A CRITICAL EVALUATION OF THE USE OF HEMP AS A SUSTAINABLE SOLUTION IN GARMENT MAKING

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Abstract

The fashion industry is one of the world's largest and most polluting industries, significantly impacting the environment and human health. The production of conventional textiles involves toxic chemicals, excessive water consumption, and significant amounts of energy, contributing to greenhouse gas emissions and other environmental problems. Recently, there has been a growing interest in more sustainable and eco-friendly alternatives to conventional textiles. A promising solution is using hemp fabrics in the textile fashion industry. Hemp is a versatile and sustainable material used to make various textile products, from clothing and accessories to upholstery and home decor. Hemp requires less water and fewer pesticides than cotton and can be grown without herbicides or fungicides. This work discusses the sustainability of hemp while exploring the use of hemp fabric in the textile garment fashion industry as part of cotton substitution. A woven hemp fabric is used to create a casual final garment to prove that it can be quickly processed using the same design patterns, cutting and sewing procedure, offering the same comfort and aesthetic result. The fabric is tested and compared to a cotton woven fabric of similar characteristics for its drape, tensile and tear strength, resistance to wear, breathability, and sewability through needle penetration force. Finally, the dyeability of hemp is tested using natural dyes.

Keywords: *hemp, sustainability, eco-friendly fashion, sustainable farming, cannabis sativa*

1. INTRODUCTION

The fashion industry is one of the world's largest and most polluting industries, significantly impacting the environment and human health. The production of conventional textiles involves toxic chemicals, excessive water consumption, and significant amounts of energy, contributing to greenhouse gas emissions and other environmental problems. Recently, there has been a growing interest in more sustainable and eco-friendly alternatives to conventional textiles.

To meet the goal of healthy soils by 2050, the EC IP/23/3565 introduced a soil monitoring law that gathers soil health data. This law makes sustainable soil management the norm and addresses unacceptable health and environmental risks from soil contamination. The proposal enables innovation and sustainability through New Genomic Techniques (NGTs), which promote the development of climate-resilient crops and the reduction of chemical pesticides. NGTs assure more sustainable, high-quality, diverse seeds and reproductive materials for plants and forests. Food and textile waste reduction will contribute to more efficient use of natural resources and decrease greenhouse gas emissions. (European Commission, 2023)

One promising solution is using hemp fabrics in the textile fashion industry. Hemp is a versatile and sustainable material used to make various textile products, from clothing and accessories to upholstery and home decor. The use of industrial hemp has been reported in the literature (Allegret, 2013; Ranalli & Venturi, 2004) The scope of the current work was to examine the feasibility of substituting a commonly used cotton fabric, such as modern denim, with hemp. Therefore, a woven hemp fabric was used to create a casual final garment to prove that it can be quickly processed using the same design patterns, cutting and sewing procedure, offering the same comfort and aesthetic result. The fabric is tested and compared to a cotton woven fabric of similar characteristics for its drape, handle, tensile strength, resistance to wear, air permeability, and sewability through needle penetration force. Finally, to test hemp's dyeability, a swatch of this fabric was dyed with natural dye extracted from beetroot. Its spectral values were recorded and evaluated against the control undyed sample.

2. SUSTAINABILITY OF HEMP PRODUCTION

2.1. Varietal Identity of Hemp and its Uses

Hemp has been used for thousands of years to make textiles and other products and was one of the most important crops in the world until it was largely replaced by cotton in the 19th century. By the 1920s, approximately 80% of clothes were made from hemp fabrics. The famous Levi Strauss created the first Levi's jeans using a lightweight hemp canvas for his original denim. Since then, hemp has been used to make many types of clothing and accessories (Schwartz, 2010) and more and more sustainable brands are now using hemp fabric to make clothing.

Industrial hemp (*Cannabis sativa L.)* is the variety of cannabis used in the textile industry and the production of other materials such as paper, rope, and biodegradable plastics. It is a landrace variant with narrow leaves, different from *Cannabis indica* and *Cannabis ruderalis* – the other two most known sub-species of cannabis. The plant's stem consists of cellular fibres in the husk and woody fibres in the core (Andre et al., 2016).

Industrial hemp used for the textile industry is genetically modified to have low percentages of D-9-tetrahydrocannabinol (THC), the primary psychoactive cannabinoid (below 0.2% for European standards). This induces the production of better and stronger bast fibres used in the textile industry. More specifically, it consists of three types of fibres: primary fibres (outer fibres), secondary fibres (bast), and hemp fibres (inner short fibres). These fibres have very high cellulose content with varying amounts of hemicellulose, lignin and pectin as their main components (Tutt & Olt, 2011).

Single hemp fibre has a density of 1.48 g/cm^3 (Sisti et al., 2018) and an excellent tensile strength of 350-800MPa (Liu et al., 2015; Sisti et al., 2018) which is three times greater than that of cotton, depending on the climate during the growing season and the genotype, soil type, fertiliser application and retting processes. Hemp fibres have a similar modulus of elasticity (75GPa) to that of glass fibres ranging from 50 to 70 GPa (Liu et al., 2015).

According to Müssig & Martens (2003), variety selection, planting density, date of sowing and harvest, and the method of harvesting and retting affect both the fibres produced and the entire production chain. (Müssig & Martens, 2003)

Low levels of THC can also be achieved through proper irrigation. Unlike cotton, It requires water only during drought and is more resilient against parasites. Consequently, it requires fewer pesticides and can be grown without herbicides or fungicides, making it a more sustainable choice for textile production. (De Miranda, 2011; Rodie, 2009)

Hemp crops help to prepare the ground for future plantations. Typically, mass cultivation causes massive erosion, making planting impossible in some soils. Hemp, due to its deep roots and the fact that it is a bio-accumulator, indiscriminately absorbs all elements from the soil, including bad ones that could harm other crops and consequently improves both soil quality and retention; in some cases, hemp is grown on the land to remove pollutants such as zinc and mercury. (Kell, 2021)

Hemp has a shorter growing cycle than cotton, which means it can be harvested more quickly and with less water consumption. It is a renewable resource that can be harvested annually without depleting the soil or damaging the ecosystem. The harvesting process for fibre production begins almost 100 days after sowing, but it depends on the climatic conditions, the cultivation area and the purpose of the cultivation (Tsaliki et al., 2016). It is produced using organic and sustainable farming practices with low environmental impact. Organic hemp farming involves the use of natural fertilisers and pest control methods and prohibits the use of synthetic chemicals and genetic modifications.

After harvesting, hemp processing involves a necessary pre-spinning stage known as retting to separate and obtain the fibres. Retting is a microbial method that breaks down the chemical bonds of the pectineus substances that keep the stem together and separates the bast fibres from the woody core of the plant and the outer shell of the plant. There are five different retting methods: dew, water, enzymatic, mechanical, and chemical. (Mass, 2009). Yarns can be spun from the fibres collected using the traditional ring span technique. The yarns are usually woven into the plain weave to create a canvas or twill weave.

2.2. Fabrics made of hemp

The natural colour of hemp fibres is various light shades of beige. (Schwartz, 2010) Once made into fabric, hemp has a similar texture to cotton but also has a canvas feel. Hemp fibres are mixed with other fibres, such as flax, cotton, wool, linen or silk, creating various specific textures and properties. (Schwartz, 2010)

Hemp fabrics have several desirable properties that can make them a popular choice for sustainable fashion as it is strong and durable, making them capable of withstanding wear and tear in daily use, rendering them a good choice for clothing and accessories with adequate serviceable life. Hemp fabrics are also highly breathable, which makes them comfortable to wear in warm weather. In addition to their practical benefits, hemp fabrics are also aesthetically pleasing. Hemp can be woven into various textures and weights, from lightweight and sheer to heavy and sturdy. Hemp fabrics have a distinctive look and feel that is rustic and refined, making them a popular choice for casual and formal wear. It also takes dyes well so that it can be produced in a range of colours.

Hemp fabrics are also biodegradable and composable, which means they can be safely disposed of at the end of their useful life without contributing to landfill waste. This contrasts with synthetic fabrics like polyester, made from petroleum-based materials that take hundreds of years to decompose in landfills.

Hemp fabric has anti-bacterial and hypoallergenic properties, so clothes made are very resistant to odour development and are suitable for sensitive skin due to their non-irritating properties (Mass, 2009).

3. MATERIALS AND METHODS

3.1. Materials

The woven canvas hemp fabric was supplied by the EcoTextil company, Spain and the cotton denim was supplied by the Denim Co, Turkey. The composition of the first fabric was 100% hemp, the denim was 100% cotton in the warp direction, and the weft yarns contained up to 2% elastane and 98% cotton. The hemp canvas was woven into a 1/1 plain design, while the denim followed a twill 3/1 diagonal in the Z direction. Both fabrics were washed and scoured. The cotton denim fabric is commonly used in casual trouser making, while the hemp canvas was selected to match the surface density for comparison. Before testing, the fabrics were left to relax in a textile laboratory environment. All samples taken were randomly taken at least 10cm away from the edge of the fabric.

3.2. Methods

A circular cutter of 100cm² and precision scales were used to evaluate the surface density of the fabrics according to the ISO 3801:1977 method. Both fabrics had a similar surface density with a mass of 262,36 g/m² for the hemp canvas and 253,72 g/m² for the cotton-rich denim, thereafter, referred to as hemp canvas and cotton denim. The construction details can be seen in **Fig.** 1 to **Fig.** 3.

The thread density was evaluated by the ISO 7211-2:1984 method using a magnified glass. The ISO 7211-5:1984 method was used to determine the linear density (tex) of the yarn removed from the fabric, and the crimp was evaluated using the Shirley crimp tester apparatus. The fabric thickness was measured according to ISO 5084 using a precision micrometre. The fabrics were evaluated for their softness using the Softness Tester for coated fabric and leather and under the ISO17235 method, using the 20mm ring with a single layer of fabric. The tensile strength and elongation of the fabrics for warp and weft were measured by the ISO 13934-1:2013 method, with the Testometric apparatus under a constant rate of extension. Fabric resistance to flat abrasion was measured using the Martindale apparatus using the ISO 12947-2:2016 method. Stiffness was measured using the Fabric Stiffness tester (SDL Atlas) apparatus under the ISO 9073-7 method. Sewability of the fabric has been evaluated through the measurement of needle penetration force (NPV) using the L&M Sewability Tester (SDL Atlas), with a 90s ball point needle, over 100 penetration in both directions for a total of 10 samples. Additionally, the sewability limit for the woven fabrics has been calculated separately for each direction using the suggested model by Karypidis et al. (2019), and the exceeding sewability high-values were recorded. Air permeability measurements were recorded with the Air Permeability Tester GT-C27 (Gester) under the ISO 9237 method. The X-Rite spectrophotometer used the CIELab system at 10° observer to evaluate the colour.

4. RESULTS AND DISCUSSION

The thread density was measured for warp and weft direction; the results are shown in **Fig.** 2. The graph shows an uneven thread distribution for denim fabric compared to the canvas. Several reasons can lead to the chosen construction, such as the inclination of the diagonal twill design and the cost as weft insertion is more expensive than warp preparation. It should be kept in mind that mechanical properties are affected by thread density. The hemp canvas exhibits a uniform thread density in both warp and weft, and a uniform mechanical behaviour in both directions can be anticipated, bearing in mind the inherent differences between warp and weft yarns.

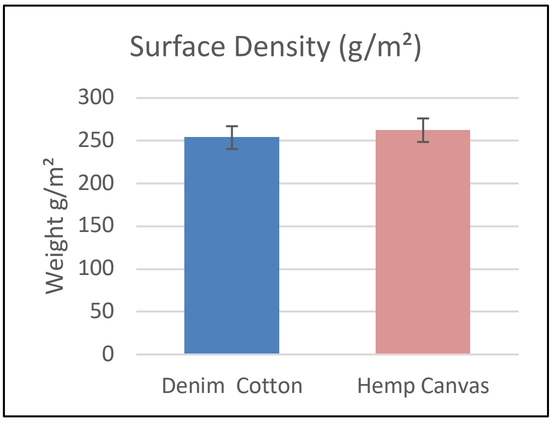


Fig. 1 Surface density of sample fabrics

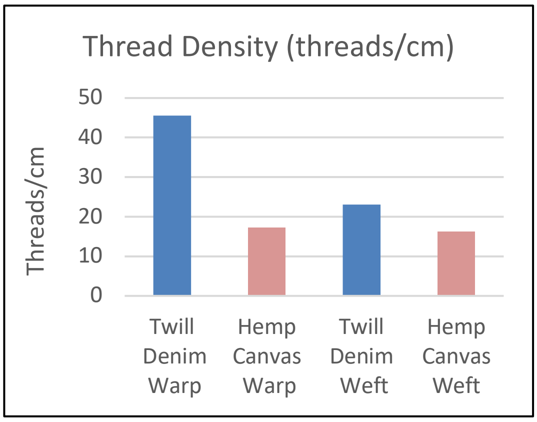


Fig. 2 Thread density of sample fabric

The linear density (tex) of the yarn removed from the fabric was determined to evaluate the fabric's cover factor accurately. Twenty threads were removed from each direction of both fabrics, and the crimp was evaluated. The liner density in Tex was evaluated and presented using the precision scales in **Fig.** 3, while the %crimp in both directions was in **Fig.** 4. The hemp fabric is made of coarser yarn with increased unevenness. The fabric's %crimp is very similar for both directions, and any variations can be mainly attributed to the yarn tension difference during the weaving of warp and weft yarns. The presence of flexible elastane in the weft yarn and higher thread density of the warp yarns manifest in the %crimp values of the denim.

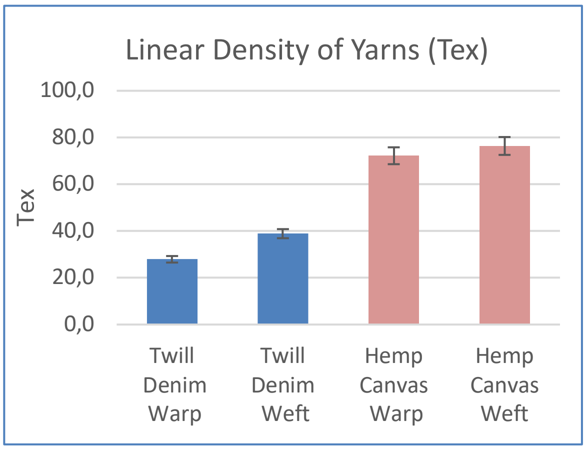


Fig. 3 Linear Density of sample fabrics

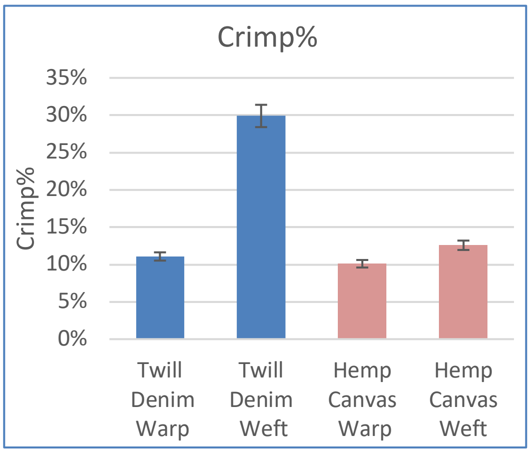


Fig. 4 %Crimp of sample fabrics

The fabric Thickness was measured according to ISO 5084; the data are presented in **Fig.** 5. Both fabrics show similar thicknesses. However, the denim 3/1 presented a more significant variability (CV% 10,52 compared to 2,04% for the 1/1 plain canvas) primarily due to the twill design's long floats on the fabric's surface.

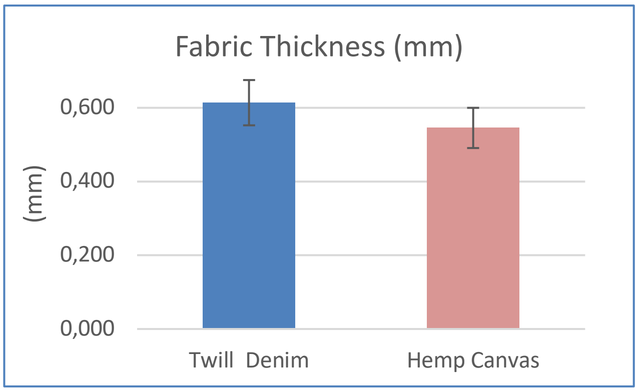


Fig. 5 Thickness of sample fabrics

The fabrics were evaluated for their softness; the deformation values are shown in **Fig.** 6. Although the composition of the denim containing elastane favours the deformation of the structure, which is further enhanced by the presence of the long float of the twill construction, the hemp canvas deformation was only marginally inferior, falling only 7.5% behind that of the denim. Again, the CV% of the denim readings were 7,87% compared to 4.50% for the canvas. However, an analysis of the student-T test with unequal variances validated the presence of denim superiority in softness, as observed by objective evaluation.

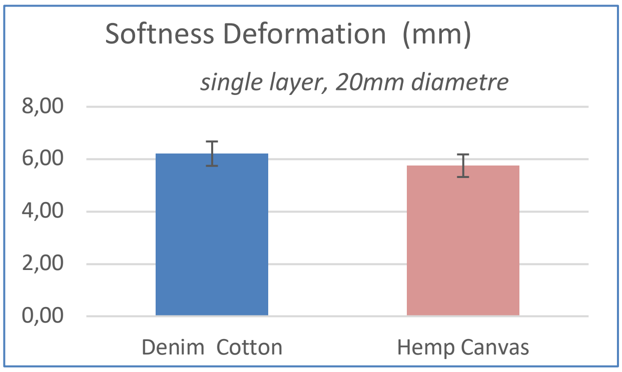


Fig. 6 Evaluation of the softness of sample fabrics through deformation

Fig. 7 and **Fig.** 8 present the tensile strength and elongation of the fabrics for warp and weft. The values of the force at break and peak show the adequate tenacity of the hemp compared to the denim. Marginal differences are seen in the warp direction, but hemp is significantly stronger in the weft direction. This can be attributed to the core spun yarn method containing the elastane filament compared to the traditional ring-spun method for hemp. The elongation values were similar except for the elastane-containing weft with higher expected values.

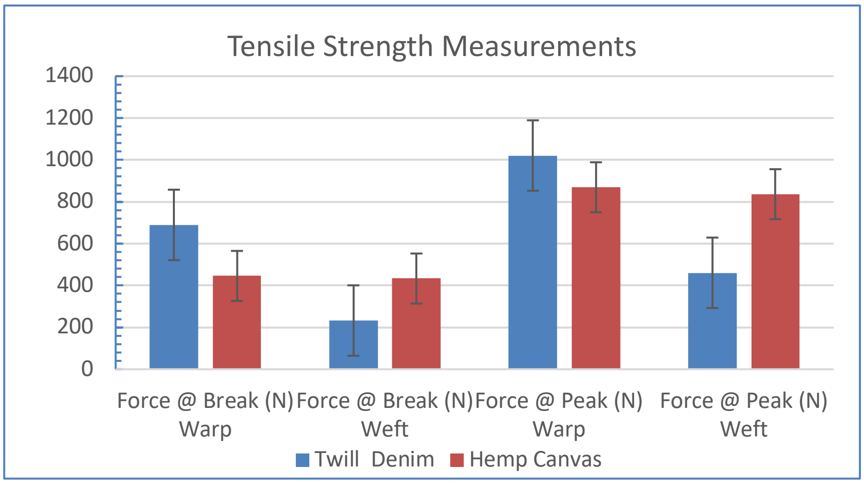


Fig. 7 Evaluation of the tensile strength of sample fabrics

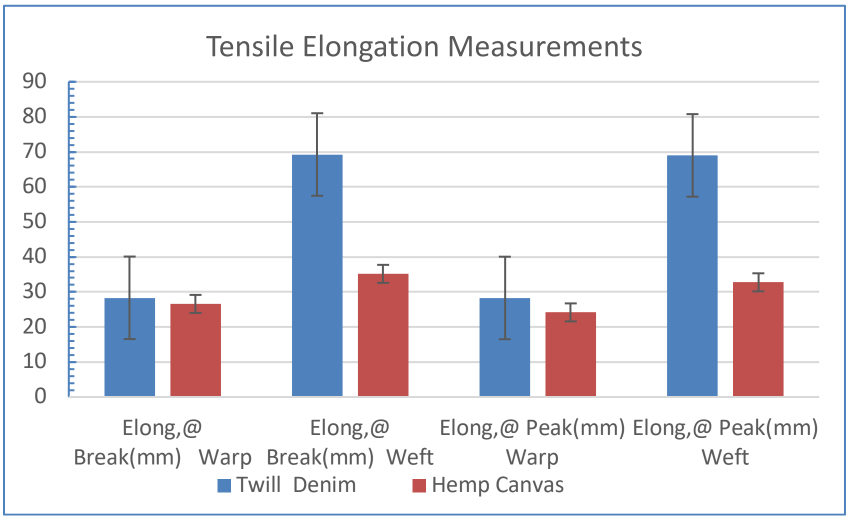


Fig. 8 Evaluation of the tensile elongation of sample fabrics

Data for %mass loss and cycles to failure from fabric resistance to flat abrasion tests were plotted in **Fig.** 9 and **Fig.** 10. The elasticity of the denim structure is the main reason for the excellent resistance. This highlights that yarn strength is not the governing property for abrasion resistance, as both fabrics had similar high strength values. The short life for the hemp fabric exhibits abrupt deterioration within the last 1000 revolutions, while the denim shows a gradual deterioration with mass loss and yarn breakage, as presented in **Picture** 1 to **Picture** 4. Failure of the structure is considered when two different yarns in the sample fail.

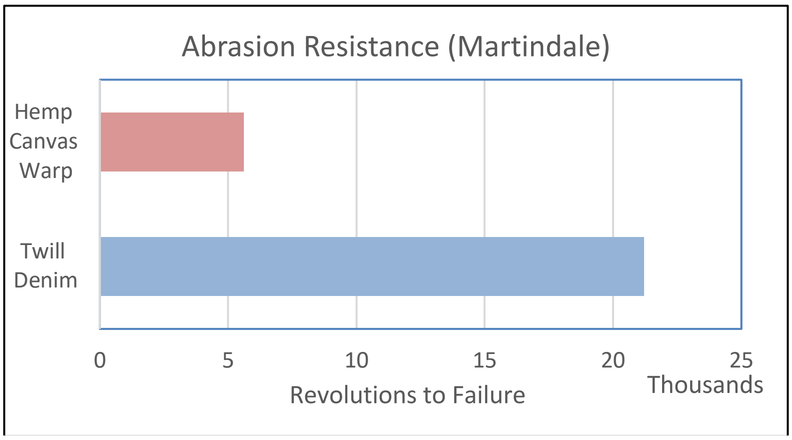


Fig. 9 Resistance to flat abrasion of sample fabrics in cycles to failure

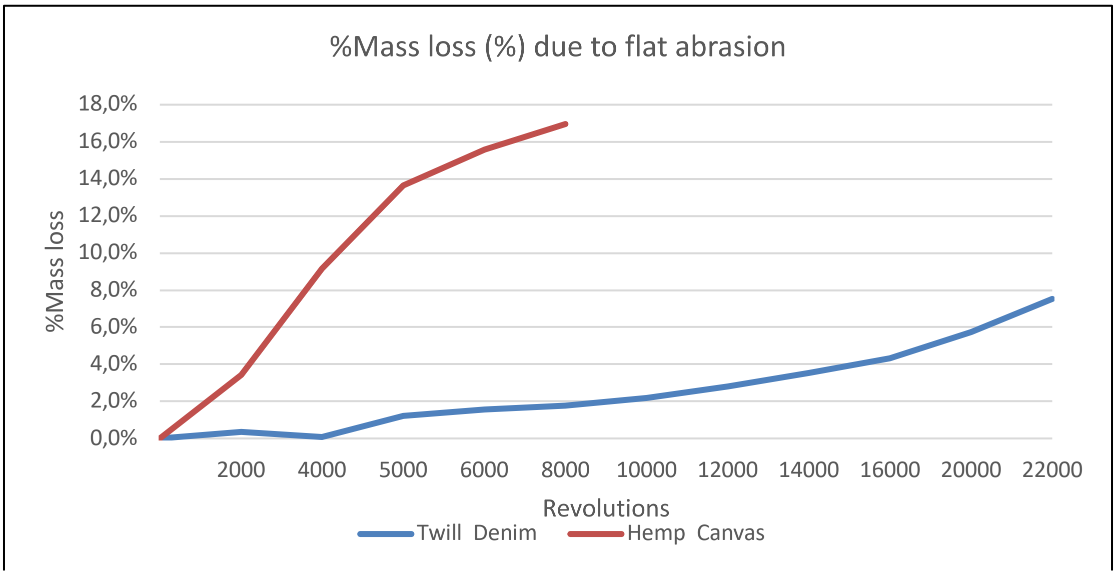
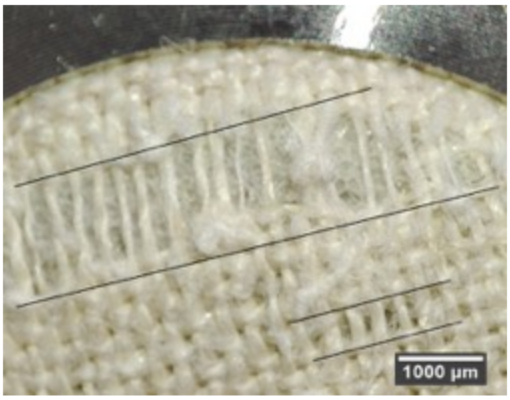
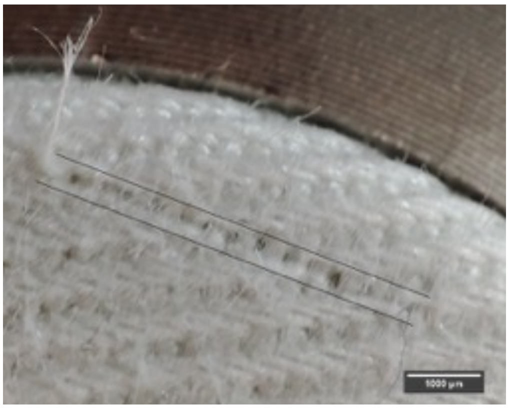


Fig. 10 Resistance to flat abrasion of sample fabrics in %mass loss

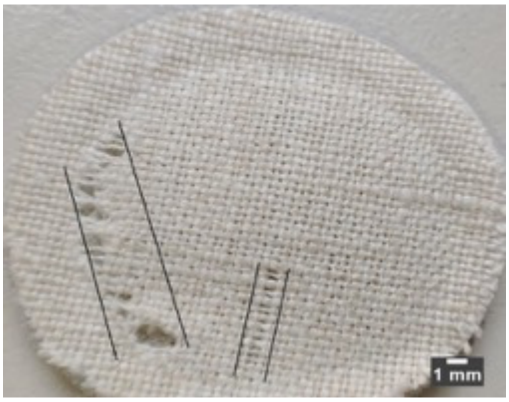
Picture 1 Failure point of denim sample in flat abrasion



Picture 2 Abrupt failure of hemp canvas in flat abrasion



Picture 3 Failure point of denim sample in flat abrasion



Picture 4 Abrupt failure of hemp canvas in flat abrasion

The fabrics' stiffness, bending modulus and flexural rigidity were calculated from the bending length, surface density and thickness; in the analysis, the denim fabric was less stiff, as seen in **Fig.** 11, **Fig.** 12 and **Fig.** 13. A deeper examination of the bending length revealed that the fabrics did not differ significantly warpwise. This suggests that easily deformable elastane in the weft threads decreased the denim’s stiffness.

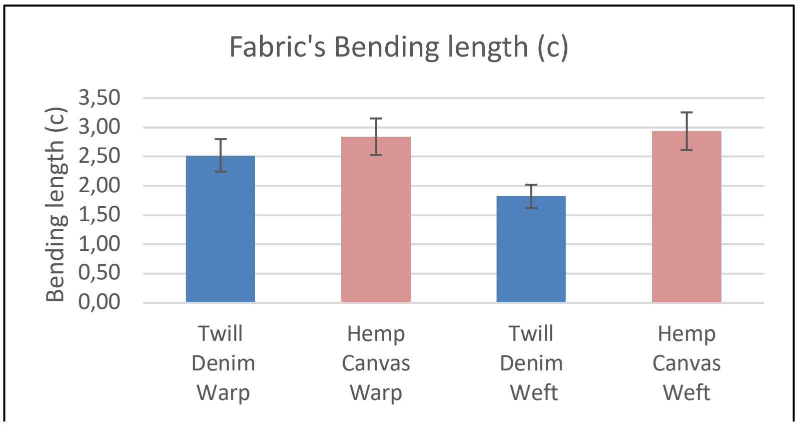


Fig. 11 Stiffness evaluation of sample fabrics over bending length

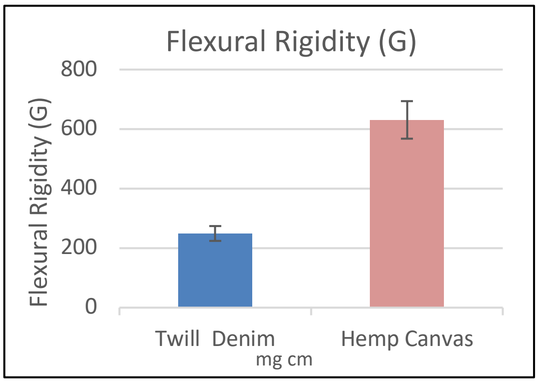


Fig. 12 Flexural Rigidity of sample fabrics

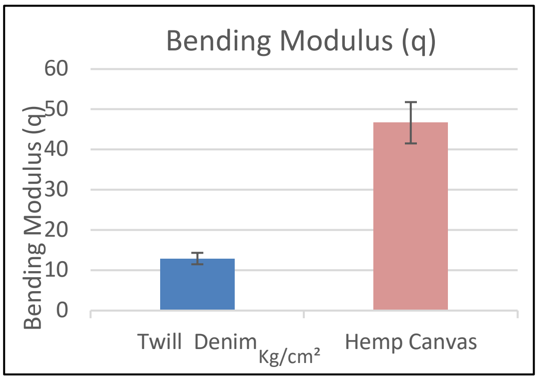


Fig. 13 Bending modulus of sample fabrics

Sewability expressed through needle penetration force (NPF) was plotted in **Fig.** 14. The sewability high values recorded for each direction were plotted in **Fig.** 15. From the graph obtained, the ease of the sewing process of hemp can be easily speculated. The objective evaluation of the fabric's sewing performance during the trouser-making confirmed the findings, as seen in **Picture** 5. Bending stiffness and fabric strength affect needle penetration, especially on rigid structures (Karypidis, 2018; Karypidis & Savvidis, 2018). Furthermore, the decreased covered factor and thread density reported earlier may have also contributed to the limited high values in sewability.

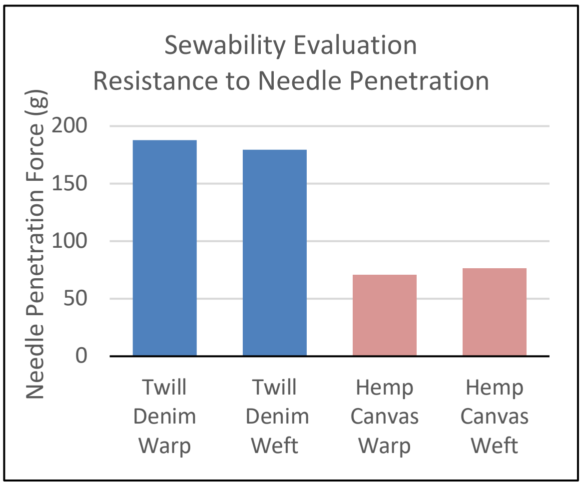


Fig. 14 Sewability of fabrics (NPF)

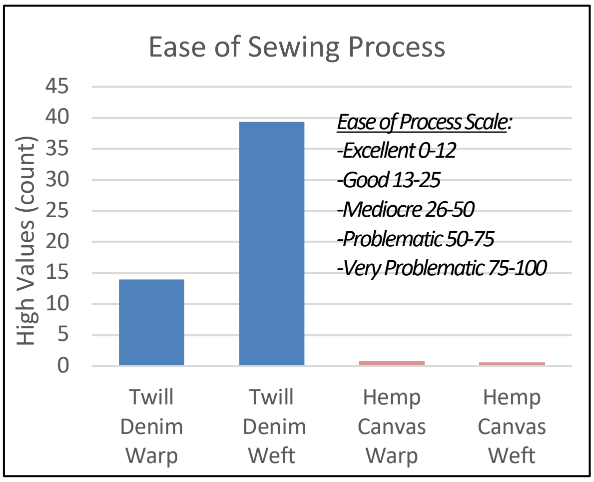


Fig. 15 Sewability -Ease of sewing process of fabrics

Picture 5 Trouser designed and made up from the hemp canvas fabric

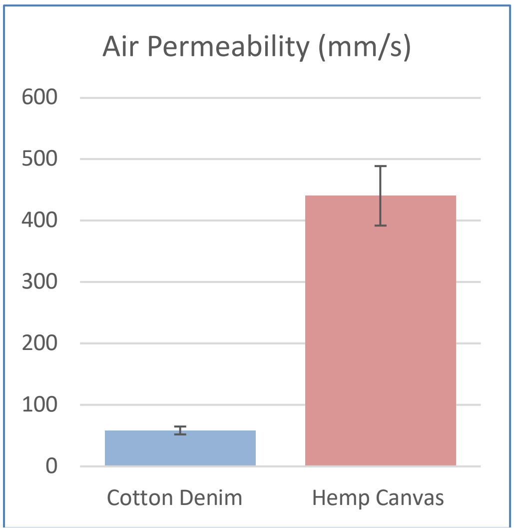


Fig. 16 Air permeability of sample fabrics as a representation of their breathability

The results for air permeability measurements are plotted in **Fig.** 16. High air permeability values reflect the hemp canvas structure's excellent breathability and confirm this fabric's preference for summer clothing despite its high surface density and increased cover factor.

Finally, the ability to dye cellulosic hemp has been demonstrated in **Picture** 6. The hemp fabric was dyed by exhaustion with beetroot-extracted natural dye achieving a colour difference of ΔE=10,84 from the control undyed sample measured over the CIELab system.

Picture 6 Dyed samples by exhaustion method of the hemp canvas with natural dye (beetroot extract

5. CONCLUSION

The sustainability of the eco-friendly farming of hemp has been analysed, and several advantages were highlighted, including reduced water consumption, low depletion of soil and ecosystem impact, and growth without the need for pesticides. From the results obtained, hemp faces some limitations in specific mechanical properties; nevertheless, it can be used to substitute denim cotton-rich blends adequately. It could be interesting to examine the use of hemp in blends with elastane; however, sustainability will suffer. Although the hemp canvas has a similar surface density and slightly smaller cover factor, it has outstanding breathability, as demonstrated by the air-permeability measurements. It is dyable, strong fibre with medium wear resistance characteristics, which appear abruptly, bearing a loss of about 15% of its mass before failure. This is not necessarily a disadvantage. Modern garments become obsolete with quick fashion changes terminating their serviceable life. This causes a significant waste of the residual life where garments still retain adequate mechanical characteristics. Garments made of hemp are expected to have a shorter residual life wastage. This also highlights the ease of decomposition and sustainability of the material.

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