INVESTIGATION OF THE QUALITY OF ORGANIC WOOL DOUBLE WEFT KNITTED FABRICS

Scientific paper
DOI: 10.5937/CT_ITI25008K

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ABSTRACT: *This study investigates the quality of organic wool double weft knitted fabrics with different knit structures. Fabrics were produced in three knit structures - 1×1 rib, half Milano rib, and Milano rib - using 20×2 tex organic wool yarn. Quality evaluation was based on volume electrical resistivity, compression, and strength properties. Compression properties were evaluated through compressibility and compressive resilience, while strength properties were assessed using bursting strength and ball traverse elongation. The results indicated that the 1×1 rib structure exhibited the highest compressibility and ball traverse elongation. The Milano rib structure demonstrated the highest compressive resilience and bursting strength, whereas the half Milano rib fabric showed the lowest volume resistivity. Based on the application of the ranking method, the Milano rib fabric exhibited the best quality, while the half Milano rib structure ranked the worst quality.*

Keywords: *quality, organic wool, double weft knitted fabric, 1x1 rib, half Milano rib, Milano rib.*

ISPITIVANJE KVALITETA DESNO-DESNIH PLETENINA IZRAĐENIH OD ORGANSKE VUNE

APSTRAKT: *U ovom radu je ispitivan kvalitet desno-desnih pletenina različitog prepletaja izrađenih od organske vune. Pletenine su proizvedene u tri različita prepletaja - 1x1 prepletaj, polumilanski prepletaj i milanski prepletaj - koristeći pređu od organske vune finoće 20×2 tex. Procena kvaliteta pletenina vršena je na osnovu njihove specifične* *zapreminske električne otpornosti, kompresionih i prekidnih svojstava. Kompresiona svojstava su ocenjena na osnovu kompresibilnosti i elastičnog oporavka, a prekidna svojstava na bazi sile probijanja i hoda kugle pri probijanju. Rezultati su pokazali da pletenina u 1x1 prepletaju ispoljava najveću kompresibilnost i hod kugle pri probijanju. Pletenina u milanskom prepletaju pokazuje najveći elastični oporavak i silu probijanja, dok pletenina u polumilanskom prepletaju ispoljava najmanju specifičnu zapreminsku električnu otpornost. Na osnovu metode rangiranja, pletenina u milanskom prepletaju pokazala je najbolji kvalitet, dok je pletenina u polumilanskom prepletaju pokazala najlošiji kvalitet.*

Ključne reči: *kvalitet, organska vuna, desno-desna potkina pletenina, 1x1 prepletaj, polumilanski prepletaj, milanski prepletaj.*

1. INTRODUCTION

Trends and innovations in the textile industry tend to comply with environmental requirements. In this regard, the textile industry is currently looking for ways to reduce its contribution to the total amount of microplastics that have recently been highlighted as a global problem. Microplastics can be distinguished as primary, when various particles such as synthetic fibers directly enter the environment, and secondary, when small particles are formed in situ by the breakdown of larger plastics [1]. Belzagui et al. estimated that textile washing is the most significant source of synthetic fibers released in environment, with a separation rate of 175 to 560 fibers per gram or 30000 to 465000 fibers per square meter of textile during washing [2]. Due to the size and density of synthetic fibers, it is likely that most will escape water purification processes, ending up in the oceans and potentially entering the food chain. The continuous release of synthetic fibers into the aquatic environment raises concerns about potential environmental and human health risks [3].
Therefore, in the textile industry, there is currently increasing interest in the application of natural fibers such as cotton, hemp, flax, silk, and wool. Wool has been an important fiber for textile manufactures for centuries. Although synthetic fibers were used more often than wool fibers in previous decades due to their lower cost, wool fibers were still highly valued for their exceptional properties. They are characterized by good elasticity, moisture management, heat insulation, gentle luster, etc. Wool clothing is comfortable to wear and brings many benefits such as reduced body odor, improved sleep quality, fire protection, and reduced eczema symptoms [4].
Due to the fast fashion trend, lower quality clothing, mostly made from synthetic fibers, is mass-produced and quickly loses its face value and useful life. In light of these detrimental factors, organic natural fibers have shown potential for the clothing market. The popularity of organic clothing has grown over the past decade or so, particularly due to constant changes in consumer lifestyle and increasing awareness of organic production launched by many major retailers and supermarkets. Consequently, today many consumers are willing to pay more if organic clothing offers good quality [5,6].

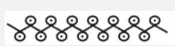
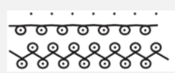
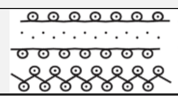
Considering the above, this study investigated the quality of three different knitted fabrics, all produced from the organic wool yarn but with the different knit structure based on rib (1x1 rib, half Milano rib, and Milano rib). The quality of these fabrics was evaluated based on their volume electrical resistivity, compressibility, compressive resilience, bursting strength and ball traverse elongation. The results obtained in this study could help the manufacturers, suppliers, and users to choose one of the tested organic wool knitted fabrics whose rib structure provides the best quality.

2. MATERIALS AND METHODS

2.1. Materials

In this study, the experimental materials consisted of double weft knitted fabrics in 1x1 rib, half Milano rib, and Milano rib structures, all made from 100% organic wool yarn (20x2 tex). The knitted fabrics were produced using a CMS 340.6L double-needle flat-bed knitting machine (Stoll, Germany) with an E12 gauge, 863 needles per needle bed, and 4 knitting systems. Throughout the production process, the stitch cam position, yarn input tension, and fabric take-down settings were kept constant. Table 1 presents the basic structural characteristics of the knitted fabrics, while Figure 1 displays their surface appearance.

Table 1: Structural characteristics of the investigated knitted fabrics

Structural characteristics	Type of knit structure		
	1x1 rib	Half Milano rib	Milano rib
			
Wales per centimeter, cm^{-1}	12.80	13.50	13.70
Course per centimeter, cm^{-1}	10.60	12.05/6.48*	10.56
Mass per unit area, $g \cdot m^{-2}$	255.9	247.7	277.7
Thickness, mm	1.220	1.042	1.227
Total porosity, %	84.11	81.99	82.85
*Knitted fabric has a different face and back side, and consequently different course per centimeter on the face and back side of fabric.			

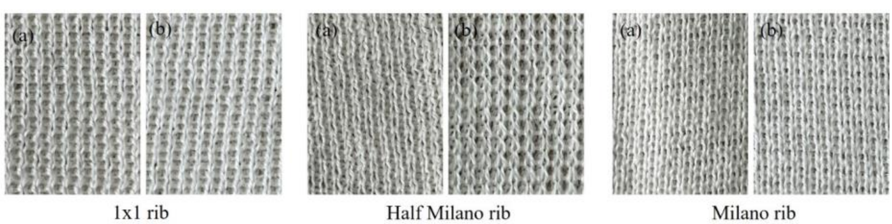


Figure 1: The surface appearance of organic wool double weft knitted fabrics in 1x1 rib, half Milano rib, and Milano rib at 10× magnification: (a) face side of fabric, (b) back side of fabric

2.2. Methods

Wales per centimeter and course per centimeter were determined following standard EN 14971:2006 (Method B) [7]. Knitted fabric mass per unit area was determined following standard EN 12127:1997 [8], while fabric thickness was measured at a pressure of 9.96 kPa using a thickness tester AMES, type 414-10, USA. The wales per centimeter, course per centimeter, mass per unit area, and thickness were considered as the average of five measurements per sample. The total porosity of the samples, representing the overall volume of air contained within them, was defined by Asanovic et al. [9].

The volume electrical resistance of the investigated knitted fabrics was determined in the course direction using the voltage method [10,11]. The measurement was performed under the decrease of the relative air humidity in the chamber from 65% down to 45%. For each sample four fabric specimens were connected to electrodes. Based on the determined knitted fabric volume electrical resistance, the volume electrical resistivity was calculated [10,11].

A thickness tester (AMES, type 414-10, USA) was used for the investigation of knitted fabrics' compression properties (compressibility and compressive resilience). The compression properties were determined according to the procedure described by Asanovic et al. [12,13]. The reported results are the mean values of five measurements per sample.

Determination of knitted fabrics' strength properties (bursting strength and ball traverse elongation) were realized using the device mounted in clamps of the dynamometer AVK, SZ type KG-2, Hungary [13]. The reported strength properties are the mean values of five measurements per sample.

Statistical analysis of the results was conducted using the *t*–test [12,13].

The quality of tested knitted fabrics was assessed based on the results obtained for fabrics' volume electrical resistivity, compressibility, compressive resilience, bursting strength and ball traverse elongation, using the ranking method (details given in the references [11].

3. RESULTS AND DISCUSSION

3.1. Volume electrical resistivity of the knitted fabrics

The values of volume electrical resistivity (in further text resistivity) in the course direction of organic wool double weft knitted fabrics in three knit structures - 1×1 rib, half Milano rib, and Milano rib, determined by decreasing the relative air humidity (in further text humidity) in the chamber, are shown in Figure 2.

The results presented in Figure 2 indicate that as humidity decreases from 65% down to 45%, the resistivity of the samples gradually increases. This confirms that the resistivity of textile materials is highly dependent on humidity, consistent with findings reported in the existing literature [14-16]. At lower humidity levels, fibers absorb less moisture, leading to decreased electrical conductivity and, consequently, increased resistivity in the tested samples. The greatest increase in resistivity was observed in the half Milano rib fabric, where the resistivity at 45% humidity was 2.58 times higher than at 65% humidity. In comparison, 1x1 rib fabric and Milano rib fabric exhibited similar increases in resistivity, with values at 45% humidity being 2.08 and 2.04 times higher, respectively, than those at

65% humidity. Across all humidity levels, the half Milano rib fabric consistently showed the lowest resistivity, while the 1x1 rib fabric exhibited the highest.

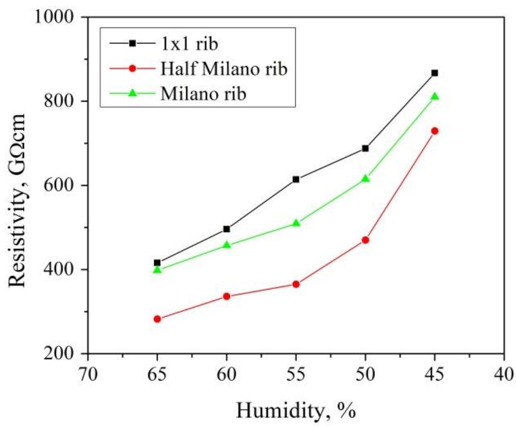


Figure 2: Resistivity of the samples throughout the humidity decrease

Since all the knitted fabrics were produced from the same organic wool yarn, these differences in resistivity are attributed to variations in the type of knit structure. The half Milano rib fabric, with the highest number of courses, and the lowest total porosity (12.05 cm⁻¹, 81.99%, respectively, Table 1) allows the easier flow of directional movement of charge, resulting in lower resistivity. This finding is in line with the investigation of Asfand end Daukantiene [17]. The slightly lower resistivity values of the Milano rib fabric, compared to the 1x 1 rib fabric, considering that both knitted fabrics have nearly identical number of courses (10.60 and 10.56 cm⁻¹, respectively, Table 1), can be attributed to greater thickness and mass per unit area, as well as lower total porosity of Milano rib fabric.

3.2. Compression properties of the knitted fabrics

In addition to resistivity, compression properties are also important properties of textile materials intended for clothing purposes. The compression properties (compressibility and compression resilience) of organic wool double weft knitted fabrics in three knit structures - 1×1 rib, half Milano rib, and Milano rib, are presented in Figure 3.

The results shown in Figure 3(a) indicate that the 1x1 rib fabric exhibits the highest compressibility, while the half Milano rib fabric shows the lowest. Specifically, the 1x1 rib fabric has 19.3% greater compressibility than the half Milano rib fabric. This is attributed to the lower stitch density and higher total porosity of the 1x1 rib fabric (Table 1), which creates a more open knit structure. This openness allows the yarns to flatten more easily under compressive force, thereby enhancing compressibility. In contrast, the half Milano rib fabric, with the lowest porosity (Table 1), has a more compact knit structure that limits yarn flattening under pressure, resulting in reduced compressibility [13,18]. Statistical analysis using a *t*-test (Table 2) confirms that the differences in compressibility among all tested knitted fabrics are statistically significant.

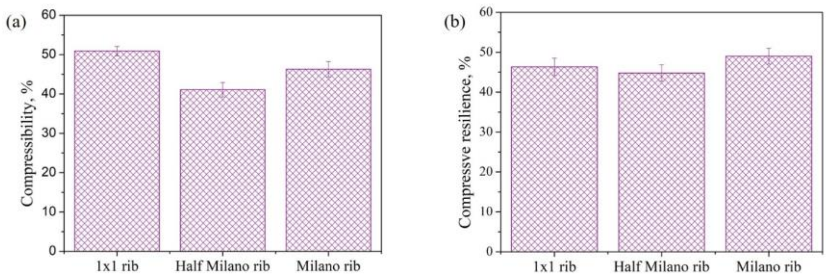


Figure 3: Compression properties of knitted fabrics: (a) compressibility, (b) compressive resilience

According to Taylor and Pollet [19], fabrics that compress more easily under a compressive load are generally perceived as softer. In this regard, the 1x1 rib fabric, which demonstrated the highest compressibility, can be considered the softest among the tested samples.

Table 2: Statistical results of the determination of knitted fabric compression properties using *t*-test

Tested parameter	Values of parameter *t* based on type of knit structure ($df=n_1+n_2-2=8$)		
	$t_{(1x1\ rib)/(half\ Milano\ rib)}$	$t_{(1x1\ rib)/(Milano\ rib)}$	$t_{(half\ Milanorib)/(Milano\ rib)}$
Compressibility	10.01 (***)	4.54 (**)	-4.35 (**)
Compressive resilience	1.15 (/)	-2.05 (/)	-3.35 (*)
(*) – 0.05 level of significance, (**) – 0.01 level of significance, (***) – 0.001 level of significance, (/) – no statistically significant difference, *df* – degrees of freedom, *n* – sample size			

In addition to softness, it is essential for knitted fabrics to exhibit good recovery after compression, a property that can be evaluated by measuring their compressive resilience [13]. The results presented in Figure 3(b) show that the Milano rib fabric has the highest compressive resilience, followed by the 1x1 rib fabric, while the half Milano rib fabric exhibits the lowest values of compressive resilience. During compression of the knitted fabrics, yarns are pressed closer together, increasing the tension between loops. This tension is greatest in the Milano rib fabric, due to the highest values of the mass per unit area and thickness among the samples. Upon decompression, the loops tend to return to their relaxed state. The greater loop tension in the Milano rib fabric facilitates a more effective return to this state, resulting in higher compressive resilience. Statistical analysis (Table 2) confirms a statistically significant difference in compressive resilience only between the half Milano rib and Milano rib fabrics ($t_{(half\ Milano\ rib)/(Milano\ rib)} = -3.35$).

3.3. Strength properties of the knitted fabrics

The results of tested strength properties (bursting strength and ball traverse elongation) for organic wool double weft knitted fabrics in three knit structures - 1×1 rib, half Milano rib, and Milano rib, are shown in Figure 4.

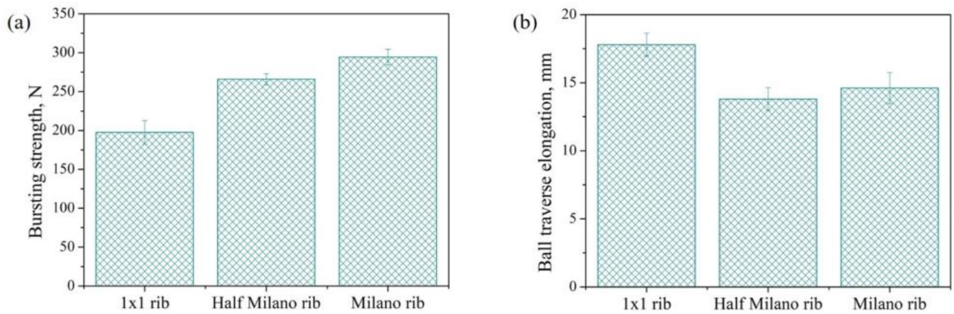


Figure 4: Strength properties of knitted fabrics: (a) bursting strength, (b) ball traverse elongation

The histogram in Figure 4(a) shows a clear upward trend in bursting strength across the knitted fabrics, increasing from the 1x1 rib fabric, through the half Milano rib fabric, to the Milano rib fabric. The superior bursting strength of the Milano rib fabric can be attributed to its higher mass per unit area and thickness (Table 1). These structural characteristics enhance the frictional forces between the yarns, increasing resistance to the ball's penetration. Statistical analysis using a *t*-test (Table 3) confirms a statistically significant difference in bursting strength among all the tested knitted fabrics at a 0.001 significance level.

Table 3: Statistical results of the determination of knitted fabric strength properties using *t*-test

Tested parameter	Values of parameter t based on type of knit structure ($df=n_1+n_2-2=8$)		
	$t_{(1x1\ rib)/(half\ Milano\ rib)}$	$t_{(1x1\ rib)/(Milano\ rib)}$	$t_{(half\ Milano\ rib)/(Milano\ rib)}$
Bursting strength	-9.19(***)	-11.94(***)	-5.16(***)
Ball traverse elongation	7.53(***)	5.06(***)	-1.26(/)
(***) – 0.001 level of significance, (/) – no statistically significant difference, *df* – degrees of freedom, *n* – sample size			

The results presented in Figure 4(b) indicate that the 1x1 rib fabric exhibits the highest ball traverse elongation, while the half Milano rib fabric shows the lowest. The 1x1 rib fabric demonstrated a 22.5% greater ball traverse elongation compared to the half Milano rib fabric, which can be attributed to its higher total porosity (Table 1). This increased porosity reduces the frictional forces between yarns, allowing the ball to travel farther before the fabric structure fails. Statistical analysis (Table 3) shows no statistically significant difference in ball traverse elongation only between the half Milano rib and Milano rib fabrics ($t_{(half\ Milano\ rib)/(Milano\ rib)} = -1.26$), probably due to the they closely total porosity values (Table 1). Figure 5 displays the surface appearance of the tested fabrics following the evaluation of their strength properties.

Figure 5: The surface appearance of organic wool double weft knitted fabrics in three knit structures - 1×1 rib, half Milano rib, and Milano rib, at 10 × magnifications following the evaluation of their strength properties

Figure 5 illustrates that the indentation left by the ball after piercing is more prominent in the half Milano rib and Milano rib fabrics, i.e. samples characterized by lower porosity (Table 1).

3.4. Quality of knitted fabrics

The average quality score for each sample was used to determine the ranking of the tested knitted fabrics in terms of quality (Table 4).

Table 4: The rank order of knitted fabrics

Type of knit structure	G_1	G_2	G_3	G_4	G_5	G_{av}	Rank of fabric
1x1 rib	3	1	2	3	1	2.0	II
Half Milano rib	1	3	3	2	3	2.4	III
Milano rib	2	2	1	1	2	1.6	I

G_1 — grade of resistivity, G_2 — grade of compressibility, G_3 — grade of compressive resilience, G_4 — grade of bursting strength, G_5 — grade of ball traverse elongation, G_{av}—average value of grades (Grade “1” indicates the best and grade “3” indicates the poorest analyzed properties).

Based on the evaluated properties, the results in Table 4 indicate that the Milano rib fabric exhibits the best quality (average grade value of 1.6 – Rank I), while the half Milano rib fabric demonstrates the worst quality (average grade value of 2.4 – Rank III).

4. CONCLUSION

The findings of this study showed that the type of knit structure influence the quality of organic wool knitted fabrics. The investigation revealed that the 1x1 rib fabric has the highest compressibility (50.92 %) and ball traverse elongation (17.80 mm), that the Milano rib fabric has the highest compressive resilience (49.02 %) and bursting strength (294.30 N), and that the half Milano rib fabric has the lowest volume resistivity (from 282 to 729 GΩcm in humidity interval from 65% to 45%, respectively). Quality analysis determined based on the ranking method (including volume electrical resistivity, compressibility, compressive resilience, bursting strength and ball traverse elongation) showed that the Milano rib fabric has the best quality, and that the half Milano rib fabric has the worst quality. The findings of this study could help manufacturers, suppliers, and users to select one of the tested organic wool knitted fabrics whose the type of knit structure provides the best quality.

ACKNOWLEDGEMENT
This work was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No.451-03-136/2025-03/200287 and Contract No. 451-03-136/2025-03/200135).

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