IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 2, June 2025
Impact Factor: 7.67

Biodegradable Packaging for Pharmaceuticals: A Step Towards Sustainability

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Abstract: *In current years littering of plastics and the problem associated with their chronic inside the environment have end up a primary awareness in each study and information. There is high need of biodegradable polymers and especially in the discipline of packing and additionally want to create biodegradable polymers for traditional packaging material. The current review paper focuses on the various types of biopolymer sources that are available in nature which can reduce the risk of environment damage using alternative of plastics as a packaging material. This review present review of the exclusive biodegradable polymers and records about biodegradable polymers which are degraded by way of microorganisms and additionally include biodegradation technique. The excellent of biopolymers can be expressed as distinct properties like gas barrier, thermal and mechanical barrier, and moisture barrier properties. Biopolymers may be classified into classes in keeping with natural, synthetic and based totally on repeating units. Biodegradable polymers can be used as an approach to the troubles posed via plastics as they effortlessly degrade inside the surroundings and mimic the properties of traditional polymers. Starch, cellulose based totally biodegradable zero waste plastics can update with non-renewable plastics with comparable packaging. properties. Some of organic substances can be incorporated into biodegradable polymers materials with the maximum common being PLA, PCA, protein, starch cellulose etc. This overview additionally nation the biodegradable polymers bundle of food programs and utilized in other discipline and which merchandise are made from this.*

Keywords: Biopolymers; Starch; Food packaging: PLA

I. INTRODUCTION

"The case for rethinking plastics, starting with packaging"

Plastics have become the ubiquitous workhorse material of the modern economy. Plastics in bundling have demonstrated helpful for various reasons, incorporating the straightforwardness with which they can be framed, their high caliber, and the opportunity plan to which they lend themselves. Plastic containers are extremely resistant to breakage and thus offer safety to consumers along with the reduction of breakage losses at all levels of distribution and use. Plastic containers comprise of at least one polymer together with certain additives. Those manufactured for pharmaceutical purposes must be free from substances that can be removed in significant amounts by the product contained. In this way, the risks of poisonous quality or physical and synthetic unsteadiness are avoided.

The rapid increase in international plastic production puts our health and the environment at extreme risk. Due to their Irreversible properties, the accelerated production of plastic manufactured using synthetic polymers raises environmental concerns. Plastic is considered the most widely used packaging material. Plastics are created by combining polymers with a variety of additional chemicals, such as dyes, stabilizers, and processing aids. Synthetic plastics have been considered the substances of the destiny remaining century, however these days they're causing serious environmental issues. The principal dangers of synthetic polymers are their long degradation system and manufacturing primarily based on non-renewable raw substances 14), Consequently, the manufacturing and use of biodegradable polymer materials are growing considerably, which may additionally assist reduce environmental troubles associated with waste polymer substances.

The word biopolymer comes from the Greek words bio and polymer, meaning essence or living organisms 1. Biopolymers are large macromolecules composed of many repeating units. Long chains of polymeric bimolecular are commonly.

produced by life organizations. The monomer units of these polymers are joined together through covalent bonds to form large architectural works. Some examples of biopolymers are DNA, RNA, fatty acids, gelatine, keratin, cellulose, starch, etc. There are many different types of biopolymers (DNA, RNA) capable of gene transfer material from generation to generation.

Cellulose and starch are the main building materials of plants. These polymers compared to synthetic plastics; they have been on earth for billions of years. Synthetic polymers while similar and random structures, biopolymers are arranged into well- defined structures. Therefore, biopolymers involve a process in which large chains are broken down into smaller chains under the influence of biological factors.[1-11]

Biodegradable materials for pharmaceutical packaging

Bio-packaging is important for future packaging.

Hydrocolloids and lipids are generally used for preparing biodegradable packaging materials. Glycerol, polyethylene glycol, and sorbitol are used in the film formulations as plasticizers, to impart flexibility.[12]

Sr no.	Eco-friendly material	Source	Description	Available Polymer/ Derivatives
1	Starch	legumes, tubers, cereals Primary Source: Corn, Potato, Wheat and Rice	Starch, a polysaccharide, is a renewable, ecofriendly and widely available raw material. Biodegradable Plasticizers such as glycerol, polyether, urea, and polyhydroxy components are used to make starch materials less brittle.	Types of starch- based polymers: Starch-based thermoplastic products Starch-polyvinyl alcohol Starch-synthetic aliphatic polyester Starch polybutylene succinate
2	Cellulose	Natural resources such as wood and glass	Cellulose-based materials, like paper and board, are commonly used in packaging. They are light- weight, tough, bio- based and effectively recyclable which have made them a well-known packaging material.	Various commercial products of cellulose derivatives Ethyl Cellulose Methyl Cellulose Cellulose acetate Hydroxyl ethyl Cellulose
3	Xylan	Naturally occurring carbohydrate found in plant cell walls and algae. Also obtained as	Biodegradable and compostable	It forms a group of substances known as hemicellulose.
		residue from agricultural industries		
			Gluten is an intense,	Used in edible films, adhesives,

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4	Gluten	Protein found in Wheat, barley and rye.	rubbery and flexible substance, which has the ability to stretch and rise because of the activity of preparing powder or yeast. At the point when flour is blended in with water, the gluten swells to form a continuous network of fine strands.	molded biodegradable thermoplastic films for agricultural uses, windows in envelopes, surface coatings on paper, water-soluble bags with fertilizers, detergents, cosmetics.
5	Soy protein	Protein that is isolated from soybean	Soy protein is the most widely used plant-derived protein for microencapsulatio n due to its good functional properties including gelformation, emulsifying activity and surface tension reducing properties	Used as adhesives or biodegradable plastics produced from soy isolate and concentrate by them molding process, inks, paper coatings, oil for lubrication, soy films as coating materials for preservation.
6	Whey	The by- product of the cheese industry	Rich in α - lactoglobulin Collagen	Use in packaging as edible coatings and films
7	Zein	Corn endosperm	Comprises a group of alcohol-soluble proteins – —prolamine	Zein based films used as biobased packaging and in pharmaceutical coatings
8	Casein	Milk derived protein	Easily processable	Used as a thermoset plastic, for bottle labeling due to excellent adhesive properties.
9	Keratin	Structural protein extracted from waste streams such as hair, nails, and feathers	Cheapest protein Poor mechanical properties	Used to produce fully biodegradable waterinsoluble plastic.
10	Collagen	Found in animal tissues particularly tendons, skin, and bones.	Fibrous, flexible and structural protein with the common repeating unit: proline, glycine, and hydroxyproline	Used as packaging material in several pharmaceutical applications.
11	Gelatin	Obtained from skin and bones.	Used as a packaging material for improving moisture sensitivity	Used as a raw material for; Photographic films Microencapsulati ng aromas Vitamins Sweeteners And as gelatin films in the pharmaceutical industry to fabricate tablets and capsules

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DOI: 10.48175/IJARSCT-27410

REVIEW OF LITRATURE:

[1] World Economic Forum (2017), The New Plastics Economy: Catalyzing Action
Abstract..This report, developed in collaboration with the Ellen MacArthur Foundation, outlines a global strategy to redesign the plastic packaging economy. It highlights the environmental impact of plastic waste and proposes actionable steps to move toward a circular economy. The report focuses on three key ambitions: eliminating unnecessary plastic, innovating for reusable and recyclable packaging, and creating effective after- use systems. It emphasizes collaboration among industries, governments, and consumers to transform plastic usage sustainably.

[2] Vikas Pareek (2014), Pharmaceutical Packaging: Current Trends and Future
Abstract..This review discusses the evolving landscape of pharmaceutical packaging, focusing on innovations that enhance drug stability, patient safety, and compliance. It covers trends such as smart packaging, tamper-evident designs, and eco-friendly materials. The paper also highlights regulatory influences and the growing role of packaging in branding and user experience, forecasting a future where technology and sustainability will shape packaging strategies.

[3] Arshdeep Kaur & Dr. Shweta Sharna (2023)
Abstract.. This paper explores bio-based alternatives to conventional petrochemical packaging, focusing on food applications. It reviews the environmental benefits, types of biodegradable materials, and current trends in sustainable packaging, emphasizing starch-based and polysaccharide materials.

[4] Paletta et al. (2019)
Abstract.. The study identifies challenges and barriers in plastic waste valorisation within Italy's circular economy framework. It uses case studies to examine regulatory, technological, and societal hurdles and proposes policy improvements to enhance plastic recycling and reuse.

[5]M. Raja & A. Murali (2011)
Abstract.. This work investigates the development of biodegradable packaging films using natural polymers. It analyzes material properties and degradation behavior, suggesting their potential to replace synthetic plastics in packaging.

[6]T. Helmer Pedersen & F. Conti (2017)
Abstract.. This article assesses waste management strategies, focusing on the environmental impacts of plastic disposal. It explores innovative recycling and waste reduction methods to support sustainable waste systems.

[7]Vroman & Tighzert (2009)
Abstract.. A comprehensive review of biodegradable polymers, detailing their synthesis, properties, degradation mechanisms, and applications in packaging. It evaluates performance compared to traditional plastics.

[8]Ezeoha & Ezenwanne (2013)
Abstract.. The study focuses on creating biodegradable packaging films from cassava starch. It examines production processes, mechanical properties, and biodegradability, showcasing cassava starch as a viable alternative to plastic.

[9]R.R. Ali et al. (2013)
Abstract.. This book chapter discusses the development of starch-based biofilms for green packaging. It outlines material selection, film-forming techniques, and environmental advantages, supporting the shift toward sustainable packaging.

[10] Guzman, Gnutek & Janik (2011)
Abstract.. A review highlighting factors affecting the degradation of biodegradable polymers in food packaging. It covers materials used, certification standards, and environmental conditions influencing breakdown.

Aim:
To develop and evaluate biodegradable packaging films using starch as the primary polymer for pharmaceutical applications, with the goal of creating an eco-friendly alternative to conventional plastic packaging.

Objectives:
1. To review the existing literature on biodegradable polymers and their use in pharmaceutical packaging, particularly starch-based films.
2. To formulate biodegradable films using corn starch, glycerol (as a plasticizer), and citric acid monohydrate (as a cross-linking agent).
3. To optimize the formulation method by adjusting concentrations, heating time, and drying conditions.
4. To characterize the physical and mechanical properties of the prepared films such as:Thickness Water vapor permeability Moisture content Folding endurance Transparency.
5. To assess the biodegradability of the developed starch-based films under laboratory or natural conditions.
6. To compare the performance of biodegradable films with conventional plastic- based pharmaceutical packaging.
7. To explore the suitability of these films for packaging solid dosage forms such as tablets and capsules.[13-20]

PLAN OF WORK:
[1] Literature Survey Conducted a comprehensive review of available research articles, journals, and case studies on starch-based biodegradable films, their formulation techniques, and pharmaceutical applications.
[2] Selection of Materials Chose corn starch as the base polymer, glycerol as the plasticizer, and citric acid monohydrate as the cross-linking agent based on their film- forming properties and biodegradability.
[3] Procurement of Materials All materials such as starch, glycerol, citric acid monohydrate, sodium hydroxide, and ethanol were procured from certified chemical suppliers or online laboratory-grade sources.
[4] Formulation of Starch-Based Film Prepared biodegradable film by dispersing starch in water, followed by heating for gelatinization, addition of glycerol and citric acid, and drying of the film solution to obtain a solid film.
[5] Characterization and Evaluation Evaluated the physical and mechanical properties of the film such as:Thickness Moisture content Water vapor permeability (WVP)Folding endurance Using standard laboratory procedures and instruments.
[6] Biodegradability Testing Tested the films for their biodegradation by burying in soil or compost and observing disintegration over a defined period.
[7] Comparative Study Compared the performance of starch-based films with conventional plastic packaging in terms of functionality, flexibility, and environmental impact.
[8] Documentation and Compilation of Results Recorded all observations, analyzed results, and compiled findings into a structured project report.[20-28]

Pharmaceutical packaging products obtained from various plastic materials.

Sr no.	Products
1	PET bottle
2	Cap and Closure
3	Dropper
4	Measuring Cup, Spoon, Cyliner
5	Stopper

6	Eye drop bottle
7	Eardrop bottle
8	Nasal drop bottle
9	PVC Film
10	PVDC Film
11	Large Volume Parenteral Container (Flexible and Non-Flexible)
12	Infusion Set
13	Pre-filled Syringe
14	Actuator
15	Applicator
16	Spray Pump
17	Special Tube-Type container

Table 2

The packaging systems must secure and be compatible with drug products and not compromise their stability, efficacy or safety. The elements of a medication item should not be consumed into the surface or relocate into the body of the plastic packaging framework. However, top local manufacturers imports nourishment grade virgin dynamic elements for creating plastic packaging materials from Korea, Taiwan, Malaysia, Saudi Arabia, UAE, China, etc. which are a little costly and the pharmaceutical manufacturer have some quality parameters to select that same.[29-30]

The major suppliers.

Sr. no.	Company	Country of origin
1	Wuxi Sunmart	China
2	Nuplas	Dubai
3	Rexam	France
4	ACG	India
5	Struble	Germany
6	Bilcare	India
7	Bprex Pharma	India
8	Doctor Pack	India
9	Meditalia	Italy
10	F.D. Enterprise	Taiwan
11	JOMA	Austria
12	BestPack	UK

Table 3

The pharmaceutical organizations who are exporting medication to semi-regulated and regulated markets are exceptionally cautious about the sources of plastic materials since there are exacting rules for packaging materials from the regulatory body. Subsequently, they anticipate certain SOP (Standard Operating Procedure) and COA (Certificate of Analysis) from the plastic maker.

Therefore, these export-oriented companies limited their purchase only from top- class plastic manufacturers[30]

The plastic problem

We come across a variety of packaged products each and every day. From containers used to contain milk and grains, to medication bottles, drinks bottles, nourishment holders and bundling folded over apparel, we're presented to a wide range of various materials every day. Research led by the Ocean Conservancy shows that plastic traces were distinguished in 100% of turtle species and 60% of seabird species. Plastic waste
— regardless of whether in a waterway, a sea, or ashore — can continue in the earth for a considerable length of time.

Fig. 1: Plastic wastes in river.

The River conveys almost 1.5 million tons of plastic waste into the Sea.

If current trends continue, our seas could contain more plastic than fish by 2050.

Statistcs

a. Plastic enters in world's oceans

In 2010:

• Global primary production of plastic was 270 million tonnes;

• Global plastic waste was 275 million tonnes (and can exceed annual primary production through wastage of plastic from prior years);

• Plastic waste most at risk of entering the oceans is generated in coastal populations; in 2010 coastal plastic waste amounted to 99.5 million tonnes;

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Fig. 2 Pathway by which plastic enters the world's oceans.

• Only plastic waste which is improperly managed (mismanaged) is at significant risk of leakage to the environment; in 2010 this amounted to 31.9 million tonnes;

• Of this, 8 million tonnes – 3% of global annual plastics waste – entered the ocean (through multiple outlets, including rivers);

• An estimated 10,000s to 100,000s tonnes of plastics are in the ocean surface waters. This inconsistency is known as the 'missing plastic issue'.

b. Cumulative global plastic production

In the diagram beneath we see the development of yearly worldwide plastic production, estimated in tons every year. This is shown from 1950 through to 2015.

In 1950 the world delivered just 2 million tons for each year.

From that point forward, yearly production has expanded to about 200-overlap, arriving at 381 million tons in 2015. For setting, this is generally comparable to the mass of 66% of thetotal population. The short downturn in yearly creation in 2009 and 2010 was transcendently the aftereffect of the 2008 worldwide financial crises

— this mark is seen over a few measurements of resource production/consumption, including energy.

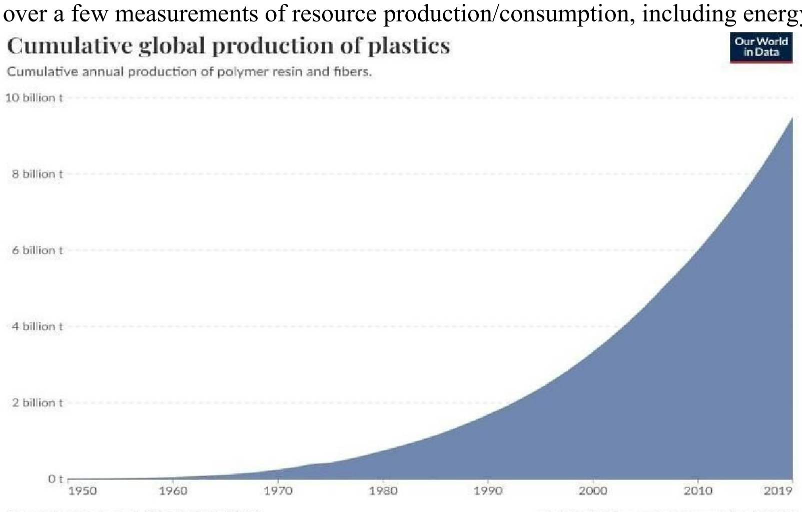

Fig. 3: Cumulative global plastic production.

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Cumulative production by 2015, the world had produced 7.8 billion tonnes of plastic — more than one tonne of plastic for every person alive today

c. Disposal of plastic

Before 1980, reusing and burning of plastic were insignificant; 100 percent was in this way disposed of. From 1980 for burning and 1990 for reusing, rates expanded on normal by about 0.7 percent every year.

In 2015, an expected 55 percent of worldwide plastic waste was disposed of, 25 percent was burned, and 20 percent reused. On the off chance that we extrapolate chronicled drifts through to 2050 — by 2050, burning rates would increment to 50 percent; reusing to 44 percent, and disposed of waste would tumble to 6 percent. Notwithstanding, note this depends on the shortsighted extrapolation of historic trends and doesn't represent concrete projections. Global plastic production to fate;

In the figure underneath we summarise worldwide plastic production to definite destiny over the period 1950 to 2015. This is given in cumulative million tonnes.

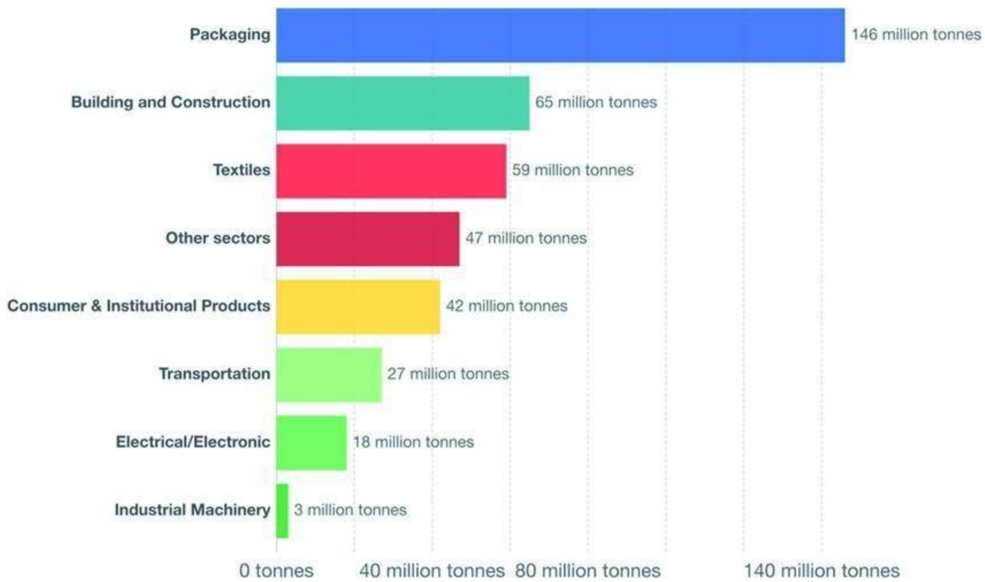

Fig. 4: Primary plastic production by industrial sector, 2015.

As shown

a) Cumulative production of polymers, synthetic fibers and additives was 8300 million tonnes;

b) 2500 million tonnes (30 percent) of primary plastics was still in use in 2015;

c) 4600 million tonnes (55 percent) went straight to landfill or was discarded;

d) 700 million tonnes (8 percent) was incinerated;

e) 500 million tonnes (6 percent) were recycled (100 million tonnes of recycled plastic was still in use; 100 million tonnes were later incinerated, and 300 million tonnes were later discarded or sent to landfill).

f) Of the 5800 million tonnes of primary plastic no longer in use, only 9 percent has been recycled since 1950.

g) The packaging was the dominant use of primary plastics, with 42 percent of plastics entering the use phase.

d. Cumulative Plastic waste generation and disposal

We estimate that 2500 Mt of plastics—or 30% of all plastics at any point produced— are right now being used. Somewhere in the range of 1950 and 2015, combined waste generation of primary and secondary (reused) plastic waste added up to 6300 Mt.

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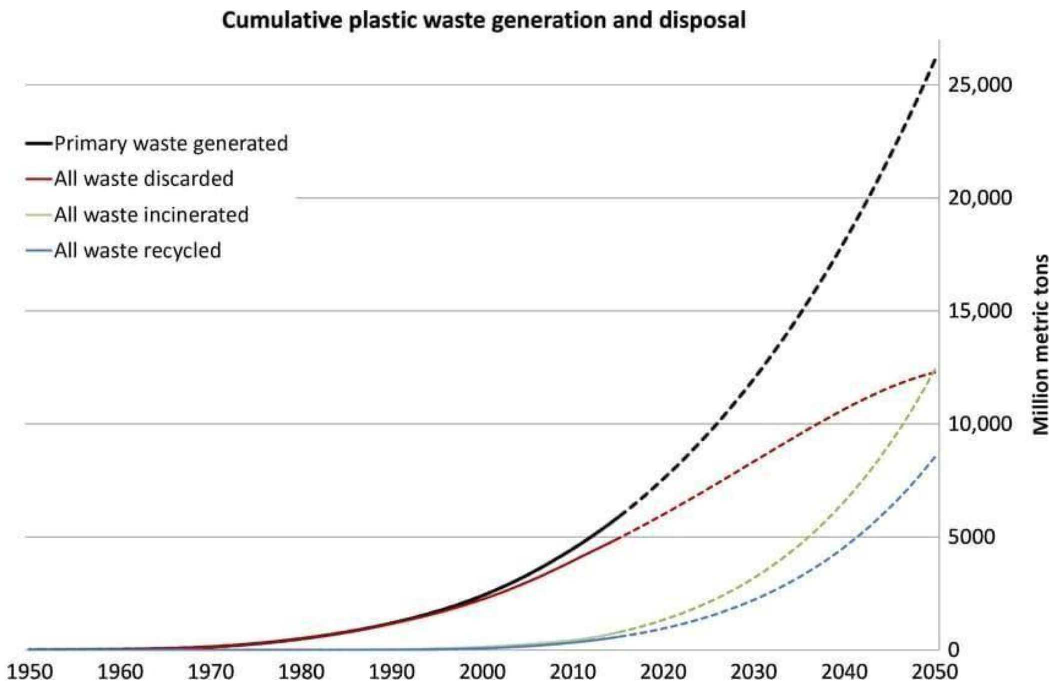

Fig. 5. Cumulative plastic waste generation and disposal (in million metric tons).

Strong lines show historic information from 1950 to 2015; dashed lines show projections of recorded patterns to 2050. We estimate that 2500 Mt of plastics—or 30% of all plastics ever produced—are currently in use. Between 1950 and 2015, cumulative waste generation of primary and secondary (recycled) plastic waste amounted to 6300 Mt. of this, around 800 Mt (12%) of plastics have been burned and 600 Mt (9%) have been reused, just 10% of which have been reused more than once.[31-35]

5. CHEMICALS

1. Corn Starch

Structure: Polysaccharide made of amylose and amylopectin.

Physical Properties: White,odorless powder; insoluble in cold water; gelatinizes upon heating.

Uses: Film-forming agent in biodegradable packaging

Fig.6

2. Glycerol
Structure: $C_3H_8O_3$ (propane-1,2,3-triol)
Physical Properties: Clear, viscous, hygroscopic liquid; boiling point ~290°C. Uses: Acts as a plasticizer to improve film flexibility and reduce brittleness.

Fig.7

3. Citric Acid Monohydrate
Structure: $C_6H_8O_7 \cdot H_2O$
Physical Properties: White crystalline powder; soluble in water; melting point ~100°C (decomposes).
Uses: Cross-linking agent to enhance moisture resistance and strength in starch films.

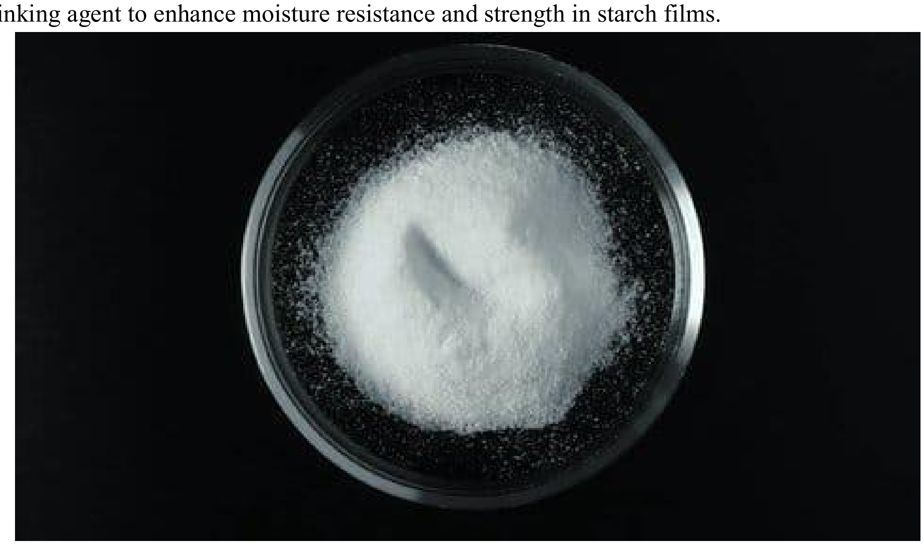

Fig.8

4. Distilled Water
Structure: H_2O (chemically pure water)
Physical Properties: Odorless, tasteless liquid; boiling point 100°C; pH ~7.
Uses: Solvent for starch gelatinization and blending ingredients uniformly.[36-41]

6. FORMULATION

Fig.9

1. Corn Starch (4g)
Selected as the primary biodegradable polymer due to its excellent film- forming properties and renewability.

2. Glycerol (1.5 mL)
Used as a plasticizer to increase the flexibility and reduce brittleness of the starch film.

3. Citric Acid Monohydrate (0.5g)
Added as a cross-linking agent to improve moisture resistance and mechanical strength.

4. Distilled Water (100 mL total)
50 mL cold water is used to disperse starch initially.
Remaining 50 mL added during heating to induce gelatinization.

5. Heating Process
The starch-water mixture is heated at ~75–85°C with constant stirring until gelatinization occurs.
This forms a uniform, viscous solution for film casting.

6. Casting and Drying
The viscous solution is poured onto a petri dish or tray and dried at room temperature for 24–48 hours to form a thin film.

7. Final Film
The resulting film is transparent, flexible, and suitable for testing various physical and mechanical properties.[42-45]

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Fig.10

7. EVALUATION
1. Thickness (Using a Screw Gauge or Vernier Caliper)
Just place the film between the screw gauge jaws. Gently tighten until it touches the film.
Take measurements at different points and average them.

2. Water Vapor Permeability (Simple Desiccator or Bowl Method) Take a small container with some dry silica gel or salt to absorb moisture. Cover the opening tightly with the film.
Put the container in a humid place.
Check if moisture collects inside after 1-2 days by weight or visually.

3. Moisture Content (Oven Drying or Sun Drying)
Weigh the fresh film.
Dry it under the sun or in an oven (if available) at 100°C for 2-3 hours. Weigh again to see weight loss (moisture content).

4. Visual Check
Just observe color, transparency, surface smoothness, cracks, or bubbles with naked eye.[46-50]

RESULT AND DISCUSSION

RESULT

Developing new, more eco-friendly packaging materials

For a long time, similar materials have been utilized to make both external and primary packaging. Presently, as pharmaceutical industries strive to do their bit to protect the environment, many are focusing on developing new, more eco-friendly packaging materials. 1271 Firms are searching for sustainable materials, but on the other hand they're sourcing and examining materials that have a significantly less harmful impact on the planet.

DISCUSSION

One of the fundamental issues with plastic is that it takes hundreds of years to break down. Therefore, identifying biodegradable alternatives is probably going to have an immense effect. The aim is to replace traditional plastics with biodegradable materials that do a similar activity however decompose much faster. Developing biodegradable materials isn't the main methods for reducing plastic waste. Pharma firms are likewise exploring and working on design and manufacturing processes that are cleaner and all the more environmentally-friendly.

II. CONCLUSION

In the era of globalization, it would be a challenge for the packaging industries, as the years ahead would observer the opening of the worldwide channels, and to coordinate the international standards and quality, it is fundamental that packaging industry upgrades in research to have a holistic approach to packaging that would go beyond functional aspect of packaging. The conventional packages accessible don't effectively provide protection against counterfeiting and quality, and the industry seems to be sluggish in adopting the technical advances in the packaging, probably on account of the prohibitive cost factor. As the packaging industry is directly or indirectly involved in the drug manufacturing process, it becomes ethically mandatory to understand and incorporate scientific methods in packaging. The need of the hour is to arrive at a sustainable solution by the adoption of technologies, upcoming innovations and eco- friendly solutions. An organized development addressing cost-effective plastic processing, along with streamlining operations of recycling of plastics could pave a path for the growth of this industry.

SUMMARY

The increasing environmental pollution caused by non-biodegradable plastic packaging has prompted the search for sustainable alternatives, particularly in the pharmaceutical industry. This project explores the development of biodegradable packaging material using starch-based films, offering an eco-friendly and renewable solution. Corn starch was selected as the primary biopolymer due to its availability, low cost, and excellent film-forming properties. To improve its flexibility and water resistance, glycerol was used as a plasticizer and citric acid monohydrate as a cross-linking agent.

The film was prepared by dispersing starch in cold water, heating to induce gelatinization, and then adding glycerol and citric acid to form a homogenous mixture. The final solution was cast and dried to form flexible, transparent films. These films were evaluated for key physical and mechanical properties, including water vapor permeability, thickness, folding endurance, and biodegradability.

Results showed that the starch-based films had good structural integrity and were capable of decomposing naturally, making them suitable for pharmaceutical packaging. This study highlights the potential of natural polymers in replacing conventional plastic
materials,promoting,sustainability,and,environmental,safety,in,pharmaceutical practic

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IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 2, June 2025
Impact Factor: 7.67

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