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Bio-geotextiles based acrylonitrile and their evaluation on radish plants (*Raphanus sativus*)

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Abstract

In this study, two innovative biopolymers (BioP) were investigated for bio-geotextile (BioG) fabrication: an acrylonitrile-2-hidroxyethyl methacrylate-starch terpolymer (ST-AN), and a composite of acrylonitrile-vinyl acetate-chitosan terpolymer (CS-AN) blended with acrylonitrile-methyl acrylate (AN-MA) copolymer. Using wet-spinning technique, bio-fiber (BioF) were produced, characterized and utilized in to construct BioG. BioF based on ST-AN and CS-AN exhibited linear densities of 10.7 and 19.8 denier, bulk densities of 1.21 and 1.16 g/cm^3, tensile strengths of 74.7 MPa and 28.5 MPa, elongation of 10.7% and 11.2%, and moisture retention capacities of 88% and 65%, respectively. The BioG made with ST-AN improved soil moisture retention by up to 130%. Radish plants biometric measurement in pots with BioG revealed improvements in growth parameters: leaf length increased by 87%, leaf width by 45%, and stem thickness by 142% compared to controls. These findings highlight the potential of bio-based materials to advance sustainable engineering through innovative strategies in synthesis, processing, and application, offering a viable alternative for the partial or complete replacement of plastics associated with microplastic generation and persistent environmental pollution.

Keywords: Acrylonitrile-vinyl acetate-chitosan, Acrylonitrile-2-hydroxyethyl methacrylate-starch, Bio-geotextile, Biopolymer, Radish, Sustainable engineering, Wet-spinning.

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Contents

Contribution of this paper to the literature

This study investigates the evaluation of novel polymeric biomaterials within a wet-spinning system to produce fibers for bio-geotextile applications. It examines the physicochemical properties of bio-base fiber and their performance in radish cultivation systems, offering insights for future research on biomaterials in sustainable agricultural practices.

1. Introduction

Microplastics (MPs) are particles with sizes between 0.05 and 5 mm [1-5] originating from manufacturing processes or the breakdown of larger plastics. Accumulation of MPs is more prevalent in soil ecosystems than in aquatic environments, whit agricultural soils showing higher concentrations than urban soils [1]. MPs found in the soil ecosystem are mainly sourced from sewage sludge, tire wear, industrial processes, plastic waste, and agricultural films [1, 2]. These particles negatively impact soil properties, nutrient cycling, microbial activity, and plant growth by interfering with roots and nutrient absorption. MPs can even enter plant tissues, affecting overall plant health and reducing soil fertility, indirectly hindering crop development. Beyond soil and aquatic ecosystems, MPs pose significant health risks when they enter the human body via food, air, or direct contact, potentially damaging the digestive, respiratory, and circulatory systems. Geotextiles are textile structures with a wide range of engineering applications; for example, they are applied in the soil filtration, drainage, separation, reinforcement, protection and revegetation of eroded areas. Due to growing environmental concerns, a shift toward biodegradable geotextiles has emerged. The 90% of geotextiles are made from synthetic polymers such as polyethylene, polyester, and polyamides, which are cost-effective and easy to produce and handle [6]. However, the exposure of these materials to environmental factors can cause their disintegration into MPs, resulting in high contamination of the environment. Materials of natural origin have been used to replace synthetic materials in the construction of geotextiles. Although these materials can be fully environmentally compatible and effective in removing heavy metals, they present some drawbacks, including hygroscopicity, which limits their filtering, drainage, and permeability capabilities, as well as short durability and significant loss of mechanical properties over time [7]. Another approach for creating such materials involves the production of fibers from biopolymers [6]. Recent advances in biodegradable polymers based on starch (ST) [8-13] and chitosan (CS) [14-18] have emerged as key candidates, that can be chemically modified, blended, or copolymerized with other monomers to enhance specific physicochemical properties such as solubility, mechanical strength, viscosity, hydrophilicity, and hygroscopicity [19-27]. These biopolymers are not only biodegradable but also exhibit multifunctional characteristics, such as the adsorption of chemical species [28, 29] and superabsorption of water [22, 30]. These advancements are critical for producing fibers suitable for the generation of geotextiles that are biodegradable, biocompatible, and capable of fulfilling roles that natural fibers cannot. Accordingly, our research aims to contribute to the development of new biopolymers that can be utilized in the production of biodegradable and biocompatible fiber to obtain bio-geotextile, with a focus on soil remediation and environmental protection. This study contributes to this field by producing biodegradable fibers from ST, CS, and acrylonitrile using a wet-spinning technique. A nonwoven bio-geotextile was then fabricated and evaluated through a simple experiment on the growth and development of radish plants.

2. Materials and Methods

Two biopolymers were synthesized for this study: Acrylonitrile-2-hydroxyethyl methacrylate-starch (ST-AN) and acrylonitrile-vinyl acetate-chitosan (CS-AN) terpolymers. The synthesis was conducted using aqueous suspension polymerization and a free-radical process, according to previous works [31]. The average molecular weight of ST-AN and CS-AN were determined to be 124 x10^3 g/mol and 49 x10^3 g/mol, respectively. The wet-spinning process was performed on a laboratory-scale spinning machine, and following the operating conditions listed in Table 1 [32]. The resulting fibers were impregnated with a 15% (w/w) aqueous NPK-UREA nutrient solution (50:50 ratio) at room temperature. After 24 h, the fibers were dried in an oven at 50°C and weighed.

Table 1. Operating conditions for wet-spinning.

Variable	ST-AN Based BioG	CS-AN Based BioG
Polymeric solution concentration, % wt*	14	18
Blend ratio, (CS-AN/AN-MA)	-	0.01
Coagulation bath concentration, % wt	30	25
Coagulation rate, m/s	1	1
Drying temperature, °C	80	70

Note: * % wt, weight percent.

For soil evaporation and plant biometric measurement, experiments were conducted using recycled PET bottles as pots. The ST-AN based BioF was manually felted to develop networks of mechanically bonded fibers. The interwoven fibers were pressed for 24 h at room temperature. Table 2 provides the conditions used to evaluate ST-AN based BioG performance.

Table 2. Evaluation conditions for ST-AN based BioG.

Test	Code	Weight, g/cm²	Nutrient*, g
1	G200	-	-
2	G201	-	0.28
3	G211	0.025	0.28

Note: * Grams of NPK-UREA nutrient per grams of geotextile.

BioG samples were placed at a depth of 15 mm and covered with soil. Radish seedlings, germinated for15 days, were placed into pots containing BioG or control soil. Experiment was conducted in a greenhouse under controlled conditions (25 ±2 °C during the day and 14 ±2 °C at night). Soil moisture content was periodically measured by collection and weighing oven-dried samples. Pots were irrigated uniformly, and plant growth was monitored for seven weeks. Two pots were used for each test condition. Control pots without BioG were fertilized with solid nutrient mixes matching the BioG nutrient composition.

3. Results and Discussions

3.1 Characterization of Fibers

BioF were produced using the wet-spinning method and characterized for their morphological and physicomechanical properties. Figure 1 and Table 3 show the results of BioF characterization. Microscopic analysis revealed differences in cross-sectional shape: ST-AN based BioF exhibited irregular shapes influenced by diffusion and counter-diffusion mechanism during coagulation, Figure 1, while CS-AN based BioF displayed circular shape. Both types of BioF showed porous morphologies whit macropores and longitudinal grooves, contributing to their functional properties. The morphology of ST-AN BioF exhibits microstructures resembling lignocellulosic fibers, which are determinant in its mechanical behavior and ability to retain moisture. According to the characterization, no significant differences in BioF density were observed. The ST-AN based BioF exhibit a high moisture retention capacity, likely due to the porous surface structure and the affinity with hydroxyl groups (OH) from starch and water. Conversely, CS-AN based BioF demonstrated a lower moisture retention capacity, which can be attributed to the hydrophobic nature of the copolymer used in the blend. Interestingly, the CS-AN based BioF show a greater capacity for nutrient absorption, which can be ascribed to the porous internal structure that allows for the penetration of the NPK-UREA solution. Mechanical testing revealed higher tensile strength for ST-AN BioF (74.7 MPa) compared to CS-AN BioF (28.5 MPa), indicating that specific interactions in the CS-AN/AN-MA composite may weaken its intermolecular forces, affecting its structural integrity.

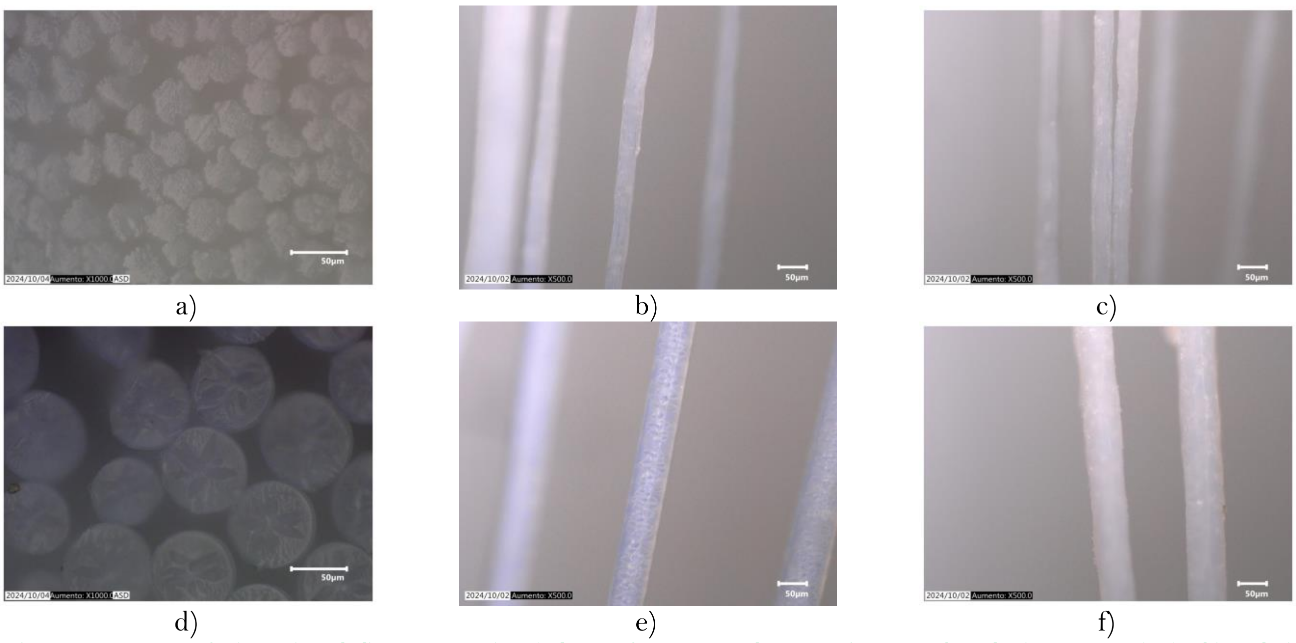

Figure 1. Images of BioF. a) and d), Cross-sectional shape of ST-AN and CS-AN/AN-MA based BioF, respectively; b) and e), longitudinal cut of ST-AN and CS-AN/AN-MA based BioF, respectively; (c) and f), longitudinal cut of ST-AN and CS-AN/AN-MA based BioF (whit nutrient NPK-UREA), respectively.

Table 3. Characterization of BioF obtained by we-spinning.

Properties	ST-AN based BioF	CS-AN based BioF
Linear density (monofilament), denier	10.7	19.8
Linear density (bundle), denier	1200	2220
Nominal diameter, µm	34.0	60.7
Density, g/cm^3	1.21	1.16
Tensile strength (monofilament), MPa	74.7	28.5
Elongation, %	10.70	11.19
Nutrient impregnation, %	39.8	58.5
Moisture retention, %	88	65

3.2 Preparation and Evaluation of Bio-Geotextile

Nonwoven BioG constructed from ST-AN BioF was evaluated for its effects on soil moisture retention and radish plant growth. In Figure 2, the ST-AN based BioG obtained is shown. A simple experiment was carried out to analyze the effect of geotextiles on radish plant growth and soil moisture retention. In the experiment, radish seedlings with germination time 14 days were used. The effective application of geotextiles can be judged by soil moisture content and biometric parameters of plants. Figure 3 show the results of radish plant crops tested with and without the use of geotextiles.

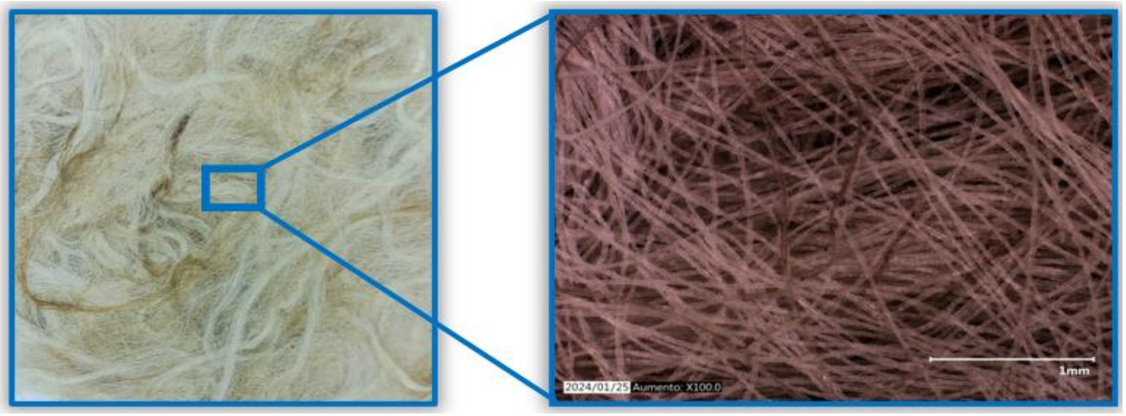

Figure 2. Nonwoven geotextiles obtained from ST-AN BioF impregnated whit NPK-UREA nutrient.

The results in Figure 3 indicate that geotextiles can aid soil moisture retention. This means that the water needed for irrigation can be reduced by using geotextiles. It should be noted that for the soil moisture retention test, all pots in the experiment were irrigated with the same amount of water, which allows for a comparative analysis. In the experiments that have soil with lower and higher percentage of moisture, experiments G201 (without geotextile, moisture retention of 5.48%) and G211 (with geotextile, moisture retention of 14.31%), respectively, a saving of more than 130% in irrigation water consumption can be achieved by using the geotextiles.

Biometric analysis of radish plants demonstrated substantial growth improvements with BioG. Compared to control plants (G200), leaf length increased by 87%, leaf width by 45%, and stem thickness by 142%. Against G201, which used nutrient-only soil, the improvements were 37%, 25%, and 128%, respectively. These results indicate that nutrient-impregnated BioG can serve as a sustainable alternative to conventional fertilization methods, providing controlled nutrient delivery and improving plant growth.

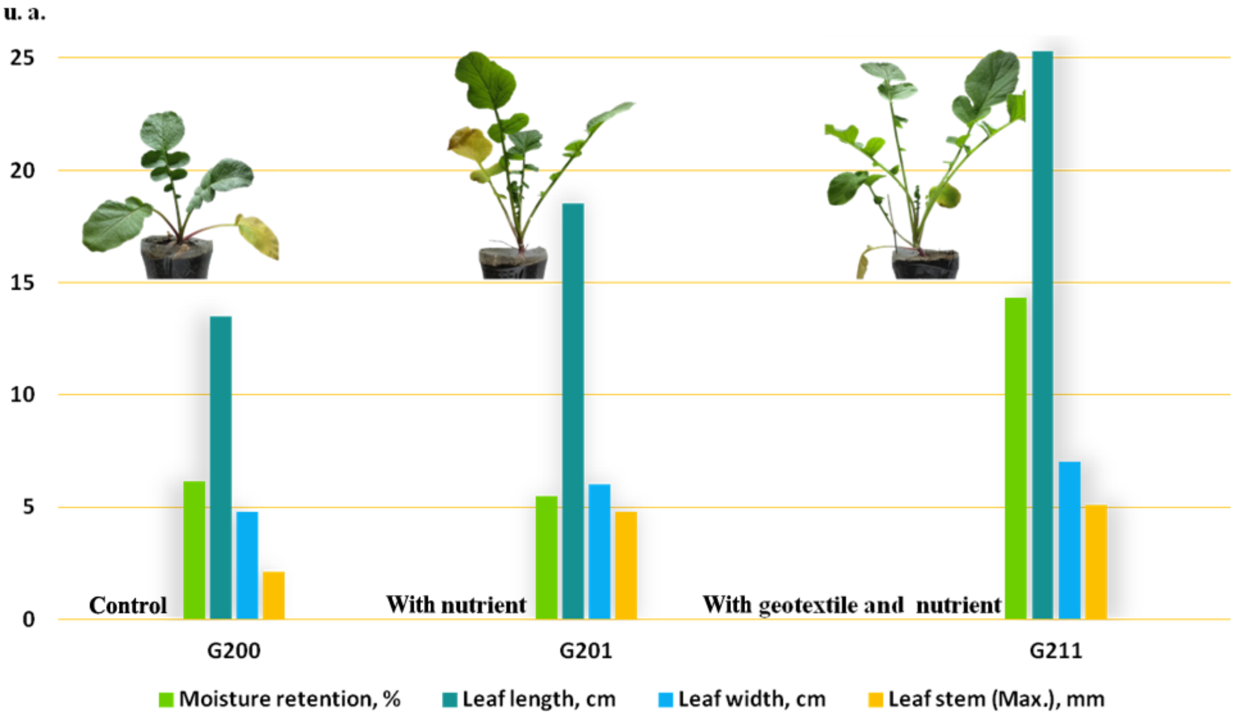

Figure 3. Biometric parameters of radish plants with and without BioG

4. Conclusion

This study successfully developed biodegradable bio-fibers (BioF) using acrylonitrile-based terpolymers for the construction of bio-geotextiles (BioG). The BioG demonstrated performance in soil moisture retention and radish plant growth enhancement. Specifically, the use of ST-AN BioG resulted in a 130% improvement in soil moisture retention, significantly reducing water requirements for irrigation. Biometric analysis of radish plants highlighted substantial increases in leaf length (87%), leaf width (45%), and stem thickness (142%) compared to control experiments. These findings underscore the potential of bio-based materials as sustainable alternatives to conventional geotextiles, offering multifunctional solutions to address agricultural and environmental challenges. By reducing the reliance on synthetic plastics and mitigating microplastic pollution, BioG presents an eco-friendly option for soil remediation and crop productivity. Future research will focus on improving the mechanical properties of these fibers and exploring their applications in soil reinforcement and environmental protection.

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