

**ODRŽIVI NETKANI TEKSTILI ZA EKOLOŠKE I POLJOPRIVREDNE
PRIMENE: MATERIJALI, TEHNOLOGIJE I BUDUĆI PRAVCI**Professional paper
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APSTRAKT: Netkani tekstili su se izdvojili kao ključni materijali u održivom razvoju zahvaljujući svojoj svestranosti, niskim troškovima proizvodnje i prilagodljivosti principima cirkularne ekonomije. Za razliku od konvencionalnih tekstilnih struktura, netkani materijali omogućavaju direktnu kontrolu rasporeda vlakana, poroznosti i načina vezivanja, što omogućava precizno podešavanje funkcionalnih svojstava. Ovaj pregled kritički analizira napredak u održivim sirovinama, proizvodnim tehnologijama i primenama u poljoprivredi i zaštiti životne sredine. Poseban naglasak stavljen je na odnos strukture i funkcije, povezujući poroznost, propustljivost i mehaničke karakteristike sa stvarnom primenom. Takođe, razmatraju se ekološki izazovi kao što su oslobađanje mikroplastike, složenost reciklaže i kompromisi između trajnosti i biorazgradivosti. Buduće perspektive usmerene su na pametne eko-netkane materijale, optimizaciju materijala vođenu veštačkom inteligencijom i strategije cirkularnog dizajna.

Ključne reči: Netkani tekstil, održivost, biorazgradiva vlakna, poljoprivredni pokrivači, filtracija, cirkularna ekonomija

**SUSTAINABLE NONWOVEN TEXTILES FOR ENVIRONMENTAL
AND AGRICULTURAL APPLICATIONS: MATERIALS,
TECHNOLOGIES AND FUTURE DIRECTIONS**

ABSTRACT: Nonwoven textiles have emerged as key materials in sustainable development due to their versatility, low production cost, and adaptability to circular economy principles. Unlike conventional textile structures, nonwovens enable direct control over fiber arrangement, porosity, and bonding, allowing precise tuning of functional properties. This review critically analyzes advances in sustainable raw materials, manufacturing technologies, and applications in agriculture and environmental protection. Structural–functional relationships are emphasized, linking porosity, permeability, and mechanical performance to real-world functionality. Furthermore, environmental challenges such as microplastic release, recycling complexity, and durability–biodegradability trade-offs are discussed. Future perspectives focus on smart eco-nonwovens, AI-driven material optimization, and circular design strategies.

Keywords: Nonwoven textiles, sustainability, biodegradable fibers, agricultural covers, filtration, circular economy

1. INTRODUCTION

Nonwoven textiles represent a rapidly expanding class of engineered materials that play a crucial role in sustainable development [1,2]. Their production eliminates traditional yarn-forming steps, reducing energy consumption and enabling direct transformation of fibers into functional structures. This efficiency makes them particularly suitable for integration into circular economy models [3].

The role of nonwovens extends across agriculture, environmental protection, and geotechnical applications, where materials must satisfy both performance and ecological requirements. Their unique advantage lies in the ability to tailor structural parameters such as fiber orientation, porosity, and bonding density, directly influencing functional behavior.

To illustrate this multifunctional role, Figure 1 presents a conceptual framework linking raw materials, manufacturing processes, and application domains within a circular economy.

The objective of this review is to critically analyze sustainable nonwoven materials, processing technologies, and applications, while identifying key challenges and outlining future research directions, particularly in the context of smart and AI-driven textile systems.

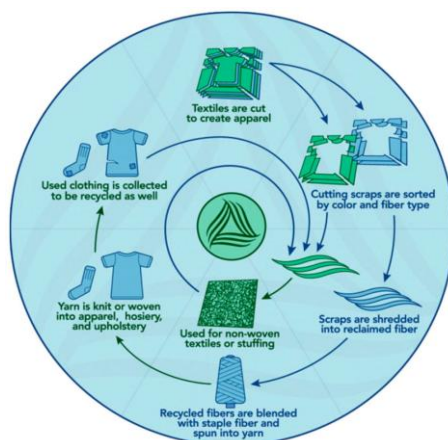


Figure 1: Gramwork of nonwoven textiles connecting materials, processing, and sustainable applications

2. RAW MATERIALS FOR SUSTAINABLE NONWOVENS

The sustainability of nonwoven textiles depends on raw material selection, affecting environmental impact and performance. Natural fibers such as cotton, hemp, flax, and jute are biodegradable but show variability and moisture sensitivity [4,5]. Their properties can be enhanced through chemical modifications, including selective and non-selective oxidation, which improve surface reactivity [6,7]. Chitosan-based treatments further enhance antimicrobial activity [8], emphasizing the importance of surface engineering in optimizing functionality for advanced textile applications.

The diversity of natural fibers used in nonwovens is illustrated in Figure 2, highlighting their structural differences and potential applications.



Figure 2: Framework of nonwoven textiles connecting materials, Recycled materials, particularly recycled PET and textile waste, and sustainable applications

Recycled materials, particularly recycled PET and textile waste, provide an important route toward circularity [9]. Needle-punched nonwovens derived from textile waste are widely applied in insulation and geotextiles, offering both environmental and economic benefits. Nevertheless, challenges such as contamination and degradation of polymer properties must be addressed.

Bio-based polymers, including PLA and PHA, represent a promising alternative to petroleum-based materials [10]. These polymers are derived from renewable resources and exhibit controlled biodegradability. However, their higher cost and moderate mechanical performance limit widespread industrial adoption.

A comparative overview of these material categories is presented in Table 1, emphasizing their sustainability and functional trade-offs.

Tabela 1: Comparison of sustainable nonwoven materials

Material	Source Type	Bio-degradability	Mechanical Strength	Cost Level	Typical Applications
PLA	Bio-based	High	Medium	High	Agriculture
PHA	Bio-based	Very High	Low-Medium	Very High	Medical, eco-films
PET	Synthetic	Low	High	Low	Filtration
Cotton waste	Natural	High	Low	Low	Insulation
Hemp/Flex	Natural	High	Medium	Medium	Geotextiles

3. MANUFACTURING TECHNOLOGIES

The manufacturing process determines the internal structure of nonwoven textiles and, consequently, their performance. Key technologies include spunbond, meltblown, needle punching, and hydroentanglement [11].

Spunbond and meltblown processes are widely used for synthetic fibers, enabling the formation of highly uniform webs. Meltblown technology produces ultrafine fibers with high surface area, making it ideal for filtration applications. Needle punching mechanically entangles fibers, resulting in thick and durable structures, while hydroentanglement uses water jets to create soft and flexible fabrics.

These processes and their structural outcomes are illustrated in Figure 3, which highlights the differences in bonding mechanisms and fiber arrangements.

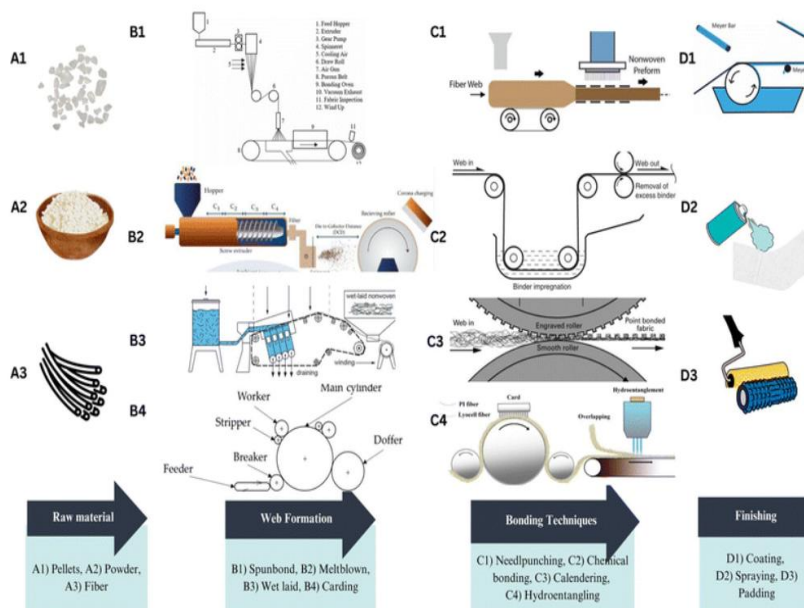


Figure 3: Schematic representation of major nonwoven manufacturing technologies

From a sustainability perspective, each process exhibits different energy requirements and environmental impacts. Meltblown processes are energy-intensive, whereas needle punching is more energy-efficient but offers less precise structural control.

A comparative evaluation is provided in Table 2.

Tabela 2: Comparison of nonwoven manufacturing technologies

Process	Fiber Type	Energy Consumption	Structure Control	Key Properties	Sustainability Score (1-5; poor-good)
Spundbond	Synthetic	Medium	High	Strength, uniformity	4
Meltblown	Synthetic	High	Very high	Finer fibers, filtration	3
Needle punction	Natural/ Recycled	Medium	Medium	Thickness, durability	5
Hydroentangle ment	Mixed	High	High	Softness, flexibility	4

4. FUNCTIONAL PROPERTIES

The performance of nonwoven textiles is governed by their structural characteristics, particularly porosity, fiber orientation, and bonding density. These parameters determine key functional properties such as air permeability, water retention, mechanical strength, and thermal insulation. Functional performance is influenced by surface chemistry and treatments. Cotton materials change after laundering, affecting durability [12-14], while chitosan functionalization enhances antimicrobial properties, highlighting the importance of surface engineering [8].

The relationship between structure and functionality is illustrated in Figure 4, where porosity and fiber arrangement are directly linked to permeability and mechanical behavior. In addition to conventional experimental approaches, recent advances in digital image processing have enabled more precise and accessible evaluation of textile structural behavior. Smartphone-based analysis methods have demonstrated the potential for rapid, non-destructive assessment of fabric properties, contributing to the digitalization of textile characterization and supporting data-driven material design [15].

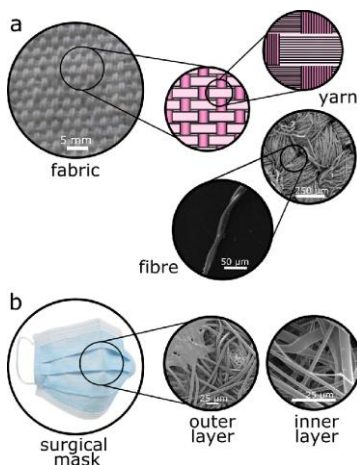


Figure 4: Structure-properties relationship in nonwoven textiles

For instance, increasing porosity enhances air permeability but may reduce mechanical strength. Similarly, higher fiber bonding density improves strength but can reduce permeability. Therefore, optimizing these competing parameters is essential.

A summary of structure–property relationships is given in Table 3.

Tabela 3: Functional properties and structural drivers

Property	Structure Parameter	Application Impact
Air permeability	Porosity, pore size	Filtration, crop covers
Water Retention	Fiber surface chemistry	Agriculture
Mechanical strength	Fiber bonding density	Geotextiles
Thermal insulation	Fiber arrangement	Frost protection

5. APPLICATIONS IN SUSTAINABILITY

Nonwoven textiles are widely applied in agriculture, environmental protection, and geotechnical engineering.

In agriculture, nonwoven covers are used for crop protection, frost control, and soil moisture retention [16]. These materials create a controlled microclimate that enhances plant growth and reduces the need for pesticides. Their practical implementation is shown in Figure 5.



Figure 5: Agricultural applications of nonwoven textiles

In environmental protection, nonwovens are used for oil absorption, air filtration, and water purification [17]. Their high surface area and customizable pore structure enable efficient capture of pollutants, as illustrated in Figure 6.

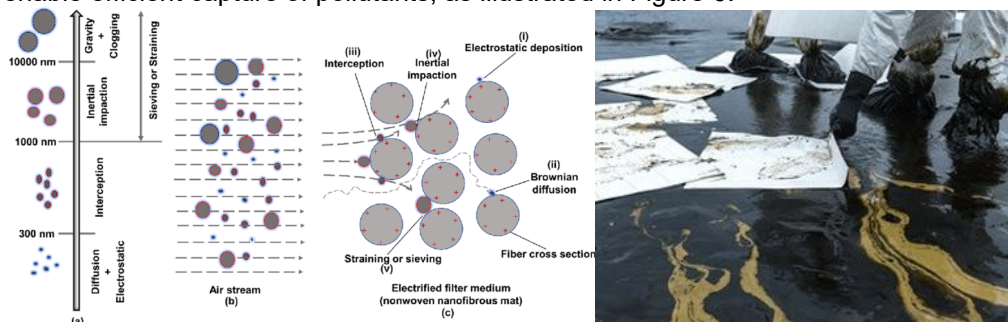


Figure 6: Environmental and filtration applications of nonwoven textiles

Geotextiles represent another important application, where nonwoven materials are used for soil stabilization, erosion control, and drainage systems.

6. CHALLENGES

Despite their advantages, sustainable nonwoven textiles face several challenges. One of the most critical issues is the trade-off between biodegradability and durability [11,18]. Materials that degrade rapidly may not meet the mechanical requirements of long-term applications. Microplastic generation from synthetic nonwovens is another major environmental concern. Additionally, recycling is complicated by mixed fiber compositions and bonding techniques.

These challenges and potential solutions are summarized in Table 4.

Tabela 4: Functional properties and structural drivers

Property	Structure Parameter	Structure Parameter	Application Impact
Durability vs biodegradability	Material composition	Limited lifespan	Hybrid materials
Microplastics	Synthetic fiber degradation	Environmental pollution	Bio-based alternatives
Recycling complexity	Mixed fiber systems	Low recyclability	Design for recycling

One of the critical challenges in sustainable textiles is maintaining durability while ensuring environmental compatibility. Studies on cotton-based textile systems have demonstrated that repeated washing and usage significantly affect structural integrity and functional properties, highlighting the complexity of achieving long-term performance in sustainable materials [12-14].

7. FUTURE TRENDS

Future developments in nonwoven textiles will focus on smart, adaptive, and intelligent systems [19]. The integration of sensors into nonwoven structures will enable real-time monitoring of environmental conditions such as soil moisture, temperature, and pollutant levels. In parallel, future nonwoven systems will increasingly rely on advanced fiber functionalization strategies, where chemical modification techniques, including oxidation and bio-based treatments, enable tailored fiber reactivity and multifunctional performance [6,7].

A particularly promising direction is the use of artificial intelligence for predictive material design. In this context, recent studies have demonstrated the effectiveness of digital image-based approaches, including GLCM texture analysis and process parameter evaluation, for assessing structural irregularities and their influence on textile performance [20,21]. These methods provide rapid and non-destructive evaluation and contribute to the digitalization of textile characterization. AI models can optimize fiber composition, structure, and processing parameters, enabling the development of high-performance, sustainable nonwoven materials.

8. CONCLUSION

Nonwoven textiles are fundamental to sustainable material innovation, offering unique advantages in versatility, scalability, and functionality. Their applications in agriculture, environmental protection, and geotechnical engineering demonstrate their broad societal impact. However, achieving true sustainability requires addressing challenges related to durability, biodegradability, and recyclability. Future progress will

depend on interdisciplinary approaches that integrate materials science, environmental engineering, and artificial intelligence. The next generation of nonwovens will not only be sustainable but also intelligent, adaptive, and fully integrated into circular material systems.

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