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Synthesis and Biodegradation Analysis of Polyvinyl Alcohol–Starch (PVA-ST) Biopolymer Films

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Abstract

This study investigates the development and characterization of biodegradable bioplastic films composed of polyvinyl alcohol (PVA), starch, and their composite blend, aiming to provide sustainable alternatives for food packaging applications. The films were synthesized using a casting method, incorporating glycerol as a plasticizer. Mechanical analysis revealed that the PVA-starch composite films exhibited a balanced combination of tensile strength and elongation, making them suitable for packaging purposes. Biodegradation studies were conducted using the bacterium Bacillus subtilis, known for its ability to produce biosurfactants. Results indicated that the PVA-starch composite films achieved approximately 70% biodegradation within 16–17 days, whereas conventional synthetic films showed negligible degradation. These findings underscore the potential of PVA-starch bioplastics as environmentally friendly alternatives to traditional plastics in food packaging, contributing to the reduction of plastic waste and its associated environmental impact.

KEYWORDS: Biodegradable bioplastics, PVA-starch composite, food packaging, mechanical properties, biodegradation, Bacillus subtilis.

INTRODUCTION

Conventional packaging polymers such as polyethylene, polypropylene, polyamides, and polyesters are extensively utilized due to their cost-effectiveness, mechanical strength, and excellent barrier performance against gases and moisture. Despite their widespread applicability, these materials pose significant environmental challenges owing to their non-biodegradable nature and reliance on finite petrochemical resources. In light of these sustainability issues, the European Union has introduced regulatory directives requiring that, by 2030, all plastic packaging placed on the market must be either reusable or recyclable in a commercially viable manner. This policy underscores the critical need for the development of environmentally sustainable and circular alternatives in packaging materials [1].

Humans consume an estimated 39,000 to 52,000 microplastic particles each year, posing potential health risks from toxins, additives, and pathogens. Environmental degradation from plastic waste is intensifying, while recycling efforts are increasingly hindered by contamination. Mechanical recycling struggles with the complexity of mixed waste streams. With plastic production expected to rise to 1,480 million tons by 2050, implementing circular economy solutions has become critically important [2].

Petroleum-based plastics are affordable, widely accessible, and have strong mechanical properties, which makes them a popular choice for packaging materials. Pollutant levels in the environment are rising, and synthetic plastic is one the major factor. Plastic particles and other pollutants derived from plastic are present in our environment and food chain, endangering human health. Recently the use of non-biodegradable/synthetic materials for the various types of food packaging applications has elevated environmental pollution [3]. Currently, the manufacturing segments actively explore biopolymer as an alternative to petroleum-based traditional plastic materials but their market adoption remains quite limited [4]. These bioplastics consist either entirely or partially from natural resources such as green materials (plant-based product). Bioplastics have the potential to decrease environmental impacts, specifically reducing carbon footprint, and limiting greenhouse gas emissions associated with polymer utilization. However, the goal of the biodegradable plastics material is to make the world greener, more sustainable, and less environmentally impactful. Since all types of Plastics leak hazardous chemicals and other toxic substances, creates negative impacts on all types living things. Environmental scientist and Engineers are still in search of various sustainable solutions to give green environment. A variety of techniques are suggested including chemical, physical, and biological methods for reducing the plastic waste and plastic degradation [5].

One of the major sources of plastic waste is the food packaging sector. When plastics made from fossil fuels reach the end of their useful lives, the environment is frequently harmed, leading to an increase in greenhouse gas emissions and the production of microplastic pollution [6]. Consequently, substitute materials for food packaging are necessary to counteract these effects and lessen the use of plastics that is not sustainable. The material's biodegradability, source abundance, and waste valorization all contribute to the sustainability of biopolymers.

Bioplastics can be bio-based, biodegradable, or possess both characteristics. Bio-based materials come from living organisms and often renewable resources, as opposed to fossil fuels. Ideally, biopolymeric active food packaging decomposes naturally in composting environments. Bioplastics based on poly lactic acid (PLA), bacterial cellulose, starch, cellulose are typically made for use in food packaging. In this research, bioplastics made of plasticized starch (extracted from corn) and polyvinyl alcohol (PVA) were blended in different weight percentages [7].

In 2021, countries produced approximately 390.7 million tones globally. Asian countries reached approximately 55% of the total production of plastics, and North and South America 22% in total. As long as proper waste management practices, like composting, are followed, biodegradable plastics can have qualities that are comparable to those of traditional plastics while also offering extra advantages because of their reduced carbon dioxide impact on the environment [8]. Among all plastics discarded into the environment polypropylene is highest. Using both physical and biological techniques, the study investigates ways to accelerate polypropylene's biodegradation. A bacterial species called Bacillus subtilis was examined to see if it could live exclusively on polypropylene. Surface-active compounds, or biosurfactants, are produced by the microbial species and aid in the process of breakdown [9].

This research aims to provide a thorough understanding of the production, applications and degradation of biodegradable plastics, as well as their sustainability, sourcing, ecological impact, and product prospects [10]. The degradation of plastic occurs in this research under bacterial specie Bacillus, the microbes first adhere onto the polymer surface, thereby exposing itself to microbial colonization. Polymer colonization is followed by the secretion of extra cellular enzymes, which bind to the polymer and cause hydrolytic cleavage. The polymer is subsequently degraded into low weight polymer and mineralized to carbon dioxide (CO2) and water (H2O), which are used by the microbes as energy source [11].

Identifying microbes that can degrade microplastic is a promising and environmentally safe strategy to facilitate natural bioremediation and influence the cleaning of natural ecosystems without imposing adverse impacts. High temperature, salinity, pH, and Organic matter content and low aeration and moisture level improve the substrate conditions to be conductive for the development of microbial populations. This study also aimed to provide degradation for Bioplastic based on PVA, Starch and blend of PVA/Starch using bacterial strains that grown aerobically at 35 °C under shake flask conditions [12].

MATERIALS AND METHOD

The PVA of 99% purity in the form of white granular powder, corn starch of 99% in the form of fine white powder (moisture-free) and Glycerol of 95% purity is used as plasticizer in this research. The casting technique is used to prepare bioplastic films however, evaluation of tensile strength of the films, dog-shaped specimens with dimensions of 100 x 4mm were employed following the guidelines outlined in ASTM Standard D-882 (ASTM, 1996c) on using Universal Testing Machine (idealTA, Taiwan). The films were positioned between two vertical grips, with the lower grip firmly attached to a static load cell with a capacity of 1KN. During the testing procedure, the lower grip remained fixed in place while the upper grip moved upward at a testing speed of 100 mm/min. The film thickness was measured using a digital micrometer with a precision of 0.001 mm and a total of nine measurements were recorded for each film sample.

SYNTHESIS OF BIOPLASTIC FILMS

Casting solution is prepared by distilled water and (3% w/w of water) corn starch & (4% w/w of water) PVA and same concentration of both for blend. Then glycerol was added as plasticizer in starch film. The film solution was then heated to 100°C for 60-80 minutes under constant stirring of 600 RPM using magnetic stirrer to obtain starch gelatinization. Automatic stirring was continued until the solution had become viscous and transparent. The solution was continuously stirred until it reached a viscous and transparent consistency. Subsequently, the solution was poured into a casting plate and dried in oven at 60±1°C for 24 hours [13].

Samples	**Size (cm)**	**Concentration**
PVA (A1)	2 x 4.8	4 % PVA and 40 % Glycerol
PVA (A2)	2 x 4.8	4 % PVA and 30 % Glycerol
Starch (B)	2 x 4.8	3 % Starch and 40 % Glycerol
Blend (AB)	2 x 4.8	4 % PVA, 3% starch and 40 % Glycerol

Table 1: Preparation of Bioplastic

LAB-SCALE BIOPLASTIC DEGRADATION SETUP

The Degradation of bioplastic was conducted using Bacterial species Bacillus subtilis that has capacity to generate biosurfactants led to their selection for the investigation. Bacillus subtilis is the producer of surfactin, a biosurfactant. The bacterial species were grown under shaking flask conditions, with bacterial strains grown aerobically at 32°C. The growth medium for Bacillus subtilis used was a mineral salts medium (MM) contains 2.5g of KH_2PO_4, 0.8g of $(NH_4)_2\ SO_4$, 3.4g of $MgSO_4$, 0.05g of $CuSO_4.7H_2O$, 0.8g of $MnSO_4.5H_2O$, with a trace element solution added (5 ml/L), comprising 200 mg of $FeSO_4$, 0.01g of $ZnSO_4$. $7H_2O$, 0.003g of

$Na_2MoO_4 \cdot 2H_2O$, 2 mg $NiSO_4$, 0.02g NaCl, 0.01g H3BO3, 0.002 mg $CaCl_2$, 1g of $NiSO_4 \cdot 6H_2O$, 0.1g of $CoCl_2 \cdot 6H_2O$ [86] [12].

Figure 1: Degradation of Bioplastic

The degradation performance of bioplastic samples was systematically studied over three weeks through visual inspection and weight loss measurements. Sample A1, characterized by a high glycerol content and a low tensile strength of 920 MPa, and exhibited the fastest degradation, with a weight loss exceeding 95%.

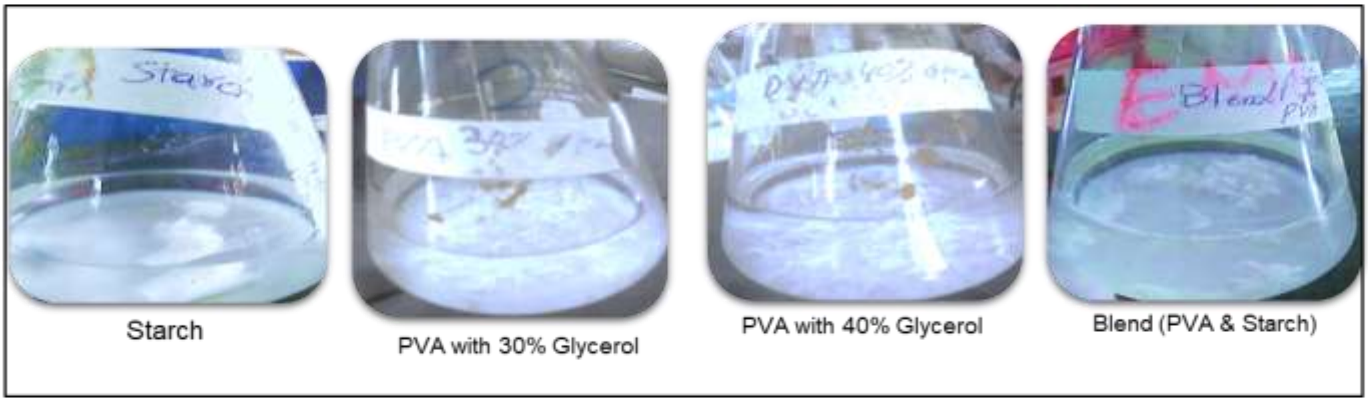


Figure 2: First week observations after starting biodegradability.

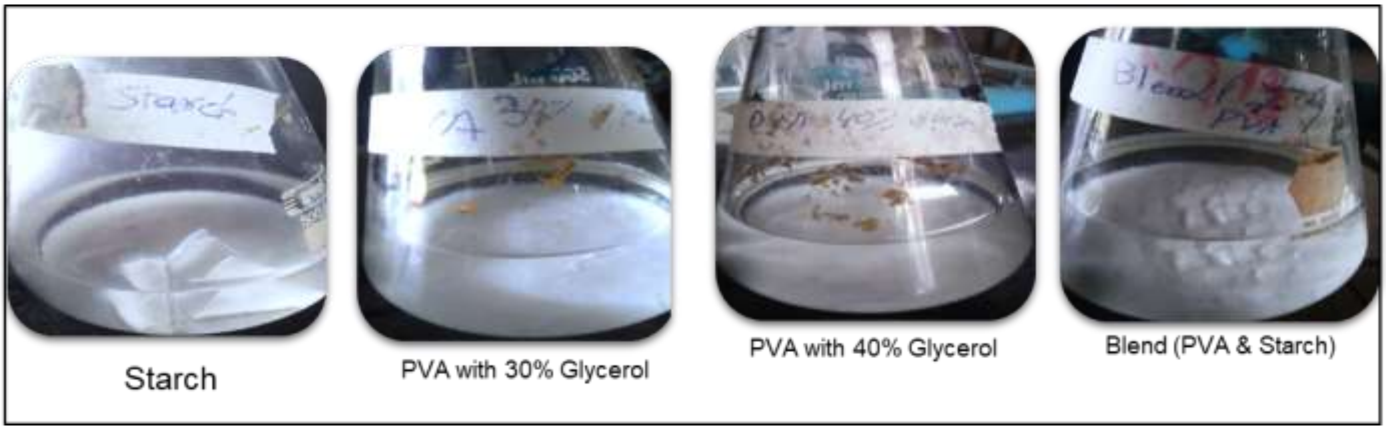
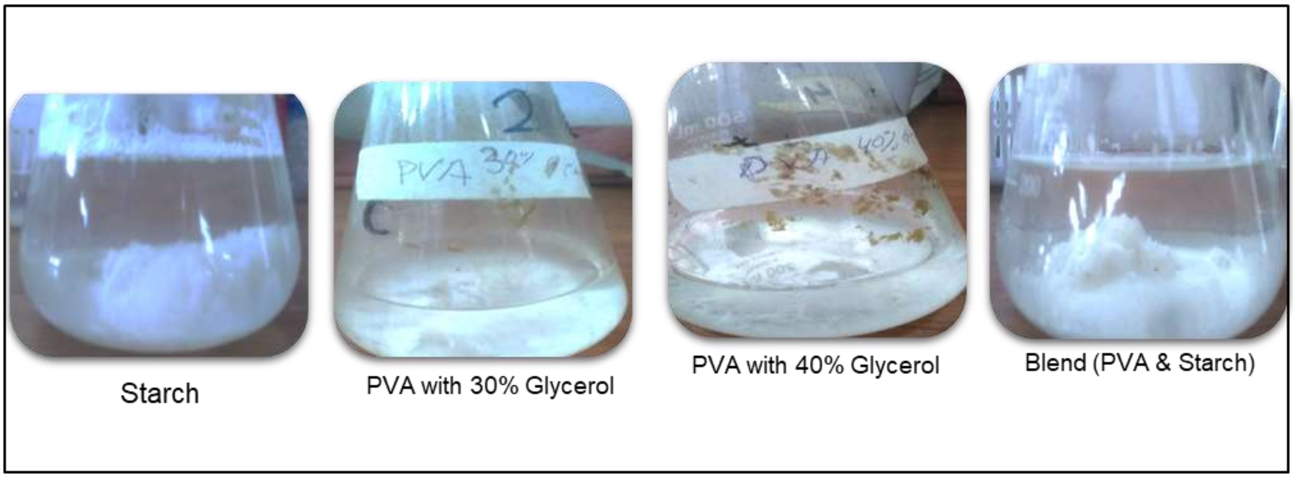


Figure 3: Second week observations after starting biodegradability.

In comparison, Sample A2, with reduced glycerol content and moderate tensile strength of 1294 MPa, showed slower degradation, losing approximately 80–85% of its mass. The PVA-starch blend (Sample AB) demonstrated moderate biodegradability, retaining 30–35% of its weight and maintaining better structural integrity due to a higher tensile strength of 1670 MPa. Meanwhile, the pure starch-based bioplastic (Sample B) showed the greatest resistance to degradation, losing only 50–55% of its mass, which correlates with its exceptionally high tensile strength of 3354 MPa.



Starch

PVA with 30% Glycerol

PVA with 40% Glycerol

Blend (PVA & Starch)

Figure 4: Third week observations after starting biodegradability.

These findings clearly highlight the critical role of material composition in governing biodegradation behavior. Higher glycerol content enhances degradation rates by reducing structural strength, whereas increased PVA or starch content contributes to greater mechanical stability and resistance to breakdown. Laboratory scale experiments are clearly shown in figures 2, 3 and 4.

RESULTS a nd DISCUSSION

Samples	Thickness (mm)	Tensile Strength (MPa)	Elongation %

PVA (A1)	28.9± 0.244	920	450
PVA (A2)	28.8± 0.081	1294	230
Starch (B)	29.2± 0.368	3353	90
Blend (AB)	28.6± 0.163	1670	190

Table 2: Properties of synthesized bioplastic

Mechanical characterization showed that PVA (A1) exhibited the greatest flexibility with the lowest tensile strength, whereas starch-based bioplastic (B) demonstrated superior tensile strength but limited elongation, reflecting its brittle nature. PVA (A2) presented a balanced profile with moderate strength and flexibility. Notably, the PVA-starch blend (AB) combined high tensile performance with acceptable ductility, indicating its potential for applications requiring both mechanical robustness and biodegradability.

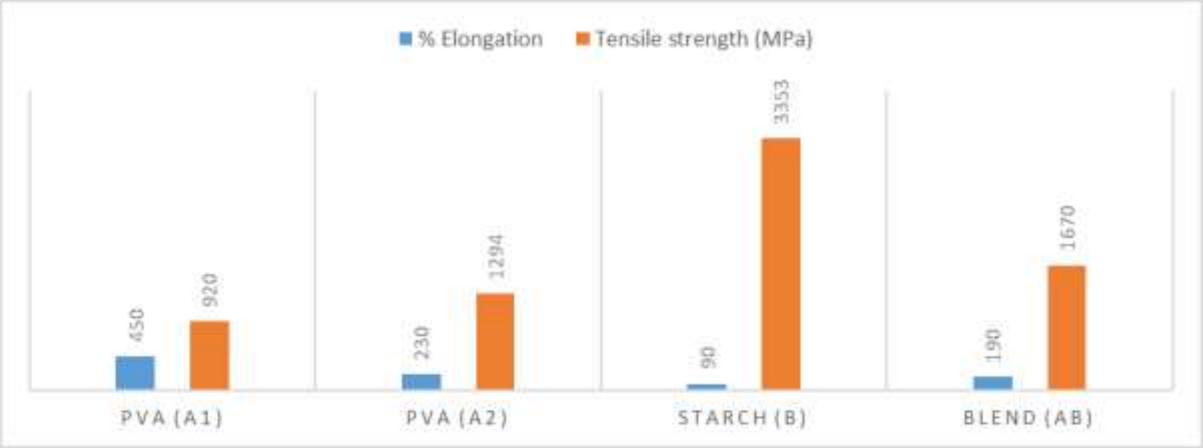


Figure 4: Mechanical Properties of synthesized bioplastic.

This study successfully developed eco-friendly bioplastic films using starch, polyvinyl alcohol (PVA), and their composite blend, demonstrating their strong potential for food packaging applications. The bioplastic films exhibited superior mechanical strength and flexibility compared to conventional synthetic plastics, offering a sustainable alternative to reduce plastic pollution. In comparative tests, the bioplastics preserved the quality of chili powder—maintaining its pungency and color over 3.5 months at 30–35°C—comparable to commercial cast polypropylene (CPP) films. Moreover, the PVA-starch composite films achieved approximately 70% biodegradation within 16–17 days in the presence of Bacillus subtilis, whereas CPP films showed negligible degradation. These findings emphasize the environmental advantages of bioplastics and their capacity to significantly reduce plastic waste.

The composite films offered a balanced combination of strength and flexibility (figure 4), making them particularly suitable for packaging applications. The enhanced biodegradability of the PVA-starch films further supports the transition to bioplastics as a practical solution to mitigate the environmental impact of petroleum-based plastics.

Looking ahead, future research should focus on optimizing bioplastic formulations and processing methods to enhance barrier properties and cost-efficiency. Exploring additional natural polymers such as chitosan or alginate could further improve mechanical and functional characteristics. Sustainable plasticizer alternatives should also be investigated to enhance eco-friendliness and scalability. Long-term performance assessments under real-world packaging conditions—such as resistance to moisture, oxygen, and microbial spoilage—will be essential to evaluate commercial viability. Additionally, broadening microbial degradation studies to include diverse bacterial strains and environmental scenarios will aid in establishing standardized, robust biodegradation protocols and further support the widespread adoption of biodegradable plastics.

CONCLUSION

This study contributes to global efforts aimed at identifying sustainable alternatives to conventional plastics, particularly in the food packaging sector, which is a significant source of plastic pollution. Consistent with previous research, the findings affirm the potential of starch and PVA-based bioplastics as viable substitutes for synthetic polymers. For instance, [15] demonstrated that starch-based bioplastics exhibit mechanical properties comparable to conventional plastics while offering superior degradation rates. Similarly, several studies have reported that starch-PVA composites enhance both mechanical strength and biodegradability, supporting their applicability in environmentally responsible packaging solutions.

Mechanical characterization in this study revealed that higher glycerol content, as seen in PVA (A1), increased flexibility at the expense of tensile strength, thereby accelerating degradation. In contrast, the pure starch-based sample (B) exhibited the highest tensile strength and the slowest degradation, reflecting its structural rigidity. The PVA-starch blend (AB) provided an optimal balance between mechanical integrity and biodegradability, underscoring the influence of formulation on performance.

The degradation outcomes align with the findings of [12] who investigated the microbial degradation of polypropylene using Bacillus subtilis. In this study, PVA-starch composites demonstrated significantly higher degradation efficiency, while conventional CPP films showed minimal breakdown, emphasizing the persistent environmental challenges posed by synthetic polymers. These results reinforce the necessity for bioplastics that can achieve both functional and ecological goals—namely, sufficient mechanical strength and rapid environmental degradation.

Furthermore, this research supports the growing body of literature advocating for renewable-resource-based bioplastics [3]. According to literature materials like starch can substantially reduce the ecological footprint of plastic packaging when paired with sustainable disposal strategies such as composting or microbial-assisted degradation. The mechanical properties observed in this study are also in line with the findings of [4], who noted that starch-PVA bioplastics demonstrate promising performance, particularly when plasticizers and additives are used to optimize their characteristics. Here, the incorporation of glycerol effectively enhanced both the flexibility and strength of the bioplastics.

Lastly, while Bacillus subtilis was employed in this study for biodegradation, other microbial species, including fungi and bacteria, have been shown to facilitate the breakdown of plastic materials, as reported by [11]. The biodegradability of PVA-starch films observed in this research highlights the potential of microbial-assisted degradation as a critical strategy in mitigating plastic pollution, further supporting the case for bioplastics as a sustainable and environmentally viable alternative.

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