

DEVELOPMENT AND CHARACTERIZATION OF BIODEGRADABLE BIOPLASTIC FILMS FROM STARCH

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1. ABSTRACT:-

The main aim of this project is creating sustainable, cost effective and eco-friendly alternative to conventional plastics. Starch, is an inexpensive, and regenerative biopolymer, This abstract summarizes the production and applications of starch-based biodegradable films. This production takes place by the solution casting or extrusion method, in which starch get gelatinized in presence of water and other plasticizer, such as glycerol which enhance flexibility. Characterization involves mechanical properties such as tensile strength, barrier properties such as solubility thermal stability the biodegradability of these films is confirmed through methods like soil burial tests With continued observation of starch-based biodegradable films are eco-friendly substitutes for traditional plastics and having various applications such as food packing, agriculture films, medicine and disposable consumer goods. Further research is required for its commercialization.

Keywords:- Biodegradable, film, polymer, bioplastic.

2. OBJECTIVE:-

1. Enhance the poor mechanical strength of starch-based biodegradable materials.
2. Improve the water stability of starch-based biodegradable materials.
3. Identify the high moisture sensitivity of starch-based materials.
4. Enhance the poor barrier property which result from strong hydrophilic behaviour.
5. Mitigate the behaviour of starch-based materials at a room temperature.
6. Minimize the high moisture content of starch-based biodegradable materials.
7. Improve the mechanical and barrier properties of starch by using nanoscale particles.
8. Montmorillonite (MMT) which is Nano-clay as a nanoscale filler which improve the property of a starch matrix for applications like food packaging.

3. INTRODUCTION:-

3.1 THE SHIFT TO BIODEGRADABLE PLASTICS AND THE PROMINENCE OF STARCH:

Modern society of consumer depend on plastics which obtained mainly from non-renewable sources, which may leads to significant environmental issues because of their nature and the large volume of solid waste generated. Biodegradable plastics offer solution by reducing environmental effect and provide waste disposal. They are inexpensive and composed of readily available, inexpensive natural polymers like cellulose and starch that were obtained from renewable biomass, such as rice, corn, potatoes, sugar cane, and agricultural waste.

3.2 ESSENTIAL FEATURES AND MARKET POSITION:

* **Degradation:** These are the materials which undergo organic degradation by naturally occurring microorganisms in environments, converting into biomass energy and make water without toxic residues

* **Market Share:** Although bioplastics have account for only about 1% of the global plastic production which is around 300 million tons annually. the market size is improving, with total co is approximately 2.44 million tons in 2022.

* **Starch Importance:** Approximately 50% of commercially used bioplastics are starch-based, with starch Know as a material due to its complete biodegradability, availability, and renewable potential. Starch from sources like cassava, potato, maize, etc. biodegradable plastic potato, starch, and sago starch is widely used, particularly for packaging applications.

3.3 DEFINITION OF BIOPLASTIC:

Many researchers definition of bioplastic if it is either bio-based, biodegradable, or possesses both characteristics of this. It can also be described as polymers that can decompose into CO₂, H₂O, and other inorganic substances or biomass.

The term bio-based indicates products sourced from biological ingredients derived from biomass or natural sources. This implies that “bio-based” refers to materials or products that are wholly or partially crafted from renewable resources. In conventional plastics, petrochemical resins are get substituted with polymers from animal or plant sources, and carbon fibre are replaced with natural fibres such as wood hemp, flax, sisal, and jute.

3.4 DEFINITION OF BIODEGRADABLE:

Polymeric materials that are "capable of undergoing decomposition into carbon dioxide, methane, water, inorganic compounds, or biomass in which the predominant mechanism is the enzymatic action of microorganisms, that can be measured by standardised tests, in a specified period of time, reflecting available disposal condition" are referred to as biodegradable polymers (BDPs) or biodegradable plastics (ASTM standard D6813). A In terms of their biodegradation in a compost system, a subset of BDPs may also be compostable; these must show that they are "capable of undergoing biological decomposition in a compost site as part of an available program.”

3.5 ADVANTAGES:

• **Lowering Carbon Emissions:** They have the capacity to lower carbon emissions. During their growth, plant raw materials absorb CO₂, which reduces greenhouse gas emissions. Utilising plant-based materials lowers carbon emissions associated with production and lessens dependency on finite fossil resources. Compared to conventional plastics, studies indicate a possible 25% decrease in carbon dioxide emissions.

- **Improving Food Safety:** Because they are made of natural ingredients, there is less chance of chemical contamination. Compared to conventional petroleum-based packaging, they are less likely to leak hazardous chemicals into food, particularly at high temperatures.
- **Adopting Environmental Responsibility:** Using bioplastic packaging reduces a company's environmental impact. It conveys a dedication to global sustainability initiatives and environmental responsibility.
- **Improving Brand Image and Reputation:** Using bioplastic packaging can improve a company's reputation and brand image among consumers who care about the environment. It can strengthen a brand's emotional bond with customers and help it stand out from rivals.
- **Potential Cost Savings:** Compared to petroleum-based polymers, production costs are less dependent on the erratic oil market. Future technological advancements and economies of scale will probably result in lower costs, particularly for bioplastics derived from food and industrial waste.
- **Gaining Regulatory Advantages:** As regulations become more environmentally conscious, companies that utilise bioplastics may be eligible for regulatory incentives or be spared future fines related to the usage of conventional plastics.
- **Indirect Support for Food Safety (via Decreased Pollution):** Because bioplastics are made from renewable resources like corn or sugar cane, they may indirectly support food safety by reducing the pollution that oil drilling and petroleum refining contribute to the water and soil.
- **Manufacturing Process Differentiation:** Bioplastics and conventional plastics are produced using quite different materials.

3.6 DISADVANTAGES:

- **Cost:** Bioplastics are typically thought to be twice as costly as regular plastics.
- **Recycling Contamination:** Bioplastics may contaminate the recycling process if they are not separated from regular plastics (for example, they cannot be separated using infrared rays in a garbage separation system).
- **Pollution and Littering:** Inappropriate and uncontrolled dumping leads to pollution of the soil and water.
- **Harm to Wildlife:** Just like ordinary trash, bioplastic waste littering has serious negative consequences on wildlife.
- **Greenhouse Gas Emissions (Landfills):** When bioplastic trash is dumped in landfills, it may add to the emissions.
- **Shorter Lifespan/Poor Mechanical Properties:** Some bioplastics have a shorter lifespan than oil-based polymers because they are more permeable to water vapour than regular plastic. Being as simple to tear as tissue paper. Being incredibly fragile. (For instance, some bioplastics made from algae decompose in the water in a matter of hours, rendering them brittle).
- **Dependency on Farming Resources:** Crop-based bioplastics are weather-dependent and require fertile soil, water, and fertiliser.
- **Supply Chain Vulnerability:** Natural disasters like drought may put the supply of raw ingredients for bioplastics at risk.
- **Misunderstanding of "Compostable" Terminology:** Bioplastics cannot be composted at home and, like organic food waste, must be processed in an industrial composting facility, which isn't always available.
- **Lack of Law and Regulation:** There are no rules governing the production of bioplastics. Several countries have not yet enacted laws governing the production, usage, or disposal of waste, despite the fact that production rose to over 6.7 million tonnes by 2019.

3.7 APPLICATIONS:

A. Food Packaging

The objectives are to avoid decomposition, maintain nutrition, extend the shelf life of both short- and long-shelf-life products, and make transportation easier. Use: Packaging for products that don't need much air or water. Materials:

Stock films (such modified environment packing) for harsher or commercial environments. The most popular bioplastic is polylactic acid, or PLA.



Fig No 3.6.1

B. Medical

Benefit: Promising, less expensive substitutes for traditional polymers. **Applications:** (Polyhydroxyalkanoates): Used for several medical devices, such as nerve, tendon, and hernia repair. PHB (polyhydroxybutyrate): Used in a variety of tissue/cell engineering procedures (plates, bones, nerve cuffs, patches, blood vessel replacement, medication administration) and surgical instruments (staples, pins, sutures). Other applications include the use of flax bandages for cell proliferation, composites containing nanoparticles for nanotechnology, biomedical engineering, and life sciences, as well as dental implants and containers used in the cosmetics industry. **Approval:** The European Medicines Agency and the U.S. FDA have authorised poly (lactic-co-glycolic acid).

C. Agriculture

Market Share: The utilisation of PLA and starch polymers in the commercial sector is 47% and 41%, respectively. **Products:** Horticultural and agricultural mulches and biodegradable seed tapes. **Features:** **Mulch films:** Supply moisture, regulate soil temperature, and stop the growth of weeds. **On mushroom fields, nets and foils are used to optimise the growth environment and quality.** **Yarns:** To stop soil erosion, cover slopes. **Soleplate mulching films:** Used in horticulture for banana bushes and vineyards. **Additional Uses:** 100% biodegradable PLA golf t-shirts and biodegradable burial pods.



Fig No.3.6

3.8 TYPES OF BIOPLASTICS:

A. Starch-based Bioplastics

Source: Starch is made from a range of agricultural products, such as corn, potatoes, wheat, rice, and sorghum. **Composition:** These are complex blends of starch and biodegradable polymeric materials like polycaprolactone (PCL), polylactic acid (PLA), and polyhydroxyalkanoates (PHAs). **Properties:** The blending process enhances the bioplastics' mechanical, thermal, and water-resistant properties.

B. Cellulose-based Bioplastics

Source: Cellulose is made from plant materials like weeds, wood pulp, bamboo, agricultural waste, and forest resources. Cellulose propionate, cellulose butyrate, cellulose nitrates, and cellulose acetate are among the esters that make up its composition. Properties & Use: They create water-resistant, gas-permeable, and mechanically strong bioplastics when mixed with starches. They can be converted into thermoplastics for use in packaging.

C. Protein-based Bioplastics

Source: Derived from high-protein sources including wheat gluten, casein, albumin, whey, and soya.

Properties: Albumin and whey bioplastics show similar thermal and viscoelastic properties. Soy bioplastics have modified viscoelastic properties and are water-sensitive.

D. Aliphatic Polyesters

Production: Mostly produced by natural bacterial fermentation of inexpensive carbon sources (such as molasses, sugar, oils, and methane). PHAs, poly (3-hydroxybutyrates (PHBs), PLAs, PCL, and polyglycolic acid (PGA) are among its constituents. Important types include linear polyesters and excellent substitutes for traditional plastics. PHBs: Made by stressed bacteria, they are 100% biodegradable but cost 20% to 100% more to produce than regular plastic. Like petrochemical mass polymers, PLA is thermoplastic and viscous, and it can be recycled without losing its mechanical qualities.

E. Polyamides

Production: Comes from the condensation of dibasic acids (like acid) and diamines. Production reduces the use of natural resources and greenhouse gas emissions. Properties and Uses: demonstrate exceptional resilience to heat. Polyamide 6 and 66 are often utilised types. They are used in high-performance applications including gas pipes, catheters and fuel lines in cars.

F. Polyethylene (Bio-based)

Source: The same as conventional polyethylene, but its constituent ethylene is derived from ethanol that is fermented from agricultural feedstock (such as corn or sugarcane). Properties: It is recyclable but not biodegradable like polyamides.

G. Lipid Polymers Synthesis:

It is .made from the triglycerides of lipid sources sourced from plants and animals, such as sunflower, palm, castor, and soybean oils. For Commercial Use: comprises lipid bioplastics such as epoxy resins, polyurethanes, and PHAs.

3.9 CLASSIFICATION OF BIODEGRADABLE POLYMERS OR BIOPLASTICS:

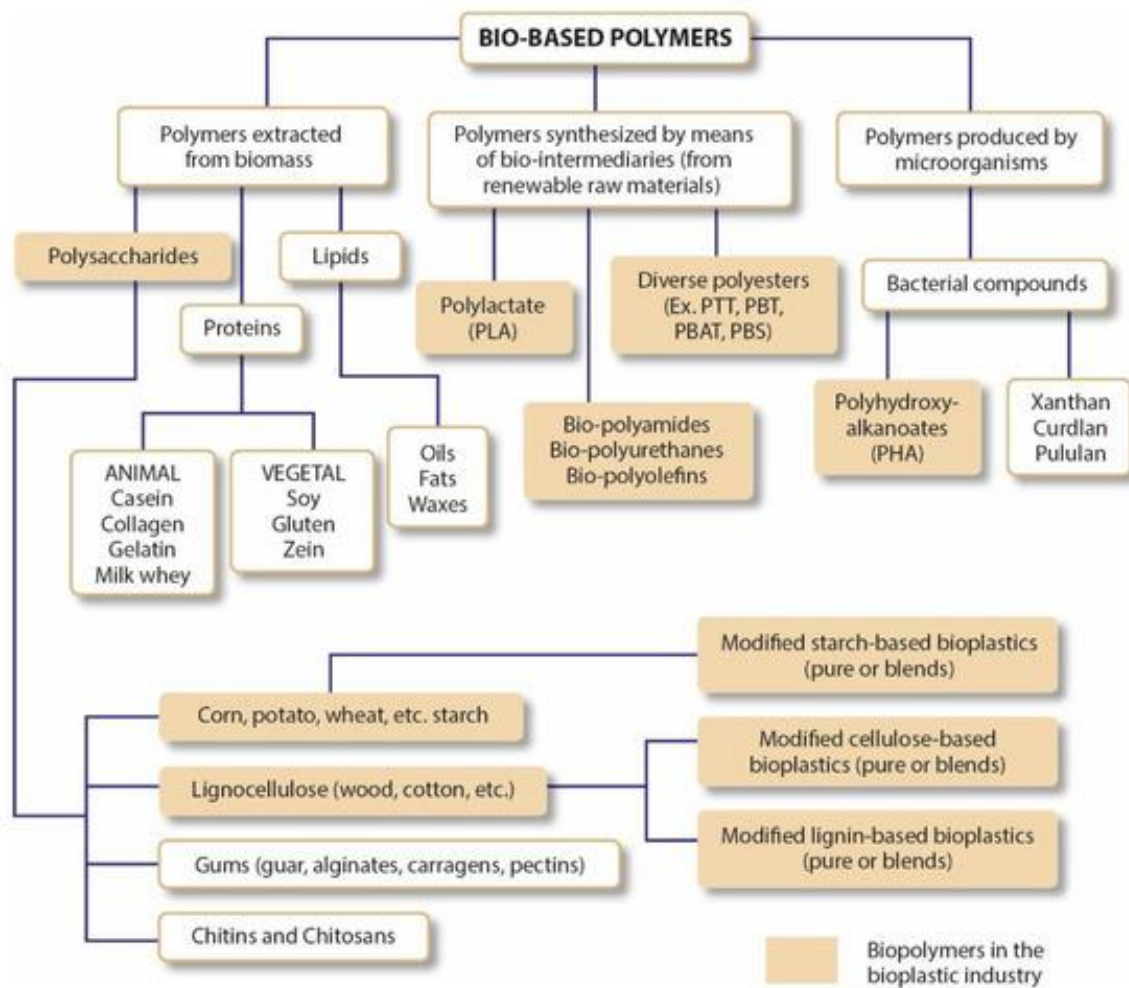


Fig No.3.8.1 classification of biodegradable bioplastic

3.10 METHODS FOR PREPARATION:

1. Extrusion Techniques:

• Co-extrusion Technique:

Intended to use more than two extruders feeding a single die to create multilayer films. The quantity of various materials and layers determines how many extruders are needed. For the two outer layers of a three-layer co-extrusion with a barrier core, only two extruders are needed. Complete and seamless melt flow is guaranteed by a high-quality film extrusion die. Die heaters and autonomously regulated heating zones make up the majority of dies.

• Blown Film Extrusion:

The melt is extruded through a circular die after entering a round die through the bottom and passing through spiral grooves surrounding the mandrel inside the die. Melt distribution is improved by adding more spiral grooves. The majority of blown film dies for polyethylene are positioned vertically to extrude downward while pushing the tube upward. Usually, the distance between the die ring and the mandrel is between 0.5 and 3 mm. The mandrel can be

moved lengthwise to alter the die opening. Although a broader ring produces more, its uneven flow may pose problems with the gauge and frost line.

• Cast Film and Blown Film Extrusion (General):

Currently, biodegradable packaging is made using both techniques. Process: To create a thin sheet or tube, resin is melted using heat and pressure inside the barrel of an extruder. The melt is then forced through a narrow slit in a die, either straight or round. After cooling, the resultant film is rolled up. Film qualities are directly impacted by temperature, cooling, screw speed, gauge control, and blow-up ratio. Temperature: Compared to blown film extrusion, barrel heat in cast film extrusion is often higher. The melt temperature must be consistent across the die's breadth. One important machine factor is screw speed, which is expressed in RPM. Increased speed reduces the requirement for external heating by increasing internal heat and output. Gauge Control: Thin film forming generally requires large die openings (around 20 mils or 0.5) The hopper must be kept completely full of resin during operation.

2. Solvent Casting Method (SCM)

Nature: A traditional, popular, and lab-scale method, also industrially applicable, often used for biopolymer-based films with exceptionally high-quality requirements.

Key Fundamentals: Bio-polymer is properly dissolved in a volatile solution. A viscous solution with minimum solid content is obtained after homogenization. The film must easily release from the casting support.

Advantages: Uniform thickness distribution, high optical density, and provides better quality than extrusion.

Disadvantages: Long drying time, film shrinkage after drying, brittleness, non-uniform drug distribution, and challenging storage conditions. The "rippling effect" (due to shear stress and lack of homogeneity) and bubble formation ("nucleate boiling") from over-drying are common drawbacks. Mitigation: Plasticizers can be added to reduce cohesive intermolecular forces, resulting in reduced tensile strength and induced flexibility.

3. Electrospinning or Electrodynamic Method

Nature: A recently used industrial method that depends on a number of variables, including temperature, voltage, flow velocity, concentration, viscosity, distances, and needle diameter. Method: A syringe needle is used to apply high electric charges to the polymer solution. As the electric field increases, the charges cause the solution to take on the shape of Taylor's cone. A collector gathers the emerging ultrafine nanofibers. Surface tension is opposed by a reciprocal repulsion force, which permits the solution to move in the direction of the electric field. Benefits: A maximal number of inter/intra fibre holes and an extreme surface area to volume ratio make it more advantageous than solvent casting. Properties: Compared to solvent casting, the obtained film has higher qualities, such as a smooth surface, increased flexibility, viscoelastic behaviour, and moderate strength. A drawback is that it takes a long time (more than 24 hours, including drying).

4. Phase Immersion Casting Technique

Use: Introduced primarily for the formation of biofilms and coatings. Process: Precipitation results from the molecular interchange of solvent and non-solvent components, which turns the liquid polymer/solvent solution into a solid state. We refer to this phenomena as "liquid-liquid demixing." Control: The properties of the solid film are greatly influenced by liquid-liquid demixing variables, which provide control over the porosity of the film. Benefits include low energy costs, quick film creation, simplicity of use, and promising future scale-up.

5. Layer-by-Layer Assembly Techniques

Based on several factors, including non-hydrophilic attraction, H-H bonds, covalent bonds, molecular entanglements, and electrostatic interactions. This procedure involves the successive deposition of film-forming materials onto a surface. The most popular method is electrostatic interaction between positive and negative layers. A negatively charged substrate, for example, is immersed in a positively charged solution. After removing the excess solution, the next layer is formed by immersing the now positively charged substrate in a negatively charged solution. This method is repeated in the film's construction. Benefits: Films with altered physiochemical and structural characteristics (thickness, strength) can be produced by selecting different materials and layer counts. It is easy, inexpensive, and doesn't call for any specialised equipment.

4. MATERIAL AND METHODS:-

4.1 REQUIREMENTS:

Chemicals-

1. Distilled water
2. Starch
3. Acetic acid
4. Glycerine

Apparatus-

1. Beaker
2. Glass rod
3. Water bath
4. Hot air oven
5. Petri plate

4.2 MATERIAL AND IT'S ROLE:

4.2.1 Starch (Base Polymer):

Principal Function: Serves as the main polymer matrix and film-forming agent. This fundamental component provides the structure of the bioplastic. Function: The crystalline structure of starch, which is composed of amylose and amylopectin, breaks down and gelatinisation takes place when it is cooked in water. When coupled with a plasticiser at high temperatures, it creates Thermoplastic Starch (TPS), which may be processed like plastic. Benefits: It is the suggested choice because to its abundance, affordability, biodegradability, and renewability (from corn, potatoes, wheat, etc.).

4.2.2. Glycerine (Plasticizer):

Main Function: Serves as a plasticiser, an essential component to improve elasticity and flexibility (elongation at break). Mechanism: It breaks the starch chains' strong intramolecular and intermolecular hydrogen bonds. It keeps the film from becoming stiff and brittle at room temperature by getting in between the polymer chains and increasing their free volume and mobility. Trade-off High glycerine concentrations generally reduce the film's tensile strength (mechanical strength) and increase its susceptibility to water absorption/swelling because of its hydrophilic nature, even while they enhance flexibility.

4.2.3. Acetic Acid:

Main Purpose: As a co-plasticizer or modifying ingredient (often in the form of vinegar, which is a diluted acetic acid solution), it improves chemical processing and film quality. **Mechanism:** The acetic acid's hydrogen ions interact with the starch polymers during heating and mixing to help break some of the links and create a more homogeneous, disordered polymer matrix. This process improves the capacity to build films and can result in better mechanical properties (such tensile strength) up to an optimal concentration. **Secondary Function:** It serves as a solvent and acidity regulator to dissolve other components (like chitosan) and facilitate complete mixing.

4.2.4. Distilled Water:

Main Function: Acts as the film-forming solution's primary solvent and reaction medium. **Function:** It is necessary to dissolve and disperse the acid, starch, and plasticiser in order to produce a uniform film-forming solution. Additionally, it is necessary for the gelatinisation process, which causes the starch granules to inflate and burst when heated above in the aqueous solution. **Method:** It is essential for the popular Solution Casting Method, in which the solid polymer film is left behind after the volatile water evaporates.

4.4 PREFORMULATION STUDIES :-

Table 4.4.1: preformulation studies

MATERIL	TEST	THEORY OF TEST	STD VALUE	OBSERVED VALUE	ACCEPTABLE/ UNACCEPTABLE
Starch	Moisture content	Affect on physical properties	Std value : <15%	10%	Acceptable
	Particle size	Affect on the solubility	Absence of large aggregates	-	
Distilled water	pH	It is important for hydrolysis of material	Approx pH: 7.0	pH : 7.0	Acceptable
Glycerine	Density	Ensure correct ammount of plasticizer	Std value: 1.25 – 1.26	Density: 1.249	Acceptable
Acetic Acid	pH	Maintain of pH	Approx pH: 2.2	pH : 2.2	Acceptable

4.5 PROCEDURE:

1.5g corn starch, 0.25g glycerine, 1ml white vinegar, and 6ml distilled water were mixed together in a beaker. The liquid was continuously spun until it got somewhat runny and then milky white. Heat was adjusted and the beaker

placed on the stove. The mixture was constantly stirred while heating, becoming thicker and more transparent. After three minutes at 85°C, the clear and thickened fluid was taken off the fire. Two drops of food colouring were added at this point, if needed. The heated mixture was then spread out on the tray or aluminium foil. For three days, the sample was allowed to dry undisturbed at room temperature.

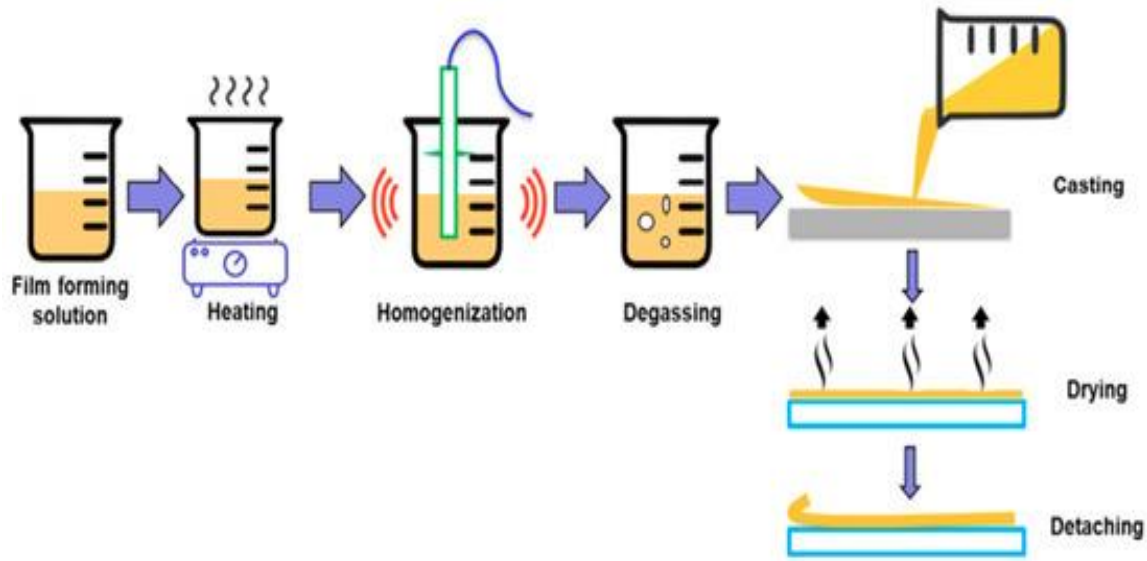


Fig No. 4.5.1 procedure (solvent casting method)

5. CHARACTERIZATION :-

1. Moisture Content Test (Standard Method – ISO 15512)

* Procedure: Bioplastic film samples are weighed and dried within oven at until constant final weight is reached.

* Purpose: For the determination of percentage of moisture absorbed by or trapped within the film, which is critical as for starch is hydrophilic.

2. Water Solubility Test

* Procedure: Film samples are weighed, immersed in 100 of distilled water, and heated for 6 hours. The remaining film was then filtered and dried in hot air oven at 110°C to find the final weight.

* Purpose: To determine the film's stability and resistance to a dissolution in water, a major limitation for starch-based materials.

3. Biodegradability Test – Soil Burial Test (Standard Method – ASTM D5338)

* Method: For 15 days, film specimens are weighed and submerged at depths of 2 and 3 cm in soil that is rich in nitrogenous bacteria. The final weight is measured after testing.

* Purpose: To confirm the film's ability to be broken down by microorganisms in a natural environment.

4. Thickness Measurement (Standard Method – ASTM F2251-13)

* Procedure: The film's thickness is measured directly using a micrometer between the stylus and anvil.

* Purpose: To ensure the film has uniform thickness, which is necessary for accurate calculations of other properties (e.g., Water Vapor Permeability, Tensile Strength).

5. RESULT AND DISCUSSION:-

5.1 RESULT:

The formulation of bioplastic film from starch show's the biodegradability in nature and provide the Eco- friendly effect on environment.

5.1 DISCUSSION:

The objective of this study that was successfully achieved by preparing Biodegradable bio-plastic Film from starch along with glycerol, acetic acid and distilled water. The characterization of film Assess the potential as an eco- friendly alternative for packaging.

• INITIAL TESTS –

Colour – Whitish

Texture – Smooth

Transperancy – clear

Nature – Sticky



Fig.No.5.2.1

• PH TEST –

The surface pH of biodegradable bioplastic film was found to be 5.

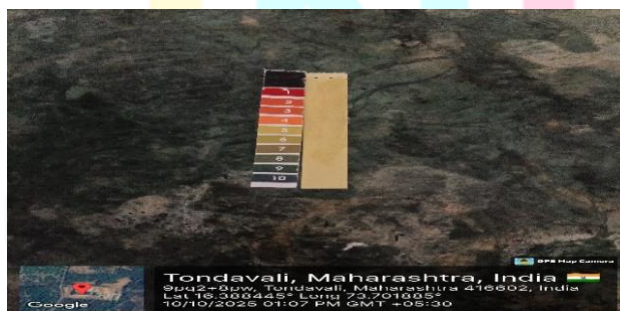


Fig.No.5.2.2

• **THICKNESS TEST-**

The Thickness of biodegradable bioplastic films was found to be 0.25mm.



Fig.No.5.2.3

• **MOISTURE CONTENT –**

Initial weight: 15mg

Final weight: 8mg

$$MC = \frac{IW-FW}{FW} * 100$$

$$= \frac{15 - 8}{8} * 100$$

$$= 87.5\%$$

• **BIODEGRADABILITY TEST-**

The biodegradability of bioplastic film from starch was takes place within the 15 days.



Fig.No.5.2.4

6. FUTURE PROSPECTS :-

1. ADVANCED MATERIAL ENGINEERING AND NANOCOMPOSITES:

The primary technological objective is to fully overcome the inherent shortcomings of starch, such as its water sensitivity and low mechanical strength. Attain higher mechanical and barrier performance to compete with conventional polymers.

Method A: Nanocomposites' Physical Modification The most important strategy is to incorporate nanofillers such cellulose nanofibers (CNFs), nanocrystals (CNCs), and nanoclays. By providing water molecules with a more complex path, these compounds not only greatly reduce Water Vapour Permeability (WVP) but also strengthen the film to improve tensile strength and elasticity.

Method B: Chemical Derivatisation: Future studies will concentrate more on modifying the starch molecule chemically, for as via acetylation or esterification. By chemically substituting hydrophobic groups for the hydrophilic hydroxyl groups, this produces a matrix that is essentially more stable and resistant to moisture and swelling.

2. INDUSTRIAL SCALE-UP EFFICIENCY:

Transitioning from small-scale laboratory methods to scalable, cost-effective production processes is crucial for success. The objective is to switch to industrial melt-processing methods.

Method: Industrial techniques like extrusion and injection moulding must replace lab-scale solution casting in research. Stable Thermoplastic Starch (TPS) formulations must be created and refined in order to accomplish this. In order to do this, starch must be blended with other commercially melt-processable biopolymers, such as Poly(lactic acid) (PLA) or Poly(butylene adipate-co-terephthalate) (PBAT), and plasticiser systems must be optimised to survive high shear and high temperature processes.

3. SMART FUNCTIONALITY AND END-OF-LIFE CONTROL:

Future films will offer a tidy end-of-life cycle and add value with clever and useful features. Objective A: Active and Intelligent Packaging The next generation will incorporate practical components into the film right away. This includes antibacterial compounds (like essential oils and natural extracts) to prolong the shelf life of food or indicators (like pH or temperature) to indicate the freshness or deterioration of food.

Goal B: Controlled Degradation: Research will try to create films with precisely triggered or controlled degradation kinetics so that they break down quickly in a controlled composting environment while remaining stable during usage.

4. SUSTAINABILITY AND SOURCING:

Future development must include safe non-food raw material sources and full environmental accountability. Design will increasingly use life cycle assessment (LCA) from the conceptual stage to examine and limit the environmental impact (e.g., carbon footprint, land use) in order to validate the net environmental advantage over fossil plastics. Unusual Raw Materials Future sourcing will prioritise the utilisation of low-cost starches from food and agricultural waste (such as peelings and side streams). In addition to lowering competition with food supplies, this can produce starch variants with desirable qualities (such a higher amylose content) for improved film strength.

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