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# Biodegradable Polymeric Blends of Thermoplastic Starch-An Overview

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***Abstract*—In today's world, biodegradable materials are a key focus of discussion. As the demand for eco-friendly products continues to grow, the use of biodegradable materials in everyday items is rising significantly. People are increasingly seeking sustainable alternatives that do not harm the environment. In this article, the key focus is on how biodegradable Thermoplastic Starch (TPS) Blends help in sustainability. Thermoplastics are polymers that can flow when heated above the glass transition temperature. Their plastic deformation involves viscous flow with complex rheology which is influenced by high molar mass, entanglements, interactions and chain branching.**

***Index Terms*—Biodegradable Polymers, Thermoplastic Starch (TPS), Polymeric Blends, Applications of TPS**

## I. INTRODUCTION

With growing environmental concerns, biodegradable polymers have emerged as a promising alternative to conventional plastics. They are designed to decompose naturally, minimizing long-term ecological impact. A significant advancement in this field is the development of biodegradable polymer blends, which combine two or more polymers, at least one of which is biodegradable to improve mechanical performance, processability, and environmental compatibility. Among these, thermoplastic starch (TPS) has gained considerable attention due to its renewability, low cost, and versatility. TPS is typically produced by dispersing starch in cold water to form a thick suspension, which transforms into a moldable material upon heating. To evaluate the properties of TPS and its blends, a variety of analytical techniques are employed, including differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), Fourier-transform infrared spectroscopy (FTIR) and nuclear magnetic resonance (NMR). Blends such as TPS/PP (polypropylene), TPS/PS (polystyrene), and TPS/ABS (acrylonitrile butadiene styrene) have demonstrated considerable potential as sustainable substitutes for non-degradable plastics. This paper explores the formulation, characterization, and performance of such TPS-based blends, highlighting their viability in eco-friendly material applications.

## II. BIODEGRADABLE POLYMERS

Biodegradable polymers are a unique and eco-friendly category of materials that offer benefits to humanity without harming the environment. In contrast to traditional petroleum-based, non-degradable polymers that contribute to pollution after use, biodegradable polymers break down through external factors, producing simple and harmless byproducts. Biodegradable polymers can be broadly categorized based on their chemical structure and synthesis methods. They comprise ester, amide, or ether bonds. One of these groups is agro-polymers, i.e. those derived from biomass. The other consists of bio polyesters, which are those derived from microorganisms or synthetically made from either naturally or synthetic monomers.[2]

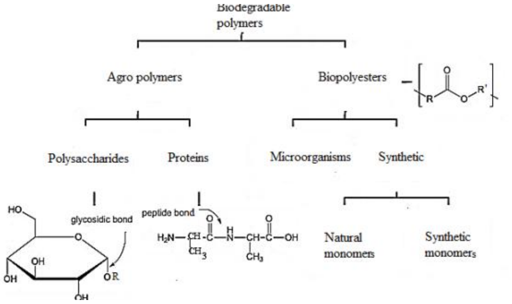

Figure 1.1: Classification of Biodegradable Polymers [2]

## III. POLYMER BLENDS

A polymer blend is a combination of two or more polymers that, when mixed, form a material with improved or altered properties. These blends have become essential in polymer science and are widely utilized to develop advanced, high-performance materials. Instead of synthesizing entirely new polymers, different existing polymers are combined to enhance the final product's functionality. Depending on the physical nature of the components, polymer blends can be categorized as thermoplastics, elastomers, plastics, and more. The blending process offers several benefits, such as improved performance, reduced costs, and adaptability. The physical or chemical compatibility between the polymers significantly influences the final material's effectiveness. Additionally, graft copolymers and block copolymers are examples of how distinct polymer chains can be linked in unique ways to create innovative materials. Overall, polymer blending is a practical, flexible approach for enhancing polymer characteristics through a relatively simple process.[32]

Polymer blends have the following characteristics:

1. Individual polymer qualities can affect the overall properties of a multicomponent system.[32]
2. It can have maxima in numerous physical and mechanical properties in the solid state as a function of blend mix.[32]
3. Miscibility state can substantially influence the mechanical,thermal and rheological properties.[32]

The following are some specific characteristics that can have an impact on the behaviors of polymer blends:

1. Effect of arrangement of polymer molecules due to forces between polymer chains.[32]
2. Size and geometry of polymer chains, including molecular weight and chain branching.[32]
3. The mechanism of polymerization determines the chain's uniformity and repeating units.[32]

## IV. STARCH SOLUTION

A starch solution can be made by first mixing starch with cold water. This forms a uniform suspension that appears milky and has a fairly thick texture. At this stage, the starch is dispersed but not dissolved. Importantly, this suspension can be safely heated without immediately clumping or setting. As you heat it slowly, the mixture becomes clearer and thicker in consistency.

If the starch-water solution is heated excessively, the starch begins to clump together in a process called flocculation. This results in a constant increase in thickness until it eventually sets into a gel. The transition from liquid to gel fits the pattern of something called lower critical solution temperature (LCST) behavior, which is typical of polymers that form a lot of hydrogen bonds with water. An example of another polymer that shows this is poly (methacrylic acid).

To turn starch into a material that can be used for packaging, it has to be transformed from its natural granular form into a soft, moldable thermoplastic. This transformation involves breaking up both the granules and their internal crystalline structure. Starches that contain a high proportion of amylose (the straight-chain form of starch) are better for this purpose because they flow more easily and are less likely to crystallize again after processing. High-amylose corn starch, which can have up to 80% amylose, is a common choice.

Before processing, the starch is mixed with water and plasticizers like alcohols of which most often used is glycerol. Water must penetrate the starch granules and form hydrogen bonds with the starch molecules. Then, during heating, the structure of the granules breaks down and the crystalline regions melt, producing a smooth, thick starch liquid.

To improve how well the starch processes and to make the final material stronger and more stable, other hydrophilic (water-attracting) polymers can be added. These might include poly (vinyl alcohol), poly (oxyethylene), poly(caprolactam), or poly(vinylpyrrolidone). When these polymers are blended in and a starch film is formed, they help stabilize the non-crystalline (amorphous) parts of the starch by bonding to it through hydrogen bonds. This helps prevent the starch from reorganizing and crystallizing again, a process known as retrogradation. Retrogradation can also be minimized by chemically modifying the starch. This is done by attaching different side groups like hydroxyethyl, hydroxypropyl, or acetoxy groups to the starch. These groups interfere with the regular structure of starch molecules, making it harder for them to pack closely and crystallize.

## V. THERMOPLASTIC STARCH

Thermoplastics are a type of polymer that pliable or flow when heated above their glass transition temperature, allowing them to be easily molded into various shapes through thermal deformation. Production involves the breakdown of starch granules and their organized molecular structures, the dissociation of starch-lipid complexes, and the melting of crystalline regions, all facilitated by the addition of water. Although starch contains some inherent moisture influenced by ambient humidity, external water is typically added to aid processing. A water content of approximately 25% by weight enables starch gelatinization within the temperature range of 60–70 °C. When moisture content is between 6–10%, mechanical shear further supports this gelatinization process.

To achieve continuous shear and thermal treatment, single-screw or twin-screw extruders are commonly used. Alternatively, batch mixers equipped with wiping action can serve the same purpose. TPS can then be formed into products such as films and pellets. As a renewable and biodegradable material that can be repeatedly melted and reshaped, thermoplastic starch represents a promising and sustainable alternative to traditional synthetic plastics.

Thermoplastic starch can be made by following synthesis:

1. Mix native starch with a plasticizer, like glycerol or sorbitol
2. Heat the mixture to a temperature above the starch's gelatinization temperature, usually between 70–90°C
3. Shear the mixture.

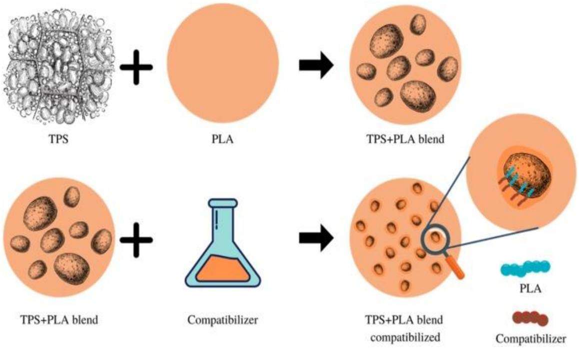

Figure 3: TPS making process [33]

## VI. THERMAL AND PHYSICAL PROPERTIES OF TPS

Thermal Properties:The thermal behavior of TPS is primarily influenced by its glass transition temperature ($T_g$), melting point, thermal stability, and heat capacity. These parameters depend on the type of starch used (e.g., corn, potato, cassava), its amylose-to-amylopectin ratio, and the presence of plasticizers like glycerol or sorbitol. TPS typically shows a low $T_g$, making it flexible at room temperature, but its thermal degradation begins at relatively low temperatures. Chemical treatments and the addition of nanofillers or other additives can enhance its thermal stability and modify its heat resistance, making it more suitable for industrial processing.

Mechanical Properties:The mechanical strength, elasticity, and toughness of TPS vary with the starch source, processing conditions (such as temperature and shear during extrusion), and the amount and type of plasticizers and reinforcing agents. TPS generally exhibits poor mechanical strength compared to synthetic polymers, but its properties can be significantly improved by incorporating natural fibers, nano clays, or other biocompatible fillers. Blending with other polymers or using cross-linking agents also enhances its structural integrity.

Barrier Properties:TPS has limited resistance to moisture and gas permeability, which restricts its application in areas that require strong barrier protection. However, the barrier properties can be improved by modifying the starch chemically (e.g., acetylation, oxidation), incorporating hydrophobic fillers, or forming multilayer structures. These enhancements help TPS better resist oxygen and water vapor transmission.

Moisture Sorption Behavior:TPS is inherently hydrophilic due to the abundance of hydroxyl groups in starch molecules. As a result, it readily absorbs moisture from the environment, which can affect its mechanical and thermal properties over time. The moisture sorption behavior is influenced by the starch source, plasticizer content, and environmental conditions such as humidity and temperature. Surface treatments and blending with hydrophobic materials can reduce moisture sensitivity.

Retrogradation of Starch:Retrogradation is a process where gelatinized starch chains, especially amylose, realign and recrystallize over time, leading to changes in texture, reduced flexibility, and increased brittleness of TPS. This phenomenon negatively impacts the shelf life and performance of TPS-based products. The rate and extent of retrogradation depend on storage conditions, starch type, and formulation. It can be controlled by modifying the processing parameters and using appropriate additives to inhibit recrystallization.

Surface Tension and Morphology:The adhesion, coating, and wettability characteristics of TPS are influenced by surface tension. It plays a crucial role in film formation and interface behavior when TPS is used in composites or multilayered materials. Surface tension is affected by the chemical composition of the starch, the type and concentration of plasticizers, and any surface treatments applied. A smoother surface morphology with controlled surface energy can improve the functional properties of TPS films and coatings.

Influencing Factors:The properties of TPS are governed by a combination of factors including:

1. Starch Source: Different botanical sources lead to different structural and functional properties.
2. Additives: Plasticizers, fillers, cross-linkers, and compatibilizers significantly alter the thermal and mechanical behavior.
3. Processing Parameters: Extrusion temperature, mixing speed, and cooling rate can all influence TPS structure and performance.
4. Chemical Modification: Acetylation, grafting, and oxidation of starch molecules can enhance TPS stability and functionality.

## VII. TESTING METHODS FOR TPS MATERIAL

These include thermal analysis (DSC, TGA), mechanical testing (tensile, flexural), spectroscopic methods (FTIR, NMR), and microscopy (SEM, TEM), all of which are also suitable for evaluating TPS materials.

1)Thermal analysis method:

The changes that take place when starch and water mixtures are heated can be tracked using a technique called differential scanning calorimetry (DSC). This method uses sealed pans that are completely filled and specially designed to handle the pressure that builds up in the sample as high as 30 bar. Figure 1 displays examples of the heat absorption (endothermic) events observed in potato starch samples with two different levels of water.[11]

When there's more water in the sample, the endothermic peak happens below 100 °C. This peak is typical of the gelatinization process, which is common in traditional starch processing. During this process, starch granules absorb water, swell, and break down structurally. As a result, amylose, a component of starch that leaks out of the granules through diffusion. In contrast, the sample with less water shows a different kind of endothermic peak, which is associated with what's known as melt formation. This process involves breaking down the crystalline structures of amylopectin (another starch component) and disrupting the molecular order inside the granule. Unlike gelatinization, this transformation happens without water moving into the granule in large amounts. At a water content of 12%, there are only about 1.2 water molecules available for each anhydroglucose unit in the starch. This limited amount of water explains why typical gelatinization doesn't occur in such samples. Interestingly, a similar pattern wherein the temperature at which structural breakdown occurs depends on the amount of water is also seen in gelatin–water mixtures.[11]

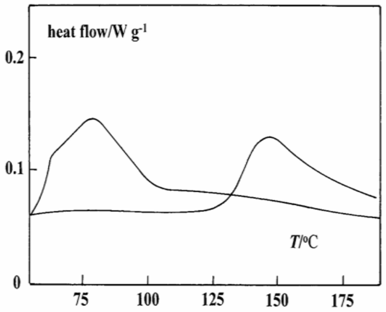

Figure 4: Examples of DSC endotherms for a potato starch at 42% and 12% water content(=100$W_{H2O}$/$W_{H2O}$+$W_{starch}$) (Reference:[11])

The temperature range and the size of the endothermic peak linked to melt formation in starch–water mixtures are influenced by both the type of starch and the specific batch used. Even small differences, such as trace amounts of metallic ions in potato starch, can shift the temperature range at which these thermal changes happen. As a result, the conditions needed for processing can also change. Typically, to fully break down the starch structure and create a uniform melt, the mixture must be heated above the temperature range where the endothermic event occurs.[11]

Molecular Changes in Starch–Water Mixtures During Heating:

Figures 5 and 6 demonstrate how the molecular structure of potato starch–water mixtures changes when they are heated in sealed glass ampoules at temperatures between 140 °C and 160 °C for varying periods of time. Over time, as the mixture is heated, hydrolysis causes a drop in the molar mass of the starch molecules, the longer the heating, the more the molecular size decreases.

In Figure 5, the data is shown in the form of a Mark–Houwink plot, which is a logarithmic graph comparing intrinsic viscosity with the mass-average molar mass ($M_w$). These values are obtained using Rayleigh light scattering. The slope of this plot, known as the Mark–Houwink exponent, is found to be 0.39, a relatively low number. This is because the hydrodynamic behavior of the starch solution is strongly influenced by amylopectin, which has a highly branched molecular structure. The intrinsic viscosity measured in the native (unheated) starch was approximately 280 $cm^3$ per gram. This value corresponds to a mass-average molar mass greater than $10^8$ grams per mole, indicating the presence of extremely large molecules before any thermal breakdown occurs.[11]

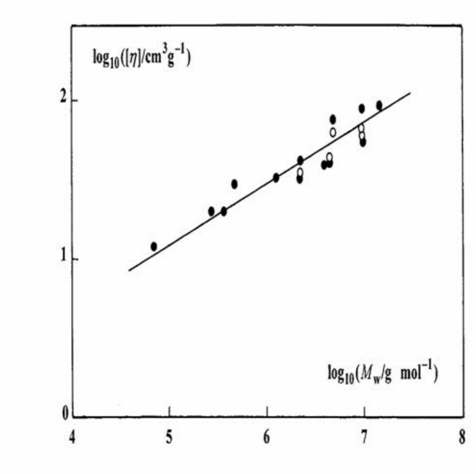

Figure 5: log10[Efficiency] versus log10$M_W$ (Mark-Houwink plot) for hydrolysed potato starches. [Efficiency] measured in dimethyl sulfoxide at 40 °C; O [17] measured in dimethyl sulfoxide / 6M urea at 40 °C; $M_w$ measured in dimethyl sulfoxide. Least-squares line gives $7/cm^3 g^1 = 0.23(M_w/g\ mol^1)^{0.39}$ Reference:[11]

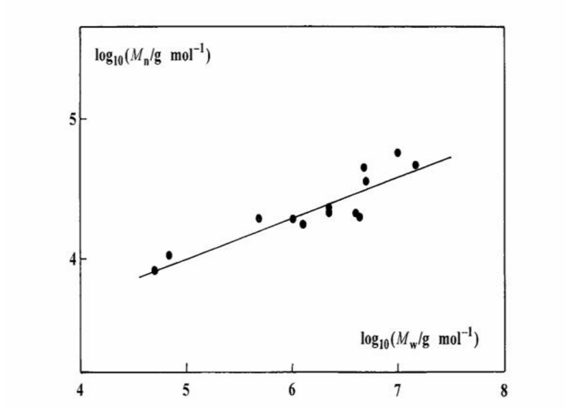

Figure 6:log10M, versus log10Mw for for hydrolysed potato starches. Least-squares line gives $M_{\{n\}}$ / g * mol$^{-1}$ = 405 * ($M_{\{w\}}$ / g * mol - $^1$) $^{0.28}$ Reference:[11]

Figure 6 presents a logarithmic graph showing how the number-average molar mass (Mn) varies in relation to the mass-average molar mass (Mw). The Mn values were obtained by measuring how many reducing end-groups were present per unit of sample mass. Since each starch molecule has just one reducing end-group, the total number of these groups is equal to the number of molecules in the sample. As a result, Mn in grams per mole can be calculated by dividing the dry mass of the sample by the number of moles of reducing end-groups:

Mn (g/mol) = (dry mass of sample) / (moles of reducing end-groups)

From the graph, it's observed that $M_n$ is approximately proportional to M raised to the power of 0.28 ($M_n \propto M_w{}^{0.28}$). This shows that as hydrolysis progresses, the polydispersity of the starch molecules decreases rapidly. In other words, the ratio of Mw to $M_n$ gets smaller because $M_w$ drops faster than $M_n$. At the upper end of the molar mass range shown in Figure 3, $M_w$ is about $1.5 \times 10^7$ g/mol, and the corresponding $M_w/M_n$ ratio is roughly 300. On the lower end, Mw is around $5 \times 10^4$ g/mol, and the ratio $M_w/M_n$ is down to about 6.2. This steep decline in the $M_w/M_n$ ratio indicates a significant drop in polydispersity, which is the spread in molecular sizes within a sample. This trend fits with the behavior expected from random chain scission during hydrolysis, where larger molecules are more prone to being broken apart. As a result, the average molecular size ($M_w$) decreases more quickly than the number of molecules ($M_n$), since breaking a big molecule in half greatly affects Mw but less so $M_n$.

When it comes to producing thermoplastic starch products (TSPs) by injection moulding, good mechanical properties are typically achieved when the Mw falls within the range of $10^6$ to $10^7$ g/mol. According to Figure 6, within this $M_w$ range, the $M_w/M_n$ ratio is generally between 100 and 300, which is considered acceptable for maintaining suitable material performance.[11]

2) Microscopic Methods:

1. SEM (Scanning Electron Microscopy)

SEM provides high-resolution, 3D-like images of the surface of TPS samples. It helps to observe the morphology, granule structure, surface cracks, and dispersion of additives or plasticizers. In blends (e.g., TPS with PCL or PLA), SEM can show how well the two materials are mixed.

2. TEM (Transmission Electron Microscopy)

TEM provides ultra-high-resolution images of the internal microstructure at the nanometer scale. It's used to examine crystallinity, phase separation, and molecular-level dispersion of starch and additives.A TEM analysis shows amorphous and crystalline regions within TPS or how nanoparticles (e.g. nano clays or cellulose nanocrystals) are dispersed inside the starch matrix, influencing strength or barrier properties.

3) Mechanical Testing of Thermoplastic Starch (TPS) involves evaluating its strength and deformation behavior under different types of forces. Two common mechanical tests are tensile and flexural tests [16]

1. Tensile Testing:

This test measures how the material behaves when pulled apart.

1. Tensile strength (maximum stress before breaking)
2. Elongation at break (how much it stretches)
3. Young's modulus (stiffness)

For example:A TPS film is clamped in a tensile testing machine and pulled at a constant rate until it breaks. Suppose it breaks at 15 MPa and stretches 30% then this gives an idea of its strength and flexibility.

2. Flexural Testing:

This test measures how the material bends under a load.

1. Flexural strength (resistance to bending)
2. Flexural modulus (stiffness during bending)

4) Thermoplastic starch (TPS) is a biodegradable polymer made by plasticizing starch (usually with water and glycerol). Spectroscopic methods like FTIR and NMR are used to analyze its structure, interactions, and chemical modifications [14]

1. FTIR (Fourier Transform Infrared Spectroscopy)

It identifies functional groups and hydrogen bonding in TPS. By measuring the absorption of infrared light by molecular vibrations, FTIR detects changes in OH (hydroxyl) stretching due to plasticizer interactions.

2. NMR (Nuclear Magnetic Resonance Spectroscopy)

NMR gives detailed information about molecular structure and dynamics. It detects the environment of hydrogen ($^1$H NMR) or carbon atoms ($^{13}$C NMR) and identifies glycerol-starch interactions and possible chemical modifications like esterification or crosslinking.[34]

Example:

In $^1$H NMR, new peaks or shifts in the chemical shift of glycerol's hydrogen atoms (around 3.5–4.0 ppm) can indicate interaction with starch chains.[34]

## VIII. COMMON TPS MATERIAL EXAMPLES

1. Pure TPS (Starch + Plasticizer, usually glycerol) [18]
   1. Composition: Starch (corn, potato, etc.) + Glycerol or sorbitol
   2. Use: Agricultural mulch films, disposable packaging
   3. Features: Biodegradable, hydrophilic (absorbs moisture), low mechanical strength unless blended
2. TPS/PLA Blends (Polylactic Acid) [18]
   1. Use: Food packaging, disposable cutlery, compostable bags
   2. Features: Improved mechanical properties and water resistance compared to pure TPS
3. TPS/PBAT Blends (Polybutylene adipate terephthalate) [18]
   1. Use: Compostable bags, films
   2. Features: Flexibility, tear resistance, and biodegradability. This is ideal for thin films.
4. TPS/PCL Blends (Polycaprolactone) [18]
   1. Use: Biodegradable films, drug delivery systems
   2. Features: Enhanced flexibility, low-temperature processability
5. TPS/Polyester Blends [18]
   1. Use: Biodegradable packaging, injection-molded products

2. Features: Stronger and more water resistant than pure TPS

## VIII. BIODEGRADABLE POLYMER BLENDS

Biodegradable Polymer Blends aim to improve the performance and environmental friendliness of the final product. They can break down naturally in the environment through the action of microorganisms, moisture, and enzymes. Common biodegradable polymers include polylactic acid (PLA), polyhydroxyalkanoates (PHA), and starch-based polymers. [35] Blending helps overcome limitations of individual polymers, such as brittleness or low thermal resistance. For example, PLA is often blended with PHA or thermoplastic starch to enhance flexibility and toughness. Compatibilizers may be added to improve the interaction between different polymers. Factors such as temperature, moisture, pH, and microbial activity influence the degradation rate of the blends. [36] Applications of biodegradable polymer blends include packaging, agricultural films, medical implants, and disposable items. As demand for sustainable materials grows, biodegradable polymer blends continue to be a focus of research and innovation.

## IX. BIODEGRADABLE POLYMER BLENDS FROM THERMOPLASTIC STARCH

1) TPS/PP blends

The properties of TPS/PP (thermoplastic starch/polypropylene) polymer blends containing glycerol as a plasticizer, with the blends prepared separately using a single screw extruder. These blends displayed shear thinning behavior, which made them easier to process with traditional machines, as their viscosity decreased with increasing shear rates. Glycerol played a lubrication role between the material and the capillary rheometer die, reducing viscosity as its content in the blend increased. The mechanical properties showed that as both TPS and glycerol content increased, the Young's modulus (stiffness) increased sharply, but the strain at break (ductility) decreased, making the material more brittle. When comparing the effects of biodiesel-derived glycerol and commercial glycerol, the results were nearly identical, indicating that either source can be used for plasticization without significant differences in the blend's performance.[39]

For enhancing the mechanical properties,montmorillonite clays (MMT) and Cloisite 30B, an organically modified MMT, were added. The unmodified MMT primarily stayed in the TPS phase due to its affinity for TPS and ability to form hydrogen bonds, while the modified Cloisite 30B was dispersed both in the TPS phase and at the interface between TPS and PP, improving the blend's mechanical properties, especially in those with high TPS content. [39]

2) TPS/PS blends

The thermal degradation of blends containing TPS (thermoplastic starch) plasticized with either glycerol or buriti oil and polystyrene (PS). The findings revealed that the blend with buriti oil-plasticized TPS had better thermal stability than the one plasticized with glycerol. However, biodegradability tests showed that the buriti oil-plasticized blend was more biodegradable compared to the glycerol-plasticized blend. Buriti oil was also used to prepare TPS and PS waste blends, which exhibited good dispersion of TPS within the PS matrix, creating distinct domains, but had poorer thermal stability than pure PS. The study also investigated that the interfacial adhesion between glycerol-plasticized TPS and PS, which was treated with maleic anhydride (MA) during melt mixing.The effect of increasing TPS content on the degradation behaviour was examined using a soil burial test, where weight loss was measured. It was found that higher TPS content led to greater weight loss, which was attributed to the role of the TPS phase in facilitating bacterial growth during the degradation process.[39]

3) TPS/ABS blends

This focused on the preparation and properties of TPS/ABS (thermoplastic starch/acrylonitrile butadiene styrene) blends, where glycerol was used to plasticize the TPS before blending it with ABS using a single screw extruder. The rheological and mechanical properties of the blends were evaluated, revealing that the TPS/ABS blends exhibited shear-thinning behavior, meaning their viscosity decreased as the shear rate increased. Additionally, the viscosity of the blend dropped as the glycerol content increased, suggesting that the material could be processed effectively through injection molding. However, the mechanical properties of the blend, including stress at break and ductility, were poor across various compositions, pointing to an incompatibility between the TPS and ABS components in the blend.[39]

## X. APPLICATIONS OF BIODEGRADABLE THERMOPLASTIC STARCH

### 1) TPS/PP Blends

Thermoplastic starch (TPS) and polypropylene (PP) biodegradable blends have potential applications in a variety of industries due to their biodegradability and renewable content. Some common applications include:

1. Packaging: TPS/PP blends can be used to create environmentally friendly packaging materials, such as biodegradable bags, films, and containers, providing an alternative to traditional petroleum-based plastics.[27]
2. Agricultural Films: These blends can be used for producing biodegradable mulch films or agricultural covers, which break down naturally over time, reducing waste in agricultural environments.[28]
3. Disposable Products: The blends are suitable for manufacturing disposable items like cutlery, plates, and cups that are both biodegradable and renewable, offering an eco-friendly alternative to single-use plastics.[29]
4. Automotive Parts: Due to their strength and moldability, TPS/PP blends are being explored for use in non-structural automotive components, such as interior panels and insulation materials.[28]
5. Consumer Goods: Items such as biodegradable packaging for food, toys, and various consumer goods can be made from TPS/PP blends, aligning with sustainability goals in product design.[30]
6. Biomedical Applications: These blends can be used in medical products, such as wound dressings or biodegradable surgical sutures, benef;iting from their biocompatibility and biodegradability.[28]

By combining the renewable and biodegradable nature of TPS with the durability and processing ease of PP, these blends offer a versatile, environmentally friendly solution across numerous industries.

### 2) TPS/PS Blends

Thermoplastic starch (TPS) and polystyrene (PS) biodegradable polymer blends have gained attention due to their potential to combine the biodegradability of starch with the desirable properties of PS, such as rigidity and ease of processing. These blends are being explored for various applications, including:

1. Packaging: TPS/PS blends are ideal for creating biodegradable packaging materials, such as containers, trays, and films. These materials offer an eco-friendlier alternative to traditional PS packaging, helping reduce plastic waste.[27]
2. Disposable Products: The blends can be used in manufacturing disposable cutlery, plates, cups, and other single-use items. These products offer the convenience of disposable plastics but with the added benefit of being biodegradable.[29]
3. Agricultural Films: The blends can be used for creating biodegradable mulch films or agricultural covers, which are designed to degrade naturally after use, reducing the environmental impact compared to traditional plastic films.[28]
4. Foam Products: TPS/PS blends are used to create biodegradable foam products, such as packaging materials (like foam peanuts or trays), offering a sustainable alternative to petroleum-based foams.[30]
5. Consumer Goods: These blends are also suitable for producing biodegradable toys, disposable cosmetic containers, and other consumer products that require rigidity and durability while still being biodegradable.[30]
6. Biomedical Applications: With some modifications, TPS/PS blends can be used in biomedical products such as biodegradable wound dressings or controlled drug delivery systems, where biodegradability and biocompatibility are important.[28]
7. Automotive Components: In non-structural parts, such as interior panels, door trims, or insulation, these blends can be used in automotive manufacturing, contributing to sustainability in the industry.[30]

By combining the biodegradability of TPS with the processing advantages of PS, TPS/PS blends offer a promising solution for creating environmentally friendly products without sacrificing functionality and performance.

### 3) TPS/ABS Blends

Thermoplastic starch (TPS) and acrylonitrile butadiene styrene (ABS) biodegradable polymer blends have applications in industries looking for sustainable materials with the rigidity and impact resistance of ABS and the biodegradability of TPS. Some potential applications for TPS/ABS biodegradable blends include:

1. Packaging: These blends can be used to create biodegradable packaging materials, such as containers, trays, and films, offering a sustainable alternative to traditional ABS-based packaging that can contribute to environmental waste.[35]
2. Disposable Products: TPS/ABS blends are ideal for disposable products like cutlery, plates, cups, and straws. By combining ABS's strength with the biodegradability of TPS, these products can offer performance similar to traditional plastics but with the added environmental benefit of biodegradability.[37]
3. Consumer Goods: These blends can be used in the production of biodegradable consumer goods such as toys, household items, or electronic casings, where a balance of strength, rigidity, and biodegradability is desirable.[38]
4. Agricultural Films: TPS/ABS blends can also be used to produce biodegradable mulch films or agricultural covers, providing an environmentally friendly alternative to traditional plastic agricultural films that need to degrade after use.[36]
5. Automotive Components: TPS/ABS blends can be used in the production of automotive parts, particularly non-structural components like interior panels or insulation materials, offering a sustainable option for reducing plastic waste in the automotive industry.[38]
6. Biomedical Products: These blends can be explored in the field of biomedical applications such as biodegradable medical devices or wound dressings, where the biodegradability of TPS and the durability of ABS can be advantageous.[36]

By combining the strengths of ABS, such as rigidity, strength, and impact resistance, with the renewable and biodegradable nature of TPS, these blends offer versatile and sustainable alternatives for a wide range of applications.

## XI. CONCLUSION

The increasing global focus on environmental sustainability has led to heightened interest in biodegradable polymers, with thermoplastic starch (TPS) blends gaining significant attention. Unlike traditional synthetic plastics, TPS offers the advantage of being derived from renewable resources and is readily biodegradable. However, its inherent limitations, such as brittleness and poor moisture resistance, have been addressed through polymer blending. Blends such as TPS/PP, TPS/PS, and TPS/ABS demonstrate improved mechanical, thermal, and barrier properties while maintaining a degree of biodegradability. These composites capitalize on the complementary strengths of individual polymers, resulting in materials suitable for a wide range of applications, including packaging, agriculture, and consumer goods. Therefore, blends must be carefully designed to maintain biodegradability without compromising performance. Testing standards ensure that these materials degrade within specific timeframes under controlled conditions. As industries worldwide transition toward eco-friendly alternatives, TPS-based blends represent a viable and sustainable solution to reduce plastic waste and dependence on petroleum-based polymers.

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