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ENHANCING THE PHYSICAL PROPERTIES OF POLYETHYLENE MULCH BY SYNTHESIS WITH BIODEGRADABLE POLYMERS TO REDUCE WHITE POLLUTION

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Abstract

The decomposition process of bio mulch increases over time because of environmental decomposition and the influence of environmental conditions such as heat, humidity, and light. Blending biopolymers enhances the physical and chemical properties of these materials, reduces environmental pollution caused by traditional plastics, and develops novel sustainable materials that are environmentally friendly. However, it is important to consider the potential negative effects of mulch on plants and soil. The objective of this study is to evaluate the functions of the mulch made of the biopolymer mixture by improving its mechanical and physical properties. An experiment was conducted to evaluate the effect of non-degradable film residue of polyethene polymer on its physical, chemical, and biological properties after 30 days and compare it with mulch manufactured from a mixture of biopolymer polyvinyl alcohol and polyethene with different volume fractions of 5%, 10%, 15%, and 20% and comparing with polyethene as mulch film. The experimental results revealed that the physical and mechanical properties of the biopolymer blends exhibit significant enhancements. The degradation of these properties occurs over time due to ageing and is influenced by environmental factors. The tensile strength of the blended polymer samples decreased by 17%, and the biodegradation resistance increased by 10%.

Keywords: Biopolymer mulch, Degradable properties, Polyvinyl alcohol, Polyethene, Tensile strength, Ternary polymer blends.

1. Introduction

Mulch is considered one of the key technologies used in the agricultural sector, which is in a state of continuous development because this field requires continuous improvement due to changing environmental conditions and the effect of mulch compounds on the soil. Mulch has evolved and is categorised as organic or inorganic. The organic section consists of materials derived from living organisms, whereas the inorganic section comprises materials that are not derived from living organisms. It is made of a synthetic material that does not decompose easily.

The use of any mulch depends on many factors: the type of soil and its characteristics, the cost and availability of mulching materials, the type of plants grown, and the effect of each mulching material is a combination of different factors, including the amount of materials used to make the mulch, the percentage of carbon and the percentage of nitrogen in the material, its thickness and colour.

Other physical characteristics and the amount of toxic substances present. Each material has certain advantages and disadvantages. Disadvantages regarding its use for coverage [1]. To mitigate the problem of white pollution occurring in the agricultural environment has become widespread. Mulch films decompose in fields due to non-biological factors such as sunlight and temperature. Also, via biological agents such as microorganisms, with final products are water and carbon dioxide [2].

The continuous development in work on researching polymeric materials used to manufacture plastic covers used to protect the soil, as there has been a continuous increase in the use of plastic mulch films. Due to the economically low cost of manufacturing covers and the ability of the mulch to raise the humidity and temperature and quickly weed germination [3], The use of polymer mulch has many economic and functional benefits, but it leaves side effects that constantly affect the soil and beyond. These mulch film removal procedures are expensive and time-consuming. Therefore, farmers burn their waste due to unwanted mulch white pollution as an environmentally friendly potential solution [4, 5].

The goal of using mulch is to cover and create a climate around the root zone by distributing the temperature. What happens to the soil, especially during a lengthy period of drought, has a negative impact on plant growth through rapid water loss. In such a case, the mulch ensures adequate moisture supply to the plant by acting as a protective means in winter and acts as a thermal insulator for the plant roots. The temperature of the soil under the plastic mulch depends on the thermal properties (reflectivity, absorption, or permeability) [6].

The use of a mixture of biopolymers has increased during the last decade to develop the specifications of biopolymers and expand the base of health, agricultural, and industrial applications. These enhanced specifications are what prompted the two researchers to create different mixtures that separate the specifications and application, mixed as a comparison with the economic costs since production will be expanded at the levels of manufacturing and consuming countries [7].

Biopolymer mixtures, whether manufactured or natural, are examined based on their chemical, physical, and mechanical characteristics. These properties influence mixture behaviours and development, which can be enhanced through natural or artificial additives. Morphological behaviours are studied through electronic scanning or electron scanning images. The phase change aims to know the molecular sizes of the polymer. The chemical formulas change depending on the presence of carbon in the structure [8]. Figure 1 shows examples of polyethene mulch used in agriculture.

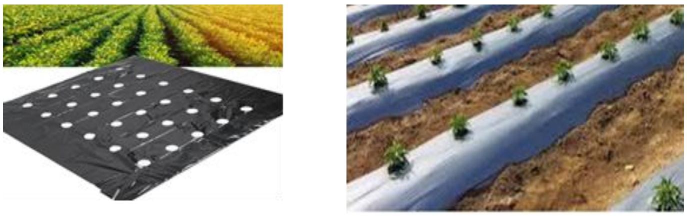

Fig. 1. Sample of the polyethene mulch [7, 8].

Polyvinyl alcohol (PVA) resistance activities using polyethene (PE), spelt as Polyethylene in American English, which has tensile properties and biodegradation, as well as dissolution, High degree of Pomerania crystallinity, fluorescence by pressure, and structural resemblance to acute spikes Polypropylene. They exhibit mechanical properties of ~4.5 GPa Young modulus and ~55 MPa light strength [9].

The reason good mixing occurs is due to similar or close values of isomeric agreements, δ. PE polymer is considered a major economic booster when mixed with PVA, and the progress achieved mechanically is truly clear with the studied resistances compared to the rest of the treatments. Polyethylene is considered an eco-friendly polymer because of its multiple treatment methods [10].

The plasticiser triacetin, also known as triacetate, is added to the main melting point and *brittleness* of the polymers. Thirty Triacetin possesses the melting point (Tm), and verification was confirmed to reduce the temperature (Tg) of PVA, thus improving it Can be processed centrally [11]. Part of the mulch layer is intentionally buried underground for retention. Because of the difficulty of removal, the fragility of plastic after being exposed to environmental weather factors. Plastic tends to disintegrate and crumble into small pieces that are difficult to extract from the soil. Polyethylene membranes are used [12].

The process of environmental cleansing was and still is the most important topic studied, despite the cost incurred in the initial manufacturing process. The cases that were studied were the use of mulch manufactured from PE. It was found that all cases improved the work relative to the cost. This improvement is what made the researchers conduct an on-site environmental assessment and recommend the use of non-toxic, scalable materials. It decomposes with water after a period, which is the period used for plant growth [13].

The more studied mulch is made from PE or low-density polyethene (LDPE). It was found that this cover requires more than 100 years to decompose, so it must be disposed of. Old methods that cause environmental pollution usually include burning, burying, and recycling [14]. However, due to soil contamination, the recycling process will be difficult and expensive [15]. Replacing them with biodegradable materials is an environmentally sustainable alternative, and it is one of the ways to overcome environmental pollution problems resulting from the use of plastic films [16], as they can be decomposed in the soil without leaving any toxic residue [17].

Despite the different types of plastic and paper mulches, which are considered more protective of the soil, the ability to decompose when the mulch is buried is minimal if it is exposed to light and wind. Rain or water makes the paper mulch more fragile, and in order not to cause any undesirable effects on the performance of the agricultural soil, it must not Any harmful substances resulting from the decomposition of biodegradable materials used as a mulching layer accumulate in the soil [18].

An alternative type of mulch made of PE was produced, compared to the use of a biodegradable polymeric material. Extensive studies to assess the environmental impact have shown a noticeable improvement in mechanical and physical properties and environmental degradation [19]. In contrast to PE-based films, biodegradable mulch films (BDMs) would be the ideal solution, according to the study [20]. The applicable strategy used to overcome the accumulation of film fragments in cultivated soil is to use biodegradable materials.

Alternative films are made of biodegradable polymers by microorganisms. Although it is difficult to understand the mechanism of degradation, they have proven successful relative to the original material used [21]. PE is used as agricultural cover helping protect the soil surface, conserving water, and improving the micro-climatic factors of the soil. An environmentally friendly solution must be found. It was replaced with biodegradable polyurethane, which effectively preserves soil moisture. It decomposes at different rates through the mechanism of corrosion [22].

Virgin BDM films have been used to determine the effect of environmental weathering on physical and chemical properties and biodegradation in soil and compost [23]. They concluded that weather impact is a significant deterioration in the mechanical properties and a change in the chemical properties (thermal stability, polymeric structure). The seasonal environmental change in which the planting and germination process takes place and its impact on the behaviour of the mulch.

The processes of decomposition of bio mulch have become the focus of researchers' attention, as well as the remains resulting from the decomposition process and the influence of environmental conditions such as heat, humidity, and light. However, the effect of biodegradable mulch on soil needs further investigation. Mulch made from biodegradable polymers could have a positive effect on the soil if used correctly.

The objective of this study was to evaluate the functions of the mulch made of the biopolymer mixture, which improves the mechanical properties, and physical properties of water solubility. The mixture changes improved tensile and mechanical elongation properties, enhanced by PE polymer compared to bio-polyvinyl polymer and altered its solubility. Water or environmental decomposition of the polymer and its impact on application with soil and plants and low light transmittance that reduces the growth of harmful weeds.

2. Materials and Methods

2.1. Materials used

PVA polymer is a synthetic polymer soluble in water. It is a white substance with no odour. It is sold in granules or the form of aqueous solutions. It is used in the paper industry and the textile and covering industries, as shown in Table 1 [24].

Table 1. The physical properties of PVA & PE [24].

Property	Polyvinyl alcohol (PVA)	polyethene (PE)
Density (g/cm^3)	1.19	0.091
Melting point °C	200	150
Boiling point °C	340	300
Toxicity	Non-toxic material	Non-toxic material
Soluble in	water	Organic solvent
Molecular formula	$(C_2Hydrogen_4Oxygen)_x$	$[-CH_2-CH_2-]_n$

It is a white substance with no odour. PVA polymer is a non-toxic, semi-crystalline, biodegradable material with hydroxyl functional groups and is highly flexible, with good barrier features, biocompatibility, water solubility, and superior chemical resistance. The process of incorporating hydrophobic components into a PVA solution seems to be an effective way to promote the Hydrophobicity of PVA compounds while maintaining structural stability [25, 26], as shown in Fig. 2.

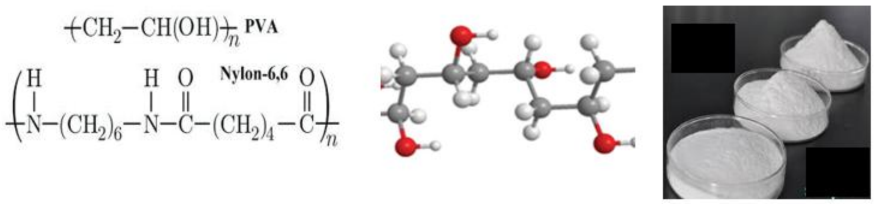

Fig. 2. Polyvinyl alcohol chemical formula and geometric shape [26].

Polyethylene is a common plastic mostly used for packaging [27]. It is a thermoplastic polymer consisting of long hydrocarbon chains, $(C_2H_4)_nH_2$, that differ in chain length [28]. The chemical structure of the polyethene is shown in Fig. 3.

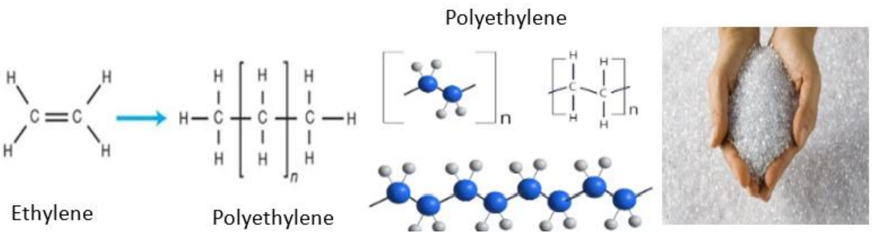

Fig. 3. Polyethene chemical formula and geometric shape [29].

Dimethyl sulfoxide (DMSO) is an organosulfur compound with the special formula $(CH_2)SO$. It is characterised by filtering a polar solvent that is not a hydrogen donor, which dissolves both the polar components. DMSO was used to dissolve PVA in different proportions and combinations with a temperature of PE up to 150 °C and by constant magnetic stirring for a full period of time for each combination. The reaction lasts between 5-10 minutes, and the combinations are poured onto glass plates with a thickness of 1 cm [30].

2.2. Preparation of the polymeric blends

Models of the biopolymer intended to be used as cover for plants are prepared. A type of polymer with good physical specifications, such as PE, was combined with a biopolymer that dissolves by water and achieves the desired purpose by means of dissolution, using DMSO as a solvent. Mixing of biopolymer to prepare the mulch with a magnetic hot plate stirrer to obtain a transparent solvent. After ensuring complete dissolution, lower the temperature and add the PVA biopolymer, then let it incubate for 3-5 hours. The biopolymer solution was heated in dishes at 100 °C for 3-5 hours to evaporate the solvent and dry it, as outlined in Fig. 4.

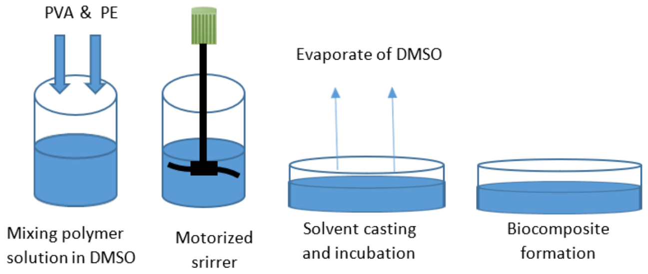

Fig. 4. Process of biopolymer formation to prepare the mulch.

The prepared and tested samples have been coded, as shown in Table 2. The table also displays the composition of each sample.

Table 2. The additives PVA % to PE %.

Sample code	PVA %	PE %
PE	0%	100%
5% PVA	5%	95%
10% PVA	10%	90%
15% PVA	15%	85%
20% PVA	20%	80%
PVA	100%	0%

2.3. Mechanical properties

The mechanical properties of the biocomposites were measured using an Instron device with a kilo-Newton force. The values of tensile strength, Young's modulus, and elongation at the breakpoint were determined from stress-strain diagrams and measurement data with the use of Eqs. (1) -(3).

$$\sigma = \frac{p}{A} \quad (1)$$

$$\varepsilon = \frac{\Delta L}{Lo} \quad (2)$$

$$E = \frac{\sigma}{\varepsilon} \quad (3)$$

where E is the young modulus (MPa), σ is tensile strength (N/mm^2), p is the maximum tensile force (N), A is cross-sectional area (mm^2), ε is strain, ΔL is the length change (mm), and Lo is the initial length (mm)

2.4. Biodegradability measurement

The measurement of such a study is carried out by preparing models of the biopolymer mixture using the soil burial method in accordance with the standard specifications ASTM D 6400-19. Ten plastic containers filled to half with soil are prepared, and the models in the form of strips are placed in the soil, the weights of which have been taken in advance. Dimensions and cover it with moist soil for 30 days, where the soil is sprayed regularly to keep it moist. The forms are taken out every 10 days, and the weights are taken. The weight loss is represented according to Eq. (4).

$$weigth\ loss\% = \frac{wt._{intitial} - wt._{final}}{wt._{intial}} * 100 \quad (4)$$

3. Results and Discussion

3.1. Phase morphology and shear viscosity of the ternary blends

The phase change of polymer mixtures becomes influential in the application of mechanical behaviour, as it explains the mechanism of concentration of the mixture and the effect of each polymer individually. The morphology of all PVA polymer mixtures is studied before the solvent-casting process. The dynamic viscosity of the mixture containing PE is shown in Fig. 5.

The viscosity of Polyvinyl Alcohol (PVA) solutions is a function of shear rate, exhibiting non-Newtonian behaviour. Here is a general overview of the viscosity-shear rate relationship. At low shear rates, PVA solutions typically exhibit a high viscosity due to the entanglement of polymer chains. As the shear rate increases, the polymer chains begin to disentangle and align in the direction of flow, leading to a decrease in viscosity. This behaviour is known as shear-thinning [31].

On the contrary, the viscosity showed PVA and PVA/triacetin solution without PE rapidly decreased, as shown in Fig. 5. Here, the PE polymer acts as a viscous agent for the PVA mixtures, where the proportioning is at the secretarial level, followed by adjustment in the mixtures in all touches. The reason for this is that most polymers do not contain neutrons and thus will change with the shear rate applied. This increase in viscosity was attributed to the coalescence and disassembly of the polymer chains [31-33].

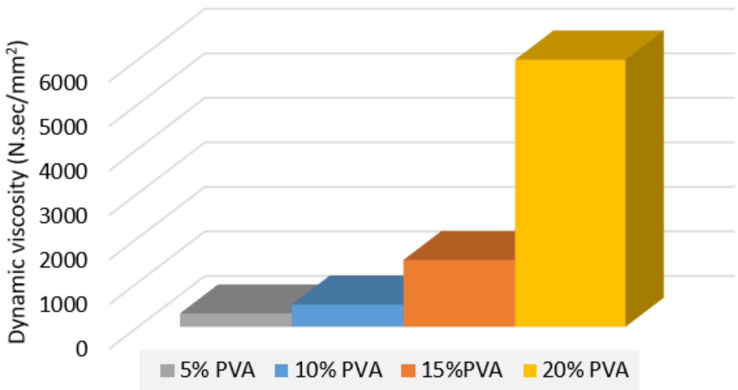

Fig. 5. Viscosity versus PE% addition in the PVA polymeric blend components.

3.2. Results and analysis of the mechanical properties

3.2.1. Tensile strength

The improvement in PVA mixtures by adding Triacetin in volume ratios with PE polymer ranging from 5% to 20% appeared through the change in mechanical properties, where the mechanical tensile resistance value increases with an increase in the proportion of PE polymer with PVA.

The enhancement of the mechanical properties appears in the mixture significantly, and the effect of the PE concentration is through the shape of the fracture on the surface of the model. It is considered more durable in the case of reinforcement than the base polymer, as the shear rate in the levels of the polymer chains is considered extremely high, which leads to the formation of large deformations, which makes the polymers more susceptible. Failure of other materials and the high concentration of PE change the basic behaviour of PVA, even under a small load. It was also observed that the elongation decreased further in the presence of high concentrations of PE polymer, as it showed interfacial adhesion with the PVA polymer at fractures and cracks, as shown in Fig. 6, and the results agree with [34-36].

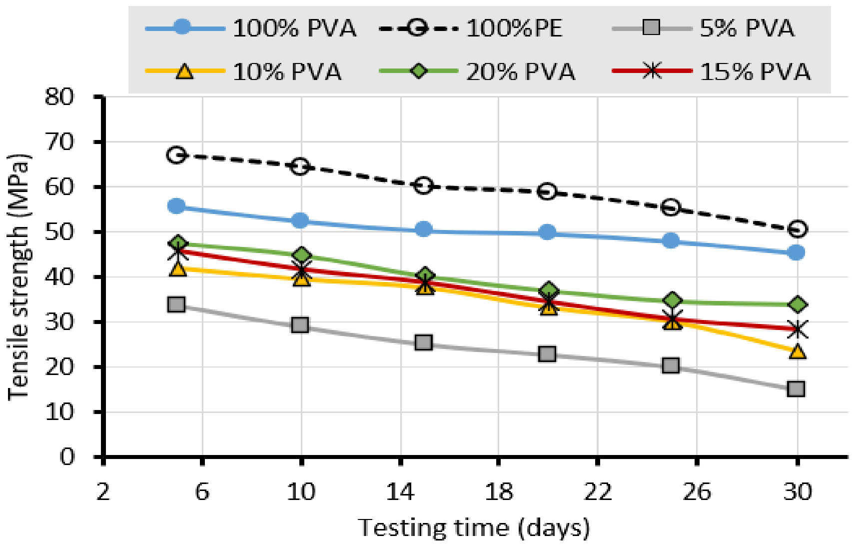

Fig. 6. Tensile strength of biopolymeric blends % with testing time.

3.2.2. Young modulus results and analysis

The elastic modulus of polymeric materials with short polymer chains has an exceptionally low tensile resistance, which affects the elastic modulus compared to polymers with long, interconnected chains, which are stronger and more resistant to tension, which makes the elastic modulus increase in value. In the case of PVA, the elastic modulus values for the bio-mixture are relatively good in comparison. With the base material and the mixed material, as shown in Fig. 7. the decrease is clear during the test period, as in Fig. 7, and that agreement with [34-36].

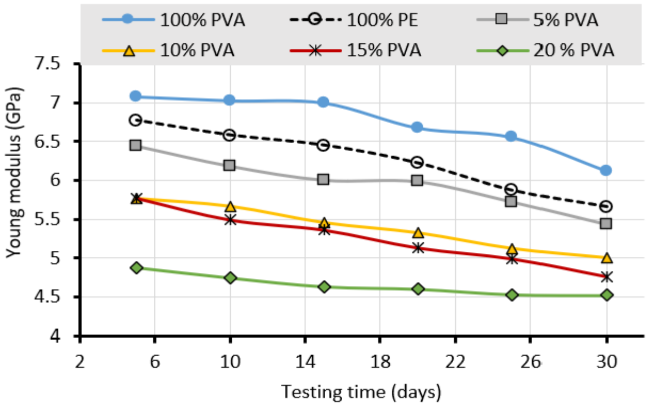

Fig. 7. Young modulus of biopolymer blend with different % of PVA during testing time.

3.2.3. Elongation analysis

The elongation changes during the burying period of the polymer models from the bio-mixture, which shows the ability of the polymer to elongate when the mixture ratio increases, as shown in the results of Fig. 8, which agrees with [37].

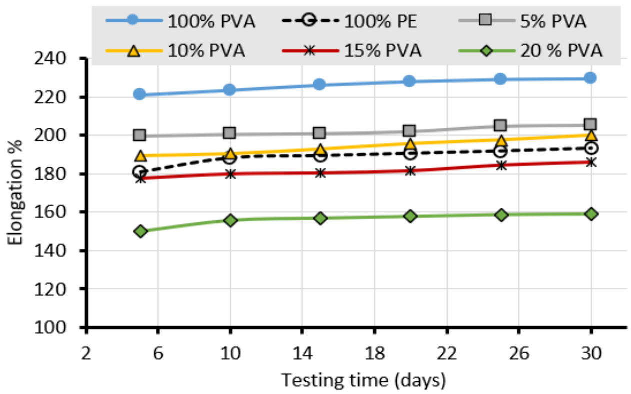

Fig. 8. Elongation % of biopolymer blend (with different % of PVA) during testing time.

3.3. Soil biodegradability

Measurements were taken before burying the prepared models for periods of time ranging from 5, 10, 15, 20, 25, and 30 days. A day where deterioration appeared After 10 days, the decrease in weight was the criterion for biological decomposition of the PVA/triacetin/PE polymer mixture model. A change in the size of the model was also observed, and the surface of the films became solid and brittle.

The best explanation for the decomposition of models prepared from the PVA polymer is due to the high sensitivity of this polymer to moisture, which causes it to swell before the decomposition process due to the absorption of water, which leads to the union of water molecules and their occupation in the polymer chains, which weakens the chain, leading to its disintegration and the decomposition of the model made from PVA, but when The comparison is when it is bonded with PE from a concentration of 105 to 205, as it is considered a hydrophobic polymer and the decomposition rate is reduced relative to the base polymer. Weight loss % of biopolymer blend (with different % of PVA) during testing time as shown in Fig. 9.

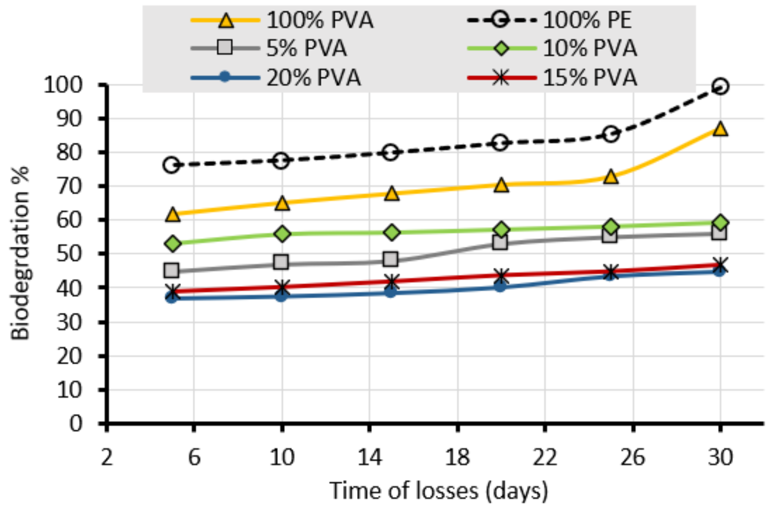

Fig. 9. Weight loss % of biopolymer blend (with different % of PVA) during testing time.

During the period between 25-30 days of burying the soil, decomposition is observed at a significant rate, which makes the presence of PE polymer a source of resistance to decomposition for a certain period. The microbial decomposition occurs because of the presence of carbon, as it is expected that the mixture reinforced with PE will undergo complete deterioration, which is attributed to microbial degradation and oxidation processes. This phenomenon emphasises the potential of the mixture as being environmentally friendly and sustainable [38].

4. Development and Limitations of Biodegradable Mulches

Since biodegradable polymers have a wide scope of use and extensive study on them in many applications, the physical and chemical limitations remain that make polymeric materials toxic and harmful to the soil. However, reinforcement with harmless types makes the mechanical limitation overcome the actual composition of the application, which makes such materials environmentally friendly.

4.1. Projected developments of biodegradable mulches

Since biodegradable polymers have a wide scope of use and extensive study on them in many applications, the physical and chemical limitations remain that make polymeric materials toxic and harmful to the soil. However, reinforcement with harmless types makes the mechanical limitation overcome the actual composition of the application, which makes such materials environmentally friendly. Proposed directions in the development of the biodegradable polymers are summarised in Table 3.

Biodegradable polymers, while widely studied and used across many applications, still face physical and chemical limitations that make them potentially toxic and harmful to the soil. However, reinforcing these polymers with non-toxic materials can help overcome mechanical limitations, enhancing their environmental friendliness. Mulches derived from renewable resources such as coconut coir, sugarcane bagasse, hemp, and biodegradable polymers like PLA, PBAT, and PHA are commonly used, as well as those made from starch-rich plants or cellulose. Compostable mulches are certified according to standards like EN 13432 and ASTM D6400. Despite their advantages, biodegradable mulches face limitations, including higher costs, reduced shelf life, variable degradation rates, and potential weed growth.

Table 3. Summary of the projected development of the biodegradable mulches.

Mulch type	Description
Natural Fiber Mulches	Derived from renewable resources like coconut coir, sugarcane bagasse, and hemp.
Bioplastic Mulches	Made from biodegradable polymers like PLA (polylactic acid), PBAT (polybutylene adipate-co-butylene terephthalate), and PHA (polyhydroxyalkanoates). Starch-Based Mulches: Produced from starch-rich plant sources like corn, potato, or tapioca
Cellulose-Based Mulches	Derived from wood pulp or plant fibres.
Compostable Mulches	Certified compostable according to standards like EN 13432 or ASTM D6400

4.2. Environmental limitations

Bbiodegradables mulches seem to be environmentally friendly and could be an alternative to traditional harmful plastics. However, their use is still causing environmental risks, including the release of additives and impurities, capability for microplastic formation, and impacts on soil health and carbon footprint. The biggest environmental problems associated with biodegradable mulch usage could be the microplastic formation and additive release caused by fragmentation, release of additives like plasticisers, dyes, and UV stabilisers, Potential Hazards caused by Some additives, like phthalates and bisphenol A, which are endocrine disruptors and have negative impacts on human and animal health.

Biodegradable mulches may not always completely biodegrade into CO_2, H_2O, and biomass, with some materials potentially accumulating in the environment. Additionally, they may struggle to withstand harsh weather, face composting challenges, and vary in performance. Environmental concerns include the generation of microplastics, soil contamination, water pollution, and potential disruptions to the soil microbiome. Future research should focus on improving the durability and shelf life of these materials, enhancing biodegradation rates, developing more cost-effective production methods, and investigating their broader environmental impacts while also working towards standardising regulations and certifications. Table 4 summarises some the challenges facing this type of plastic to be used in the industry, mainly in the agricultural sector.

Table 4. Summary of the limitations and challenges in the production and use of Biodegradable mulches.

Limitations	Property
Higher Cost	Biodegradable mulches are often more expensive than traditional plastic mulches.
Limited Shelf Life	Biodegradable mulches degrade over time, reducing effectiveness.
Variable Degradation Rates	Degradation rates depend on environmental conditions (temperature, moisture, soil type).
Potential for Weed Growth	Biodegradable mulches can create an environment conducive to weed growth.
Limited Durability	Biodegradable mulches may not withstand harsh weather conditions or heavy machinery.
Compo Stability Issues	Inadequate composting infrastructure can limit effective disposal.
Performance Variability	Quality and effectiveness vary among biodegradable mulch products. Regulatory
Frameworks	The lack of standardised regulations and certifications can create confusion.
Microplastic Generation	Biodegradable mulches can break down into microplastics.
Soil Contamination	Inadequate degradation can lead to soil contamination.
Water Pollution	Biodegradable mulch fragments can enter waterways.
Impact on Soil microbiome	Altering soil microbiota can have unintended consequences.

5. Conclusions

An experiment was conducted to evaluate the effect of non-degradable film residue of polyethene polymer on its physical, chemical, and biological properties after 30 days and compare it with mulch manufactured from a mixture of biopolymer polyvinyl alcohol and polyethene with different volume fractions of 5%, 10%, 15%, and 20% and comparing with polyethene as mulch film. The experimental results revealed that the physical and mechanical properties of the biopolymer blends exhibit significant enhancements. However, the degradation of these properties occurs over time due to ageing, which is further exacerbated by environmental factors. It was observed that the tensile strength decreased by 17%, while the biodegradation resistance exhibited a 10% increase in the blended polymer samples.

Future research should focus on investigating degradation mechanisms, assessing toxicity impacts, optimising scalable production, developing high-performance biodegradable blends, and evaluating the broader environmental consequences of biodegradable mulches, as highlighted in studies such as "Sustainable Agriculture and Biodegradable Mulches. Also, future recommended research on the topic of biodegradable mulches is to explore durability and shelf-life improvement, enhance biodegradation rates, develop cost-effective production methods, investigate the environmental impact, and standardise regulations and certifications.

Nomenclatures

A	Area, mm^2
E	Young modulus, MPa
Lo	Initial length, mm
P	Load tensile, N
Tg	Glass transition temperature, ºC
Tm	Melting temperature, ºC

Greek Symbols

ΔL	Change in specimen length, mm
σ	Tensile strength, N/mm^2
ε	strain

Abbreviations

ASTM	American Standard testing of materials
BDMS	Biodegradable mulch films
DMSO	Dimethyl sulfoxide
LDPE	Low-density polyethylene
PE	Polyethylene
PVA	Polyvinyl alcohol

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