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Original Article

Designing textiles with 3D surfaces using hemp fiber and natural dyes

Kenevir lifi ve doğal boyalar kullanılarak 3B yüzeyli tekstillerin tasarımı

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ABSTRACT

This design-oriented experimental study focused on developing a collection of woven fabrics made from hemp and hemp-blended yarns, dyed with natural dyes (turmeric, sage, pomegranate peel, walnut shell, and madder) to highlight the value of hemp fiber and contribute to sustainable textile design. The collection included fabrics made from hemp and hemp blends, Tencel™, and elastane, using various weaving structures, including dobby weaving, single- and double-layer structures, extra-weft weaving, and pleating, to create visually rich fabric surfaces with three-dimensional effects on both a handloom and an automatic sample weaving machine. Two pre-mordanting natural dyeing methods were applied: dyeing hemp-cotton blend yarns and fabrics woven from hemp and hemp-blended yarns. Yarns were dyed before weaving for four of the six designs, whereas for the other two, the fabrics were dyed after weaving. Two designs were selected for production on the automatic sample weaving machine. Notably, some designs exhibited striped patterns with varying dye absorption across fibers. The findings revealed that the three-dimensional effect was less pronounced in 100% hemp sections than in blends. Various combinations, elastane yarn, and the hot-water shrinkage process contributed to the desired effects. In Designs 5 and 6, pleated structures were pulled by hand after weaving and took on a wavy form due to the stiff nature of the hemp yarn. This enhanced the visual impact of the designs. The study concluded that the appropriate combination of yarns and techniques is essential for creating innovative fabric designs.

ÖZ

Tasarım odaklı bu deneysel çalışmada, kenevir lifinin değerini vurgulamak ve sürdürülebilir tekstil tasarımına katkıda bulunmak amacıyla, doğal boyalarla (zerdeçal, adaçayı, nar kabuğu, ceviz kabuğu ve kök boya) boyanmış kenevir ve kenevir karışımlı ipliklerle oluşturulan bir dokuma kumaş koleksiyonunun geliştirilmesi hedeflenmiştir. Koleksiyon, görsel açıdan zengin yüzeyler ve üç boyutlu etkiler oluşturmaya yönelik olarak, kenevir ve kenevir karışımları, Tencel™ ve elastan kullanılarak armürlü dokuma, tek katlı ve çift katlı yapılar, ekstra atkı ve pilise gibi çeşitli dokuma yapılarıyla hem el tezgâhında hem de otomatik numune dokuma makinesinde üretilen kumaşlardan oluşmaktadır. İki farklı ön mordanlamalı doğal boyama yöntemi uygulanmıştır: kenevir-pamuk karışımlı ipliklerin doğal boyanması ile kenevir ve kenevir karışımlı ipliklerden dokunan kumaşların doğal boyanması. Altı tasarımın dördünde iplikler dokumadan önce boyanırken, ikisinde kumaşlar dokunduktan sonra boyanmıştır. Bu tasarımlardan ikisi otomatik numune dokuma makinesinde üretim için seçilmiştir. Dikkat çekici olarak, bazı tasarımlarda farklı liflerin boyayı farklı oranlarda alması nedeniyle çizgili desenler oluşmuştur. Üç boyutlu etkinin %100 kenevir kısımlarında karışımlı kısımlara kıyasla

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daha az belirgin olduğu ortaya çıkmıştır. Farklı iplik kombinasyonları, elastan iplik kullanımı ve sıcak suyla çektirme işlemi istenen etkilerin elde edilmesine katkı sağlamıştır. Tasarım 5 ve 6' da, piliseli yapılar dokuma sonrasında elle çekilerek şekillendirilmiş ve kenevir ipliğinin sert yapısı sayesinde dalgalı bir form kazanmıştır. Bu durum, tasarımların görsel etkisini artırmıştır. Yenilikçi kumaş tasarımları oluşturabilmek için uygun iplik kombinasyonları ile tekniklerin bir araya getirilmesinin önemli olduğu sonucuna varılmıştır.

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INTRODUCTION

Many new plant fibers have been explored, including hemp, apocynum, mulberry bast, pineapple leaf, banana, bamboo, and kapok fibers (Karthik et al., 2015). Hemp fiber is notable for its environmental friendliness and sustainability. It holds significant ecological potential because it requires no chemical pesticides, uses minimal water, and is biodegradable. Therefore, hemp fiber is expected to have significant potential across various fields in the coming years (Kurtuldu and İşmal, 2019).

The use of hemp in textiles has grown across product categories, including clothing, home textiles, accessories, footwear, yarn, twine, rope, and cord. Today, hemp is attracting the attention of academic researchers and sustainability-focused brands. Recently, companies producing hemp products have emerged in numerous countries.

The review covered hemp agriculture; fiber properties; yarn spinning, weaving, knitting, and nonwoven production; dyeing and finishing processes; end-use and application areas of hemp fibers in textiles; and the status of hemp in the textile industry (Gedik and Avinç, 2022).

A comparison of the environmental impacts of cotton and hemp indicates that cotton's water footprint is three times that of industrial hemp (Averink, 2015). Hemp fibers are more durable and versatile than cotton fibers. Since no chemicals are used in its production, it is an environmentally friendly and sustainable material. Additionally, its fiber structure is strong, antibacterial, and recyclable (Nath, 2022).

Hemp fiber exhibits high durability, antimicrobial properties, UV resistance, natural resistance to mold, mildew, and rot, breathability, and good dye affinity. It wrinkles easily, has poor resilience, and exhibits low drapeability (www.fabriclink.com/University/Hemp.cfm). The cottonization and cotton-spinning processes cause hemp fibers to lose their inherent properties, such as high tensile strength, a cool touch, resistance to pilling, and bioactivity, although they help prevent fabric wrinkling (Zimniewska, 2022).

By the 1890s, the development of cotton-harvesting machines had made cotton more competitive as a fabric for clothing (Johnson, 2018). Throughout the twentieth century, industrial hemp production declined as the textile industry shifted toward cotton and synthetic fibers and as many countries imposed restrictions on hemp cultivation because of the psychoactive compound THC (Mishra et al., 2022). Beginning in the early 20th century, the rise of the petrochemical industry—later, the Marijuana Tax Act of 1937, enacted by the US government—prevented the development of hemp (Merfield, 1999). In recent years, the number of studies comparing hemp with synthetic fibers has increased. These investigations demonstrate that hemp fiber can serve as an alternative to synthetic fibers in composite structures, highlighting both its advantages and limitations (Manaia et al., 2019). Although hemp clothing has historically been more expensive, it still appeals to some consumers (Small and Marcus, 2002). The study investigated young consumers' perceptions, attitudes, and purchase intentions regarding hemp fiber textiles and clothing (Zhang et al., 2025).

Christopher Frayling classified research in art and design into three categories: Research into Art and Design, Research through Art and Design, and Research for Art and Design. Research into Art and Design encompasses historical, aesthetic, and perceptual studies, as well as a range of theoretical perspectives on art and design. Research through Art and Design treats the design process as a primary means of knowledge generation, encompassing materials research, development work, and action research. It also advocates documenting and communicating the knowledge and experience gained throughout studio practice in a research report. By contrast, Research for Art and Design refers to studies in which the primary aim is the creation of an artifact through visual or imagistic communication rather than the production of verbal knowledge (Frayling, 1993). Within this classification, Research Through Design treats the design artifact not only as the subject of investigation but also as a means of generating and communicating knowledge. From this perspective, research through design offers a research process that integrates theoretical and practical knowledge (Koskinen et al., 2011). A study using this approach outlined the stages of the research process (Biçer and Enes, 2025).

Hemp, natural dyeing, and weaving techniques are well established in the literature; however, design-oriented studies focused on creating woven fabrics with three-dimensional effects remain limited. This study adopted the Research through Art and Design approach. Previous studies on hemp textiles have mainly focused on material properties, natural dyeing, and single-layer woven and knitted structures, while woven surfaces with three-dimensional effects have been produced primarily using synthetic or thermoplastic yarns. From the designer's perspective, the study aims to enhance three-dimensional surface effects in woven fabrics by combining hemp, hemp-blended, and elastane yarns, employing diverse weave structures, and applying natural dyeing techniques, thereby increasing the value of hemp fiber through innovative design approaches.

LITERATURE REVIEW

Numerous studies have examined the use of hemp fibers in the textile industry. 100% hemp fabrics were naturally dyed with red beetroot, onion peel, and black tea (Budeanu et al., 2014). The impact of yarn folding on the thermal and tactile comfort of plain knitted hemp fabrics was examined (Stankovic and Bizjak, 2014).

Natural dyeing and eco-printing techniques were applied to 100% hemp and 100% linen knitted fabrics. Eco-print patterns were digitized for clothing designs (Topoyan, 2022). The collection included woven and knitted fabrics made from hemp and hemp blends. The woven collection featured a single layer and was dyed with natural dyes (Aksoy Gülen, 2022).

Innovative textile design methods can use three-dimensional effects to create visually engaging, richly textured fabric surfaces. Designers often describe this look with terms such as puffy, wrinkled, embossed, and three-dimensional.

Various methods for creating pleats through shrinkage and finishing processes were explored as alternatives to traditional weaving techniques. Polyurethane, wool, and cotton yarns served as reinforcement wefts. Felting wool fibers and treating cotton fibers with sodium hydroxide produced localized shrinkage and pleat formation (Acar et al., 2019).

Combining thermoplastic yarns with non-thermoplastic ones enabled the development of relief effects of varying sizes. Thickness, hardness, and twist were crucial for thermoplastic yarns to retain a permanent shape after thermal treatment. Double-layered bag structures produced more pronounced relief effects than single-layered designs (Kurtuldu and Önlü, 2022).

Silk, linen, cotton, elastane, polyester, and reflective weft yarns influenced the visual appearance and texture of women's clothing. Despite identical weave structures, raw silk fabrics were lightweight, semi-transparent, and stiff, whereas elastane fabrics were opaque with three-dimensional surfaces. Silk–elastane combinations produced distinct textures, and elastane sections narrowed and shaped the garment (Yaşar, 2016).

On the Jacquard weaving hand loom (Halaçeli, 2012), relief effects on fabric surfaces were created by using elastic and low-elasticity yarns in combination with weave structures such as brocade, double cloth, and overshot.

Some artworks combine weaving and dyeing techniques. The woven shibori technique, inspired by traditional Japanese shibori, was developed in the early 1990s (ellistextiles.com/woven-shibori). Fabrics made from various fibers are colored using the cross-dyeing method (Ellis, 2016). Dobby- and Jacquard-weaving designs were generated using color and texture data from the trials. Wool, linen, silk, and cotton yarns were dyed in a one-bath process with natural onion-skin dye and mordants such as potassium aluminum sulfate, copper sulfate, and iron sulfate (Acar et al., 2023).

MATERIALS AND METHODS

The experimental woven fabric designs created three-dimensional surface effects using dobby weaving techniques. Various structures were implemented, including extra-weft structures, single-layer structures, double-layer structures (specifically, weft-interchanging double fabrics and self-stitching double fabrics), and pleated structures. The use of elastane yarn enhanced the fabrics visually, creating rich, three-dimensional surfaces. A pleated appearance was achieved through manual intervention with a single beam to form the pleating structure after the fabric was woven and removed from the loom. Two natural dyeing methods were used: (1) dyeing hemp-cotton blend yarns (Designs 1, 2, 5, and 6); and (2) dyeing fabrics woven from hemp and hemp-blended yarns using pre-mordanting (Designs 3 and 4). In four of the six fabric designs, the yarns were dyed naturally before weaving; in the remaining two designs, they were dyed after weaving. Two of the woven fabric designs were selected for production on the CCI Tech-brand automatic sample-weaving loom.

Natural Dyeing

Details of the natural dyeing procedures are presented in Table 1. Yarns composed of 78% cotton and 22% hemp (Ne: 7.5) were dyed with natural dyes extracted from turmeric, sage, pomegranate peel, walnut shell, and madder for Designs 1, 2, 5, and 6. Fabrics for Designs 3 and 4 were dyed with walnut shell and iron (II) sulfate, and with sage and iron(II) sulfate, respectively. Dye materials were extracted by boiling at 100°C for 1 hour at the following concentrations: 10 g/L madder, 20 g/L walnut shell, 20 g/L turmeric, 30 g/L pomegranate peel, and 30 g/L sage. The dye liquor was then filtered, and any lost liquid volume was replenished with water. Dyeing was carried out using the pre-mordanting method with 3 g/L alum (potassium aluminum sulfate), iron(II) sulfate, and copper(II) sulfate at a bath ratio of 1:30 and at 100°C for 1 hour. After dyeing, the yarns and fabrics were washed and dried at room temperature.

Woven Fabric Designs

Table 2 presents the technical specifications for six woven fabric designs produced on a single-beam, 16-shaft dobby desktop handloom.

The properties of the yarns used in the designs are listed in Table 3.

Table 1. Natural dyeings

Experiment	Natural dye concentration	Mordant concentration	Colour
Turmeric	20 g/L	3 g/L alum (potassium aluminum sulfate)	
Sage	30 g/L	3 g/L alum (potassium aluminum sulfate)	
Sage	30 g/L	3 g/L copper II sulfate	
Sage	30 g/L	3 g/L iron II sulfate	
Pomegranate peel	30 g/L	3 g/L iron II sulfate	
Madder	10 g/L	3 g/L alum (potassium aluminum sulfate)	
Walnut shell	20 g/L	3 g/L iron II sulfate	

Table 2. Technical specifications for woven fabric designs

Weaving Technique: Dobby hand weaving

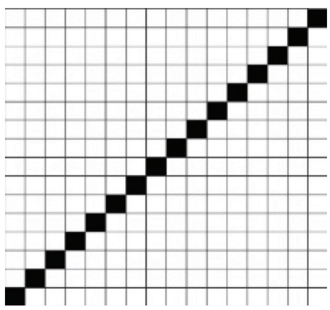
Drafting plan: Straight draft

Shaft: 16 shafts

Reed number: 70

Two warp yarns were threaded through each heddle eye, and during weaving, two weft yarns were inserted into each shed.

Drafting plan



RESULTS AND DISCUSSION

Woven Fabrics with Extra Weft Structure

A polyester-elastane blend (87% polyester, 13% elastane; Ne 15.5) was used to produce two woven fabrics with an extra-weft structure, incorporating hemp and hemp-blended yarns. This blend is designed to create a three-dimensional effect on the fabric's surface by leveraging the elastane yarn's shrinkage. The striped patterns in Designs 1 and 2 were developed using naturally dyed hemp-blended yarns (78% cotton/22% hemp; Ne = 7.5). Designs 1 and 2 were dipped in boiling water, then removed to promote shrinkage, and subsequently rinsed. The fabrics were then dried at room temperature. Variations in the weft yarn handle produced distinct effects on the fabric surface. Figure 1 shows Design 1 before and after the hot-water shrinkage process. Tables 2 and 4 present the technical details, drafting and pegging plans, and warp and weft yarns for the woven fabrics of Design 1. The fabric for Design 1 was initially woven to a width of 40 cm, but shrank to 19 cm after removal from the loom. After hot-water shrinkage and drying, the fabric was only

Table 3. Characteristics of the yarns used in weaving designs

Yarn type	Handle and appearance of the yarn
% 78 cotton- % 22 hemp - Ne: 7.5 (Warp and weft yarn)	Soft, matte
% 45 organic cotton- % 55 hemp - Ne : 11/1 (Weft yarn)	Soft, matte
% 80 cotton -% 20 hemp– Ne : 8/1 (Weft yarn)	Soft, matte
% 85 cotton- % 15 hemp – Ne: 12 (Weft yarn)	Soft, matte
% 100 hemp - Nm: 9.6/1 (Weft yarn)	Stiff, semi-gloss
% 87 Polyester- % 13 Elastane - Ne: 15.5 (300 Denier/140 Flam/156 Dt) (Weft yarn)	Flexible, resilient
% 100 Tencel ™ - Ne: 12 (Weft yarn)	Soft, lustrous

Figure 1. Design 1: **(a)** before the hot-water shrinkage process; **(b)** after the hot-water shrinkage process.

15 cm wide. The elastane yarn shrinks more during this process, producing a three-dimensional appearance with a more pronounced zigzag pattern on the fabric surface. Shaping areas with 100% hemp yarn proved more difficult than shaping those woven with a hemp-cotton blend. Although hemp yarn is slightly more difficult to shape than hemp-cotton blends due to its stiffer structure, a three-dimensional form has been achieved through a combination of factors, including the weaving structure, the shrinkage properties of elastane yarn, and hot-water treatment.

Figure 2 shows the appearance of Design 2 before and after the hot-water shrinkage process. Tables 2 and 4 present the technical details, drafting and pegging plans, and the warp and weft yarns for the woven fabrics of Design 2. Initially, the fabric width of Design 2 was 40 cm; however, it shrank to 18.5 cm after removal from the loom. After hot-water shrinkage followed by drying at room temperature, the woven fabric shrank to a width of 15 cm. At this stage, the elastane yarn contracted more than the other components, resulting in a three-dimensional appearance on the fabric surface. It was also observed that shaping areas woven with 100% hemp yarn were more challenging than those woven with hemp-cotton blend yarns. While hemp yarn is slightly more difficult to shape due to its stiffer structure compared to hemp-cotton blends, a three-dimensional form has been

Figure 2. Design 2: **(a)** before the hot water shrinkage process, **(b)** after the hot water shrinkage process.

achieved through the combination of components, including its weaving structure, the shrinkage properties of elastane yarn, and hot-water treatment.

Natural Dyeing with Single-layer and Double-layer Woven Fabrics

Table 5 presents the pegging plan, warp and weft yarns, and dyeing properties of the woven fabric designs (Designs 3 and 4) that incorporate single- and double-layer structures. Table 2 provides the technical details and draft plans used. After Designs 3 and 4 were woven, the samples were dyed with natural dyes. In the second-layer weaving areas of Designs 3 and 4, a yarn composed of 87% polyester and 13% elastane (Ne:15.5) was used. In these two designs, the fabrics were engineered to achieve a three-dimensional surface effect by utilizing the shrinkage properties of the elastane yarn. In the double-layer section of Design 3, the weft-interchanging method was used to create a double layer. On the other hand, the double-layer section of Design 4 was obtained using the self-stitching method. The elastane yarn did not fully exhibit its shrinkage properties after weaving. Both designs shrank during the natural dyeing process using hot water. This shrinkage is intended to enhance the fabric's surface appearance. It was observed that weft yarns with different hand properties produced distinct surface effects. Additionally, different fibers exhibited varying degrees of dye uptake during natural dyeing, resulting in striped patterns with alternating light and dark tones.

From the darkest to the lightest colored yarns;

78% cotton / 22% hemp Ne: 7.5> 100% Tencel™ Ne: 12 > 100% hemp Nm: 9.6/1 bleached > 87% polyester - 13% elastane - Ne: 15.5 (300 denier /140 flam/156 Dt).

Figure 3 shows Design 3 before and after the natural dyeing process. In Design 3, a hemp–cotton blend, Tencel™, and 100% hemp yarns formed the first layer in the double-layer woven areas, while elastane yarn formed the second layer. The fabric's initial width was 40 cm and decreased to 27 cm after removal from the loom. After natural dyeing, the width was further reduced to 15 cm. The dyeing process produced a three-dimensional striped pattern with varying degrees of dye absorption.

Figure 4 shows Design 4 before and after the natural dyeing process. In Design 4, the double-layer woven regions were produced using 100% hemp yarn in the first layer and elastane yarn in the second. The fabric initially measured 40 cm in width but shrank to 39 cm when removed from the loom. After dyeing, the width decreased to 15 cm, resulting in a three-dimensional appearance. This effect appeared as a zigzag in areas woven in double layers, which exhibited varying surface textures and produced a striped appearance on the fabric surface due to differential dye absorption.

Table 4. Technical properties of woven fabric designs with extra weft structure

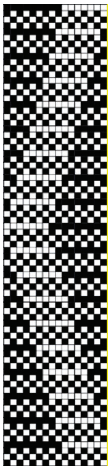
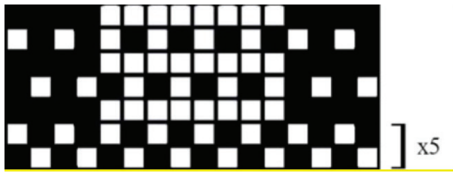
Design 1	**Design 2**
	
Warp yarn: 78% cotton/ 22% hemp Ne: 7.5	**Warp yarn:** 78% cotton/ 22% hemp Ne: 7.5
Weft yarns: 78% cotton/ 22% hemp Ne: 7.5	**Weft yarns:** 78% cotton/ 22% hemp Ne: 7.5
100% hemp Nm: 9.6/1	100% hemp Nm: 9.6/1
87% polyester- 13% elastane - Ne: 15.5 (300 denier /140 flam/156 Dt),	87% polyester- 13% elastane - Ne: 15.5 (300 denier /140 flam/156 Dt),
78% cotton /22% hemp Ne: 7.5 yarn natural dyed with sage, madder, walnut shell	100% Tencel™ Ne: 12,
	78% cotton /22% hemp Ne: 7.5 yarn natural dyed with sage, pomegranate peel, walnut shell
Two warp yarns were threaded through each heddle eye, and during weaving, two weft yarns were inserted into each shed.	*Two warp yarns were threaded through each heddle eye, and during weaving, two weft yarns were inserted into each shed.*

Table 5. Technical specifications of single-layer and double-layer woven fabrics

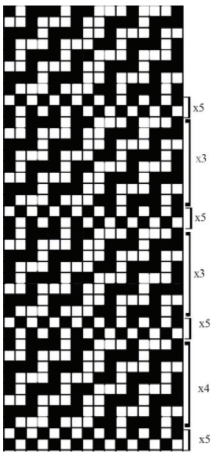
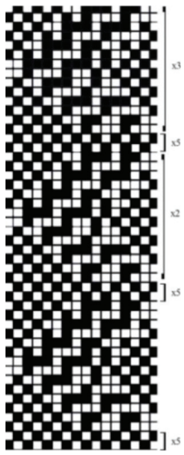
Design 3	**Design 4**
	
Warp yarn: 78% cotton/ 22% hemp Ne: 7.5	**Warp yarn:** 78% cotton/ 22% hemp Ne: 7.5
Weft Yarns: 78% cotton / 22 % hemp Ne: 7.5,	**Weft Yarns:** 78% cotton / 22 % hemp Ne: 7.5
100% hemp Nm: 9.6/1	100% hemp Nm: 9.6/1
87% polyester-13% elastane - Ne: 15.5 (300 denier /140 flam/156 Dt),	87% polyester-13% elastane - Ne: 15.5 (300 denier/140 flam/156 Dt)
100% Tencel™ Ne: 12	Natural dyeing with sage.
Natural dyeing with walnut shells.	
Two warp yarns were threaded through each heddle eye, and during weaving, two weft yarns were inserted into each shed.	*Two warp yarns were threaded through each heddle eye, and during weaving, two weft yarns were inserted into each shed.*

Figure 3. Design 3: **(a)** Before natural dyeing, **(b)** after natural dyeing.

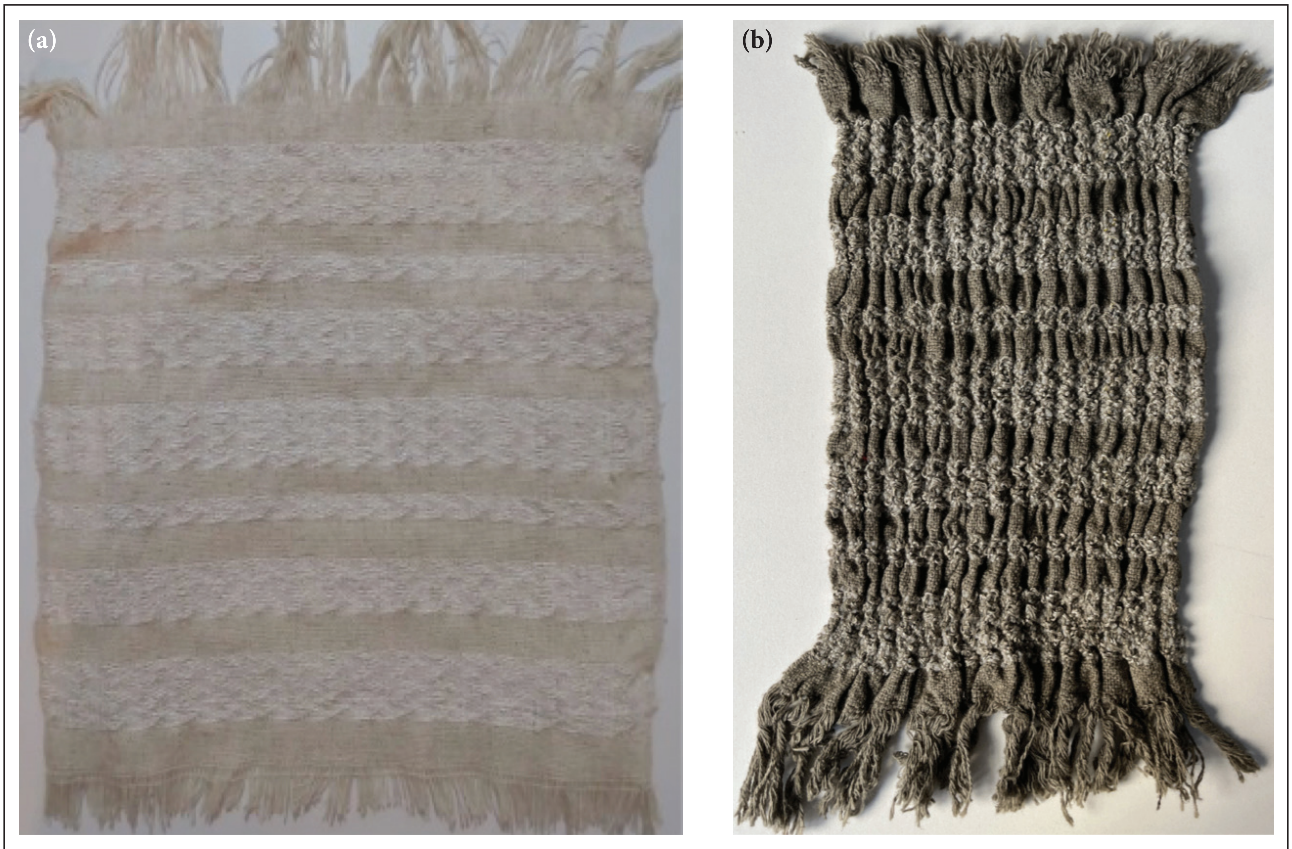
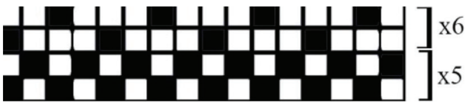
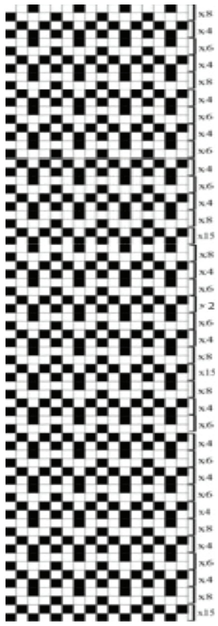


Figure 4. Design 4: **(a)** Before natural dyeing, **(b)** after natural dyeing.

Table 6. Technical properties of pleated woven fabrics

Design 5	**Design 6**
	
Warp yarn: 78% cotton/ 22% hemp Ne: 7.5	**Warp yarn:** 78% cotton/ 22% hemp Ne: 7.5
Weft Yarns: 78% cotton/ 22% hemp Ne: 7.5	**Weft Yarns:** 78% cotton/ 22% hemp Ne: 7.5
100% hemp Nm: 9.6/1	100% hemp Nm: 9.6/1
78% cotton/ 22% hemp Ne: 7.5 yarn natural dyed with sage, pomegranate peel, and walnut shell.	55% hemp / 45% Organic cotton Ne: 11/1
	80% cotton / 20% hemp Ne: 8/1
	85% cotton / 15% hemp Ne: 12
	78% cotton /22% hemp Ne: 7.5 yarn natural dyed with madder and walnut shell.
Two warp yarns were threaded through each heddle eye, and during weaving, two weft yarns were inserted into each shed	*Two warp yarns were threaded through each heddle eye, and during weaving, two weft yarns were inserted into each shed.*

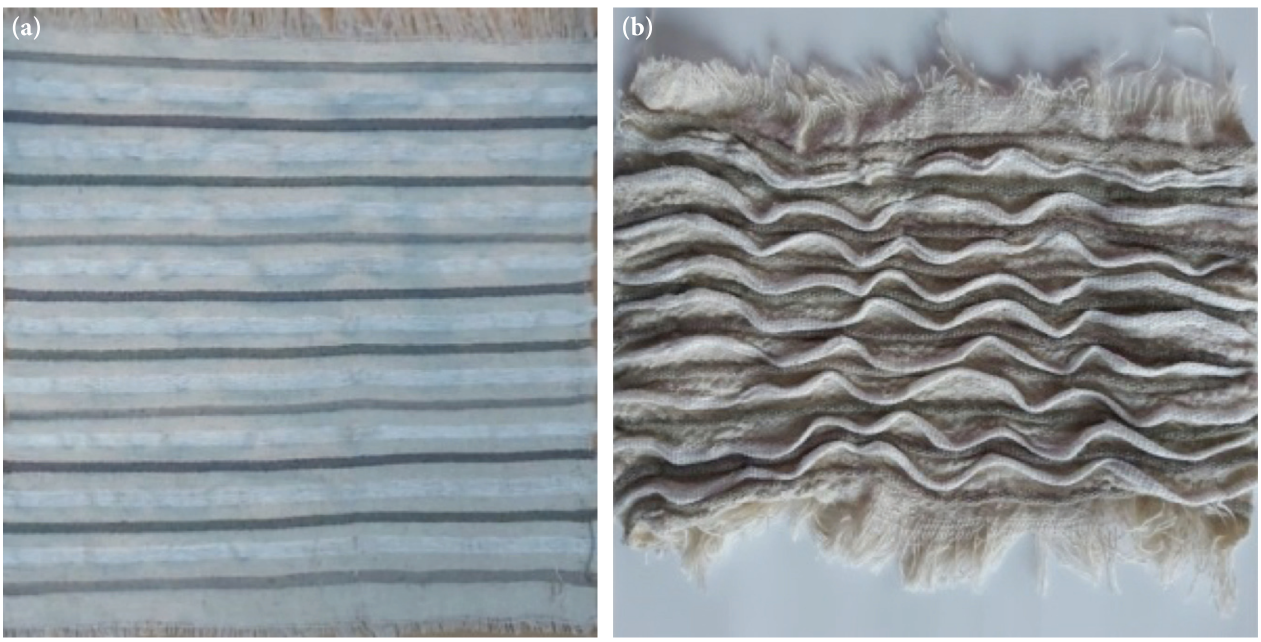


Figure 5. Design 5: **(a)** pleated yarns before compression, **(b)** pleated yarns after compression.

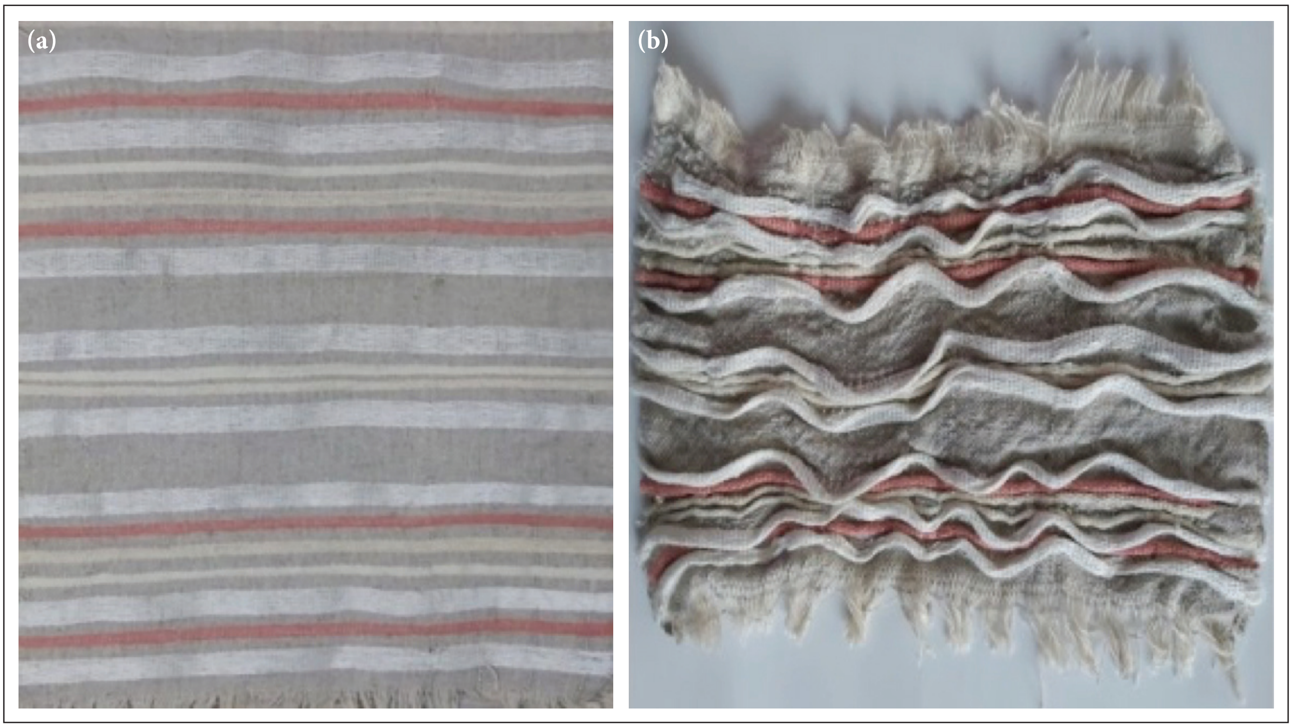


Figure 6. Design 6: **(a)** pleated yarns before compression, **(b)** pleated yarns after compression.

Figure 7. Design 1: **(a)** fabric woven on an automatic sample loom and **(b)** after the hot-water shrinkage process.

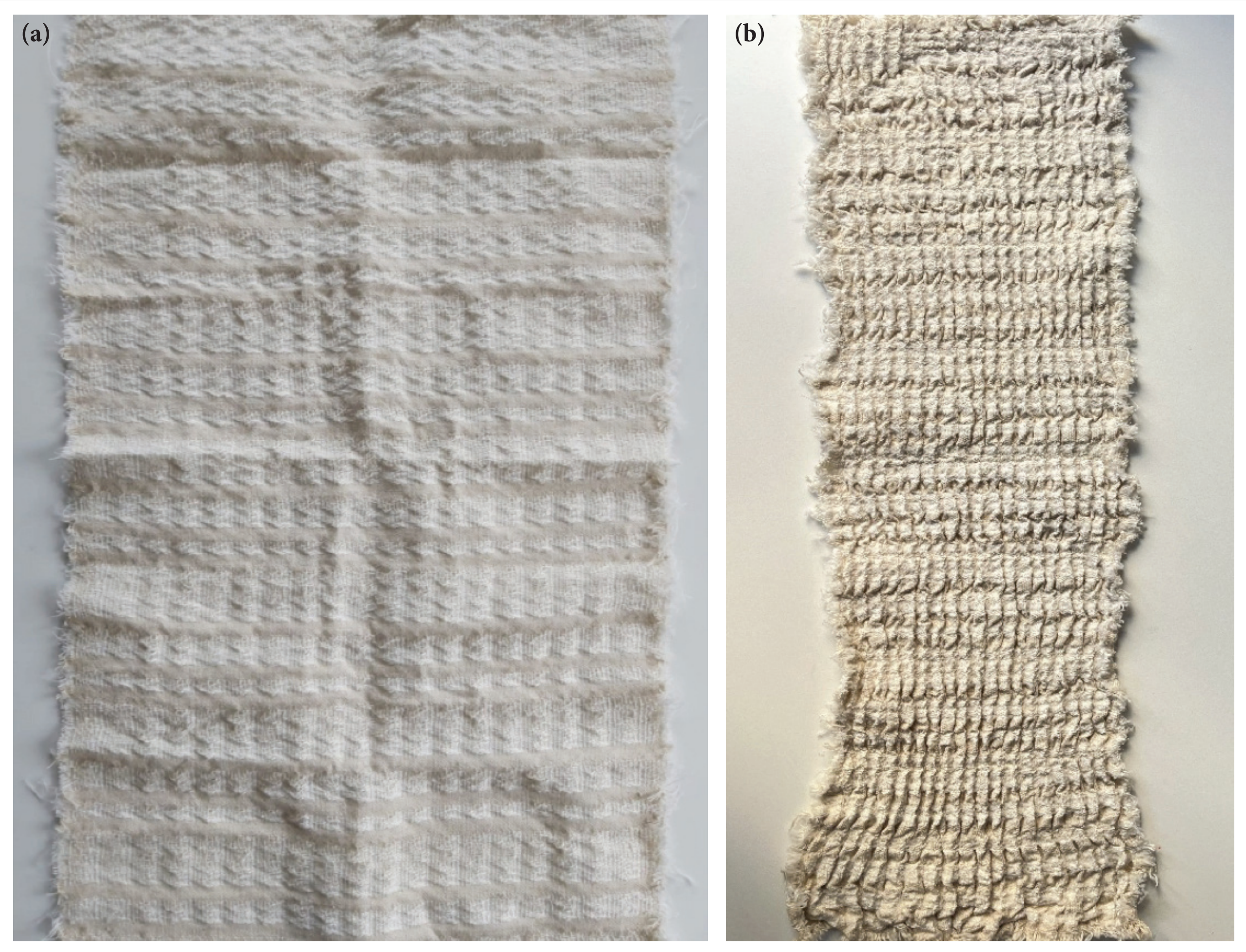


Figure 8. Design 4: **(a)** fabric woven on an automatic sample loom and **(b)** after the hot-water shrinkage process.

The stiffness of the 100% hemp yarn limited the shrinkage of the elastane yarn. Consequently, differences in pegging plans and yarn selection led to variations in post-loom shrinkage behavior and fabric surface texture.

Pleated Woven Fabrics

The pegging plans for Designs 5 and 6, along with the weft and warp yarns used, are outlined in Table 6. Table 2 provides the technical details and draft plans. Both designs aim to create a three-dimensional effect in the fabric through a pleated structure. Although the pleated structure is typically woven on a double-warp beam, Designs 5 and 6 employ a single-warp beam. After weaving, the pleated yarns were manually pulled and compressed. For the striped pattern in Designs 5 and 6, hemp-blended yarns (78% cotton, 22% hemp; Ne 7.5) were naturally dyed.

In Figure 5, the pleated yarns of Design 5 are shown both before and after compression. The fabric for Design 5 was originally 50 cm long. After the pleated yarns were hand-pulled, the fabric length was reduced to 25 cm. Different yarn orientations produced distinct visual effects. Notably, the 100% hemp yarn produced a wavy surface.

Figure 6 shows the pleated yarns of Design 6, both before and after compression. The fabric was initially woven to a length of 50 cm. After manually pulling the pleat yarns, the fabric length was reduced to 25 cm. The yarns produce varied visual effects because the materials have different tactile properties. Specifically, 100% hemp yarn exhibits a wavy surface.

Trials Using Automatic Sample Weaving Loom

Designs 1 and 4 were selected and produced on an automatic sample loom. The automatic sample loom has an 18-shaft weaving capacity and a maximum weaving width of 45 cm. Consequently, the fabric width was consistently maintained at 45 cm across all woven fabric applications. The automatic sample-weaving loom can also accommodate up to six weft yarns.

Figure 7 shows Design 1 after it was woven on an automatic sample loom and subjected to hot-water shrinkage. This design reduced the number of weft yarns from seven to six. The weft yarns comprise a hemp–cotton blend, pure hemp, and elastane, each contributing distinct tactile qualities. As a result, the rapier had difficulty picking up the weft yarns during weaving. Using hemp yarn combined with elastane proved challenging, particularly when used as the weft yarn. The fabric was initially woven to a width of 45 cm and a length of 40 cm. However, after removal from the loom, it measured 24 cm in width and 38 cm in length. During the hot-water shrinkage process, the woven fabric was immersed in boiling water and then washed. After drying at room temperature, the final measurements showed that the width had decreased to 17 cm, while the length remained at 38 cm.

Figure 8 shows Design 4 after it was woven on an automatic sample loom and subjected to hot-water shrinkage. The weft yarns consist of a hemp-cotton blend, pure hemp, and elastane, each with a distinct texture. Consequently, the rapier had difficulty picking up the weft yarns during weaving. The fabric was initially woven to a width of 45 cm and a length of 90 cm. However, after removal from the loom, its dimensions were measured at 42 cm in width and 86 cm in length. No dyeing was performed at this stage. The woven fabric was then immersed in boiling water and washed. After drying at room temperature, the fabric's width and length decreased to 19 cm and 83 cm, respectively.

CONCLUSION

As part of sustainability efforts, this study focused on designing unique fabrics with three-dimensional surfaces using various hemp and hemp-blend yarns, weaving techniques, and natural dye combinations from a designer's perspective. Some yarns used in the designs were dyed with natural dyes, following an ecological approach that minimized the use of synthetic dyes.

Incorporating elastane yarns produces three-dimensional textures, noticeable ripples, and increased fabric surface volume due to their high elasticity. Combining elastane with other fibers had variable effects on fabric volume. For instance, 100% hemp fiber was more difficult to shape than hemp-cotton-blended yarns because of its greater stiffness. In this context, integrating yarns of varying structures enhanced the woven surfaces, imparting a distinctive appearance to the designs. Designs 1, 2, 3, and 4 exhibited a three-dimensional surface appearance after the elastane yarn shrank in hot water. Designs 5 and 6 also featured a three-dimensional, pleated structure. In Designs 3 and 4, where different yarns were woven together, a striped pattern emerged on the surface due to variations in dye uptake among the yarns during natural dyeing. Designs 1 and 4 were rewoven on an automatic sample loom. The hemp-cotton blend, hemp, and elastane weft yarns exhibited distinct properties. The rapier had difficulty picking up the 100% hemp and elastane weft yarns during weaving. Using different yarn types on woven fabric surfaces enriches and diversifies the fabric's texture. In this regard, determining appropriate combinations is essential. This approach enables the production of unique, high-value-added textile products that align with the principles of ecological design and production.

This study acknowledges limitations, particularly the small-scale production of samples and current technological constraints in processing hemp fiber for industrial textile applications. Future research should focus on large-scale weaving and finishing trials, examine the performance of hemp relative to other sustainable fibers, and assess its applications in real-world industrial settings. As awareness of hemp's ecological benefits and design potential grows, future studies and design practices are likely to broaden its applications. The findings provide valuable insights for textile education through the study of hemp-based design innovation and for industry practice by supporting the development of sustainable raw-material strategies in textile manufacturing. Additionally, the findings may contribute to design education and promote sustainable approaches in textile production.

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