitted fabrics

As stated in the experimental section, all the knitted fabrics under investigation were knitted using a pure cotton yarn of 72 tex. The current section focuses on the impact of types of relaxation on the structural parameters of the knitted fabric tested. The main structural characteristics of the fabric, including the number of wales (WPC) and courses (CPC), stitch density (S), average loop length of yarn (l_a), weight (W_s), and fabric thickness (t), are important in determining the fabric's behavior during wearing and washing. These properties play a significant role in defining the fabric's dimensional properties; thus, their consideration is paramount.

The structural characteristics of the half-Milano knitted fabrics are presented in Table 3. Figure 3 illustrates the number of wales (WPC) and courses (CPC) per centimeter for the technical back of the half Milano rib knitted fabrics.

Table 3: Experimental values of structural characteristics of half Milano rib knit fabrics after relaxation

Type of relaxation	WPC_b, loops/cm	CPC_b, loops/cm	S_b, loops/cm^2	l_1, mm	l_2, mm	l_a, mm	W_s, g/m^2	t, mm
DR1	5.7±0.08	8.1±0.07	46.44±0.76	5.76±0.04	5.69±0.06	5.72±0.04	225.7±6.93	1.50±0.05
DR10	5.7±0.05	8.0±0.02	45.72±0.95	5.76±0.04	5.69±0.06	5.72±0.04	230.9±6.51	1.50±0.05
IR1	5.6±0.08	7.8±0.09	43.68±0.83	5.86±0.08	5.71±0.06	5.78±0.05	260.5±3.98	1.52±0.04
IR2	5.6±0.04	7.8±0.05	43.30±0.34	5.97±0.10	5.67±0.09	5.82±0.06	271.5±4.34	1.52±0.04
IR3	5.6±0.05	7.8±0.05	43.17±0.42	6.00±0.07	5.66±0.14	5.83±0.07	272.8±4.43	1.52±0.04
IR4	5.6±0.05	7.7±0.05	43.03±0.45	6.00±0.07	5.69±0.16	5.85±0.08	278.4±10.52	1.52±0.04
IR5	5.5±0.05	7.7±0.04	42.77±0.48	6.01±0.07	5.72±0.12	5.86±0.06	283.1±9.03	1.46±0.07
WR1	6.0±0.09	8.5±0.07	51.35±0.84	5.94±0.09	5.73±0.05	5.84±0.07	272.4±4.29	1.54±0.05
WR4	6.0±0.07	8.5±0.07	51.52±0.70	6.00±0.12	5.83±0.06	5.91±0.06	283.2±3.97	1.66±0.05
WR10	6.0±0.05	8.5±0.06	51.38±0.60	6.00±0.13	5.87±0.06	5.94±0.07	286.5±3.51	1.69±0.03

As explained in the "Materials and Methods" section, the structure of half Milano rib knitted fabrics differs on the technical face and back sides. The technical face consists of knit loops in a 1x1 rib stitch and plain, while the technical back comprises knit loops in a 1x1 rib. After analyzing the technical back of knitted fabrics following dry relaxation (DR) and ironing relaxation (IR), it was found that both types of relaxation have similar effects on the number of wales and courses (Figure 3).

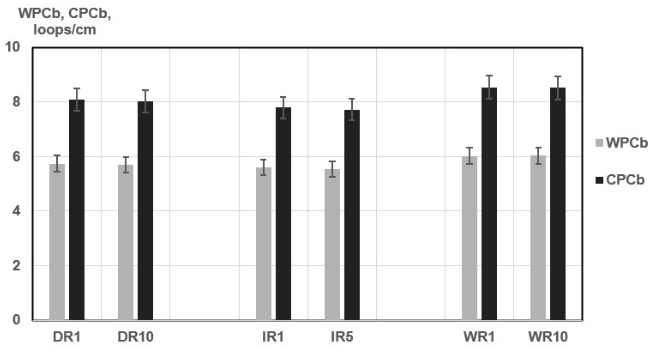

Figure 3. The number of wales and courses per centimeter for the technical back of the half Milano rib knitted fabrics

Dry relaxation has no significant impact on the structural characteristics of knitted fabrics, as shown in Table 3 and Figure 3. On the other hand, ironing relaxation can increase the weight of the fabrics (Table 3). However, the number of wales and courses and the yarn length remain unchanged (Table 3). After subjecting the knitted fabric to ten washing cycles, it was observed that the weight of the fabric increased by 5.2%, while the thickness increased by 9.7%. This finding is significant as it suggests that the fabric may have undergone some changes in its structural integrity due to the washing process. In the meantime, the relaxation process after ironing and washing differs, which explains the variations in the structural properties of the knitted fabrics.

After comparing the structural characteristics of half Milano knitted fabrics that underwent five ironing relaxations and ten washes with those that had ten days of dry relaxation, it was found that washing had the most significant influence on the fabric's structure. After five ironing relaxations (IR5), the number of wales and courses decreased by 3.3% compared to that after ten days of dry relaxation (DR10). However, the number of wales on the technical back and courses increased by approximately 3.4-6.3%.

After undergoing ironing and washing relaxations, the length of the yarn loop in double stitch (l_1), single stitch (l_2), and the average length of yarn loop (l_a) slightly increased by roughly 3.8% in comparison to that after ten days of dry relaxation (Table 3). Additionally, the weight of the knitted fabrics increased by approximately 21.6% after ironing and washing relaxations, compared to the weight of the knitted fabrics after dry relaxation. Moreover, the thickness of the knitted fabrics increased by 8.7% after washing, which can be explained by an increase in the weight of the knitted fabric.

The dimensional change of the knitted fabrics

A critical aspect of knitwear is its ability to maintain its dimensions, which greatly affects the consumer properties of the final product. During the knitting process, the yarn and resulting knitwear are subject to various influences, including bending, stretching, and friction, accumulating residual stresses. After the knitting process, relaxation, achieved through either dry or wet processing, is important in releasing these stresses.

Tables 4 and 5 present the final measurements (FM) and dimensional changes (DC) for half Milano rib knitted fabrics in both directions (length and width) after one day and ten days of dry relaxation (DR), five ironing (IR), and ten washing (WR). Using the formula (1), the dimensional changes of the fabrics in length and width were calculated. The original measurement (OM) of the fabric was 200 mm.

Table 4. The final measurements (FM_l) and dimensional changes for the half Milano knitted fabric in the length (DC_l) after dry relaxation (DR), ironing (IR), and washing (WR)

The number	TYPE OF RELAXATİON					
of days or	dry (DR)		ironing (IR)		washing WR)	
cycles (K)	FM_l, mm	DC_l, %	FM_l, mm	DC_l, %	FM_l, mm	DC_l, %
1	194.3±0.95	-2.8	190.5 ±1.72	-4.8	177.4±1.36	-11.3
2	-	-	189.5±2.46	-5.3	176.7±1.01	-11.7
3	-	-	186.7±1.34	-6.7	175.3±1.00	-12.4
4	-	-	186.5±1.18	-6.8	175.2±0.46	-12.4
5	-	-	185.3±1.06	-7.3	175.6±1.07	-12.2
6	-	-	-	-	175.2±0.92	-12.4
7	-	-	-	-	174.8±1.48	-12.6
8	-	-	-	-	174.3±1.49	-12.9
9	-	-	-	-	174.2±1.40	-12.9
10	192.2±1.32	-3.9	-	-	173.6±1.35	-13.2

Table 5. The final measurements (FM_w) and dimensional changes for the half Milano knitted fabric in the width (DC_w) after dry relaxation (DR), ironing (IR), and washing (WR)

The number	TYPE OF RELAXATİON					
of days or	dry (DR)		ironing (IR)		washing (WR)	
cycles (K)	FM_w, mm	DC_w, %	FM_w, mm	DC_w, %	FM_w, mm	DC_w, %
1	192.2±1.32	-3.9	202.0±1.25	1.0	222.1±1.55	11.1
2	-	-	203.6±0.97	1.8	223.2±0.63	11.6
3	-	-	204.0±0.94	2.0	223.2±0.58	11.6
4	-	-	205.8±1.69	2.9	223.1±0.49	11.6
5	-	-	208.9±1.45	4.5	222.1±1.20	11.1
6	-	-	-	-	221.5±1.18	10.8
7	-	-	-	-	222.1±1.45	11.1
8	-	-	-	-	221.0±1.41	10.5
9	-	-	-	-	221.2±1.32	10.6
10	193.3±3.37	-3.3	-	-	220.4±1.58	10.2

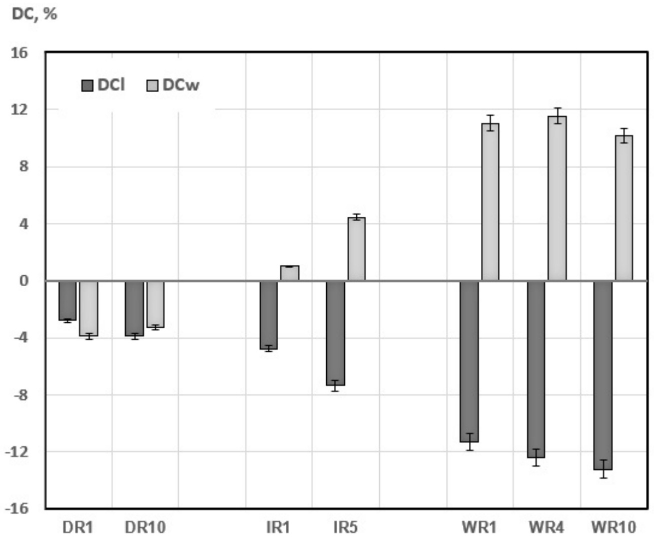

Figure 4. The dimensional changes of half Milano rib knitted fabrics after relaxation (dry DR, ironing IR and washing WR)

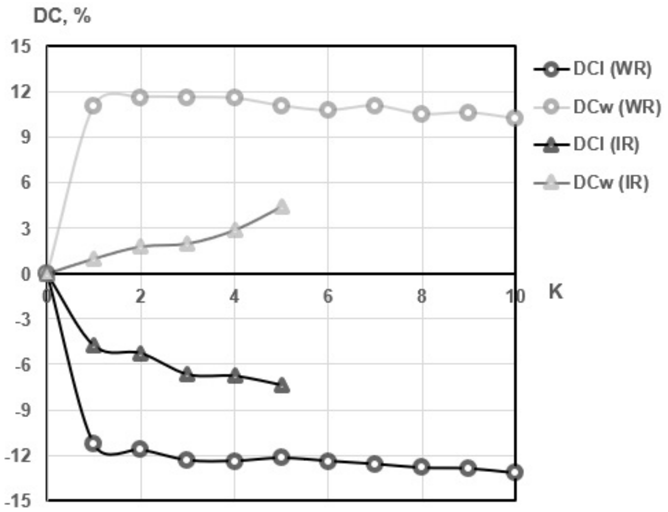

Figure 5. The dimensional changes of knitted fabrics after five ironings and ten washings

Figure 4 displays the alterations in dimensions of half Milano rib knitted fabrics after undergoing relaxation processes such as dry (DR), ironing (IR), and washing (WR) in the length (DC_l) and width (DC_w). Furthermore, Figure 5 reveals the dimensional changes in knitted fabrics in the length and width after five ironing (DC_l(IR), DCw(IR)) and ten washings (DC_l(WR), DC_w(WR)).

The dimensional changes of knitted fabrics depend on the types of relaxation. The knitted fabrics experience concurrent length (DC_l) and width (DC_w) shrinkages after ten days of dry relaxation (DR10), which is known as isotropic behavior. The half Milano rib knitted fabrics have been observed to exhibit anisotropic behavior after undergoing five cycles of ironing and ten washings (Tables 4 and 5, Figures 4 and 5). This behavior is characterized by length shrinkage (DC_l (IR) and DC_l (WR)), typically accompanied by width expansion (DC_w (IR) and DC_w (WR)), as shown in Figure 5. The repeated application of heat and mechanical stress is believed to cause the relaxation of residual stresses and the realignment of fibers within the fabric, resulting in this phenomenon. These observations significantly affect the design and durability of clothing and textile products that use Milano rib knitted fabrics.

Following a ten-day period of relaxation (DR10), it has been observed that the knitted fabrics underwent an average shrinkage of approximately 3.9% both lengthwise (DC_l) and widthwise (DC_w). It is therefore recommended that the effects of dry relaxation on knitted fabrics are taken into consideration during the manufacturing process design.

Knitted fabrics undergo the most significant dimensional change during the first two washing cycles, both in the lengthwise (DC_l (WR)) and widthwise directions (DC_w (WR)), as seen in Tables 4 and 5, Figure 5. The research results were supported by additional studies [3, 13, 34]. However, after these initial washes, the changes become insignificant during subsequent washings. It's interesting to note that the lengthwise shrinkage (DC_l (WR)) slightly increases, while the widthwise expansion (DC_w (WR)) decreases with an increase in the number of washing cycles (K). The lengthwise shrinkage (DC_l (WR)) ranges from 11.3% to 13.2%, while the widthwise expansion (DC_w (WR)) ranges from 10.2% to 11.6%. These findings can help better understand knitted fabrics' behavior and make informed decisions while designing and manufacturing garments. Additionally, it's worth noting that with an increase in the number of ironing cycles (K), the lengthwise shrinkage (DC_l (IR)) of knitted fabrics increases from 4.8% to 7.3%, and the widthwise expansion (DC_w (IR)) also increases from 1.0% to 4.5%.

The experiment aimed to analyze the dimensional changes of yarn and knitted fabrics. The findings showed that the dimensional changes in the yarn and fabrics are quite similar, particularly for the lengthwise shrinkage of the fabrics and the shrinkage of the yarn (Tables 2 and 4). It was evident during the first five ironing cycles that the shrinkage levels of the yarn and fabrics were comparable. The yarn shrinkage ranged from 3.8% to 6.1%, while the lengthwise shrinkage of fabrics was between 4.8% to 7.3%. The analysis also revealed that the main dimensional changes in the yarn and fabrics were observed after the first two washings. Further analysis was conducted to understand the dimensional changes of the yarn and fabrics after ten washings. The results showed that the dimensional changes of the yarn and the lengthwise shrinkage of the fabrics displayed a similar tendency, although the shrinkage levels differed. The yarn experienced shrinkage ranging from 4.2% to 6.3%, whereas the lengthwise shrinkage of the fabrics was between 11.3% and 13.2%. Overall, the experiment suggests that the dimensional changes in the yarn and fabrics are quite comparable, particularly in terms of the lengthwise shrinkage of the fabrics and the shrinkage of the yarn. The experiment also highlights that the dimensional changes become more observable after repeated washings.

Conclusion

This study aimed to investigate the impact of ironing and washing on the dimensions of cotton yarn, as well as the structural and dimensional changes of half Milano rib knitted fabrics made from this yarn. The research aimed to understand how different types of relaxation affect the dimensional stability of the yarn and fabric, and the structural characteristics of the fabric produced on 10-gauge flat-bed knitting machines. Specifically, the study examined the effects of dry relaxation for ten days, five ironing cycles, and ten washes. The research findings provide valuable insights into the optimal relaxation methods for achieving dimensional stability in cotton yarn and knitted fabrics.

The research results show the following:

- During the first five cycles, yarn shrinkage after ironing and washing is similar. However, significant changes occur after the 4-5 washes.
- Dry relaxation has no significant impact on the structural characteristics of the knitted fabrics. Ironing and washing relaxations increase weight, while the structural properties remain unchanged. After ten washes, knitted fabrics gain weight and thickness, indicating changes in their structural integrity.
- Knitted fabrics change size depending on the type of relaxation they undergo. Dry relaxation leads to isotropic behavior, where fabrics shrink in length and width. Half Milano rib knitted fabrics show anisotropic behavior after ironing and washing, with length shrinkage and width expansion. This realignment of fibers due to stress and heat affects clothing and textile products that use Milano rib knitted fabrics.
- After ten days of relaxation, knitted fabrics experience similar levels of shrinkage in both the lengthwise and widthwise directions, at 3.9% and 3.3% respectively.
- Knitted fabrics experience significant size changes in the first two washes, but not in subsequent washes. Lengthwise shrinkage slightly increases, while widthwise expansion slightly decreases with more washing cycles.
- The experiment aimed to compare dimensional changes in yarn and knitted fabrics. Findings showed similarities, particularly in lengthwise shrinkage of fabrics and yarn shrinkage during the first five ironing cycles. After two washings, dimensional changes were observed. After ten washings, yarn shrinkage ranged from 4.2% to 6.3%, while lengthwise shrinkage of fabrics was between 11.3% to 13.2%. The experiment suggests that dimensional changes in yarn and fabrics are comparable, particularly in lengthwise shrinkage of fabrics and shrinkage of yarn, and become more observable after repeated washings. To ensure the best quality and longevity of knitted fabrics made from cotton yarn, it is highly recommended to include a wash cycle during the manufacturing process. This step not only improves the overall quality of the fabric but also helps to prevent any potential dimensional changes that may occur after the product is in use.

These research findings provide valuable insights into identifying optimal relaxation methods to achieve dimensional stability in cotton yarn and knitted fabrics. These insights are essential for designers and manufacturers seeking to optimize fabric performance for specific applications.

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Izvod

UTICAJ VRSTE RELAKSACIJA NA STRUKTURNE KARAKTERISTIKE I DIMENZIONALNU STABILNOST PAMUČNE PLETENINE PREPLETAJA POLU MILANSKI PATENT

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Ova istraživanja su imala za cilj da se ispita uticaj pranja i peglanja na dimenzije pamučnog prediva i strukturne karakteristike u pletenini prepletaja polu Milanski patent. Primarni cilj je bio da se razume uticaj različitih metoda relaksacije na dimenzionalnu stabilnost i prediva i pletiva, kao i na strukturna svojstva dobijene pletenine. Konkretno, razmatrani su efekti tri različite metode relaksacije: suva relaksacija tokom deset dana, pet ciklusa peglanja i deset pranja. Istraživanja su pokazala da suva relaksacija ima minimalne efekte na strukturne karakteristike pletenine. Sa druge strane, pranje je značajno uticalo na strukturna svojstva pletenine. Istraživanja su imala za cilj da se uporede promene u dimenzijama prediva i pletenine iz nje. Rezultati su ukazali na sličnosti, posebno u skupljanju po dužini uočenom kod pletenine i prediva tokom prvih pet ciklusa peglanja. Međutim, nakon dva pranja, postale su očigledne jasne promene dimenzija. Eksperiment naglašava promene dimenzija prediva i pletenine, koje pokazuju sličnosti, posebno u skupljanju po dužini, i postaju sve izraženije sa ponovljenim pranjem. Ovi istraživanja pružaju vredan uvid u identifikaciju optimalnih metoda relaksacija kako bi se postigla dimenzionalna stabilnost pamučnog prediva i pletenina.

Ključne reči: predivo; pletenine; strukturne karakteristike; dimenzionalna stabilnost; relaksacija