

# MILITARY FABRICS MADE OF HEMP FIBERS

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## ABSTRACT

The relevance of this research is determined by the necessity to replace the existing camouflage fabrics on the Ukrainian market, which are made with synthetic fibers for military clothing, with eco-friendly fabrics produced from natural raw materials – hemp fiber. The aim was to analyze the qualitative properties of mixed hemp fabrics developed by scientists of Kherson National Technical University and to determine their potential use in military uniforms. Comprehensive methods of analysis, synthesis, observation, measurement, comparison, and generalization of results were applied, as well as standard methodologies widely used in the light industry. The paper provides a detailed analysis of the current state of the global protective and military textile market. Samples of existing camouflage fabrics for military uniforms and equipment were examined, and results of testing new hemp fiber-based fabrics were presented. Physico-mechanical, aesthetic, and operational tests demonstrated that hemp-based materials surpass most existing analogs in their qualitative characteristics. The introduction of hemp fabrics into military textile production may ensure increased reliability, functionality, and environmental safety of defense products.

## KEYWORDS

Assortment, Camouflage Fabrics, Comparative Analysis, Mixed Hemp Fabrics, Properties, Purpose.

## INTRODUCTION

In the context of Russia's full-scale invasion, Ukraine's need for high-quality, functional, and safe military textile materials has become critically important. Providing service members with advanced fabrics is not merely a matter of comfort or protection but a strategic factor directly influencing the nation's defense capability. Modern warfare is characterized by rapidly changing conditions, elevated risks, and the necessity to adapt military gear to extreme climatic, physical, and tactical loads.

Traditional synthetic materials used in military uniforms possess several significant drawbacks: high production costs, considerable energy consumption, limited environmental performance, and potential adverse health effects for personnel. These materials do not always ensure adequate comfort across Ukraine's diverse climatic zones, and prolonged wear may lead to skin irritation and allergic reactions [1]. Under such circumstances, the search for alternative fibrous resources with improved hygienic, ecological, and operational properties becomes particularly relevant.

Ukraine possesses substantial fibrous potential—namely hemp fibers, which have been historically cultivated in the country and are once again demonstrating high technological and economic promise. Hemp fibers exhibit high tensile strength,

abrasion resistance, hygroscopicity, inherent bactericidal properties, and environmental purity [2]. These characteristics make them a promising raw material for the development of advanced military textiles capable of ensuring comfort, protection, and durability under demanding operational conditions. The use of domestic natural resources would also strengthen the national textile industry and reduce dependence on imported raw materials.

Global trends indicate the dynamic development of innovations in military textile materials—from nanotechnologies to bioactive, bacteriostatic, and ultra-high-molecular systems [3-7]. Improvement of such materials aims to enhance ballistic protection, reduce equipment weight, improve camouflage performance, and increase the physical resilience of military personnel. For Ukraine, which remains engaged in prolonged warfare, integrating these technologies into the production of natural, environmentally safe, and competitive hemp-based textiles represents a strategically significant direction.

Thus, the relevance of the study lies in the need to develop innovative, eco-friendly, and high-performance military textile materials using Ukraine's own fibrous resources. This will improve the effectiveness and safety of service members and enhance the country's defense-industrial capacity under conditions of armed aggression.

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## **LIBRARY STRUCTURE**

Contemporary research in military textiles is focused on developing high-performance materials capable of providing comprehensive protection for service members across a wide range of operational environments. The demand for next-generation military fabrics is driven by increasingly stringent requirements for wear resistance, durability, camouflage performance, moisture resistance, contamination resistance, and stability against microorganisms, chemicals, and mechanical stressors. For this reason, researchers are actively engaged in improving artificial and synthetic fibers while also investigating natural components, particularly bast fibers.

Among natural fibers, hemp has attracted special scientific interest owing to its advantageous performance properties, which make it suitable for use in technical and, specifically, military textiles. For example, researchers at the U.S. Army Natick Soldier Research, Development and Engineering Center in Natick, Massachusetts, including Quoc T. Truong and Natalie Pomerantz [8], are working on enhancing the performance of military textiles through the application of omniphobic coatings. Such coatings improve garment durability, enable self-cleaning behavior, and provide protection against moisture as well as hazards encountered during operations in chemically and biologically contaminated environments.

In the study by Jasti A. and co-authors, a comprehensive characterization of elementary hemp fibers and hemp-based fabrics was conducted. The authors demonstrated that hemp possesses high tensile strength, an optimal cellulose content, considerable crystallinity, and a favorable strength-to-weight ratio, making it competitive with conventional synthetic technical fibers [9]. The study also emphasized the excellent hygienic properties of hemp materials, an important factor for military uniforms used across diverse climatic conditions.

A review by Zimniewska M. systematizes current data on the physico-mechanical and technological properties of hemp fibers, including their suitability for processing, spinning, and weaving. The author concluded that hemp is a promising material for eco-textiles and technical fabrics due to its combination of environmental sustainability and functional performance. Compared to cotton or flax, hemp exhibits higher strength, lower shrinkage, and strong resistance to microbial degradation, qualities that are particularly relevant for military applications [10].

Issues of standardization and the lack of unified methodologies for assessing hemp fiber quality are discussed in the review by Kirk H. et al. The authors provide a detailed analysis of different approaches to studying the morphology, structure, and properties of hemp fibers and emphasize the need for harmonized

testing methods, which would facilitate broader industrial adoption, including in high-technology sectors such as protective textiles [11]. The review also highlights natural variability among hemp fibers as a key technological challenge that must be addressed through improved primary processing methods.

One promising direction in current research is the modification of hemp fiber structure to enhance spinnability and fiber uniformity. In the study by Rastorhueva M. et al., the effects of pulsed electric treatment on the cottonization process of hemp fibers were examined. The results showed that electric-pulse treatment improves fiber flexibility, reduces stiffness, and enhances fiber fibrillation, all of which are crucial for obtaining stable spinning blends and fabrics with superior mechanical properties [12]. This approach opens new opportunities for large-scale use of hemp fibers in the production of specialized textiles.

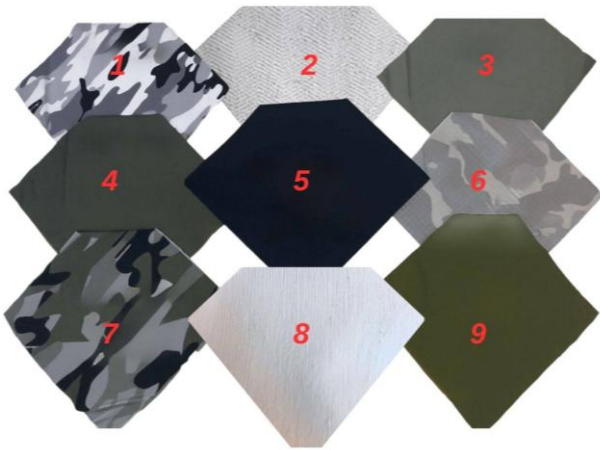
According to V.M. Durach and L.G. Nikolaychuk [13], the production of apparel for military personnel is a promising segment of the Ukrainian market; however, the performance requirements for such products are exceptionally high. To establish a reliable technological process for manufacturing military uniforms and to supply high-quality products for defense needs, the availability of high-quality natural fabrics preferably made from domestic raw materials is essential.

Given the studies summarized above, hemp fibers demonstrate significant potential for use in military textile production, as they combine high strength, natural hygroscopicity, biological resistance, comfort, environmental sustainability, and the capacity for property modification through modern technological methods. An additional advantage is Ukraine's domestic raw-material base for hemp cultivation, which makes this field strategically beneficial in the context of import substitution and development of the national defense-industrial complex. The use of Ukrainian-grown hemp fibers in next-generation military textiles can ensure independence from external suppliers, reduce production costs, and enhance overall fabric functionality.

## **MATERIALS AND METHODS**

### **Materials**

Nine fabric samples were selected for the study, including seven camouflage materials of different fiber compositions and two blended hemp fabrics with different weave structures. Fabric samples were purchased from various Ukrainian enterprises specializing in the production of military fabrics. The camouflage fabric samples had the following characteristics: sample №. 1 – Rip-Stop "Komfort", khaki color; sample №. 2 – Rip-Stop "Komfort", dark



**Figure 1.** Investigated camouflage fabric samples: Sample №1 – Rip-Stop "Comfort", khaki color; Sample №2 – Rip-Stop "Comfort", dark blue color; Sample №3 – Rip-Stop "TC"; Sample №4 – "Olive"; Sample №5 – "Khaki"; Sample №6 – "Defensa"; Sample №7 – "White Night". Investigated blended hemp fabric samples: Sample №8 – Blended hemp fabric, broken twill weave 2/2; Sample №9 – Blended hemp fabric, plain weave 1/1.

blue; sample №. 3 – Rip-Stop "TC"; sample №. 4 – "Olivka" (olive green); sample №. 5 – "Khaki"; sample №. 6 – "Defensa"; and sample №. 7 – "Bila Nich".

For comparative analysis, two samples of blended hemp fabrics were also included: sample №. 8 featured a broken twill 2/2 weave, while sample № 9 had a plain weave 1/1. The samples were developed by researchers of Kherson National Technical University and manufactured at the Edelvika private joint-stock company, which specializes in the production of linen fabrics. A visual representation of all examined samples is presented in Figure 1.

The selected materials allow for a comprehensive assessment of the physico-mechanical properties of traditional camouflage fabrics alongside newly developed blended hemp fabrics and enable evaluation of their suitability for military applications.

## Methods

The investigation of textile materials was carried out in accordance with the requirements of DSTU 21790:2008 "Cotton and Blended Fabrics for Clothing" and DSTU 4057–2001 "Textile Materials. Method for Fiber Identification" (ISO 833:1977) [15]. The research was carried out in the laboratories of Khmelnytskyi National University and the production laboratory of the Edelvika company. The results were based on the average values from ten repeated experiments.

For each tested parameter, measurements were performed on a series of specimens in accordance with the requirements of the relevant standards. Unless otherwise specified by the standard method, not less than five test specimens ( $n = 5$ ) were used for each fabric property. The values presented in the tables and figures represent the arithmetic mean of repeated measurements. Error bars in the graphical representations indicate the variability of the results

and correspond to the standard deviation calculated from the repeated tests.

The purpose of fiber identification was to determine the homogeneity and quantitative composition of the fibrous content. The samples were separated into warp and weft yarns, which were analyzed by combustion to assess odor, burning behavior, and ash residue. Additionally, microscopic examination of the longitudinal and cross-sections of fibers was performed, enabling identification of fiber type, morphological characteristics, and compliance with standards. All analyses were conducted based on the requirements of current normative documentation governing the testing of textile materials [16-25].

The surface density of fabrics was determined by weighing a 10 x 10 cm specimen and recalculating the value per 1 m<sup>2</sup>. This parameter characterizes the material's mass and its suitability for different categories of clothing. Warp and weft densities were determined by counting the number of yarns per 50 mm and recalculating the value per 100 mm, providing information on fabric structure and weave uniformity. The linear density (tex) was calculated from the mass and length of the yarn, allowing assessment of yarn thickness and uniformity.

Mechanical properties, tensile strength and elongation, were determined on an RT-250 tensile testing machine under constant extension. The maximum breaking load, absolute elongation, and relative elongation were measured, providing a characterization of fabric strength and deformation behavior.

Crease recovery was assessed using an FG-07 device by measuring the recovery angle after folding and loading. This indicator depends on the elastic properties of fibers and the weave structure and is used to evaluate the fabric's shape retention.

Dimensional stability after laundering was determined to evaluate fabric performance in use. Samples marked with control indicators were subjected to standard washing at 70–80 °C, followed by drying and ironing. Shrinkage was calculated as the percentage reduction in dimensions in both warp and weft directions.

Air permeability was measured on the AT-2 device, recording the amount of air passing through 1 m<sup>2</sup> of fabric in 1 s at a constant pressure drop. The indicator characterizes the comfort and functionality of the material. Water permeability was determined using a special device, which determined the volume of water passing through the sample under a pressure of 200 mm of water. The water permeability coefficient allows you to assess the hydrophilicity and suitability of the fabric for use in wet conditions.

Abrasion resistance was determined on an IT-3M apparatus using an abrasive gray overcoat cloth. The average number of cycles to destruction was recorded, representing the primary criterion for fabric durability.

## RESULTS AND DISCUSSION

In global science and industry, an active search continues for new solutions aimed at improving military textiles, particularly materials with enhanced performance characteristics, increased resistance to external influences, and reduced environmental impact. Despite significant progress in innovative textile development, the use of natural bast fibers, particularly hemp, in military fabrics still requires thorough scientific justification and systematic comparison with existing materials. This underscores the need to examine the physico-mechanical properties of hemp-based fabrics to evaluate their suitability for operation under the specific conditions of military use.

Given the increasing requirements for the functionality and reliability of textile materials, it is essential to determine the extent to which hemp fabrics meet the standards applied to materials intended for military applications, and whether they are capable of providing an adequate level of strength, abrasion resistance, air permeability, and dimensional stability. In this context, comparative analysis of natural fibers against traditional synthetic materials, currently dominant in the military sector, becomes particularly relevant.

To address these scientific objectives, a comprehensive study of modern military textile samples was conducted, and their physico-mechanical characteristics were analyzed. Based on the obtained results, and considering the inherent properties of hemp fibers, researchers at Kherson National Technical University developed samples of hemp-based fabric whose functional parameters and application potential are comparable to those of materials traditionally used in the defense industry. The developed sample served as the foundation for further experimental studies and for assessing its potential as an alternative material for military purposes.

The physico-mechanical properties of the fabrics were determined in accordance with standard methodologies outlined in the relevant normative documents [16-20], and the obtained results were compared with the requirements of current standards.

All determinations were carried out in compliance with the relevant ISO and EN standards using the specified number of test specimens for each test method. For linear density, 5–10 yarns were tested in both warp and weft directions. For surface density, thread density, breaking load, elongation at break, abrasion resistance, air permeability, water permeability, dimensional change after wet treatment, and crease resistance, the number of specimens tested was as defined by the corresponding standards. The values recorded in the table are the average results of the measurements (5 yarns). The

results of the study regarding the physico-mechanical properties of camouflage fabrics and blended hemp fabrics are presented in Table 1.

The analysis of the physico-mechanical properties of camouflage fabrics made it possible to assess their suitability for various military operating conditions. The samples with a dominant share of hemp fibers (№ 8-9) demonstrated higher tensile strength and abrasion resistance compared to most camouflage samples. This indicates the real potential of hemp-based fabrics as durable raw materials for products exposed to intensive wear. The high thread counts and increased surface density of the hemp samples explain their enhanced mechanical strength and abrasion resistance.

Air permeability ranged from 61.1 to 245.4 dm<sup>3</sup>/m<sup>2</sup>·s, with sample № 8 exhibiting the best performance. The hemp-based samples showed higher air permeability and water absorption, making them more breathable and comfortable, though less water-resistant. For field conditions, where both moisture protection and ventilation are critical, combined solutions (hemp fabric + hydrophobic coating/membrane) are advisable. The hemp fabrics also demonstrated superior behavior during wet processing (0% shrinkage) and significantly higher crease recovery coefficients. This represents a substantial advantage for military uniforms, ensuring the preservation of garment shape and dimensions during use and maintenance. Furthermore, the hemp samples exhibited considerably higher relative elongation at break, which may indicate increased plasticity, an additional benefit in the manufacture of military apparel.

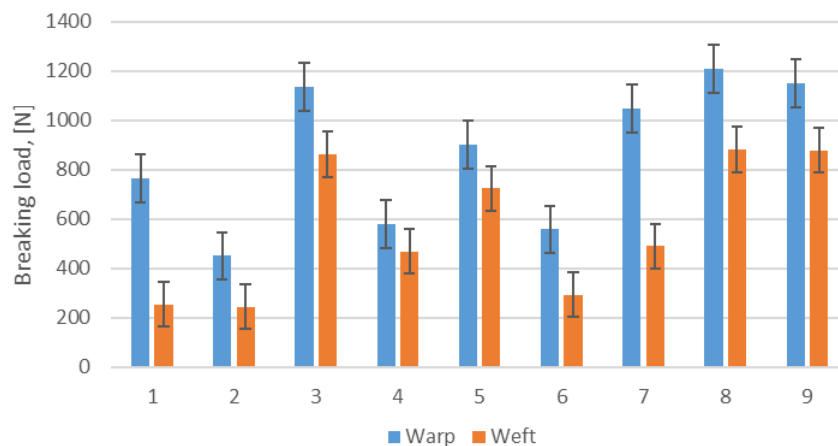
After wet processing, the smallest deformation was observed in samples № 3 and № 4, while samples № 8 and № 9 maintained their original dimensions entirely, indicating strong dimensional stability after laundering. The highest crease recovery coefficients were recorded for samples № 7 and № 9 (75%), enabling them to retain their shape and appearance after wear.

To visually demonstrate the advantages and limitations of the developed hemp fabrics in comparison with existing camouflage materials, graphs of the most significant properties were prepared, including tensile strength, abrasion resistance, and water permeability (Figs. 2-4).

Hemp fabric samples (№ 8 and № 9) demonstrate the highest breaking load indicators both in the warp and in the weft. Traditional synthetic and cotton samples have lower values, especially in the weft, which emphasizes the superiority of hemp fabrics in strength. Synthetic mixed fabrics (№ 1, № 4) show stable results, but are inferior to hemp in absolute values.

**Table 1.** Results of the study of physico-mechanical properties of camouflage fabrics and blended hemp fabrics.

Property		Sample								
		1	2	3	4	5	6	7	8	9
Material composition		30% cotton, 70% polyester	100% cotton	100% cotton	30% cotton, 70% polyester	100% cotton	100% cotton	70% cotton, 30% polyester	70% hemp, 20% cotton, 10% polyester	70% hemp, 20% cotton, 10% polyester
Linear density, [tex]	Warp	25	20	40	25	27	34	33	40	38
	Weft	25	20	33	25	25	38	40	48	46
Surface density, [g/m <sup>2</sup> ]/ ISO 3801:2019		191	136	211	200	182	187	202	326	314
Threads per 10 cm, [pieces]/ EN 1049-2:2004	Warp	460	530	450	420	580	410	370	642	610
	Weft	230	290	230	240	310	250	280	354	322
Breaking load, [N]/ ISO 5082-82	Warp	765	451	1137	579	902	559	1049	1210	1150
	Weft	255	245	862	470	725	294	490	882	879
Elongation at break, [%]/EN ISO 13984-1:2018	Warp	7.5	7.0	16.5	11.5	10.0	10.0	27.0	24.8	26.7
	Weft	10.0	17.5	16.0	13.0	15.5	13.5	21.0	27.0	28.4
Abrasion resistance to hole formation, [cycles]/ ISO 12947-2:2005		3142	2038	6023	4925	2410	2075	5256	6100	5980
Air permeability, [dm <sup>3</sup> /m <sup>2</sup> .s]/ ISO 9237:2003		191.7	144.4	61.1	100.0	69.4	208.3	225.0	245.4	220.8
Water permeability, [dm <sup>3</sup> /m <sup>2</sup> .s]/ EN ISO 811:2018		0.17	0.20	0.22	0.16	0.25	0.18	0.23	0.31	0.28
Dimensional change after wet treatment, [%]/ ISO 5077-2001	Warp	-1.5	-2.5	0	-1.5	-2.0	-1.5	-1.0	0	0
	Weft	0	-1.0	-2.5	0	0	-0.5	-0.5	0	0
Crease resistance, [%]/ISO 5077-2001		35	33	52	21	27	31	75	70	75



Error bars represent ±5 % measurement uncertainty.

**Figure 2.** Breaking load of the studied fabric samples (mean ± SD).

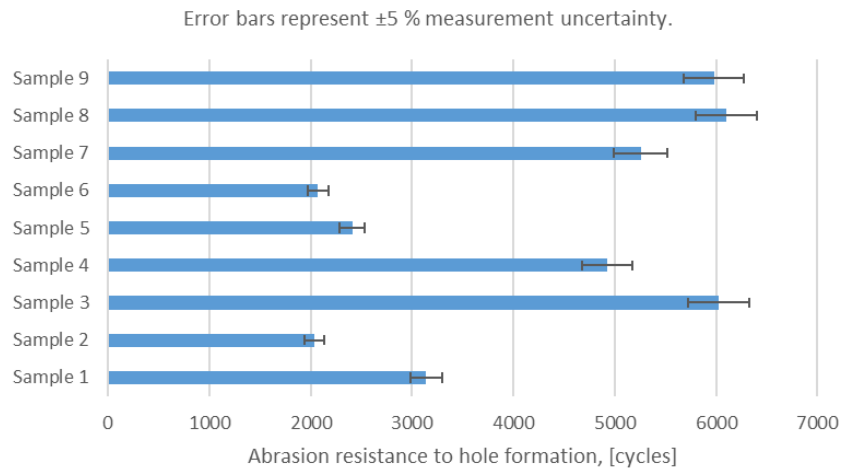


Figure 3. Resistance of the studied fabric samples to wiping (mean ± SD).

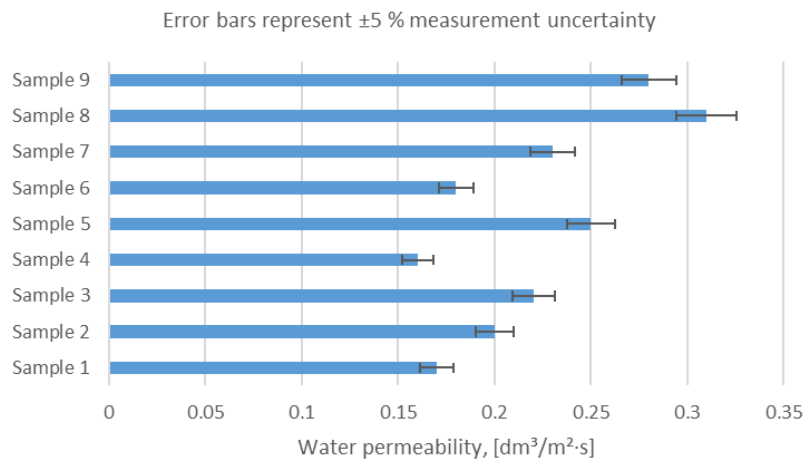


Figure 4. Water permeability of the tested fabric samples before wiping (mean ± SD).

The analysis of resistance to wiping indicated the superiority of samples № 8 (6100 cycles) and № 9 (5980 cycles), which confirms their high wear resistance, the closest to these indicators from camouflage fabrics is № 3, which withstood 6023 cycles.

Water permeability showed minor variations among the samples, with the highest levels observed in samples № 8 and № 9. The water resistance of the blended hemp fabrics is influenced by the chemical composition and microstructure of hemp fibers. According to studies conducted by researchers at Kherson National Technical University [26][27], hemp fibers are covered by a cuticle – a thin layer of waxes and lipids exhibiting hydrophobic properties, which reduces the fiber’s ability to absorb water. This layer acts as a natural protective barrier, enabling the fibers to maintain moisture resistance under environmental exposure and preventing excessive water uptake that could lead to structural degradation.

Owing to the combined effect of the hydrophilic nature of cellulose, the primary chemical component of hemp fibers, and the hydrophobic waxy coating on

their surface, modified hemp fibers possess balanced hydrophilic-hydrophobic characteristics. As a result, they are capable of absorbing moisture from the environment and maintaining a stable level of humidity without forming large droplets on the surface. This combination makes hemp fibers more resistant to moisture and contamination compared to other natural fibers, such as cotton.

Thus, based on the conducted physico-mechanical studies of camouflage fabric samples and the developed mixed hemp fabric samples, it was determined that samples № 8 and № 9 outperform existing camouflage fabric samples in terms of strength, wear resistance, dimensional stability, elasticity, and water resistance. Additionally, hemp fiber fabrics exhibit high air permeability, which supports oxygen retention within the textile structure, preventing the development of anaerobic bacteria and their proliferation in various types of clothing, footwear, and underwear. The use of such materials not only provides the defense sector with high-quality products but also promotes the use of domestic raw materials.

Further studies were aimed at determining:

- the colorfastness of camouflage fabrics, which defines their durability and scope of application;
- wash fastness, ensuring suitability for everyday and military clothing;
- resistance to distilled water, which is important for textiles used in wet conditions;
- resistance to organic solvents, a necessary requirement for industrial and technical fabrics;
- resistance to dry friction, which affects color retention in areas of intensive contact;
- resistance to ironing, which is important for maintaining the aesthetic appearance of the material.

Assessment of these characteristics allows for determining the compliance of fabrics with operational and functional requirements and estimating their service life.

Since the study investigated mixed hemp fabrics without dyeing or bleaching, these samples were tested for all the aforementioned factors except colorfastness. The evaluation of all camouflage fabric samples for resistance to various environmental and mechanical factors was conducted following the methods outlined in the relevant standards [23][24][25]. The results of the tests are presented in Table 2.

Analysis of the resistance of camouflage fabrics and mixed hemp fabrics showed that all investigated samples exhibit high wash fastness, resistance to distilled water, and resistance to organic solvents (5/5), indicating their durability under various operational conditions.

Resistance to dry friction varied from 3/4 to 5/5, with sample № 5 demonstrating the lowest rating, which may indicate a higher susceptibility to mechanical impact. Other fabrics exhibited stable resistance within the range of 4-5/5, making them suitable for intensive use.

Regarding ironing resistance, all samples except sample № 5 demonstrated the maximum score of 5/5, indicating their ability to maintain shape and structure after thermal treatment.

Overall, all camouflage fabrics and mixed hemp yarn fabrics exhibit excellent operational characteristics, making them promising for use in military clothing of various types. The highest overall resistance was observed in samples № 7 and № 9, whereas sample № 5 requires additional attention regarding friction and ironing resistance.

The conducted studies of physico-mechanical properties and colorfastness indicate that the most suitable samples for clothing production are № 7, № 3, № 8, and № 9. Samples № 7, № 8, and № 9 exhibit high elasticity (ranging from 24.8% to 28.4%), ensuring comfort during wear and ease of movement. These samples also demonstrate the best air permeability, making them suitable for lightweight and

breathable garments. Additionally, they have the highest crease recovery coefficients, ensuring the preservation of garment shape even after frequent use and laundering.

Samples № 3, № 8, and № 9 are the strongest and show the highest wear resistance, as confirmed by breaking load values and abrasion cycles, making them ideal for military clothing as well as workwear subjected to intensive mechanical stress.

To determine the aesthetic characteristics of all investigated samples, organoleptic evaluation was performed, assessing the following properties: color, gloss, texture, pattern, touch, and plasticity. Table 3 presents the results of the organoleptic assessment of the aesthetic properties of the camouflage and mixed hemp fabric samples.

According to Table 3, camouflage fabric samples № 1 and № 3, as well as mixed hemp fabric samples № 8 and № 9, are soft, non-prickly, and pleasant to the touch. In contrast, samples № 2, № 4, № 5, and № 6 are stiff, coarse, and slightly prickly, making them unsuitable for the production of undergarments and military underwear. Samples № 1, 2, 4, 5, 8, and № 9 do not exhibit pronounced patterns, ornaments, or a highly textured woven structure. Samples № 3, № 6, and № 7 differ in coloration, which makes them suitable for use in military camouflage clothing. The colors of samples № 8 and № 9 are closer to their natural shades without the use of dyes, making them suitable for eco-friendly footwear and clothing, as well as for summer-season military camouflage apparel. Figure 5 presents a profilogram of the organoleptic evaluation of the aesthetic properties of the investigated camouflage and mixed hemp fabrics intended for military applications.

According to the results of the organoleptic profilogram analysis, several key patterns can be identified:

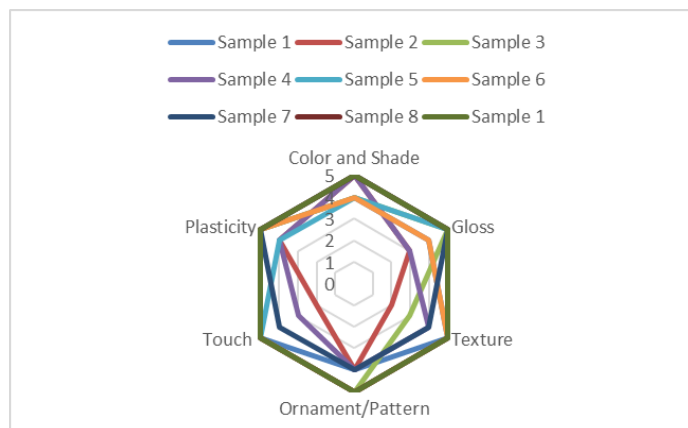
1. Camouflage fabric samples № 1 and № 3, as well as blended hemp fabrics № 8 and № 9, exhibit softness, smoothness, and pleasant tactile sensations, which makes them suitable for products that come into direct contact with the skin, including underwear and next-to-skin military apparel. Samples № 2, № 4, № 5, and № 6 are characterized by greater stiffness, roughness, and a slight pricking effect. Although these properties limit their use in direct-contact garments, they do not preclude their application in outerwear or technical textile products.
2. Samples № 1, 2, 4, 5, 8, and № 9 possess a uniform texture without pronounced relief or ornamentation, making them suitable for solid-color or camouflage garments where fabric neutrality is required. In contrast, samples № 3, № 6, and № 7 feature varying shades and noticeable surface relief, which enhances their applicability for military camouflage clothing, where the texture supports blending with the natural environment.

**Table 2.** Resistance of camouflage fabrics and mixed hemp fabrics to various influencing factors, points.

Fabric Name	Property Name				
	Wash Fastness	Resistance to Distilled Water	Resistance to Organic Solvents	Resistance to Dry Friction	Ironing Resistance
Sample №1	5/5	5/5	5/5	4/5	5/5
Sample №2	5/5	5/5	5/5	4-5/5	5/5
Sample №3	5/5	5/5	5/5	4-5/4-5	5/5
Sample №4	5/5	5/5	5/5	4-5/5	5/5
Sample №5	5/5	5/5	4-5/5	3/4	4-5/4-5
Sample №6	5/5	5/5	5/5	4-5/5	5/5
Sample №7	5/5	5/5	5/5	5/5	5/5
Sample №8	5/5	5/5	5/5	4-5/5	5/5
Sample №9	5/5	5/5	5/5	5/5	5/5

**Table 3.** Organoleptic evaluation of the aesthetic properties of the investigated fabric samples.

Property	Sample1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9
<b>Color and Shade</b>	Khaki with a grayish tint	Dark blue	Camouflaged coloration with shades from light gray to dark gray	Olive with a dark green tint	Khaki with a light gray tint	Camouflaged coloration with shades from light green to dark green	Camouflaged coloration with shades of white, black, gray, and green	Gray with beige tint	Beige with grayish and brownish tints
<b>Gloss</b>	Matte	Slight, barely noticeable	Silky gloss	Slight, barely noticeable	Silky gloss	Matte	Matte	Silky gloss	Silky gloss
<b>Texture</b>	Smooth, cool, light, pleasant to touch	Dense, rough, coarse, not very pleasant to touch	Fuzzy, embossed, slightly rough	Smooth, warm, pleasant to touch	Smooth, cool, light, pleasant to touch	Smooth, cool, dense, light, pleasant to touch	Fuzzy, rough, not very pleasant to touch	Moderately textured, warm, fluffy	Pleasant to touch, textured, warm, fluffy
<b>Ornament/Pattern</b>	No pattern or ornament, uniform	Textured without patterns or ornaments	Camouflaged pattern, not prominent	Solid, without patterns or ornaments	Solid, structural, without ornaments	Camouflaged pattern with distinct multicolor streaks	Camouflaged pattern with distinct multicolor streaks	No pattern, barely noticeable twill ornament, uniform	Natural structure, no patterns or ornaments
<b>Touch</b>	Soft	Feels dense and firm	Soft	Soft, dense fabric	Firm	Soft, dense	Moderately stiff, firm	Soft	Soft
<b>Plasticity</b>	Slightly plastic	Almost non-plastic	Plastic	Slightly plastic	Moderately plastic	Moderately plastic	Plastic	Well plastic	Well plastic



**Figure 5.** Profilogram of the organoleptic evaluation of the aesthetic properties of camouflage and mixed hemp fabrics.

3. Hemp-based samples № 8 and № 9 demonstrate a natural, unprocessed fiber color without additional dyes. This makes them suitable for environmentally oriented products, including lightweight camouflage clothing and footwear, that meet the requirements for environmental resistance and reduced chemical impact.

The profilogram clearly demonstrates that blended hemp fabrics № 8 and № 9 combine pleasant tactile properties, natural coloration, and sufficient surface versatility, making them the most promising materials for next-to-skin, camouflage, and eco-oriented military textile applications. Camouflage fabric samples № 3, № 6, and № 7, owing to their relief and tonal variation, are more appropriate for outer camouflage garments.

## CONCLUSION

The conducted studies encompassed the analysis of physico-mechanical, operational, and aesthetic properties of commercially available military camouflage fabrics, as well as experimental samples developed from mixed hemp yarn. The results indicated that while traditional synthetic and blended materials exhibit satisfactory characteristics, they are outperformed by the new hemp-based samples in several key parameters. Specifically, hemp fabrics show increased tensile and abrasion strength, improved vapor and air permeability, high hygroscopicity, and resistance to biological factors.

Comprehensive evaluation demonstrated that the use of hemp fabrics not only provides a higher level of operational reliability but also enhances wearing comfort, which is especially important under military service conditions. Therefore, hemp fabrics can be considered more promising for use in the production of military clothing, footwear, and underwear, supporting the rationale for their further implementation in military textiles.

Studies of the resistance of camouflage and hemp fabrics to various external factors, such as washing, friction, organic solvents, and ironing, determine their durability and suitability for operational conditions.

The high color stability of camouflage fabrics ensures the preservation of both camouflage functionality and aesthetic qualities, which is critical for military apparel. Hemp fabrics, due to their natural beige-gray-green shades, can be used to produce garments with protective coloration without the need for dyes. This makes them practical for military and specialized applications in sandy or desert environments, as the material is simultaneously eco-friendly, durable, and naturally camouflaging.

The research confirmed the importance of further development of military fabrics made from mixed hemp yarn, their adaptation to modern military needs, technical textiles, and military equipment. Advancing production technologies and analytical methods will

allow for optimization of material properties, ensuring effectiveness, durability, and environmental safety.

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