Mechanical performance of woven fabrics made from virgin, semi-recycled, and fully recycled cotton/polyester yarns after natural weathering

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ABSTRACT – REZUMAT

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Global warming and environmental pollution, which are the main problems of today's daily life, make the issue of sustainability increasingly important. Increasing UV radiation and climate change driven by global warming significantly affect the performance and lifespan of textile products, especially for outdoor use. In addition, sustainability research in the textile sector is increasingly focusing on the recycling of pre- and post-consumer textile waste and the use of fibres recycled from these wastes in yarn and fabric production. However, more scientific data is needed to determine the long-term resistance of textile products produced from recycled materials to environmental conditions. In this context, revealing the effects of natural weathering on the mechanical properties of textile fabrics by comparing them with fabrics produced from virgin fibres is very important in terms of both correct material selection and optimum product life. This study investigated and compared the mechanical performance of outdoor upholstery fabrics made from fully and semi-recycled cotton/polyester blended yarns, as well as virgin cotton/polyester blended yarns, which were exposed to natural weathering for three months in summer and three months in autumn. The results showed that virgin fabrics maintain their mechanical properties more effectively under natural weathering conditions, while semi-recycled fabrics exhibit acceptable mechanical performance comparable to virgin fabrics. These findings highlight their strong potential as a promising sustainable alternative for outdoor textile applications.

Keywords: *recycled cotton, recycled polyester, virgin and recycled blended yarns, woven upholstery fabric, tensile strength, natural weathering*

Caracteristicile mecanice ale țesăturilor realizate din fire din bumbac/poliester virgine, parțial și complet reciclate, după expunerea la intemperii naturale

Încălzirea globală și poluarea mediului, care reprezintă principalele probleme ale vieții cotidiene de astăzi, fac ca tema sustenabilității să capete o importanță din ce în ce mai mare. Creșterea radiației UV și schimbările climatice cauzate de încălzirea globală afectează în mod semnificativ performanța și durata de viață a produselor textile, în special a celor destinate utilizării în exterior. În plus, cercetarea în domeniul sustenabilității din sectorul textil se concentrează din ce în ce mai mult pe reciclarea deșeurilor textile pre- și post-consum și pe utilizarea fibrelor reciclate din aceste deșeuri în producția de fire și țesături. Cu toate acestea, sunt necesare mai multe date științifice pentru a determina rezistența pe termen lung a produselor textile fabricate din materiale reciclate la condițiile de mediu. În acest context, evidențierea efectelor intemperiilor naturale asupra proprietăților mecanice ale țesăturilor, prin compararea acestora cu țesăturile fabricate din fibre virgine, este foarte importantă atât din perspectiva alegerii corecte a materialelor, cât și a duratei de viață optime a produsului. Prezentul studiu a investigat și a comparat performanțele mecanice ale țesăturilor de tapițerie pentru exterior realizate din fire din amestec de bumbac/poliester complet și parțial reciclate, precum și din fire din amestec de bumbac/poliester virgine, care au fost expuse la intemperiile naturale timp de trei luni în timpul verii și trei luni în timpul toamnei. Rezultatele au arătat că țesăturile din fibre virgine își păstrează proprietățile mecanice mai eficient în condiții naturale de expunere la intemperii, în timp ce țesăturile semi-reciclate prezintă performanțe mecanice acceptabile, comparabile cu cele ale țesăturilor din fibre virgine. Aceste constatări evidențiază potențialul lor ridicat ca alternativă durabilă și promițătoare pentru aplicațiile textile de exterior.

Cuvinte-cheie*: bumbac reciclat, poliester reciclat, fire virgine și reciclate în amestec, țesătură pentru tapițerie, rezistență la tracțiune, intemperii naturale*

INTRODUCTION

Research in the textile industry has increasingly focused on sustainable solutions due to global environmental challenges such as climate change and limited natural resources. Textile products that are produced with recycled fibres have gained attention recently. One of these textile products is upholstery fabrics.

Upholstery fabrics are widely used in both indoor and outdoor furniture applications. Since they are in direct contact with users, they are expected to offer good aesthetic and comfort properties, along with mechanical durability under varying conditions. Woven fabrics are commonly preferred in the production of upholstery fabrics thanks to their durability, comfort, and good air and water permeability properties.

These fabrics are generally produced in main weave types, and plain weave is one of the most basic weaving structures in the textile industry [1].

Various natural and synthetic fibres are used in the production of upholstery fabrics. Cotton and synthetic fibres are among the most widely used raw materials due to their superior quality [2]. Additionally, the growing need for bio-based and recyclable materials is becoming even more apparent with new sustainability-related regulations expected [3].

The limited number of previous studies in the literature have examined the mechanical properties of woven upholstery fabrics made of recycled yarns. Results revealed that although slight decreases occur in mechanical properties, high-value-added and sustainable products can successfully be produced by using recycled textile wastes [4, 5]. Outdoor upholstery fabrics are exposed to various environmental stresses, including sunlight, moisture, and temperature fluctuations. Sunlight is a major source of energy for life on Earth and also a source of UV radiation, which consists of harmful UV rays [6]. When fabrics are exposed to UV radiation, both natural and synthetic fibres undergo photodegradation, which causes a decrease in mechanical properties, a loss in fabric flexibility, and colour [7, 8]. All these environmental factors can significantly impact the mechanical properties of fabrics, such as strength, durability, and appearance. Therefore, there is a rising interest in determining the performance of different types of recycled and virgin yarns under challenging outdoor conditions as a result of the need for sustainable raw material use.

Degradation in material structure caused by UV radiation and environmental factors is evaluated through weathering tests conducted in a laboratory or under natural environmental conditions. Natural environmental conditions provide more reliable and realistic data compared to accelerated laboratory tests. However, as a disadvantage, the weathering process under real-world conditions requires a longer time. Nevertheless, outdoor tests are considered one of the fundamental tools for predicting degradation, as they provide both quantitative and qualitative information [9]. Previous research has examined various aspects of outdoor fabric durability [10]. Outdoor exposures caused strength losses for all materials; cotton blends exhibited the smallest decreases. In another recent study, standard and recycled polyester sportswear knits under natural weathering were examined, and significant strength and moisture-management degradations were reported for recycled samples [11].

Despite the studies mentioned, there is still a knowledge gap concerning how fully and semi-recycled cotton/polyester blends perform as outdoor upholstery fabrics under natural weathering. Especially, data that compares mechanical property alteration across virgin, semi-recycled, and fully recycled yarns in a plain-weave construction after a specified period of natural weathering are insufficient. Addressing this gap is crucial for guiding manufacturers toward sustainable choices without compromising durability and also providing knowledge for researchers who study this subject. However, no previous study has systematically compared the mechanical deterioration of virgin, semi-recycled, and fully recycled cotton/polyester plain-weave upholstery fabrics under identical natural weathering durations.

This study aimed to provide science-based insights for recycled outdoor textiles in terms of sustainability and durability under outdoor conditions by comparing them with untreated fabrics. Therefore, the study investigated the impact of natural weathering on the mechanical properties of outdoor upholstery fabrics produced from three types of cotton/polyester blended yarns: virgin, semi-recycled, and fully recycled. In this direction, tensile strength, elongation at break, circular bending rigidity, and weight loss percentage after abrasion were measured, and fabric performance and yarn types were compared after different exposure durations. The findings will contribute to the development of upholstery fabrics that are sustainable with acceptable performance.

MATERIALS AND METHODS

Fabric production

In this study, three different types of cotton/polyester blended yarns were used as weft yarns to produce woven fabrics in plain weave construction. All purchased yarns were Ne 20/2 open-end yarns, and the recycled ones were produced from pre-consumer

Table 1

DETAILED INFORMATION OF YARNS AND FABRIC PRODUCTION

Yarn code	Yarn type	Weft yarn composition	Warp yarn composition	Weft density	Warp density	Fabric construction
FRY[1]	Recycled cotton/ recycled polyester	50% recycled cotton, 50% recycled polyester	100 % cotton	20 and 28 picks/cm	14 ends/cm	Plain weave
SRY[2]	Recycled cotton/ virgin polyester	50% recycled cotton, 50% virgin polyester				
VY[3]	Virgin cotton/virgin polyester	50% virgin cotton, 50% virgin polyester				

Note: [1]FRY: Full recycled blended yarn; [2]SRY: Semi recycled blended yarn; [3]VY: Virgin blended yarn.

textile wastes. The fabrics were woven on a Sulzer Ruti projectile weaving machine, and six types of plain fabrics with two different weft densities were produced. Information regarding the yarns and fabric production details is given in table 1.

Natural weathering of fabrics

Natural weathering was carried out in Izmir, Türkiye (38° 24' 09" N and 27° 09' 21" E). Fabrics were divided into three groups for testing. The first group was exposed to sunlight and natural outdoor conditions for three months during summer (June-August), while the second group was subjected to the same conditions for an additional three months during autumn (September-November) to ensure a total of 6 months' exposure. To ensure better exposure of the samples to sunlight, the fabrics were positioned at an angle of approximately 45° towards the south. Meteorological data, including temperature, relative humidity, UV index, cloud cover, and rainfall, were obtained from publicly available meteorological records and monitored at two-hour intervals throughout the exposure period. Table 2 summarises the natural weathering conditions.

All fabrics were greige fabrics and were not exposed to any finishing processes except home laundering. Home laundering was conducted to reduce the stresses formed during fabric production and to prevent possible shrinkage effects that may occur during the following washing processes [12, 13]. The laundering process was performed at 40°C for 90 minutes, using 50 g of colormatic detergent, followed by air-drying at room temperature. This procedure was repeated for all fabrics at the end of each month during the natural weathering process. The third group was the control group and was only exposed to a single laundering cycle once before mechanical tests.

The UV Index (UVI) is defined as an irradiance scale computed by multiplying the erythemally weighted UV irradiance, and is converted to erythemally weighted UV irradiance (E_{ery}, W/m^2) using the internationally accepted formula given in equation 1. This conversion factor of 40 m^2/W corresponds to the definition of the UV Index, which represents forty times the erythemally weighted irradiance [14–16]. Thus, UV Index values were consistently expressed as physical irradiance (W/m^2) to enable quantitative comparison with fabric exposure data and the calculated UV irradiance values for each month are presented in table 2.

$$E_{ery}\ (\text{W/m}^2) = UVI/40 \quad (1)$$

Mechanical tests

Various tests were conducted on both untreated and naturally weathered fabrics. Fabric weight (TS EN 12127) and fabric thickness (TS 7128 EN ISO 5084) were measured initially for untreated fabrics, and measurements were repeated after three and six months of natural weathering. All fabrics were subjected to abrasion on the James Heal Martindale device, following the TS EN ISO 12947-2 standard. In this study, sandpapers were used instead of standard wool fabric as an abradant to observe yarn breakage at lower cycle numbers and to perform the tests more efficiently and effectively [17–19]. Two different sandpaper grit sizes (Atlas P600C and P1200C) were selected to simulate the performance of fabrics under varying abrasive conditions, as reported in previous studies [17, 20, 21]. P600 sandpaper, providing a coarser and faster abrasion, and P1200 sandpaper, serving as a finer and milder abrasive, were used. After a specified number of cycles, the fabric weights were measured, and weight loss percentages were calculated. Tensile strength tests of fabric samples were carried out on a Lloyd tensile tester (TS EN ISO 13934-1), and circular bending rigidity was measured using a Shirley circular bending tester (ASTM D 4032).

Statistical analysis

The results obtained from the mechanical tests were statistically analysed using SPSS Statistics 25 software. The data collected from tests such as weight loss percentage after abrasion, tensile strength, elongation, and circular bending rigidity were first subjected to a normality test. Since the fabric tensile

Table 2

NATURAL WEATHERING CONDITIONS					
Months	Temperature (°C) M±SD	Humidity (%) M±SD	UV Index M±SD	Cloud cover (%) M±SD	Rainfall amount (mm) M±SD
1st Month	27.80±3.46	49.00±16.14	5.50±2.79	30.6±28.55	0.14±0.63
2nd Month	34.12±3.28	30.20± 8.32	6.07±2.85	9.30±11.73	0.00±0.00
3rd Month	32.64±2.83	42.84±10.39	5.25±2.80	9.26±11.50	0.00±0.00
4th Month	28.60±3.62	42.50±11.28	3.72±2.39	24.90±19.92	0.05±0.68
5th Month	23.20±4.02	41.36±10.51	2.23±1.67	25.17±25.57	0.00±0.00
6th Month	15.02±4.02	59.59±18.38	1.16±1.00	42.31±34.60	0.15±0.78

No rainfall was recorded during the 2nd, 3rd and 5th months.

CALCULATED ERYTHEMALLY WEIGHTED UV IRRADIANCE VALUES						
Month	1	2	3	4	5	6
UV Irradiance (W/m²)	0.138	0.152	0.131	0.093	0.056	0.029

Table 3

FABRIC WEIGHT(g/m^2) AND FABRIC THICKNESS (mm) VALUES OF UNTREATED AND NATURALLY WEATHERED FABRICS						
Fabric code	**Untreated**		**3-month natural weathering**		**6-month natural weathering**	
	Weight	**Thickness**	**Weight**	**Thickness**	**Weight**	**Thickness**
1	232.833	0.729	233.667	0.781	235.500	0.790
2	306.833	0.815	310.137	0.831	306.333	0.803
3	225.333	0.690	228.333	0.745	227.000	0.738
4	290.833	0.757	297.833	0.814	297.333	0.794
5	225.333	0.703	228.667	0.728	227.833	0.717
6	290.500	0.727	302.000	0.792	301.167	0.759

strength values showed a normal distribution, a one-way ANOVA was performed. In contrast, the data obtained from the abrasion-induced weight loss and circular bending tests did not meet the normality assumption; therefore, the nonparametric Friedman test was conducted to evaluate the fabric properties measured in the untreated condition and after exposure to different natural weathering durations. The Wilcoxon signed rank test was used to compare two related samples, such as the effect of different sandpaper types on the same fabrics under various weathering conditions. The Bonferroni correction was applied in the post hoc tests.

RESULTS AND DISCUSSION

Fabric weight and thickness values of untreated fabrics and naturally weathered fabrics are given in table 3.

The fabric weight and thickness values slightly increased after natural weathering. This small increase may be explained by the moisture absorption of fabrics from the air, because the moisture in the structure of textiles directly affects the weight and thickness of the fabrics [22]. In addition, the monthly home laundering performed during the study may contribute to this minor change, as indicated in the literature [23]. Even though the values became slightly higher for some samples, the differences were not very noticeable. Therefore, it can be said that up to six months of natural weathering does not cause any serious damage to the structure of the woven fabrics.

Weight loss percentages of untreated and naturally weathered fabrics after 200 abrasion cycles with P1200 sandpaper are presented in table 4. The weight loss values of the fabrics slightly decreased after three months of natural weathering. This result indicates a temporary improvement in abrasion resistance. However, after six months, the values tended to increase again for some samples, especially for the 1st, 2nd, and 6th fabrics. According to this result, it can be said that long-term exposure to outdoor conditions weakened the fibres and reduced the abrasion resistance of fabrics. A similar trend was reported in a study on knitted cotton fabrics exposed to outdoor conditions [24]. Nevertheless, statistical analysis revealed no significant difference between the weight loss values of the samples abraded with P1200 sandpaper in the untreated condition and after three or six months of natural weathering ($p>0.05$).

Table 4

WEIGHT LOSS (%) AFTER 200 ABRASION CYCLES WITH P1200 SANDPAPER			
Fabric code	**Untreated**	**3-month natural weathering**	**6-month natural weathering**
1	1.4	1.2	1.4
2	1.2	0.2	1.4
3	0.4	1.0	0.6
4	1.8	1.2	0.8
5	1.2	1.6	1.0
6	1.8	1.0	1.2

Table 5 presents the weight loss of fabrics after 50 abrasion cycles with two different sandpapers. As expected, the fabrics tested with P600 showed slightly higher weight loss than those tested with P1200 due to its rougher surface. After three months of natural weathering, weight loss generally increased, especially for fabrics abraded with P600, which suggests that short-term outdoor exposure made the surface fibres slightly weaker, as mentioned above. After six months, however, the weight loss tended to decrease for several samples. Friedman test results indicate that the differences among the weight loss percentages of the same samples were not statistically significant for either P1200 or P600 sandpapers ($p>0.05$). In addition, the possible effect of sandpaper type on the same samples under different conditions (untreated, 3-month, and 6-month weathered) was also investigated. Based on the Wilcoxon test results, no statistically significant relationship was found between them ($p>0.05$). Some samples showed slightly negative weight loss values (e.g., –0.2% for samples 2 and 4). These values reflect the limits of experimental measurement, including the sensitivity of the precision balance, the low number of abrasion cycles, minor fibre accumulation remaining on the fabric surface, and possible static effects during weighing. Therefore, these small negative values are within acceptable measurement uncertainty and do not indicate an actual increase in fabric mass.

Table 5

COMPARISON OF WEIGHT LOSS % AFTER 50 ABRASION CYCLES WITH P600 AND P1200						
Fabric code	**Untreated**		**3-month natural weathering**		**6-month natural weathering**	
	P600	**P1200**	**P600**	**P1200**	**P600**	**P1200**
1	1.6	1.0	1.6	0.8	0.6	0.0
2	1.0	0.6	1.6	-0.2	0.6	1.0
3	0.8	0.2	1.8	0.6	0.4	1.0
4	0.8	0.8	–0.2	0.6	0.6	0.0
5	0.4	1.8	1.0	1.0	0.8	1.0
6	0.6	0.6	1.4	0.4	0.6	0.6

Fabric tensile strength and elongation at break values of fabric samples are given in table 6. For all samples and all conditions, the tensile strength values in the weft direction are higher than those in the warp direction, as expected, due to the presence of polyester fibres in the weft. Therefore, it can be concluded that polyester fibre's crystalline structure plays a decisive role in tensile behaviour [25]. Although tensile strength remained higher in the weft direction, the percentage reduction in strength after exposure to natural weathering was greater in the weft direction, which may be attributed to interfacial weakening between polyester and cotton fibres under prolonged UV and moisture exposure, as also emphasised in a previous study [26]. Nevertheless, the weft yarns still maintained higher overall tensile strength due to the inherent durability of polyester fibres against environmental stress.

The results also clearly demonstrate the effect of weft density (20 and 28 picks/cm) and yarn type (FRY, SRY, and VY) on the tensile strength of the fabrics. As expected, fabrics with higher weft densities exhibited significantly higher tensile strength, particularly in the weft direction [27]. When evaluated based on yarn type, fabrics containing VY exhibited the highest tensile strength, followed by SRY and FRY, as reported in [28]. The tensile strength of recycled yarns and fabrics was found to be lower than that of virgin ones. Additionally, when tensile strength and tensile elongation at break values of the same samples under different conditions were evaluated, a general decreasing trend was observed in both warp and weft directions from the untreated state to six months of outdoor exposure, as also reported in previous studies [29–31]. This trend was also statistically supported by the ANOVA results, showing significant differences among different time periods ($p<0.05$) in both warp and weft directions for all yarn types. Bonferroni pairwise comparisons revealed that the greatest decreases occurred between the untreated and weathered samples (Un–3M and Un–6M), with p-values mostly below 0.05, indicating significant strength loss after exposure. Conversely, the differences between 3-month and 6-month exposures (3M–6M) were statistically insignificant in most cases (p-values ranging from 0.13 to 0.86). This finding suggests that the majority of mechanical degradation occurred within the first three months of natural weathering. After this initial stage, the rate of degradation slowed because the most easily damaged fibre surfaces and weak fibre bonds had already separated from the fabric structure during the early exposure period.

In terms of elongation at break, a gradual decrease occurred in both warp and weft directions with increasing exposure time. This reduction indicates that fibres became more brittle and less flexible after natural weathering [31]. Additionally, elongation at break values were generally higher in the weft direction due to the presence of polyester fibres, which provide better elasticity and resilience compared to cotton [32]. Significant differences ($p<0.05$) were observed in elongation values for most weft directions,

Table 6

FABRIC TENSILE STRENGTH AND ELONGATION AT BREAK												
Fabric code	**Untreated**				**3-month natural weathering**				**6-month natural weathering**			
	Tensile strength (N)		**Elongation at break (mm)**		**Tensile strength (N)**		**Elongation at break (mm)**		**Tensile strength (N)**		**Elongation at break (mm)**	
	Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft
1	593.43	626.71	56.10	75.21	465.09	515.66	42.18	72.59	488.74	399.02	48.30	64.87
2	640.33	1004.13	38.60	89.13	505.85	832.52	30.21	85.66	581.15	747.61	34.99	82.10
3	587.85	918.02	56.59	77.45	504.33	580.14	53.80	63.59	426.60	443.73	51.62	60.53
4	614.44	1331.13	41.19	89.44	559.15	850.86	36.50	77.73	426.21	776.05	35.27	77.82
5	627.93	904.79	57.00	78.09	526.84	584.72	50.33	69.79	501.58	598.78	51.81	68.30
6	664.03	1354.33	40.14	91.60	613.21	1031.11	34.94	87.10	557.47	862.81	36.93	79.93

particularly between untreated and 6-month naturally weathered samples.

Statistical analysis showed clear differences in tensile strength among the same samples at different exposure times. These differences were consistent across all samples (1–6) with $p<0.05$.

Similarly, noticeable changes in elongation at break values were observed for most samples. Pairwise comparisons were conducted, and the outcomes of the ANOVA and Bonferroni tests are summarised in table 7. Overall, the statistical results confirm that both tensile strength and elongation at break were significantly influenced by exposure duration, fabric structure, and yarn composition, with the most obvious statistical significance for tensile strength observed in the weft direction ($p<0.001$).

Circular bending rigidity results of the fabric samples are presented in table 8. Generally, a slight increase in rigidity values was observed after natural weathering, indicating a moderate stiffening effect. This finding suggests that extended outdoor exposure may have slightly altered the fibre surfaces and increased the structural compactness of the fabrics due to monthly repeated home laundering. Thereby, it causes a decrease in fabric flexibility. The degree of this change seems to vary depending on the fabric structure and yarn composition. Rigidity values gradually increased from the untreated condition to the 6-month exposure for samples 4, 5, and 6. In contrast, samples 2 and 3 exhibited a minor increase for the first three-month period, followed by a minor decrease for the last three-month period. Fabric stiffness tends to increase with higher weft density. Minor differences between samples related to yarn type were also observed, but these can be considered negligible.

Table 7

ONE-WAY ANOVA RESULTS FOR TENSILE STRENGTH AND ELONGATION AT BREAK

Fabric code	Direction	Tensile strength			Elongation at break		
		F (2,6)	Sig. (p)	Post Hoc	F (2,6)	Sig. (p)	Post Hoc
1	Warp	22.611	**0.002**	Un–3M=**0.002** Un–6M=**0.006** 3M–6M=0.866	30.366	**0.001**	Un–3M=**0.001** Un–6M=**0.014** 3M–6M=**0.043**
	Weft	118.648	**<0.001**	Un–3M=**0.001** Un–6M=**0.000** 3M–6M=**0.001**	10.362	**0.011**	Un–3M=0.932 Un–6M=**0.014** 3M–6M=0.051
2	Warp	8.314	**0.019**	Un–3M=**0.020** Un–6M=0.371 3M–6M=0.189	67.951	**<0.001**	Un–3M=**0.000** Un–6M=**0.007** 3M–6M=**0.002**
	Weft	30.469	**0.001**	Un–3M=**0.006** Un–6M=**0.001** 3M–6M=0.133	4.741	0.058	-
3	Warp	13.557	**0.006**	Un–3M=0.107 Un–6M=**0.006** 3M–6M=0.138	1.779	0.247	-
	Weft	383.609	**<0.001**	Un–3M=**0.000** Un–6M=**0.000** 3M–6M=**0.001**	54.971	**<0.001**	Un–3M=**0.001** Un–6M=**0.000** 3M–6M=0.376
4	Warp	61.664	**<0.001**	Un–3M=0.058 Un–6M=**0.000** 3M–6M=**0.001**	15.707	**0.004**	Un–3M=**0.017** Un–6M=**0.005** 3M–6M=0.940
	Weft	84.363	**<0.001**	Un–3M=**0.000** Un–6M=**0.000** 3M–6M=0.474	35.542	**<0.001**	Un–3M=**0.001** Un–6M=**0.001** 3M–6M=**1.000**
5	Warp	59.813	**<0.001**	Un–3M=**0.001** Un–6M=**0.000** 3M–6M=0.253	24.450	**0.001**	Un–3M=**0.002** Un–6M=**0.006** 3M–6M=0.569
	Weft	100.293	**<0.001**	Un–3M=**0.000** Un–6M=**0.000** 3M–6M=1.000	15.060	**0.005**	Un–3M=**0.015** Un–6M=**0.007** 3M–6M=1.000
6	Warp	22.501	**0.002**	Un–3M=0.056 Un–6M=**0.002** 3M–6M=**0.038**	17.005	**0.003**	Un–3M=**0.004** Un–6M=**0.036** 3M–6M=0.206
	Weft	75.731	**<0.001**	Un–3M=**0.001** Un–6M=**0.000** 3M–6M=**0.018**	15.867	**0.004**	Un–3M=0.224 Un–6M=**0.004** 3M–6M=**0.042**

Pairwise comparisons: *Un–3M: Untreated-3 Month weathering, Un-6M: Untreated-6 Month weathering, 3M-6M: 3 Month weathering-6 Month weathering*

Nevertheless, differences between measurements of the same samples at different exposure times were also statistically evaluated. Statistical analysis revealed that significant differences were only observed between the measurement periods for samples 2 ($p=0.050$) and 6 ($p=0.050$). According to pairwise comparisons, significant differences were found for sample 2 (between 3-month and 6-month natural weathering periods), and for sample 6 (between untreated and 6-month natural weathering conditions) ($p<0.05$).

Table 8

CIRCULAR BENDING RIGIDITY			
Fabric code	**Untreated**	**3-month natural weathering**	**6-month natural weathering**
1	4.10	4.00	4.65
2	7.65	8.53	7.20
3	4.43	5.15	4.63
4	7.10	7.88	8.20
5	4.10	4.43	4.88
6	7.43	8.20	8.98

CONCLUSION

This study comprehensively evaluated how the mechanical performance of outdoor upholstery fabrics produced from virgin, semi-recycled, and fully recycled cotton/polyester yarns changed after exposure to natural weathering conditions such as UV radiation, temperature, and humidity in comparison with their untreated references. The study results clearly demonstrate that the mechanical stability of the fabrics is significantly affected by yarn type after exposure to natural weathering conditions.

Virgin fabrics demonstrated the highest durability across all measured properties and retained a significant portion of their tensile strength, flexibility, and abrasion resistance even after six months of outdoor exposure. Semi-recycled fabrics exhibited moderate but acceptable performance, although with some reductions in strength and elongation. Fully recycled fabrics exhibited the highest mechanical deterioration, although they are environmentally advantageous. The most apparent mechanical deterioration occurred during the first three months of natural weathering, after which the rate of degradation slowed considerably. Semi-recycled yarn blends demonstrated mechanical performance close to that of virgin fabrics, particularly in tensile strength retention, indicating their feasibility for outdoor applications.

Overall, the results confirm that fabric structure, yarn type and exposure time significantly affect the mechanical behaviour of outdoor upholstery fabrics. Additionally, the data obtained from the research reveals that recycled yarns are applicable for sustainable textile solutions when the raw material blend ratio of yarns is carefully optimised. Semi-recycled yarns, in particular, are clearly a sustainable and promising alternative to virgin yarns, demonstrating comparable performance to virgin yarns for outdoor applications.

In conclusion, this study provides valuable scientific data for the field of sustainable textiles, which has gained increasing importance in recent years, by examining and comparing the mechanical performance of recycled fabrics under natural weathering conditions.

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