

FABRICATION OF NANO SELENIUM INCORPORATED BIODEGRADABLE FOOD PACKAGING FILM

Submitted in partial fulfilment for the award of
Bachelor of Technology degree in Biotechnology

By

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**DEPARTMENT OF BIOTECHNOLOGY
SCHOOL OF BIO & CHEMICAL ENGINEERING**

**SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of Muthu Bharath T (40230029), R Rameshwar Chandran (40230039) who carried out the project entitled "Fabrication of Nano Selenium Incorporated Biodegradable Food Packaging Film" under our supervision from September-2023 to April-2024.

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I/We **Muthu Bharath T (40230029), R Rameshwar Chandran (40230039)** hereby declare that the Project Report entitled “**Fabrication of Nano-selenium Incorporated Biodegradable Food Packaging Film**” done by me under the guidance of **Ms. E. Jancy Mary**, Assistant Professor, Department of Biotechnology (Internal) and **Dr. T. Stalin Dhas**, Assistant Professor (Research), Centre for Ocean Research, Sathyabama Research Park (External) at **Sathyabama Institute of Science and Technology, Chennai, Tamilnadu, India**, is submitted in partial fulfilment of the requirements for the award of **Bachelor of Technology degree in Biotechnology**.

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ABSTRACT

Plastics are considered to be the greatest invention of mankind. However, the chemical structure of most of the synthetic polymers renders them resistant to many natural processes of degradation and as a result these polymers have destroyed the environment by contaminating land, water and the ecosystem around us. Polymers used for food packaging contribute to nearly 35 % of the total plastic accumulation in the environment. In this study, we investigated the fabrication of a novel biodegradable nano biowrap from plant-based polymers for food packaging applications. The pectin biowrap is enriched with selenium nanoparticles which improves the structural integrity and the antimicrobial properties of the wrap. The biowrap had increased opacity, swelling percentage with a comparatively lower moisture content. The biowrap was also subjected to real time testing with corn and grapes, in a week's time for weight loss percentage and to study the morphological changes. The degradation assays were carried out in soil and water and visual data sets were promising enough to prove the biodegradable nature of the film. The DPPH radical scavenging activity assay proved that the film had 94.6 % of scavenging activity which is high enough to counter the free radicals that cause oxidation to spoil the food during the packaging process. The antibacterial activity of the film was done against *Pseudomonas aeruginosa* and *Staphylococcus aureus*, and the film displayed excellent biofilm inhibition properties compared to the nanoparticle devoid film. Thus, these biowraps have the capacity to replace the conventional plastic wraps in the industry and help to preserve foods in a sustainable and efficient manner.

Keywords: *Pollution, Biopolymers, Food Packaging, Pectin, Antimicrobial.*

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LIST OF ABBREVIATIONS

ACRONYM	FULL FORM
Commercial Film	Biodegradable film purchased from the market
PG	Pectogel Biowrap (control film without nanoparticles)
PGN	Pectogel Nanobiowrap (nanoparticle incorporated film)
CaCl ₂	Calcium Chloride
PVA	Polyvinyl Alcohol
FTIR	Fourier Transform Infrared Spectroscopy
NP	Nanoparticles
g/cm ³	gram per centimetre cube
Hrs	Hours
mm	millimetre
μm	micrometre
Na ₂ SeO ₃	Sodium Selenite
<i>S. aureus</i>	<i>Staphylococcus aureus</i>
<i>P. aeruginosa</i>	<i>Pseudomonas aeruginosa</i>
UV-Vis	Ultraviolet-visible spectroscopy
SeNP	Selenium Nanoparticles
mV	Millivolts
UTM	Universal Testing Machine

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1. INTRODUCTION

Plastics were considered to be the greatest invention of mankind mainly because of their versatile functions. Plastics were able to substitute almost any substance in a process, and were also able to improve the efficiency of that particular process as well, because plastics were cheap and durable (Chandran et al., 2023).

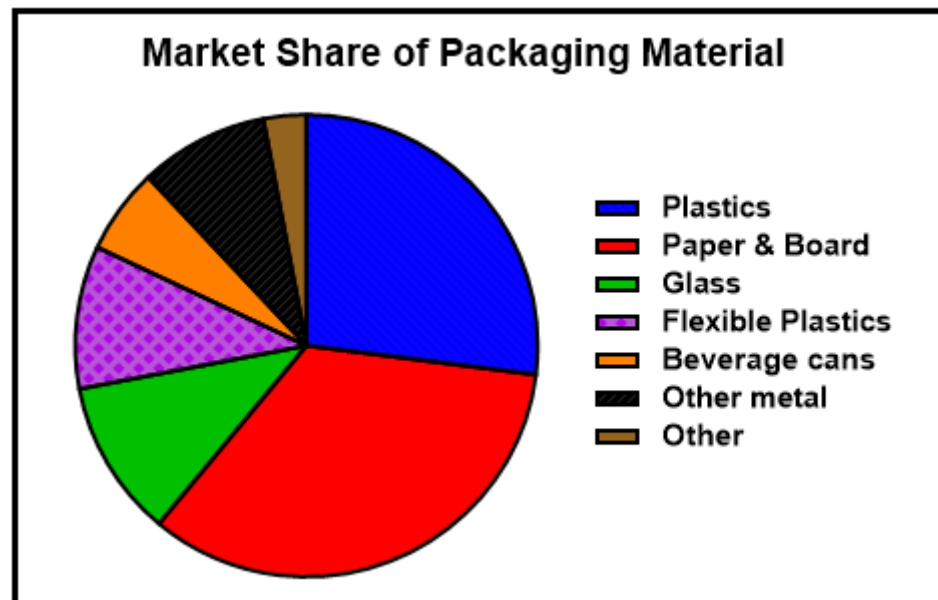


Fig 1.1: Contribution of plastics in food packaging
(Food Packaging Materials | Food Packaging Forum, n.d.)

From the figure, it is clearly visible that the majority of the packaging is done with the help of single use plastics and rigid plastics, which do not easily degrade and cause calamities to the environment. Nowadays, the accumulation of these plastic poses a huge risk in all the natural environments (Meijer et al., 2021). Plastics are non-biodegradable and hence they do not get degraded even after a hundred years (Weiss et al., 2021). The most alarming issue that has to be addressed now is the over-exploited usage of single-use plastics throughout the world. The below image depicts the unchecked and overexploited status of plastic pollution in our country. This problem has ranked India on a higher position amongst countries generating plastic wastes on a daily basis.(Simon et al., 2021)

These plastics require specialized machinery and processes to degrade them, but in reality, this is not the case. These types of plastics get accumulated in landfills and water bodies and disrupt the ecosystem (Barnes et al., 2009). The major contributor of single-use plastic pollution is the usage of polythene food wraps to transport and store the food items (North & Halden, 2013). They are efficient in storing

the food items, as they have good tensile properties, act as an efficient barrier against water vapor and gasses.

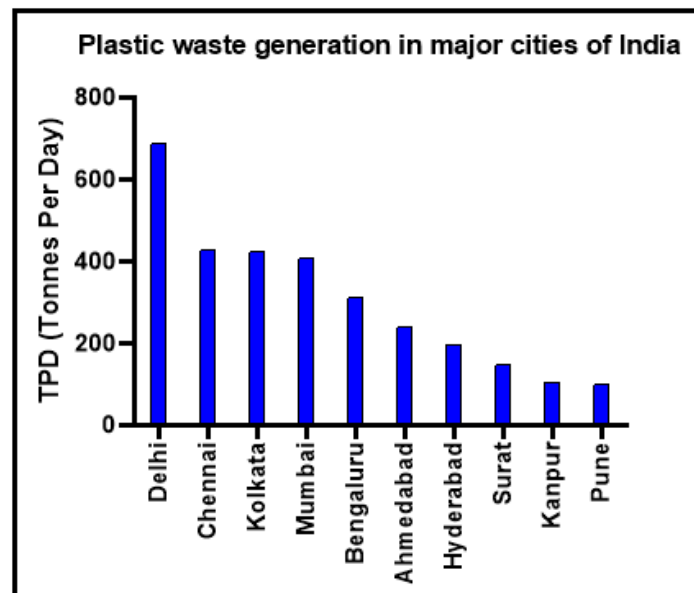


Fig 1.2 Estimated plastic waste generation by developing and developed cities in the year 2019

(India Has a 26,000-Tonne Plastic Waste Problem | India News - Times of India, n.d.)

From the above figure, it is clearly visible that the developed cities generate a large amount of this menace, making it a big burden for the governments to handle and dispose them safely.

The problem with these plastic wraps is that, they are not segregated and degraded properly, and they end up in oceans and lakes and break down to form microplastics.(Thompson et al., 2009)



Fig 1.3: Floating plastic wastes in ocean

The marine organisms mistake these microplastics as food, and consume them. The plastic concentration follows an upward trend in the food chain due to biomagnification (Wright & Kelly, 2017). When these food wraps are buried or thrown on the land, they interfere and damage the niche in that area and intervene in the root expansion of plants and also prohibit the rain water from reaching the water table as well (Geyer et al., 2017).



Fig 1.4: Single use plastic pollution in the water bodies

Despite the fact that the biodegradable wraps have been around for a while, breaking them out in the market has been an enormous undertaking. When it comes to durability, plastic food wrappers usually outlast their biodegradable counterparts. They may help keep food fresher for longer by creating a tighter seal around it. Better clarity and transparency are typically provided by plastic wraps, making it easier for customers to see what's within wrapped goods. This can be crucial for food products

in particular, as appearance counts. Due to its high level of moisture resistance, plastic wraps can help keep food from rotting when it comes into contact with moisture. This function is especially helpful for things that need to be kept in a refrigerator. Plastic food wraps are a cost-effective choice for both customers and companies because they are frequently less expensive than biodegradable substitutes. Plastic wraps are easily accessible in a variety of shapes and sizes and have been used extensively for decades. Compared to more recent biodegradable solutions, consumers may find them more convenient to use because they are accustomed to using them. Plastic wraps are used for a variety of food storage tasks, such as encasing specific food items, covering dishes, and wrapping sandwiches. They provide a wide range of applications. Generally speaking, plastic covers survive longer than their biodegradable counterparts. They are appropriate for bulk purchasing and storage because they don't deteriorate when kept for long periods of time. Plastic wraps can be used for a greater variety of food storage applications since they often work better in harsh environments like high temperatures or contact with oils and fats.

To get a solution for this problem, the introduction of sustainable food packaging solutions was inevitable. The major component of these sustainable food wraps is basically a plant polymer, which can be extracted from a sustainable natural resource and the major advantage of these polymers is that, they are biodegradable and do not require any specialized process to degrade them (Zareie et al., 2020). These wraps can be successfully disintegrated by the scavenging microorganisms present in our environment (Qin et al., 2013).

The introduction of these sustainable biowraps into the market could reduce the infusion of plastics into the body in the form of microplastics, and with the added advantage of antimicrobial properties, these food wraps could reduce the dependency of the market on non-biodegradable substances, and increase the shelf life of the food products on an eco-friendly note.

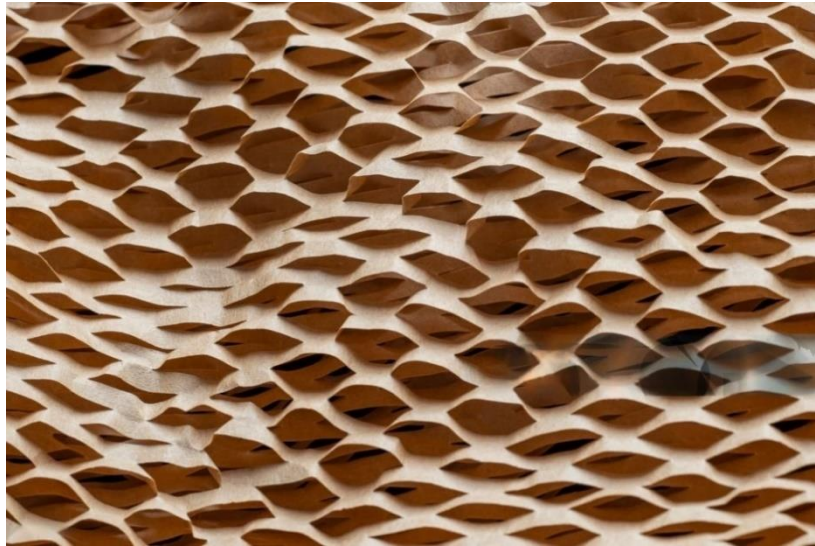


Fig 1.5: Biodegradable packaging solutions

The new age biodegradable packaging solutions aim to use crop wastes, and other leftover biomass or material to fabricate novel packaging products. The problem with the pilot scale implementation of these biodegradable wraps is that they're unable to match with the tensile and elastic properties of the available conventional plastic films that are currently being used in the industry. The non-reacting behaviour of the polyethene films with the food material is a vital property in the food packaging industry. It is a huge task to find a biodegradable wrap to no interact with the food material under varied environmental conditions. The cost for the production from the petrochemicals is comparatively lower than the production of these bio-polymer wraps, and this creates a huge gap in the market. The only way to beat these disadvantages is to come up with a novel biodegradable film, that can be sustainably sourced to lower the cost of production, and to compete with the polyethylene wraps on the grounds of elasticity and stress and strain management. These biodegradable food wraps can revolutionize the food industry as they have the potential to increase the shelf life of the food material and protect the environment as well (X. Liu et al., 2022).

2. LITERATURE SURVEY

2.1 GELATIN AND ITS PROPERTIES

Gelatin is mostly employed in the preparation of medicine shells for accurate drug delivery, while it is also utilised as a gelling agent in ice cream recipes (Ramos et al., 2016). The urgent demand for an environmentally friendly packaging solution propelled gelatin's invasion of the food packaging sector. The food packaging industry has taken notice of it owing to its remarkable film-forming abilities, biodegradability, and biocompatibility (Lu et al., 2022). Gelatin is an excellent addition to food packaging wrap due to its many qualities, including its antibacterial activity, barrier qualities, support for additive integration, and environmental sustainability. Since gelatin-based materials can form films, are biodegradable, and are versatile, they present interesting alternatives for sustainable food packaging (Mihalca et al., 2021). To enable broad usage in the food sector, more research is necessary to solve issues including enhancing barrier qualities and manufacturing scalability (Othman, 2014).

2.2 POLYVINYL ALCOHOL AND ITS PROPERTIES

Polyvinyl alcohol (PVA) has been used for several years as a key component in producing water soluble films. It is the only affordable synthetic polymer with the ability to dissolve in water and cause no harmful effect in it (Lee et al., 2009). PVA, or polyvinyl alcohol, has shown great promise in the food packaging sector because of its special mix of qualities, which include good film-forming ability, barrier qualities, biodegradability, and compatibility with food items (B.; Liu et al., 2022). Several scholarly articles have examined the multifarious uses of polyvinyl alcohol (PVA) in food packaging, elucidating its capacity to tackle a range of obstacles within the sector (Dutta et al., 2002). Scientists' manufacture and characterisation of PVA-based nanocomposite films are explored in detail, with an emphasis on how these films improved mechanical and gas barrier capabilities qualify them for use in food packaging applications that demand longer shelf lives. Researchers are also looking into adding nano clay to PVA films, which shows better barrier qualities against water vapour and oxygen, which is important for preserving the freshness and quality of food (Kim et al., 2015). In addition, the research highlights the potential of antimicrobial compounds to suppress microbial growth and improve food safety during storage by integrating them into PVA matrices to create active packaging films. All of these

studies highlight the flexibility and promise of PVA in tackling different packaging issues in the food sector, opening the door for the creation of creative and environmentally friendly packaging solutions that satisfy consumer expectations for quality, safety, and environmental responsibility (Patil et al., 2020).

2.3 PECTIN AND ITS PROPERTIES

The polysaccharide pectin is hydrophilic, meaning that it has both carboxyl and hydroxyl groups. This property contributes to its high biocompatibility, degradability, and low toxicity. The hydrophilic groups in pectin enhance its chemical and physical characteristics through the processes of esterification, transesterification, coordination, and electrophilic addition (Li *et al.*, 2021). Pectin can be helpful in modifying the surfaces of implants and other medical instruments (Fullana et al., 2010). However, Pectin is also known to have unfavourable corrosive and swelling properties. Pectin is strongly advised for its packaging applications because it contains Rhamnogalacturonan II, which is an essential component to enhance biocompatibility (Li *et al.*, 2021). The polysaccharides of pectin are recommended for packaging and long-term storage uses as they lack toxicity, are affordable and possess anti-bacterial and anti-inflammatory properties (Clifford et al., 2020). There is proof that when the concentration of Pectin is increased in a Gelatin-Pectin-based colloidal solution, the viability of cells increased to a greater extent (Nguyen *et al.*, 2015). Pectin can be subjected to degradation by microorganisms in the colon and hence can be used for sustainable food packaging, as even its infusion would not result in any toxic reactions.

2.4 SELENIUM NANOPARTICLES AND ITS PROPERTIES

Selenium nanoparticles have recently been introduced into the industry, and they are being used as a replacement for silver nanoparticles due to their cheaper cost of production and feasible method of incorporation (Shoeibi & Mashreghi, 2017). Selenium nanoparticles, or SeNPs, have attracted a lot of attention from a variety of industries, especially the food packaging and healthcare sectors, because of their special antibacterial qualities and possible uses (Pérez-Soto et al., 2021). Studies show that SeNPs have a variety of uses in the fight against microbiological diseases and in maintaining food safety. Research looks on the synthesis and characterization of SeNPs and emphasises how effective they are as natural antibacterial agents against a variety of harmful bacteria and fungi (Sans-Serramitjana et al., 2023). The

integration of SeNPs into packaging materials is also being investigated by scientists in an effort to create active packaging solutions that can prolong the shelf life of perishable food items by preventing microbial development (Yuan et al., 2023). Scientists are also looking at the safety and biocompatibility of SeNPs to make sure they are suitable for usage in materials that come into touch with food (Filipović et al., 2021). All things considered, these studies show how potential SeNPs are for the food sector, especially in food packaging, where they work as powerful antimicrobials to improve food safety and prolong shelf life (Shahbaz et al., 2023).

2.5 COMPOSITE FILMS

The growth of composite films in the field of active food packaging has been on the rise for the past decade. Scientists have been storming the field by trying out various polymer and nanoparticle combinations to produce a film that can compete with the plastic film that's currently dominating the market (Azeredo et al., 2017). Biodegradable composite films have drawn a lot of interest because of their many uses in a variety of sectors, including the packaging and biomedical industries. Generally made of natural polymers like chitosan, starch, or cellulose mixed with synthetic polymers or reinforcement agents like nano clay or nanofibers, these films are superior to conventional plastic films in terms of their mechanical, barrier, and biodegradability qualities (S. Liu et al., 2021). Studies have indicated that the integration of nanoparticles into biodegradable matrices improves their functionality and allows them to fulfil particular application needs. These composite films also have outstanding biocompatibility, which means that they can be used in biomedical applications like scaffolds for tissue engineering and drug delivery systems (Khan et al., 2017). Moreover, their eco-friendly attributes coincide with the increasing need for sustainable substitutes for traditional plastics. Numerous studies highlight how biodegradable composite films can help solve the environmental issues related to non-biodegradable packaging materials, opening the door to a more sustainable and environmentally friendly future (Xiao et al., 2022).

2.5.1 ANTIBACTERIAL PROPERTIES OF COMPOSITE FILMS

The main advantage of using these novel biodegradable composite films is their flexibility to accommodate multiple facets of compounds which can increase its durability and its antimicrobial characteristics as well. This makes the film more

efficient and helps us to preserve the food products for a longer period (Khubiev et al., 2023). The antibacterial qualities of biodegradable composite films are promising, which renders them very appropriate for a range of applications, including wound dressings, medical equipment, and food packaging. Natural antimicrobial substances that prevent the growth of bacteria, fungus, and other microbes are frequently used in these films. Examples of these substances include chitosan, essential oils, and silver nanoparticles (Espitia et al., 2012). Studies have indicated that the deliberate discharge of these antimicrobial compounds from the composite matrix successfully increases the shelf life of food goods that are packaged by averting microbial infection and spoiling. Additionally, by modifying the composition and manufacturing parameters, these films' antimicrobial activity can be customised to effectively combat particular infections while preserving their biocompatibility and safety for human usage (Figueroa-Lopez et al., 2019). Furthermore, these films' biodegradable nature guarantees an eco-friendly disposal process after usage, reducing the possibility of microbiological contamination. Numerous investigations have exhibited the capacity of biodegradable composite films to function as efficacious antimicrobial barriers, thereby catering to the increasing need for sustainable solutions across diverse industries (Shen & Kamdem, 2015).

2.5.2 APPLICATIONS OF COMPOSITE FILMS

The application of these novel composite films worldwide is being conducted at a rapid pace, and the results are promising too. Extensive research activities are being planned to initiate the transition phase from petroleum-sourced polyethylene films to sustainably sourced, eco-friendly biodegradable wraps. Biodegradable composite films are proving to be adaptable materials with practical uses in a range of sectors, demonstrating their ability to meet functional needs and address urgent environmental issues (Leceta et al., 2013). These films provide efficient barriers against air, moisture, and microbiological contamination in the field of food packaging, extending the shelf life of perishable items. Additionally, they help with weed suppression, moisture retention, and soil temperature moderation when used in agricultural operations like mulching films, which supports sustainable crop production (Kaniuk & Stachewicz, 2021). Because of their controlled breakdown qualities and biocompatibility, biodegradable composite films are potential options for drug delivery systems, scaffolds for tissue engineering, and wound treatments in the biomedical area.

Additionally, the addition of these materials to consumer goods like hygiene items and disposable cutlery helps to lessen the amount of plastic trash that ends up in landfills and the ocean (Azeredo et al., 2016). Biodegradable composite films have the potential to significantly contribute to the advancement of sustainable practices in a variety of industries, resulting in favourable effects on the environment and society, thanks to ongoing research and innovation.

3. AIM AND OBJECTIVE

- To replace the commercial plastic films used in the market for the purpose of food packaging.
- To research and assess the qualities of the several bio-polymer combinations that are available for the production of food packaging film.
- To add the synthesised selenium nanoparticles to the film complex to get distributed in a uniform manner in the colloidal condition of the gel-casting solution.
- To conduct tests for physical property characterisation using the synthesised film to evaluate its durability and efficiency.
- To examine the new synthetic film's biodegradability, food preservation effectiveness, and antimicrobial characteristics.

4. MATERIALS AND METHODS

4.1 MATERIALS UTILISED FOR PROCESSING

Gelatin powder sourced from porcine skin supplied by Sigma-Aldrich, St. Louis, MO, USA, was used as the primary gelling agent. Polyvinyl alcohol purchased from Fisher Scientific, USA, served as the best polymer for improving the tensile characteristics of the film as it readily dissolved in hot water and provided excellent elasticity to the film. Sodium alginate and calcium chloride were added as additional gelling agents and as stabilisers to improve the durability of the film. Pectin purchased from Sisco Research Laboratories, India, is the key component, as it was used to provide antimicrobial activity to the film, had the capacity to evenly disperse in the solution, and provided a translucent look to the film. The starch powder was purchased from Merck Specialities, India to be used as the cross-linking agent in the film's matrix. Sodium selenite purchased from Sisco Research laboratories in India was used as the metal precursor for the selenium nanoparticle synthesis.

4.2 SELENIUM NANOPARTICLE SYNTHESIS BY CHEMICAL SYNTHESIS METHOD

A 1 mM sodium selenite solution was prepared by adding 0.17294 g of sodium selenite as the metal precursor. It was dissolved in 100 mL of deionized water. This solution was kept under stirring using a magnetic stirrer for 24 hours. A 1 % acetic acid solution was prepared by adding 1 mL of acetic acid to 99 mL of deionized water. To this solution, 0.5 g of chitosan was slowly added to prevent agglomeration. This acetic acid solution was kept stirring for 24 hours (Sowmiya et al., 2023).

The 1 mM sodium selenite solution was added to the acetic acid solution while the solution was maintained in the mixing regime. 10^{-3} ascorbic acid solution was prepared by adding 0.17612 g of ascorbic acid to 100 mL of deionized water. This solution was stored in an amber bottle to prevent it from getting denatured by light.

20 mL of ascorbic acid was added in a burette, and this was attached in a position above the mixed solution while stirring using a magnetic stirrer. The ascorbic acid was slowly mixed drop by drop with the metal precursor solution until a colour change was observed from orange to brick red. An additional 30 mL of ascorbic acid can be added to bring about the exact colour change.

The prepared nanoparticle solution was centrifuged, and the pellets were collected. The solution was transferred to tubes and spun for 20 minutes at 27°C and at 7500 revolutions per minute. The pellets contain chemically synthesised selenium nanoparticles.

4.3 CHARACTERIZATION

The UV absorbance of the synthesized selenium nanoparticles was measured using UV-1800, Shimadzu Japan. The UV absorption spectrum was measured from 200 to 800 nm.

4.3.1 PARTICLE SIZE ANALYSIS AND ZETA POTENTIAL

The particle size analyser used was Nanopartica PSA, HORIBA, Japan. Zeta potential measurement and particle size analysis are crucial methods for describing colloidal systems and nanoparticles. By analysing the size distribution of the particles in a sample, particle size analysis can reveal important details about the physical characteristics and behaviour of the particles (Soares et al., 2014). Conversely, zeta potential measurement measures the amount of electric charge surrounding particles scattered in a liquid media in order to evaluate the electrokinetic stability of colloidal suspensions. The repulsive forces between the particles are impacted by this charge, which also has an impact on the particles' stability, aggregation, and interactions with other parts of the system (Bourgeat-Lami et al., 2016).

4.4 METHODS FOR FILM FABRICATION

The gelatin powder was dissolved in deionized water at a temperature of 60°C and placed on a magnetic stirrer with a hot plate. The deionized water was kept under constant agitation, and the gelatin was allowed to completely dissolve.

Multiple combinations were tried out, using bio-polymers like gelatin, polyvinyl alcohol, sodium alginate, calcium chloride, pectin and glycerol. The combinations were carried out in different concentrations as mentioned in the table 4.1, and the best combination was found out using trial and error method.

After the dissolution of gelatin, the polymers responsible for elasticity were added, which are PVA, sodium alginate and calcium chloride was tried out as a stability inducing agent. The resulting solutions were cast onto glass plates for drying. The

synthesized films were dried for a period of 24 hours at standard room temperature conditions (25°C). For a final touch, the films were dried in a Riviera Rivotek vacuum oven at 50°C for 10 minutes to remove any wet spots and to preserve the films for a longer period from potent fungal contamination.

This step was done with care, as longer exposure periods to such high temperatures could lead to the charring of the films and make them stick to the substrate in an irreversible manner.

Table 4.1: Concentration of different polymers for the film-casting solution

Sample	Gelatin (%)	Polyvinyl Alcohol (%)	Sodium Alginate (%)	Calcium Chloride (grams/ 100 mL)	Pectin (%)	Glycerol (mL)	Selenium NP (mL)
S1	1	0.5	-	-	0.5	1.2	-
S2	1	0.5	-	-	0.5	1.2	1
S3	4	0.5	-	-	0.5	1.2	-
S4	4	0.5	-	-	0.5	1.2	1
S5	4	-	-	-	1	1.2	-
S6	4	-	-	-	1	1.2	0.4
S7	-	-	1	0.03	1	1.2	-
S8	-	-	1	0.03	1	1.2	0.4
S9	-	-	1	0.01	1	1.2	-
S10	-	-	1	0.01	1	1.2	0.4
S11	-	-	1.25	1	2.5	1	-
S12	-	-	1.25	1	2.5	1	0.4
S13	-	-	1.25	1	2.5	5	-
S14	-	-	1.25	1	2.5	5	0.4
S15	-	0.5	0.5	0.03	1	1.2	-
S16	-	0.5	0.5	0.03	1	1.2	0.4

After the physical examination of all these combinations, the most favourable combination was chosen to proceed with the final product. The concentration was chosen on the basis of the film's feasibility of getting separated from the glass

substrate after complete drying without any tears or breaks. Some of the concentrations did not yield positive results, as they dried up to become dehydrated, brittle sheets with little or no elasticity. Those combinations were excluded, and based on the method of trial and error, the best polymer concentration that offered the highest elasticity and physical integrity was chosen and is given in the table 4.2

Table 4.2: Finalized concentration of the polymers in the gel casting solution
(Values are given for 1 litre)

	Gelatin (g)	PVA (g)	Pectin (g)	Glycerol (g)	Starch solution 2% (mL)	SeNP (mL)
PG	8.333	4.166	4.166	6	166.666	-
PGN	8.333	4.166	4.166	6	166.666	2

Starch solution was added to act as a cross-linker to form bonds between the polymers. The starch solution was prepared separately, as 3.333 g of starch powder was added to 166.666 mL of deionized water at 60°C, such that the starch powder dissolves completely and a clear, transparent solution is obtained. This solution was then mixed with the volume of 833.334 mL of the polymer gel casting solution with all the above-mentioned polymer powders mixed in a uniform state before the addition of the plasticizer (glycerol) to initiate the cross-linking activities.

4.4.1 PECTOGEL NANOBIOWRAP (PGN) FABRICATION

The synthesized film solution was kept in stirring at a temperature of 50°C to 60°C. The SeNP solution was vortexed and sonicated respectively for about 10 minutes, to remove any clots or agglomerations. The SeNP solution was taken in a pipette and transferred to the gel casting solution, and this solution was cast onto glass plates for drying.

The casting process was done by adding the solution as horizontal lines using a 1 mL pipette. The gel solution was casted evenly on the glass plate with top care to prevent the formation of air bubbles, as these bubbles would evaporate and create holes, leading to the easy disintegration of the film during wear and tear activities. The

films were dried for a period of 24 hours at standard room temperature conditions (25°C). After complete drying of the films, the films were dried in a vacuum oven at 50°C for 10 minutes to remove any wet spots and to preserve the films for a longer period from potent fungal contamination. The glass plates were retrieved from the oven and the film was carefully peeled off from the glass substrate and pasted onto clean and wiped low density polyethylene support bases, for storage purposes. The films along with their support bases were stored in a desiccator to prevent any contaminations.

4.5 FTIR ANALYSIS

The Fourier Transformed Infrared Microscopy was performed with the Agilent Cary 630-ATR FTIR instrument. The results were used to identify the functional groups. Through FTIR spectroscopy, the chemical composition, molecular structure, and interactions within the composite films can be thoroughly investigated. Researchers have employed FTIR to study the incorporation of various additives such as nanoparticles, antimicrobial agents, and natural extracts into polymer matrices, elucidating their effects on the film's properties (Zolfi et al., 2014).

The films (PG and PGN) were cut into squares with sides of 2 cm. The films were placed under the tip and the screws were tightened until the sample was held in a firm position. The infrared ray passes through the sample, and the vibrations of the chemical bonds in the structure of the films absorb some of the radiation. This absorbed amount is detected by the detector, across a series of wavelengths. This produces a unique fingerprint like structure for every composite film.

4.6 PHYSICAL PROPERTIES OF THE FILM

The physical properties of the nanoparticle incorporated Pectogel nanobiowrap were assessed, and were compared with the Pectogel biowrap and the results were documented.

4.6.1 MOISTURE CONTENT EVALUATION ASSAY

An important analytical method for analysing composite films' water uptake behavior which is critical for determining their stability and performance in humid environments is the moisture content test. In this assay, the composite films are exposed to regulated moisture levels, and the weight gain that results from water

absorption is then measured. Studies reveal that a number of characteristics, including structure, content, and processing settings, have a major impact on the kinetics of moisture absorption. In practical applications, the resistance of the film to water penetration and its shelf life can be improved by optimising material compositions and processing conditions with the help of an understanding of the behaviour of moisture content. The methodology was obtained from (Núñez-Flores et al., 2012) and the protocol was drafted and modified to accommodate the films.

The moisture content of the film was calculated by measuring the initial dry weight of the film size of 2 cm x 2cm and placed it in a beaker containing 15 mL of water for 15 minutes. The film was then collected, and the final weight was calculated. Moisture content was calculated by;

$$\text{Moisture content (\%)} = \left[\frac{M_i - M_f}{M_i} \right] * 100$$

where,

M_i – initial weight of the film

M_f – final weight of the film

4.6.2 SWELLING PROPERTY EVALUATION ASSAY

The films were cut into squares with sides of 2 cm. They were immersed in 25 mL of distilled water at room temperature. The weight gain of swollen films (W_s) was measured for 50 minutes by taking 5 readings at standard intervals of 10 minutes. Undissolved films were removed with Whatman No. 1 filter paper (Scarfato et al., 2017).

The Swelling Ratio (SR) was calculated using the following equation:

$$\text{Swelling ratio (\%)} = \left[\frac{W_s - W_d}{W_d} \right] * 100$$

where,

W_s – weight of the swollen film

W_d – initial weight of the dry film

4.6.3 WATER SOLUBILITY ASSAY

The films were cut into squares with sides of 2 cm. They were placed in beakers with 15 mL of distilled water, then sealed with parafilm and kept undisturbed for 4

hours. The solution was then filtered with Whatman no.1 filter paper to recover the remaining undissolved film. Water solubility (WS) of films was determined according to the method described by Nunez-Flores et al. (2013).

Water Solubility was calculated by;

$$\text{Water solubility (\%)} = \left[\frac{W_i - W_f}{W_i} \right] * 100$$

where,

W_i – initial weight of the film

W_f – final weight of the film

4.6.4 OPACITY ANALYSIS

The absorbance of the films was calculated to incorporate the rate of absorption into the formula for the calculation of opacity. The film was cut into dimensions of 5 cm x 2 cm and fixed sternly onto a clear glass slide without the possession of air bubbles and the glass slide was made sure that it was devoid of fingerprints or any interfering obstacles.

The opacity analysis was done by measuring the thickness of the film using the Stylus Profilometer. The absorbance of the films was measured using the UV 1800 UV visible spectrophotometer and the valued were substituted in the formula.

The opacity of the film was measured by using the formula:

$$\text{Opacity} \left(\frac{A}{\mu m} \right) = \left[\frac{\text{Absorbance @ 600 nm}}{\text{Thickness}} \right]$$

4.6.5 TENSILE STRENGTH AND ELONGATION AT BREAK

The tensile strength analysis and elongation at break were performed on the synthesised samples. Tensile strength analysis is vital to test the elasticity of the films and make sure that they are on par with market standards. For composite films, tensile strength and elongation at break are essential mechanical characteristics since they dictate the film's capacity to tolerate external forces and deformations without rupturing. Tensile strength, which reflects a material's structural integrity and endurance under strain, is the highest stress it can withstand before breaking. Elongation at break, on the other hand, gauges a material's ductility and flexibility by indicating how far it can stretch before breaking. The film's ability to tolerate mechanical loads during handling and use is guaranteed by its high tensile strength,

and its adequate elongation at break allows for flexibility and distortion without catastrophic collapse.

The mechanical properties (TS and Eb) of the films were investigated by the Universal Testing Machine (Computer-Controlled Universal Testing Machine, M-50,2022/81). The dimensions of the test films were 140 mm x 23 mm. The PG, PGN and Commercial films were cut in the above given dimensions, and they were subjected to testing in the universal testing machine.

4.7 CONTACT ANGLE MEASUREMENT AND SURFACE ENERGY:

The basic ideas in surface science, contact angle and surface energy are often employed to describe the wetting behaviour and surface characteristics of materials. The balance of intermolecular forces between the liquid, solid, and vapour phases is represented by the contact angle, which is the angle created between the tangent to the liquid-solid interface and the solid surface. The interaction between the surface and its surroundings determines surface energy, which, on the other hand, measures the energy needed to form a unit area of the surface.

The water contact angles of the commercial PG and the nanoparticle-incorporated PGN wrap were measured. The film was cut into the size to fit inside a glass slide (5 cm x 2 cm) and sealed on top of the glass slide without any air bubbles. This setup was used to measure the contact angle and the surface energy of the films using water as the standard. The water contact angle and surface energy were measured using the Rame Hart Model 90 Goniometer, New Jersey, USA. Contact angle measurements were done by using a 3 µl droplet of deionized water addition on the surface of the samples.

4.8 DPPH RADICAL SCAVENGING ASSAY

DPPH (2,2-diphenyl-1-picrylhydrazyl) is a chemical which scavenges free radicals. It is a dependable technique for determining antioxidant activity, and the food packaging industry uses it widely (Atarés & Chiralt, 2016). Its use entails assessing the effectiveness of antioxidants added to packing materials to stop oxidative processes from causing food to deteriorate. This technique is frequently used to assess the antioxidant potential of edible coatings applied to food surfaces and active packaging films containing natural extracts (Samsudin et al., 2017). Additionally, the

usefulness of antioxidant additives in prolonging the shelf life of packed goods is assessed, and the antioxidant qualities of packaging materials infused with plant-derived compounds are evaluated through the use of DPPH assays. All things considered, the use of DPPH tests in the food packaging sector makes it easier to create creative packaging solutions that improve food safety and quality by reducing oxidative deterioration (Caleb et al., 2013).

The gel casting solution of the film was used to perform the DPPH radical scavenging assay. The stock solution was prepared by dissolving 0.00394 g of DPPH in 100 mL of methanol. The working standard was prepared by adding 10 mL of the stock solution to 45 mL of methanol.

1.425 mL of the gel casting solutions were prepared according to the protocol (PG and PGN films solutions) were taken in Eppendorf tubes, and 0.075 mL of the prepared working standard DPPH was added to the tubes. This solution was incubated for 30 minutes. The purple colour given by the DPPH chemical slowly begins to disappear in the presence of antioxidants. It reacts with the antioxidants present in the sample, and these samples are then transferred to a 96-well plate, and the absorbance is measured at 517 nm. The readings were obtained and the scavenging activity was calculated using the formula:

$$\text{Scavenging Activity (\%)} = \left[\frac{A_o - A_i}{A_o} \right] * 100$$

where,

A_o – value of the blank

A_i – optical density of sample at 517 nm

4.9 BIODEGRADABILITY ASSESSMENT ASSAY

Environmental elements including heat, light, moisture, and chemical agents are frequently applied to composite films, and this can cause deterioration over time. In addition to chemical modifications like polymer chain scission or cross-linking, the degradation pathways could also involve physical changes like loss of mechanical strength. Evaluating variables including degradation rate, mass loss, modifications to mechanical characteristics, and surface morphological changes is part of studying the behaviour of degradation. Studies have indicated that the kinetics and mechanisms of composite film degradation are greatly influenced by variables such as the kind and

concentration of additives, the composition of the polymer matrix, and the processing parameters. Comprehending these attributes facilitates the creation of composite films that exhibit enhanced resilience against deterioration, augmenting their robustness and longevity in practical uses.

4.9.1 SOIL DEGRADATION ASSAY

The Biopolymer film PG and PGN were buried separately under red soil collected from a nursery and beach soil from the coastal areas of Chennai. The film was cut into a square with sides of 2 cm and the samples were buried at a depth of 5 cm from the surface and was observed for a period of 3 weeks. Two soil environments were maintained, one was wetted regularly to maintain the moisture content and to support the wild microorganisms and another was kept dry. Small holes were made in a LDPE film and the film was placed on top of it, for easier retrieval and observation.

4.9.2 WATER DEGRADATION ASSAY

PG and PGN films were subjected to degrade in salt and RO water to check their biodegradable nature in the open environment, as one of the batches was conducted in an ideal state, while the other batch of samples were kept in an environmental shaker throughout the day to mimic the environment. The film was cut into squares of sides of 2 cm and was placed inside the beaker containing water maintained at the natural environmental parameters. The experiment was carried out for 2 to 3 weeks, until complete dissociation or degradation was observed.

4.9.2.1 SEA WATER DEGRADATION ASSAY

Two pairs of PG and PGN films were cut into squares of sides 2 cm were placed inside the pair of beakers containing sea water. The sea water was mildly filtered using cotton, and the diverse microbial environment in the water was maintained. One pair of beakers is placed in the ideal state, without any disturbances to depict the natural environments of stagnant water and another pair was kept in an environmental shaker to mimic the turbid marine environment.

4.9.2.2 REVERSE OSMOSIS TREATED WATER DEGRADATION ASSAY

Two pairs of PG and PGN films were cut into squares of sides 2 cm were placed inside the pair of beakers containing sea water. One pair of beakers is placed in the

ideal state, to mimic the lakes and stagnant fresh water bodies and another pair is kept in an environmental shaker to depict the vibrant dams and agitated water bodies.

4.10 COMPATIBILITY TESTING

The film was put into real-time testing using corn to check its preserving efficiency in comparison with the control and commercial ones. These films are made of two or more components, most frequently polymers along with additional reinforcements or additives. They provide barrier qualities against gases like oxygen and ethylene, which can hasten ripening and decay, among other uses in prolonging the shelf life of perishable goods. Furthermore, composite films can reduce spoilage brought on by microbial growth and physical damage by providing mechanical strength, flexibility, and antibacterial qualities. To further improve preservation efficacy, they can also be engineered to release active substances like antioxidants or antibacterial agents.

The synthesized film was used to wrap baby corn (*Zea mays*) purchased freshly from the market. The corn's dry weight was calculated, and one piece was kept uncovered; another was wrapped with the commercial biodegradable wrap purchased from the market; another with the Pectogel biowrap; and another with the Pectogel nanobiowrap. The protocol was adopted from the research work (Long et al., 2022) and modified according to the need. The packed samples were kept in an environment to study their resistance against environmental microbes at room temperature. The samples were handled with sterile hands every day, and the weight of the samples was measured. The weight loss was computed, and a weight loss bar diagram was drawn to study the weight loss percentage for every alternate day. The corn was then finally unwrapped after 7 days, and photographs were taken to study the effects.



Fig 4.1: Baby corn wrapped with the films

4.11 ANTIBACTERIAL ACTIVITY

Nanoparticle-infused composite films have strong antibacterial activity, making them intriguing materials for a range of uses, especially in the biomedical and food packaging industries. When bacteria come into touch with the distributed nanoparticles inside the polymer matrix of the composite films, they release ions or produce reactive oxygen species, which causes oxidative stress, damage to the bacterial cell membrane, and eventually bacterial death. The protocol was obtained from the research works and modified to accommodate the films (Welch et al., n.d.).

P. aeruginosa and *S. aureus* broth cultures in the ratio of culture: broth = 1:100 was introduced to freshly prepared medium, rinsed with phosphate-buffered saline, and incubated for a full day at 37 °C in an orbital shaker. Figure 4.9 depicts the configuration of the films arranged in a 24-well plate. The first two rows from the top were meant for the assay using *P. aeruginosa* and the next two rows were used to recognize the activity against *S. aureus*. The wells were filled with plain media, the square films along with media to understand their dispersion and the other wells hosted the bacterial cultures and the films respectively. The film was cut into squares with sides of 1 cm and placed firmly at the bottom of the 24-well plate in a sterile manner. The films were placed in the assigned wells and 2 mL of the bacterial cultures were added. The plate was sealed in a sterile manner using parafilm and was covered on all the four sides to prevent contamination.

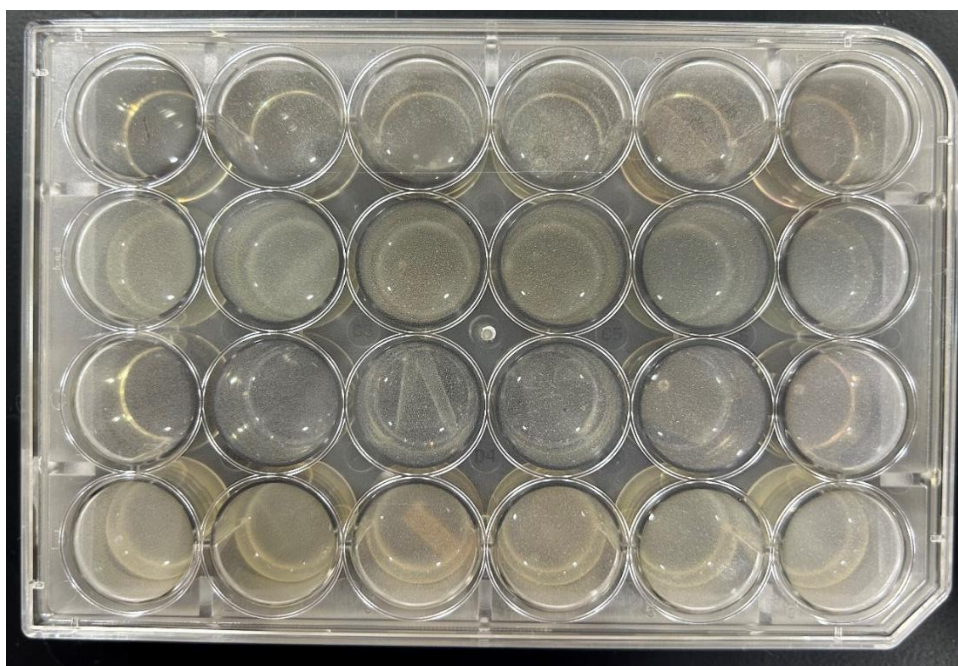


Fig 4.2: Films placed inside the 24-well plate for biofilm inhibition assay

After incubating for 24 hours, the films and the bacterial culture was discarded. Phosphate buffer saline was used to rinse the left-over film and media components. The biofilm was fixed to the surface using 70% ethanol for 20 minutes, to conserve it from disintegrated from further processes. The ethanol was removed and 200 µl of crystal violet was added to the wells and incubated for 20 minutes for staining the biofilm forming bacteria. Crystal violet is a cationic dye that has the ability to attach itself to the bacteria and extracellular polymeric substances (EPS) in the biofilm matrix, staining the entire biofilm and enabling measurement and visualisation. The crystal violet was removed and the wells were washed with phosphate buffer saline for three times. 30% acetic acid was prepared and added to the wells and incubated for 10 minutes for dissolving the crystal violet from the adhering biofilm, for quantifying purposes. 200 µl of the incubated acetic acid was recovered from each well, and transferred to a sterile 96-well plate for measuring the absorbance at 570 nm.

Using a Synergy H1 Biotek, USA microplate reader, the adhering cells' optical density was measured. and the antimicrobial activity was assessed.

4.12 BIOCOMPATIBILITY ANALYSIS

The product film contains selenium nanoparticles, a slightly toxic metal to the human body if consumed beyond the recommended limits. A research study conducted on *P. caudatum* revealed that up to 800 mg/L of selenium nanoparticles are non-toxic to the organism(Badgar et al., 2021). For correlating this, the amount of nanoparticle that can be potentially infused into the food product has to be calculated. The surface area that is potentially required to cover a food material, in our case study, baby corn (*Zea mays. L*) was calculated and this amount has to be compared with the safety regulation limit. The films were prepared by drying up droplets of 0.5 mL, 0.25 mL and 0.125 mL of the film casting solution onto glass plates and were dried and recovered. The weight of these films was measured, to infer with the amount of possible nanoparticle infusion into the food product.

The amount of biomagnification should also be taken into account, as the consumption rate can increase the deposition of the metal inside the body.

5. RESULTS AND DISCUSSION

5.1 SELENIUM NANOPARTICLE CHARACTERIZATION

5.1.1 UV-VISIBLE SPECTROSCOPY

UV-Vis Spectroscopy (also known as Spectrophotometry) is a quantitative method for calculating how much light an individual molecule absorbs. This is accomplished by comparing the amount of light that passes through a sample to the amount of light that goes through a reference sample or a blank. It is a common practise to measure selenium nanoparticles (SeNP) using its UV absorption, which commonly occurs at 200 - 300 nm (Jayavardhini et al., 2022). The absorption peak was observed at 250 nm. The absorbance maxima of Se nanoparticles fabricated with reducing agents, including carboxylic groups are predicted to be in the 200-300 nm range and this confirms the presence of selenium nanoparticles.

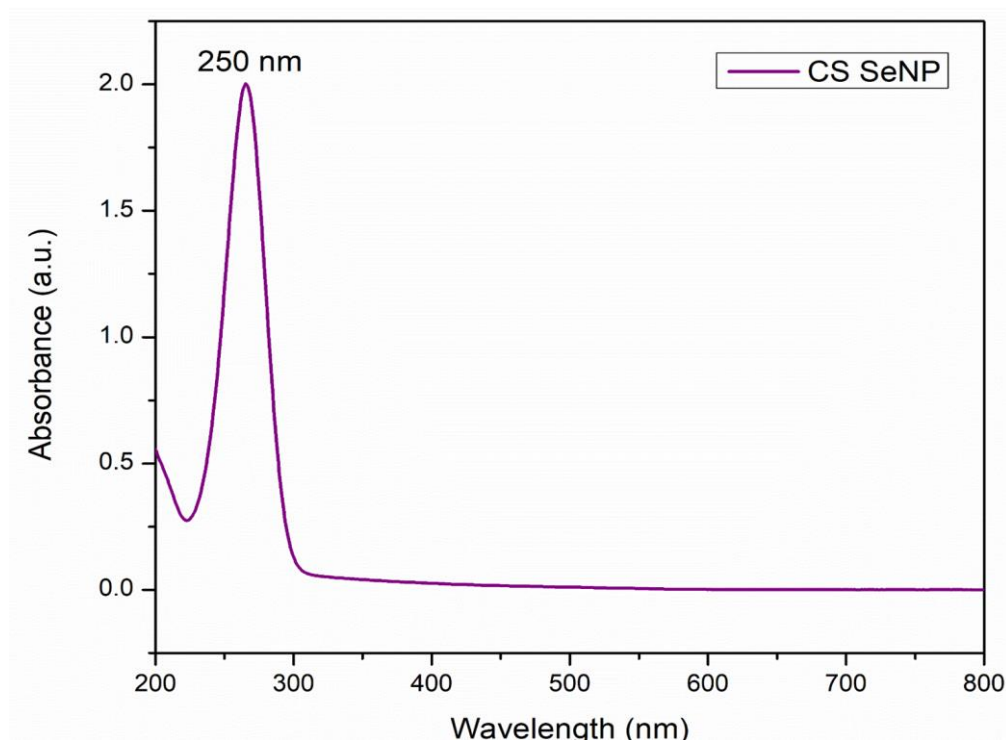


Fig 5.1: UV-visible spectroscopy of Selenium Nanoparticle

5.1.2 PARTICLE SIZE ZETA POTENTIAL

The phrase particle size analysis refers to a variety of technical approaches used in laboratories to estimate the size distribution and/or average or mean size of the particles in a powder or liquid sample. The particle size analysis results are shown in Figure 5.2. The average size of the particle is found to be around 164 nm. The selenium nanoparticles are reduced during the synthesis process, which can introduce

several functional groups such as carboxyl, hydroxyl and epoxy groups, which could have possibly resulted in the particle size band of 150 – 200 nm.

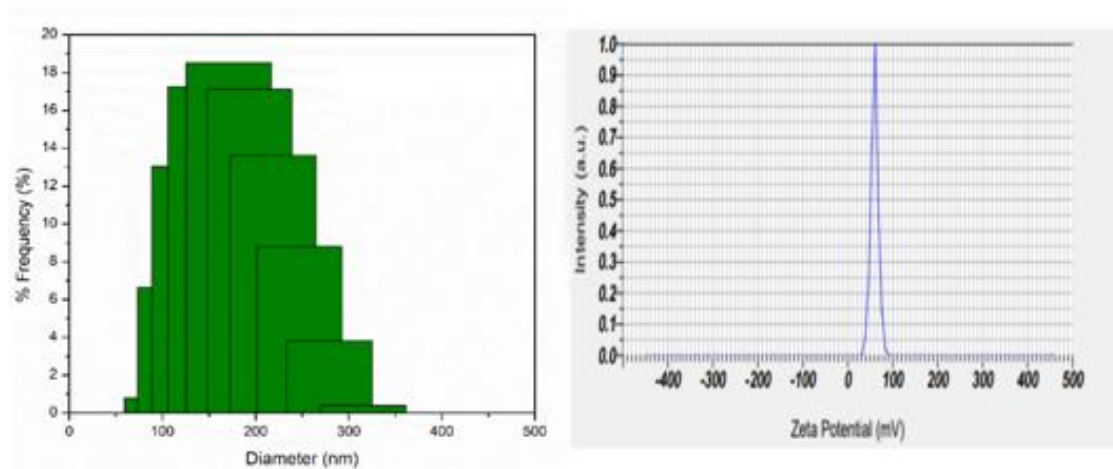


Fig 5.2: Particle size and zeta potential of selenium nanoparticles

The stability of nanoparticles in suspension depends on the zeta potential, which also plays a significant role in the initial adsorption of nanoparticles onto the cell membrane. The mobility is counted positive if the particles move toward lower potential and negative in the opposite case. (Rasmussen *et al.*, 2020). Zeta potential of selenium nanoparticles is found to be 59.6 mV, as shown in Figure 5.2. The zeta potential of nanoliposomes directly relates to their stability; a value of +30 mV or less than -30 mV is regarded as appropriate for the vesicle's stability. The more the nanoliposomes oppose and resist the formation of aggregates, the higher the absolute value of zeta potential.

5.2 FILM FABRICATION

The film was prepared by casting the gel-casting solution onto clear glass plates. They were completely dried, and were peeled from the glass surface without any breaks or tears. The elasticity and the similarity of the film to the plastic wraps that are being used in the market, were clearly visible while peeling the film from the glass plate (Bierhalz *et al.*, 2012). The films were synthesized by modifying the protocol from the publication and the extraction process yielded supportive and similar results. The films were peeled and stuck onto sterile and stern low density polyethylene support and were stored in an airtight chamber or in a desiccator to protect it from environmental fungi.



Fig 5.3: Pectogel Nanobiowrap

5.3 FTIR ANALYSIS

5.3.1 FTIR OF COMMERCIAL FILM

FTIR is used in the characterization of unknown materials. The FTIR peaks were compared with the peaks of the stored polymers in the library. It was found that the FTIR had a close relation with the Polyethylene peaks obtained in the research work (D'amelia et al., 2016). The film's FTIR reading also had a close relation with the polyethylene readings stored in the Agilent polymer handheld ATR library as seen in Figure 5.4. The peaks at 2850 cm^{-1} and 2910 cm^{-1} are the indicators of polyethylene, and these peaks were obtained in close relation with the library pre-stored modules.

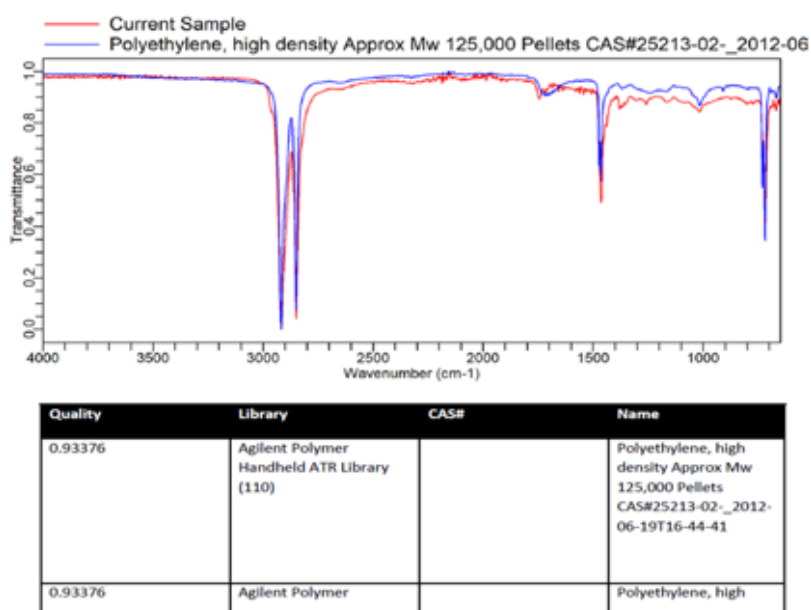


Fig 5.4: FTIR results of Commercial film

5.3.2 FTIR OF PECTOGEL BOWRAP

The peaks at 3278.2 cm^{-1} signifies O-H stretching signifies the presence of polyvinyl alcohol, and the 2953 to 2883 cm^{-1} depicts the presence of polyvinyl alcohol's C-H stretching vibration of the alkyl groups (Sun et al., 2022). The peaks at 1638.2 cm^{-1} represent the C=O stretching carbonyl bonds giving the presence of pectin and the peak at 1545.9 cm^{-1} depicts the C=O stretching, denoting the presence of gelatin (Zhang et al., 2013). The peak at 1239.3 cm^{-1} signifies the aliphatic C-C stretching of the bonds. The peak at 1019.4 cm^{-1} gives states the presence of N-H amide (I) stretching denoting the presence of cross-linking bonds formed by the starch polymer (Zhang et al., 2013), and the final peak at 851.7 cm^{-1} denotes N-H bending. The peaks at 2931 cm^{-1} – 2935 cm^{-1} depict the C-H stretching vibrations of the methylene groups of pectin (Asfaw et al., 2023).

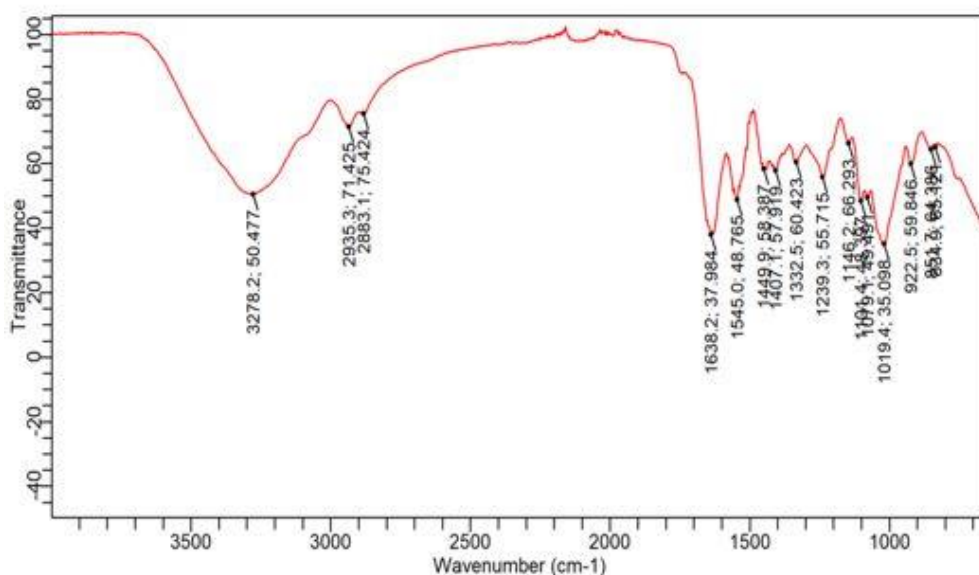


Fig 5.5: FTIR results of Pectogel biowrap

5.3.3 FTIR OF PECTOGEL NANOBOWRAP

The peaks at 3278.2 cm^{-1} signifies O-H stretching signifies the presence of polyvinyl alcohol, and the 2953 to 2883 cm^{-1} depicts the presence of polyvinyl alcohol's C-H stretching vibration of the alkyl groups (Sun et al., 2022). The peaks at 1638.2 cm^{-1} represent the C=O stretching carbonyl bonds giving the presence of pectin and the peak at 1545.9 cm^{-1} depicts the C=O stretching, denoting the presence of gelatin (Zhang et al., 2013). The peak at 1239.3 cm^{-1} signifies the aliphatic C-C stretching of the bonds. The peak at 1019.4 cm^{-1} gives states the presence of N-H amide (I)

stretching denoting the presence of cross-linking bonds formed by the starch polymer (Zhang et al., 2013), and the final peak at 851.7 cm^{-1} denotes N-H bending. The peaks at 2931 cm^{-1} – 2935 cm^{-1} depict the C-H stretching vibrations of the methylene groups of pectin (Asfaw et al., 2023). The peak at 672.8 cm^{-1} denotes the vibrations of the metal selenium nanoparticles, signifying the presence of selenium nanoparticles in an active nature inside the film.

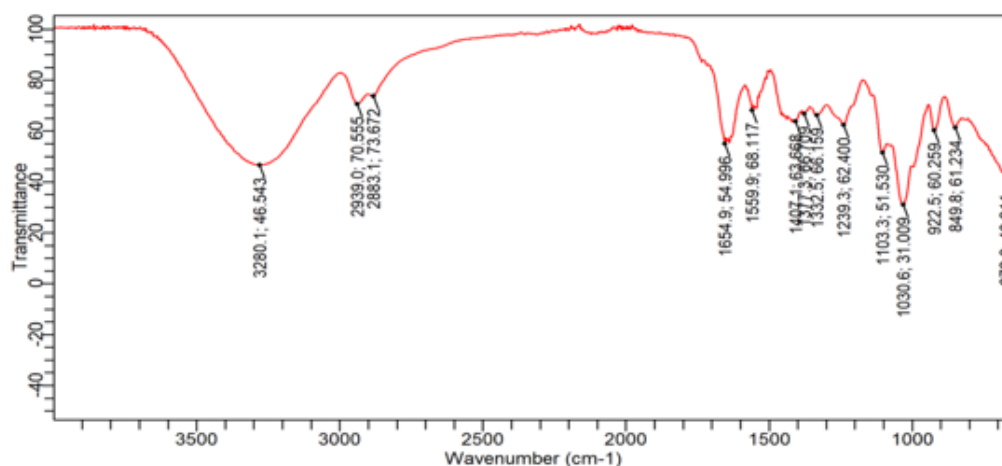


Fig 5.6: FTIR results of Pectogel nanobiowrap

5.4 PHYSICAL PROPERTIES ANALYSIS

The physical property tests for the synthesized samples were carried out, and the results were promising.

5.4.1 MOISTURE CONTENT EVALUATION ASSAY

On a comparison study of the PG film and the PGN film, the PGN film had a lower moisture content, which is ideal as a higher moisture content would invite a range of microorganisms, leading to contamination of the food material. The PG film displayed a moisture content percentage of 251.235%, which might serve as a breeding ground for microorganisms. The PGN film had a comparatively lower moisture content percentage of 204.955%, which signifies its unsaturated nature, and its ability to shield itself and the food material to be packaged inside from potent microorganisms. A lower moisture content also signifies that the film can accommodate more water vapours in its complex until it gets saturated, and this helps in the prevention of water vapour exchange between the environment and the product microsystem.

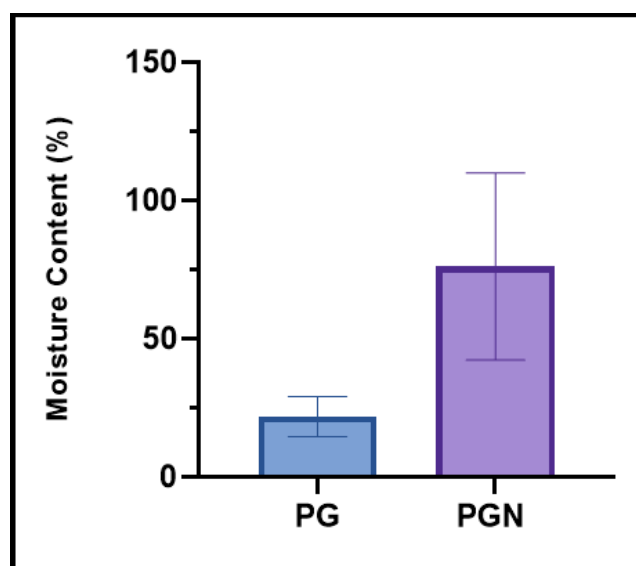


Fig 5.7: Moisture content percentage of the films

5.4.2 SWELLING PROPERTY EVALUATION ASSAY

The swelling ratio of the PGN film increases as it has higher water holding property compared to the PG film. Both the films displayed a good swelling rate until 30 minutes, as the PG film displayed a mean value percentage of 395% increase in its mass and the PGN film displayed a whopping 412.35% increase in mass. The values started to decrease after 30 minutes, as the film began to solubilize in the water, signalling its breakdown and disintegration. PGN film could absorb water at a better rate when compared to the PG film, serving ideal for food preservation. This shows that the film can act as a barrier between the food material and the environment. The film also has the ability to preserve the microenvironment inside the food material.

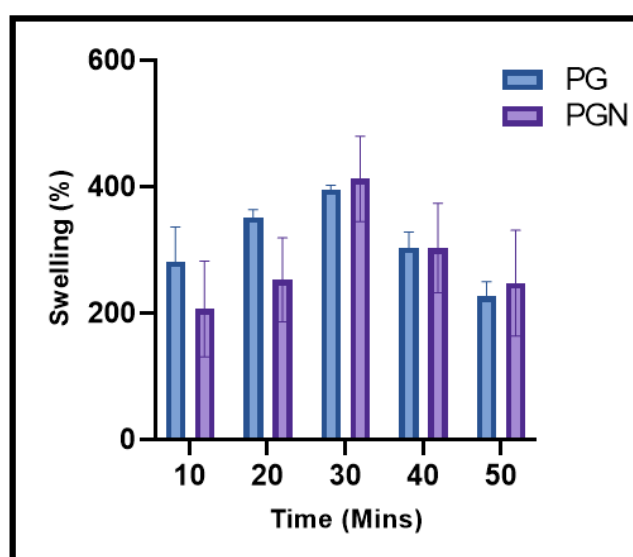


Fig 5.8: Swelling percentage of the films

5.4.3 WATER SOLUBILITY ASSAY

The solubility of edible film in water is an essential asset, and water resistance is typically mandatory for commercial applications of food packaging. After 15 minutes of being submerged in distilled water, the PG loses its shape. While the selenium nanoparticles incorporated PGN film, they were found to retain their integrity. The PG film had a solubility percentage of 104.92%, indicating its weak stability. The PGN film displayed a greater resistance to getting solubilised with water and had a comparatively lower solubility percentage of 83.33%. The addition of selenium nanoparticles to film caused a pronounced decrease in film solubility.

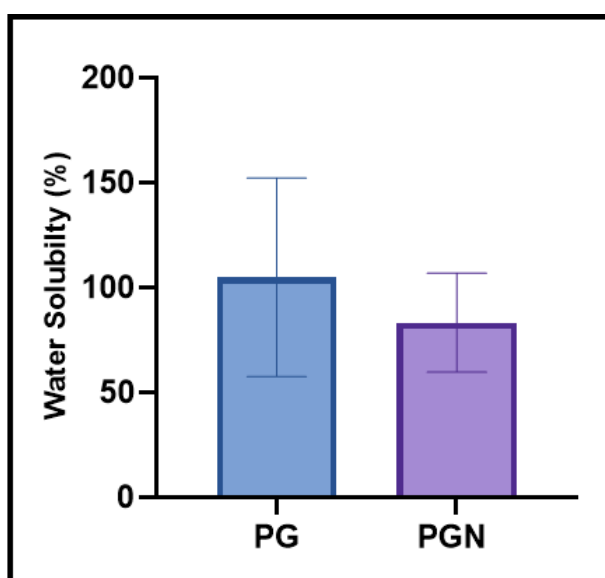


Fig 5.9: Water solubility percentage of the films

5.4.4 OPACITY ANALYSIS

The opacity results were promising enough to prove the barrier properties of the film. The nanoparticle incorporated film was opaquer compared to the control film, and this infers that the Pectogel Nanobiowrap can protect the food material from external radiations in a better and efficient manner, including sun light etc. which can damage the natural characteristics of the food material that is packed inside. While the Pectogel biowrap film could only offer 2.227 A/ μ m opacity, the Pectogel nanobiowrap offered 5.052 A/ μ m opacity. This displays the increased opacity of the film after the addition of the selenium nanoparticles.

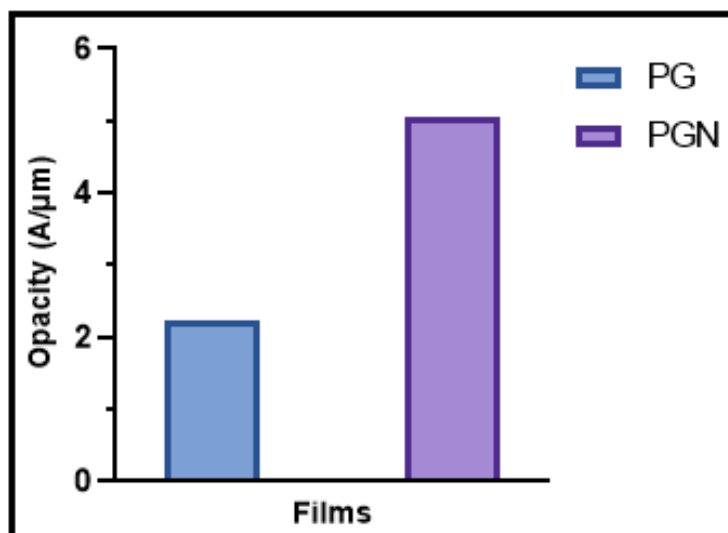


Fig 5.10: Opacity analysis of the film

5.4.5 TENSILE STRENGTH AND ELONGATION AT BREAK

PG film had an elongation at break at 12.564 mm and a tensile strength of 0.013 N/mm², whereas the PGN film had an elongation at break of 21.004 mm and a tensile strength of 0.233 N/mm². The tensile strength of PGN film improved significantly due to the selenium nanoparticle addition. The PG film had several breaking points as the load was increased, as the transition periods in the graph clearly give away the break or tear points. On the other hand, the PGN film had a suitable and efficient load management physical structure, as no break or tear was obtained until the load value reached 1.4 N. The commercial film also exhibited high load bearing capacities, due to the linear alignment of composed of long chains of ethylene monomer units (-CH₂-CH₂-). The chemistry behind stretching polyethylene bags lies in the arrangement of these polymer chains and the intermolecular forces within them. The bonds also result in the permanent deformation of the plastic film, while our product film had the ability to retract and heal if it is stretched and released until a certain point.

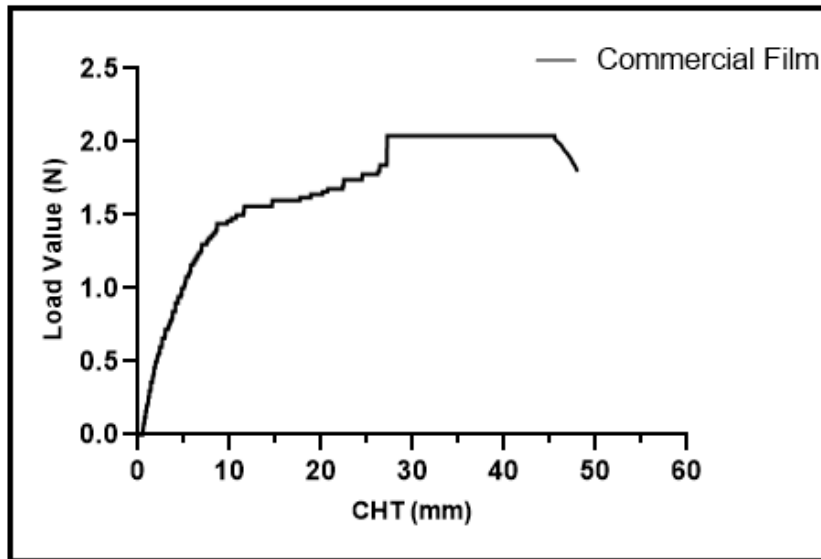


Fig 5.11: Tensile strength analysis of commercial film

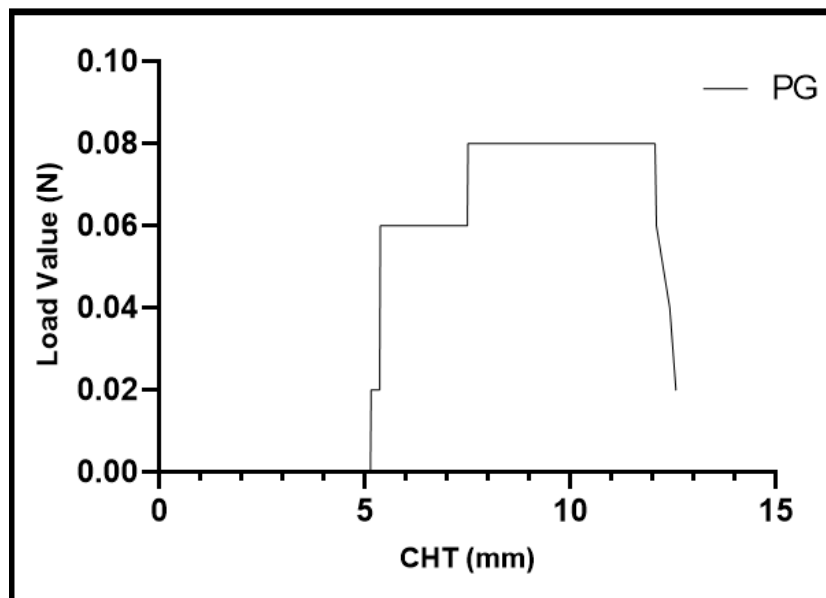


Fig 5.12: Tensile strength analysis of film PG

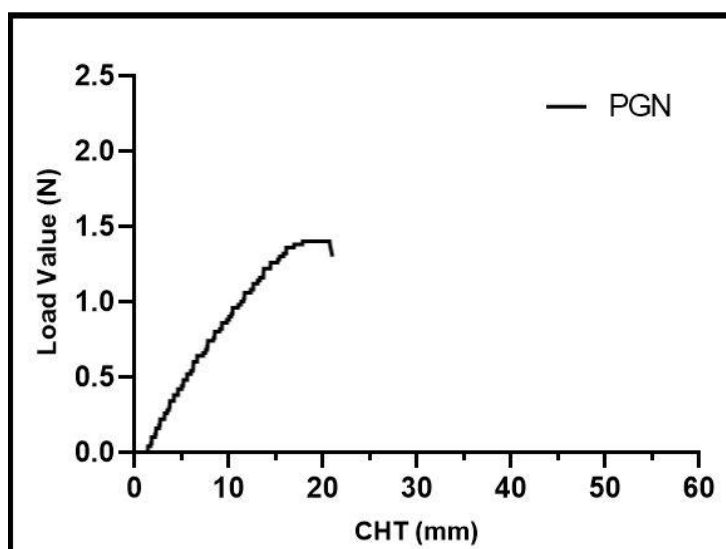


Fig 5.13: Tensile strength analysis of film PGN

5.5 CONTACT ANGLE MEASUREMENT AND SURFACE ENERGY ANALYSIS

Any value between 70° and 90° is considered to be hydrophobic, and a value below is considered to be hydrophilic (Latthe *et al.*, 2014). It was found that the commercial film had a water contact angle of 86.56° the PGN film had a contact angle of 74.98°, and the PG film had a contact angle of 48.29°. The water repelling rate of the PGN film was commanding enough to prove its hydrophobic nature, and this proves its ability to repel moisture from the surface of the food material and increase the shelf life of the packed food material.

The surface energy of the commercial film was 31.37 J/m², the PGN film was 38.62 J/m², and the PG film was 54.75 J/m². The lower surface energy of the PGN film competing in line with the commercial film is a standing point to prove the hydrophobic capacity of the film. The film interacts with the water molecules at a lower rate, which proves its barrier nature against the environmental moisture content.

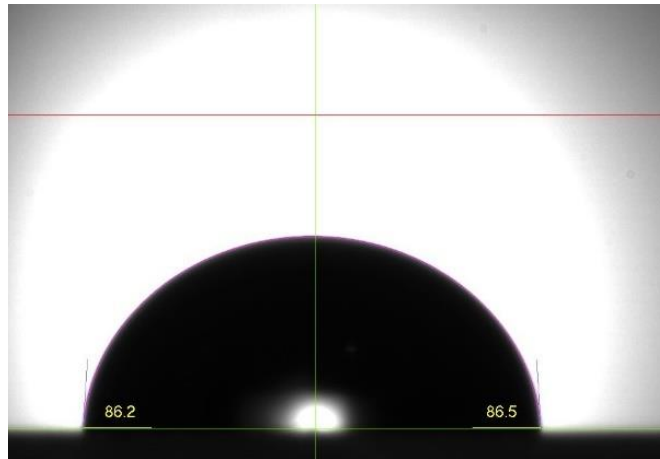


Fig 5.14: Droplet of water placed on commercial film

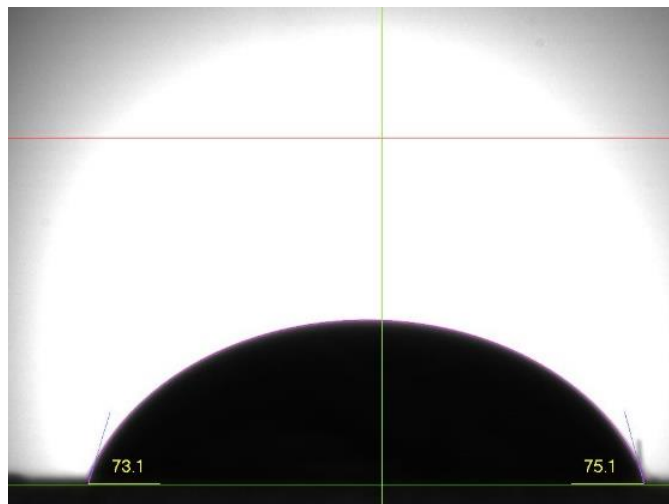


Fig 5.15: Droplet of water placed on PGN film

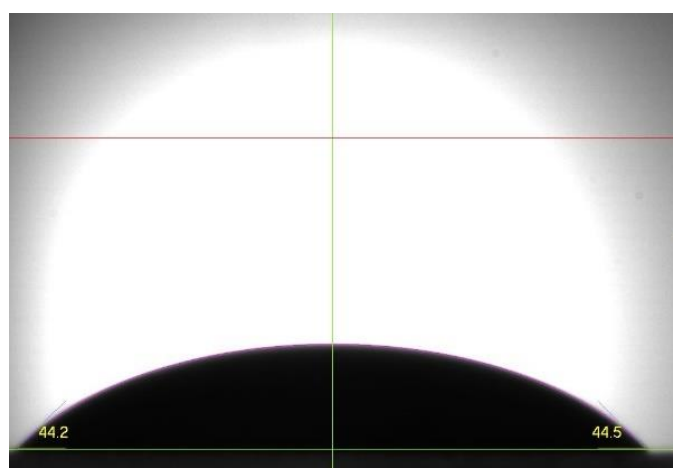


Fig 5.16: Droplet of water placed on PG film

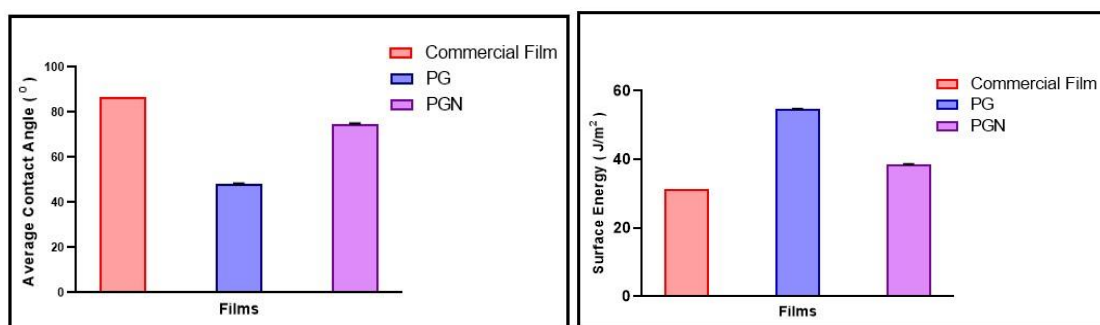


Fig 5.17: Average contact angle and the surface energy values of the films

5.6 DPPH RADICAL SCAVENGING ASSAY

The results obtained were promising enough to prove the preserving the nature of the film. The PGN film had a higher free radical scavenging rate, which proves that it could consume the free radicals that emerge from the packaged food material, and increase its shelf life. The PGN film had a scavenging activity percentage of 94.69% and the PG film had a scavenging activity percentage of 69.56%. The higher scavenging activity of the film assures its ability to preserve the food for a longer life span, a property that is lacked by the plastic films that are currently being used in the market.

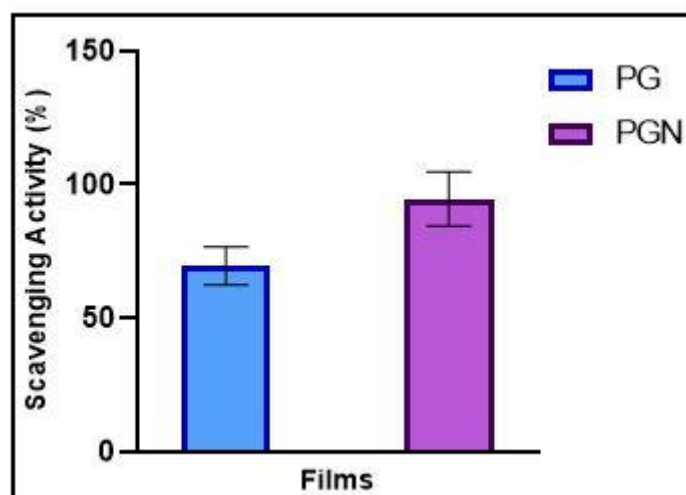


Fig 5.18: DPPH radical scavenging assay of the films

5.7 BIODEGRADABILITY ASSESSMENT ASSAY

5.7.1 DRY SOIL

The tests were performed in dry soil, and the results were promising enough to prove the biodegradable nature of the films.

5.7.1.1 DRY RED SOIL

The film on the first day buried in red dry soils exhibited no change except a little discoloration after 24 hours in the soil. On the second day, after being buried for 48 hours, The film shrunk but has its characteristics. On the 21st day, parts of the film were visually disintegrating and had broken down into pieces. Even in the harsh red soil dry conditions, biodegradable films demonstrate a capacity for eventual degradation.

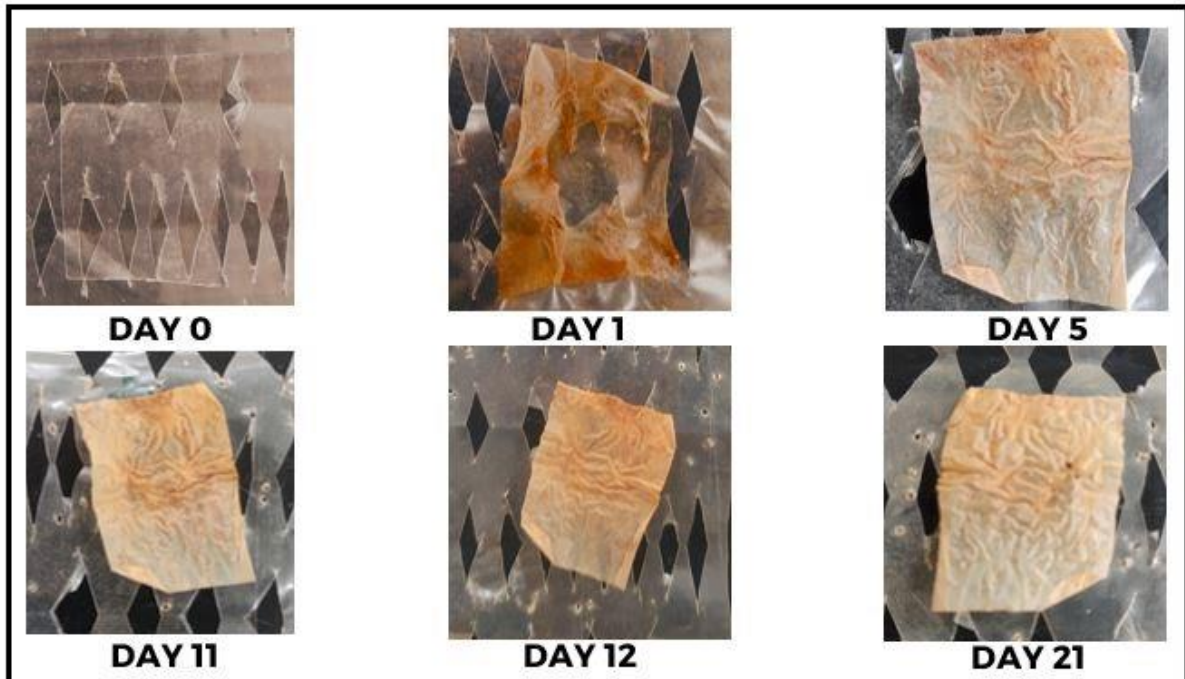


Fig 5.19: Degradation assay of PG film in dry red soil

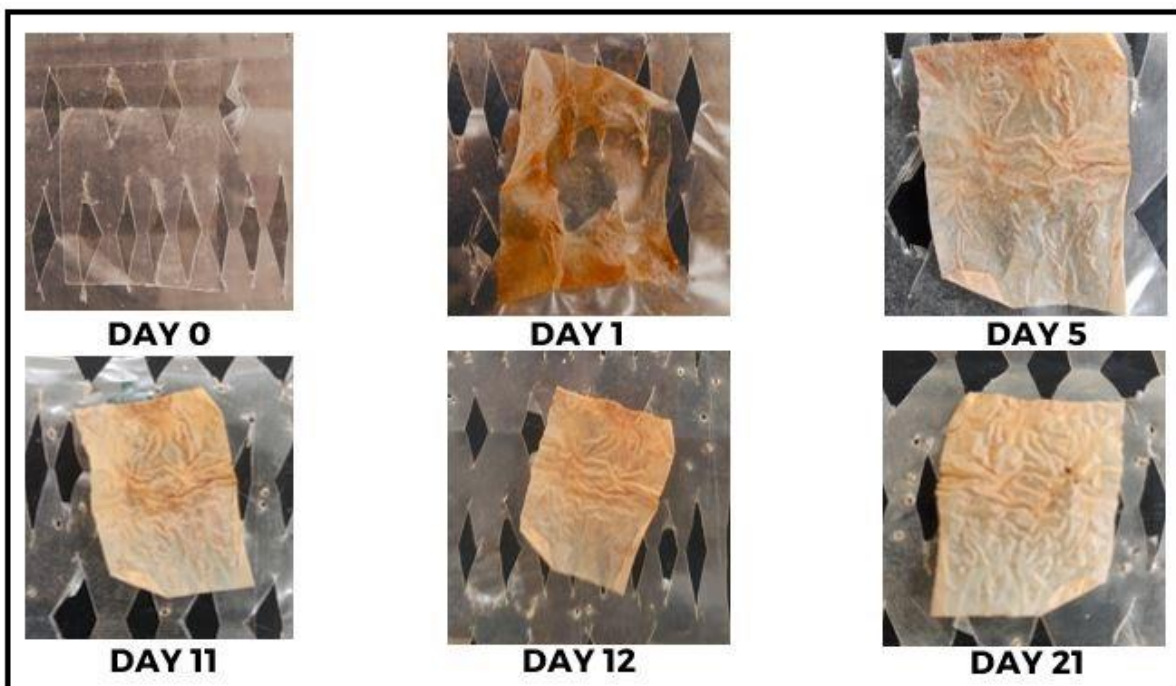


Fig 5.20: Degradation assay of PGN film in dry red soil

5.7.1.2 DRY BEACH SOIL

The test was conducted to analyse the degradation of biodegradable films over a period of 21 days in dry beach soil conditions. On day 1, there was no significant change in its structure. The prolonged exposure to dry beach soil led to the film becoming brittle. The low humidity in the soil environment caused the film to undergo structural changes, resulting in a loss of elasticity and an increase in fragility. This brittleness was evident through the formation of cracks and fissures on the surface of the film.

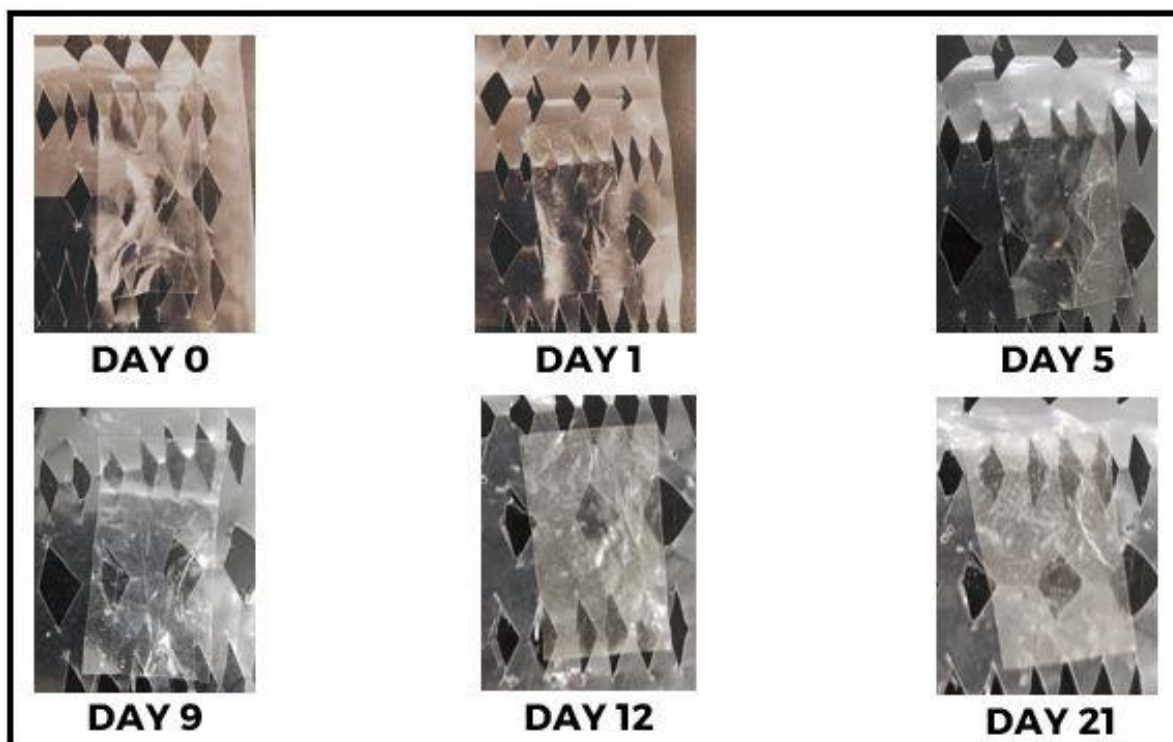


Fig 5.21: Degradation assay of PG film in dry beach soil

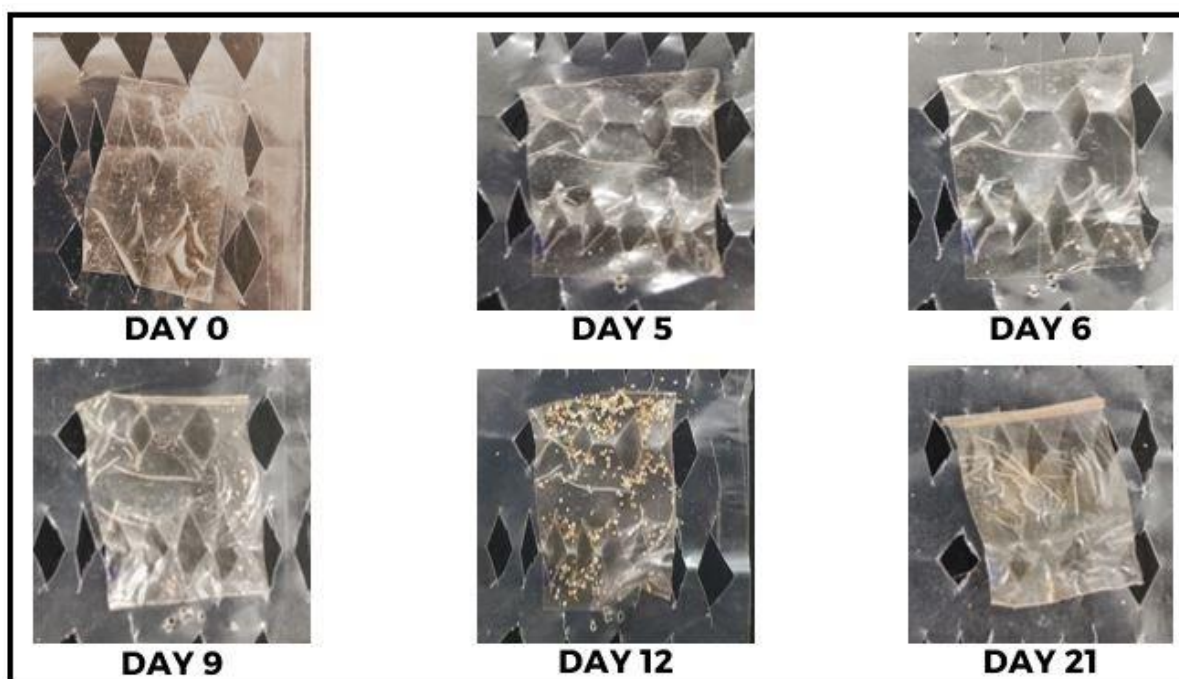


Fig 5.22: Degradation assay of PGN film in dry beach soil

5.7.2 WET SOIL

The film was completely degraded and consumed by the scavenging fungi at the end of the assay, as the moisture content made the environment completely habitable for many microorganisms.

5.7.2.1 WET RED SOIL

The film is buried in the wet red soil, water is sprayed on it every day to maintain moisture content. The film on the first day buried in wet soil swelling of films were observed. On the second day swelling of the film was observed. On the 10th day 50% of the films were disintegrated. On day 12, only traces of the film were observed where a few chunky pieces, extremely sticky and almost semi-solid, were observed. On the twentieth and twenty-first day the film getting degraded was visible clearly as the pieces went missing and started completely disintegrating to nothing. By the end of the 3rd week, the film was completely gone with no traces, and it was almost like there was no film there. It was observed that the film produced had impeccable degradation properties.

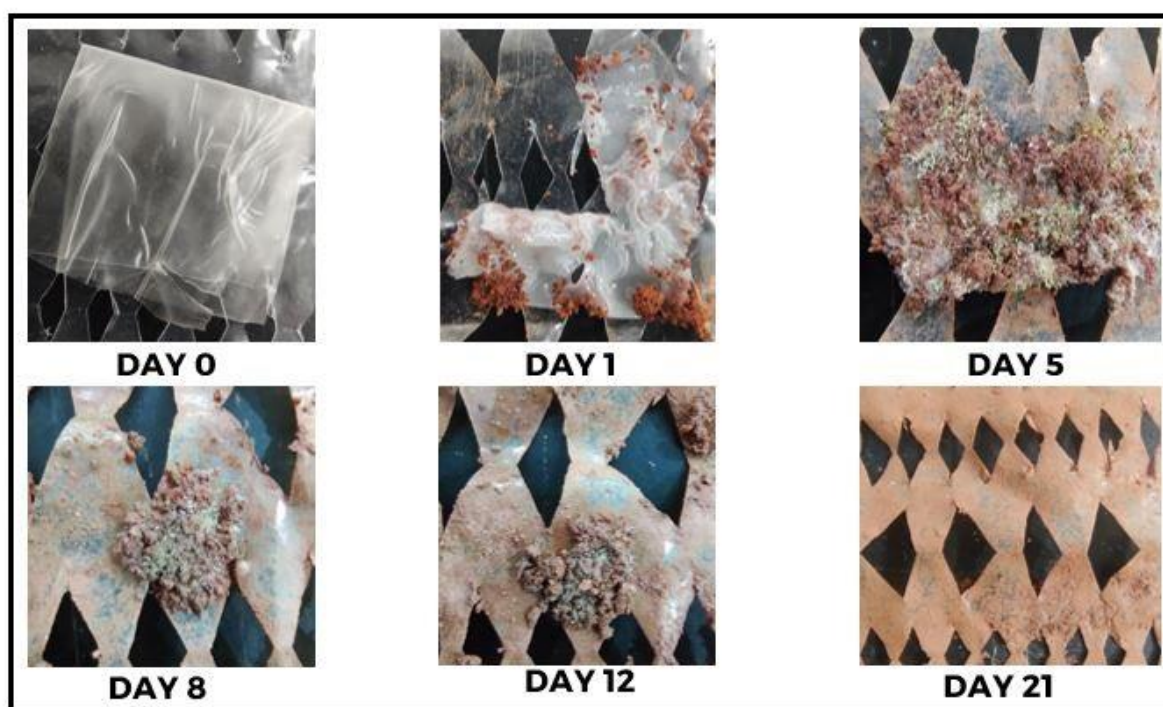


Fig 5.23: Degradation assay of PG film in wet red soil

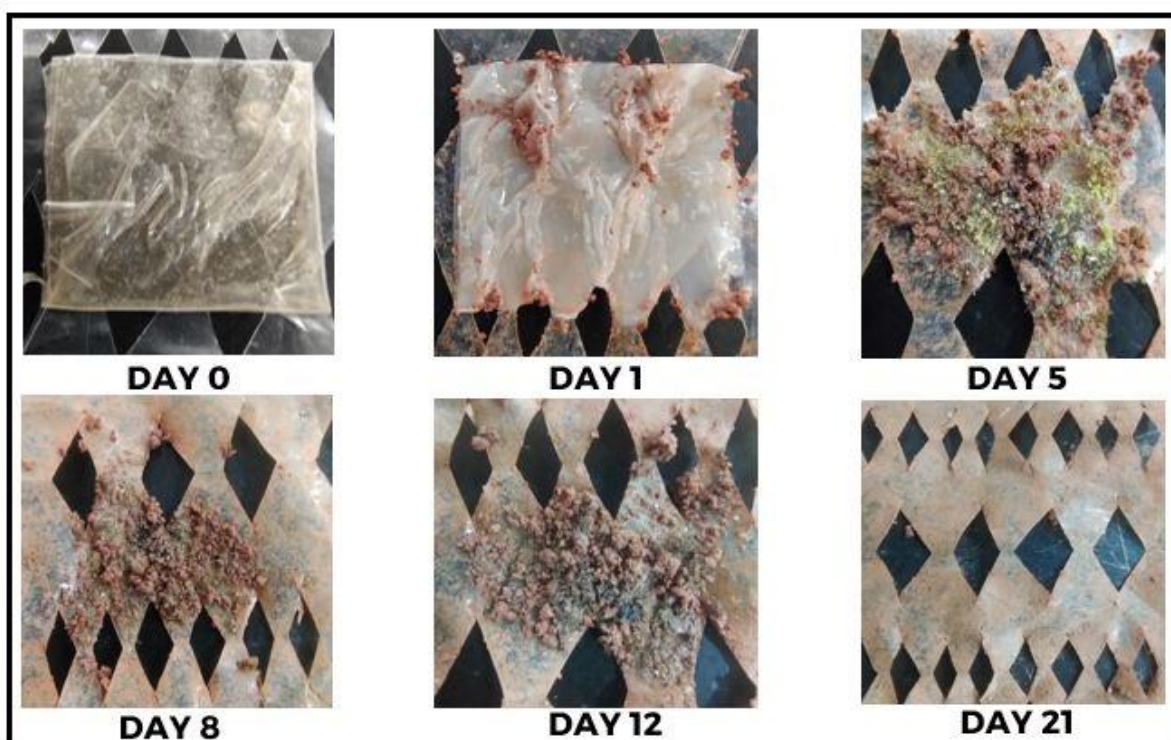


Fig 5.24: Degradation assay of PGN film in wet red soil

5.7.2.2 WET BEACH SOIL

The biodegradable films exhibited a remarkable degree of degradation, with complete degradation occurring by the conclusion of the 21-day period. The wet beach soil environment, rich in moisture and microbial activity, provided optimal conditions for biodegradation to occur. The film lost its structure after 5th day and starts to denature. In moist condition the soil sticks along with the film and reduced the degradation time of the film.

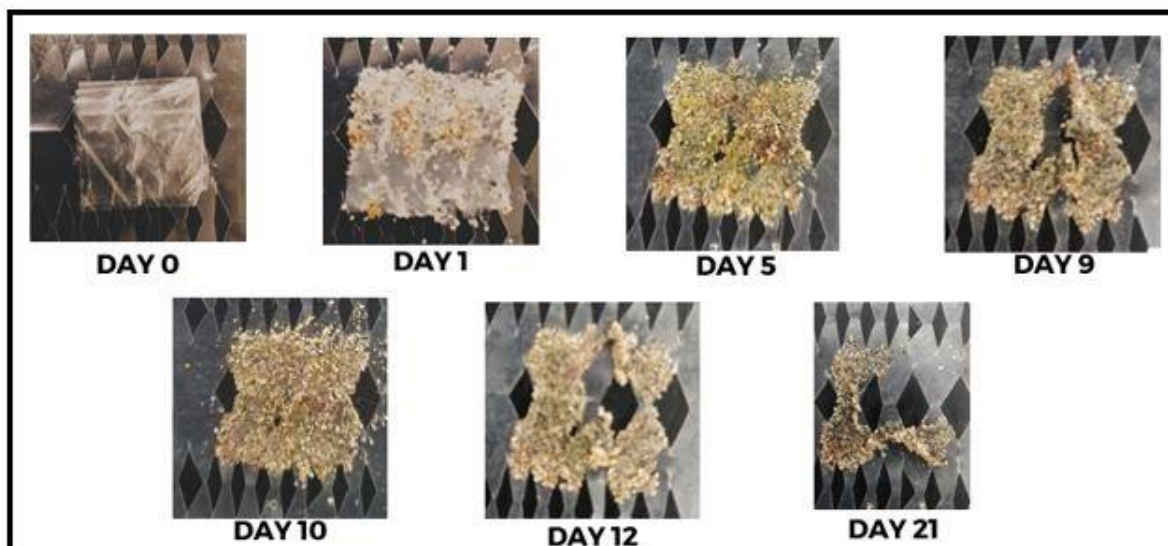


Fig 5.25: Degradation assay of PG film in wet beach soil

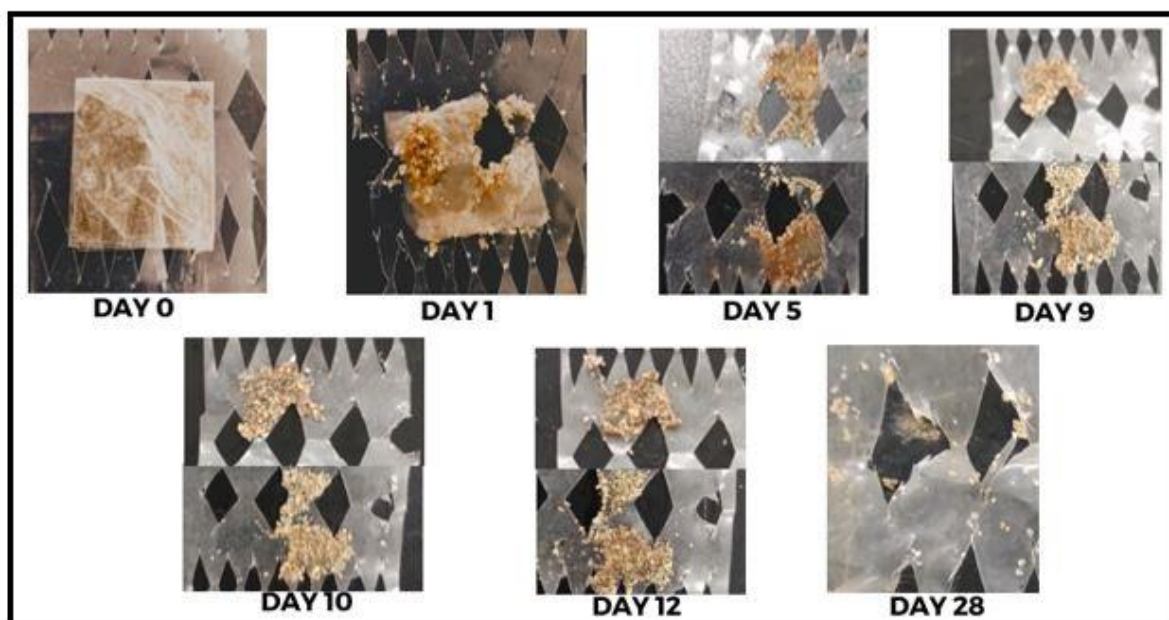


Fig 5.26: Degradation assay of PGN film in wet beach soil

5.7.3 SEA WATER

The below results show PG and PGN films are disintegrating from the 8th day and completely degraded after the 20th day. This proves that PG and PGN are degradable in sea water. After immersing biodegradable films in seawater for 21 days, significant degradation was observed. The combination of saltwater's corrosive properties and microbial activity led to visible deterioration of the films. Additionally, prolonged exposure to seawater results in changes in the chemical composition of biodegradable films, as the salt content and other dissolved ions interact with the

polymer matrix. This interaction led to alterations in the mechanical properties, such as tensile strength and elasticity, of the film. Furthermore, the presence of sunlight and waves in the marine environment can exacerbate the degradation process through photochemical and mechanical degradation mechanisms, respectively.

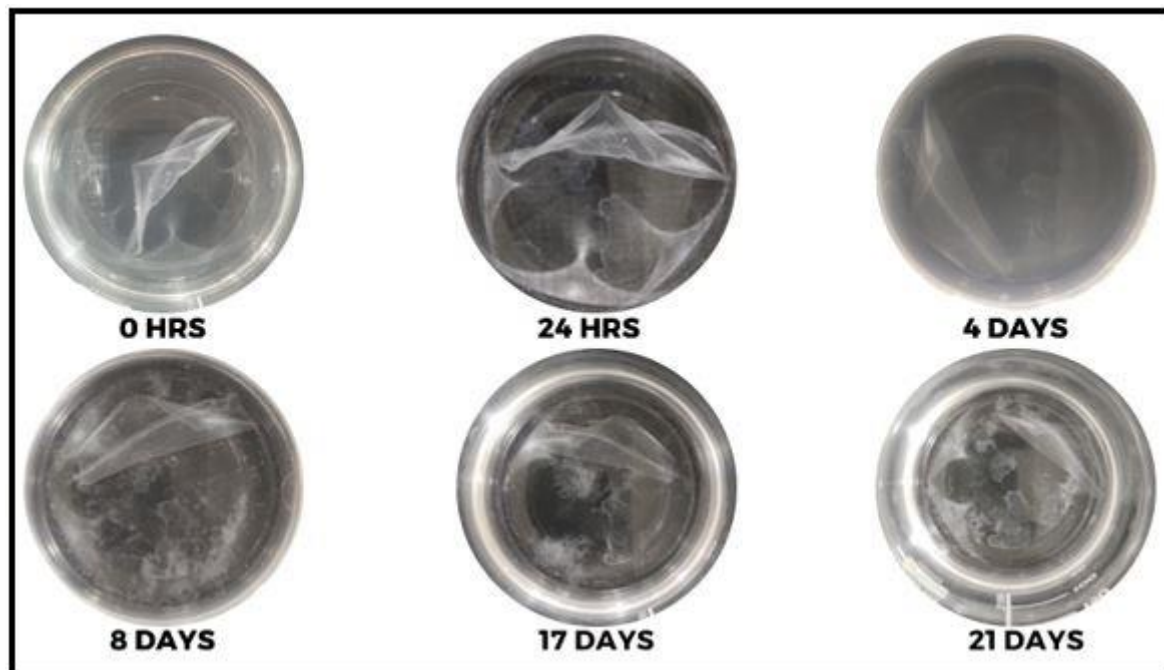


Fig 5.27: Degradation assay of PG film in idle sea water

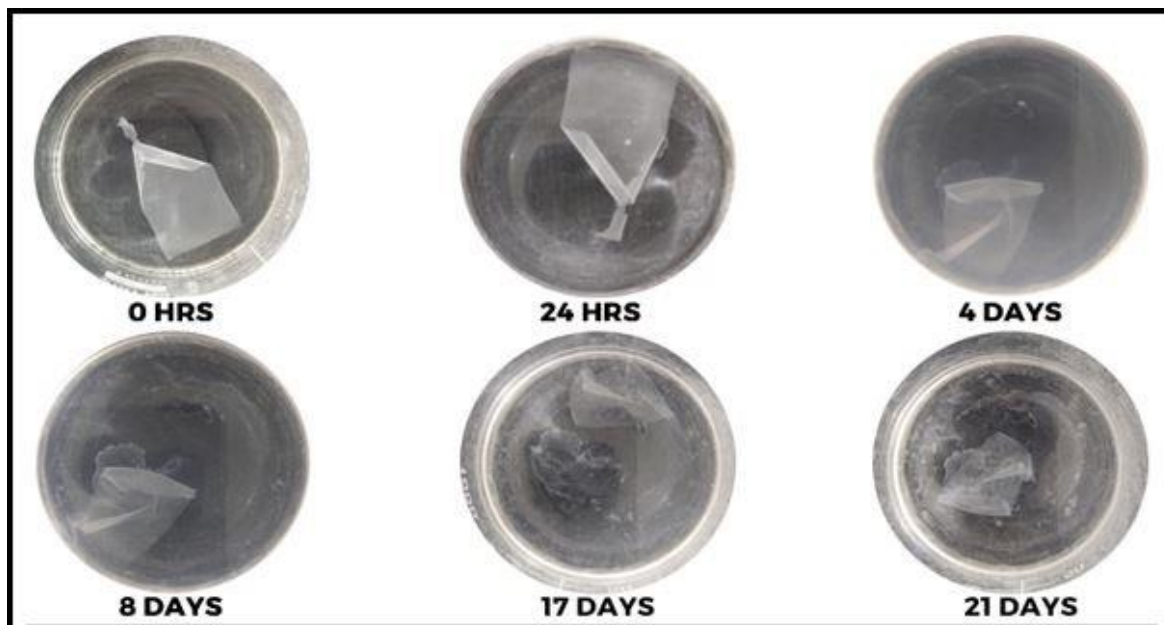


Fig 5.28: Degradation assay of PGN film in idle sea water

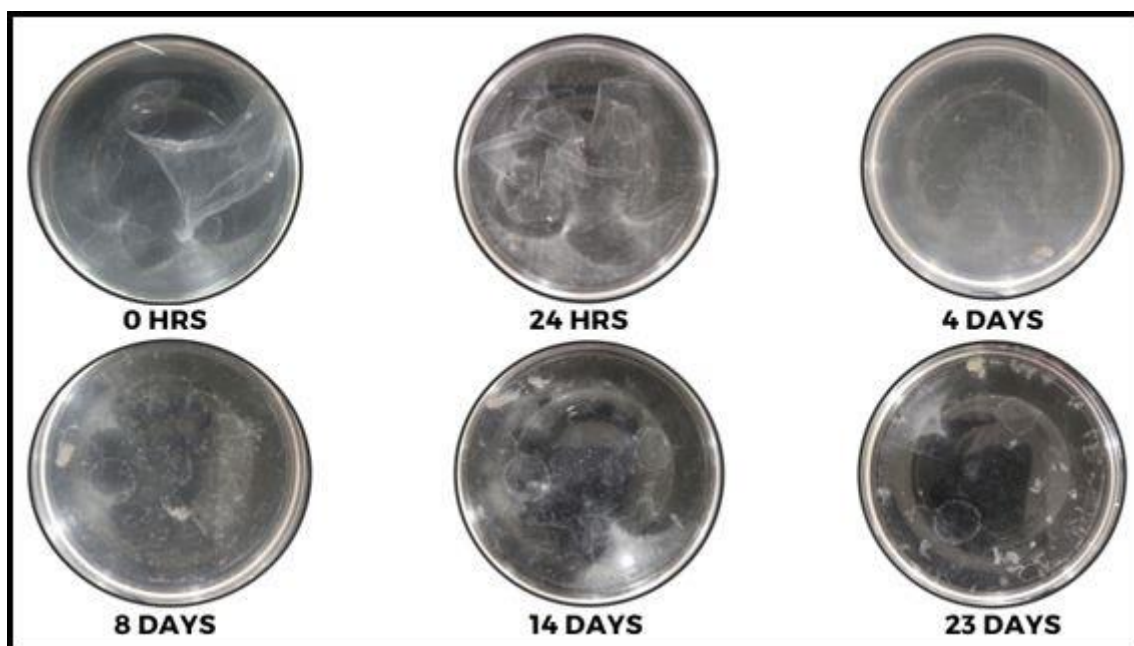


Fig 5.29: Degradation assay of PG film in agitated sea water

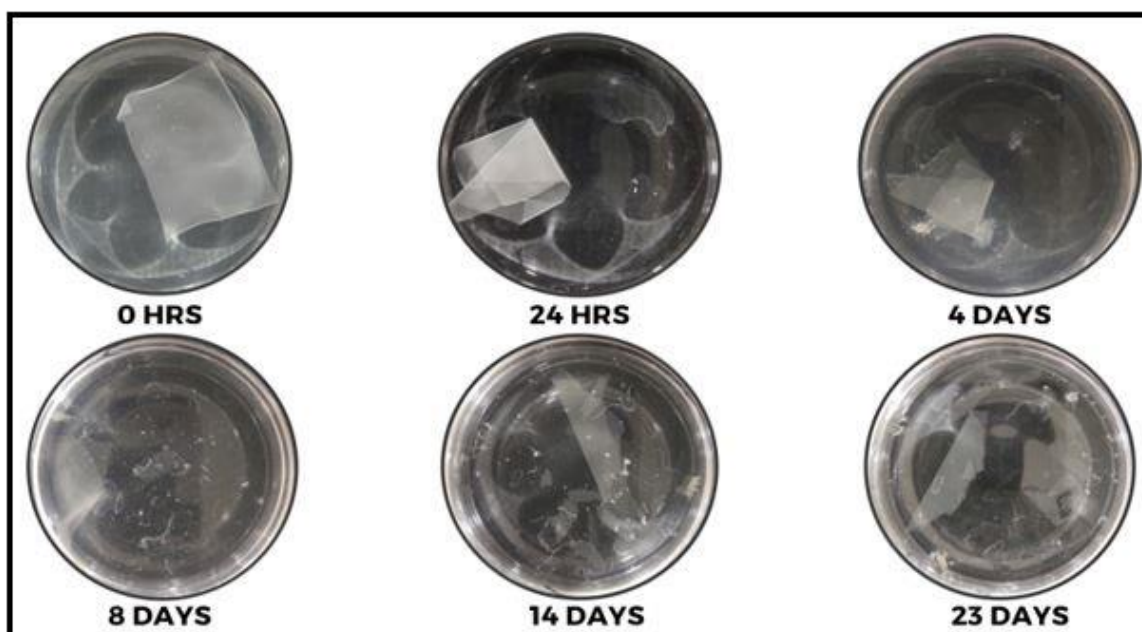


Fig 5.30: Degradation assay of PGN film in agitated sea water

5.7.4 REVERSE OSMOSIS TREATED WATER

The results show PG and PGN films are disintegrating from the 4th^{day} and completely degrading after the 9th day. This proves that PG and PGN are degradable in RO water, which contains fewer microbes compared to salt water. The study progressed day by day, the degradation of the biodegradable films in RO water became increasingly apparent. Daily observations revealed a gradual decline in the

structural integrity of the films, accompanied by noticeable changes in their surface texture and appearance.

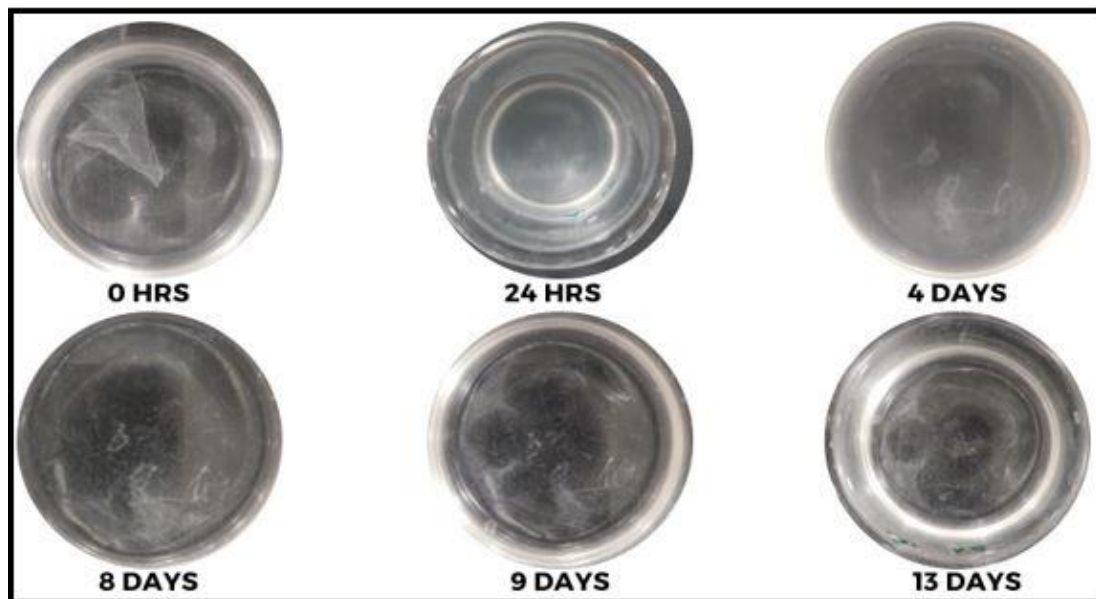


Fig 5.31: Degradation assay of PG film in idle Reverse Osmosis treated water

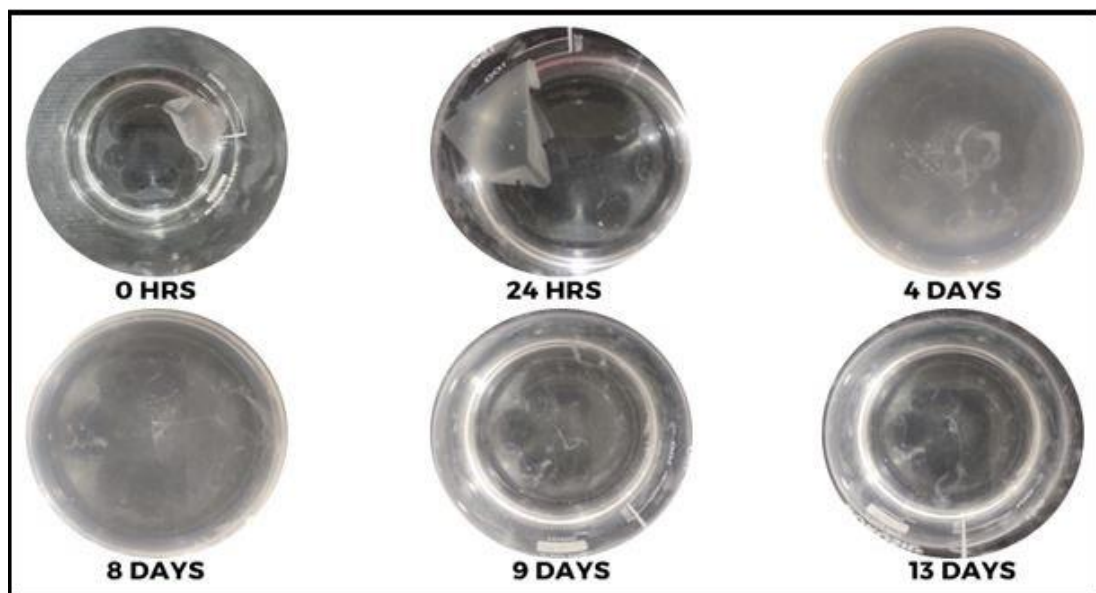


Fig 5.32: Degradation assay of PGN film in idle reverse osmosis treated water

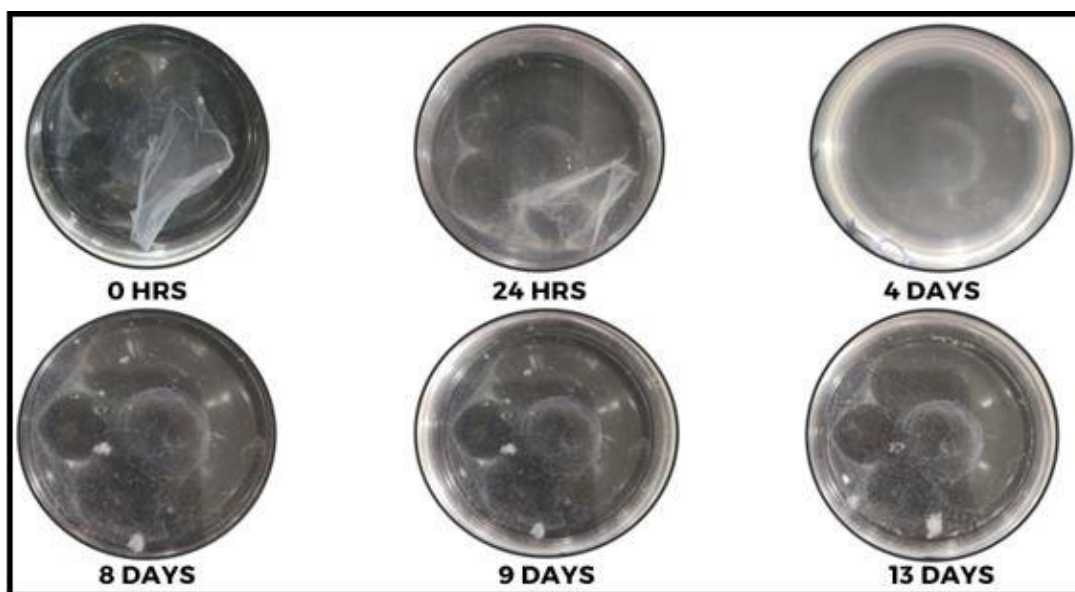


Fig 5.33: Degradation assay of PG film in agitated reverse osmosis treated water

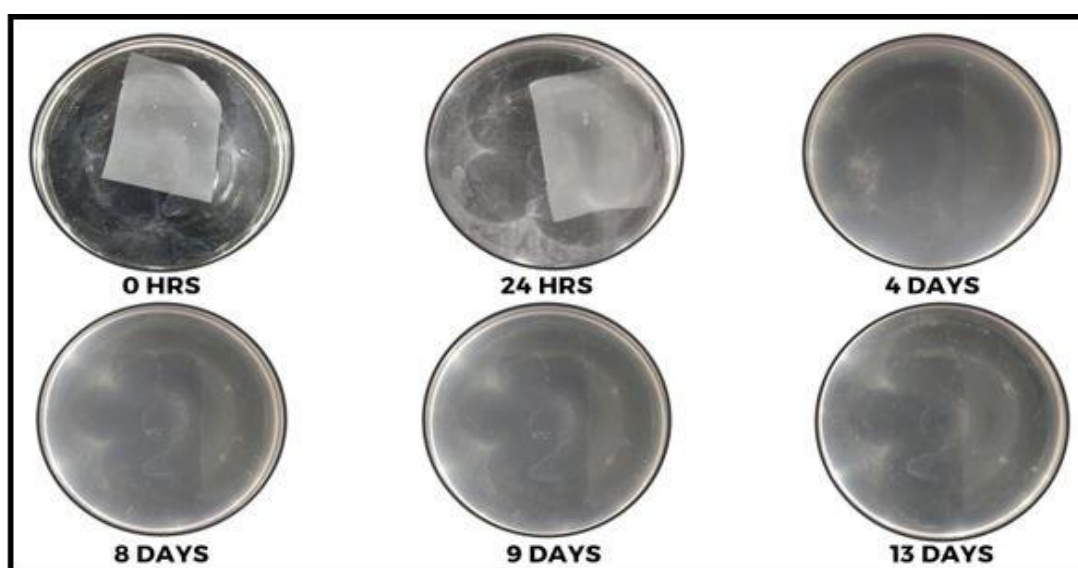
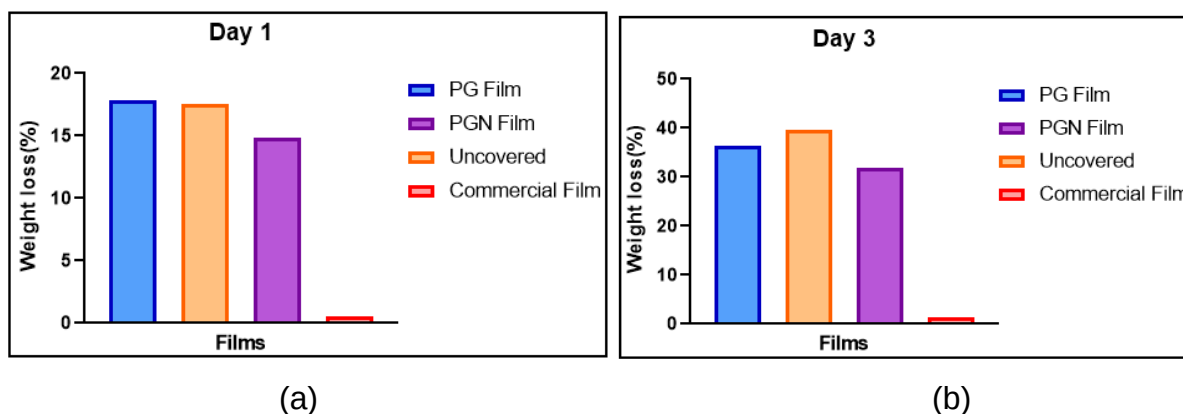


Fig 5.34: Degradation assay of PGN film in agitated reverse osmosis treated water

5.8 COMPATIBILITY TESTING

The results obtained were documented and segregated as data sets for every alternative day (Long et al., 2022). The corn lost a good amount of moisture, as it was left in the open environment. The commercial film composed of plastic had a very good moisture retention capacity, as it acted as a strong barrier between the corn microenvironment and the external environment. The Pectogel nanobiowrap had a

better moisture conservation rate compared to the Pectogel biowrap and the uncovered ones. This was due to its high moisture conservation property, and increased integrity. As the experiment progressed, the uncovered corn lost moisture at a vigorous rate. At the end of day 1, the uncovered one had a weight loss percentage of 17.52%, the Pectogel biowrap covered corn had a weight loss percentage of 17.80%, the Pectogel nanobiowrap covered corn had a weight loss of 14.84% and the commercial film covered corn had a weight loss percentage of 0.53%. At the end of day 3, the uncovered one had a weight loss percentage of 39.52%, the Pectogel biowrap covered corn had a weight loss percentage of 36.26%, the Pectogel nanobiowrap covered corn had a weight loss of 31.84% and the commercial film covered corn had a weight loss percentage of 1.28%. The Pectogel biowrap now offers better protection compared to the uncovered one, as the harsh humidity conditions have now rendered the natural preservation processes of the corn ineffective. The Pectogel nanobiowrap stands tall with its preservation capacity, as it maintains a good barrier property against the environment. At the end of day 5, the uncovered one had a weight loss percentage of 60.16%, the Pectogel biowrap covered corn had a weight loss percentage of 61.48%, the Pectogel nanobiowrap covered corn had a weight loss of 53.69% and the commercial film covered corn had a weight loss percentage of 1.43%. The Pectogel nanobiowrap still maintained a good conservation rate as the corn was now becoming a breeding ground for several environmental microorganisms. At the end of day 7, the uncovered one had a weight loss percentage of 75.20%, the Pectogel biowrap covered corn had a weight loss percentage of 75.30%, the Pectogel nanobiowrap covered corn had a weight loss of 66.80% and the commercial film covered corn had a weight loss percentage of 2.20%. Even though the Pectogel nanobiowrap couldn't compete with the commercial film in the preservation grounds, it stands as a decent barrier against the open environment.



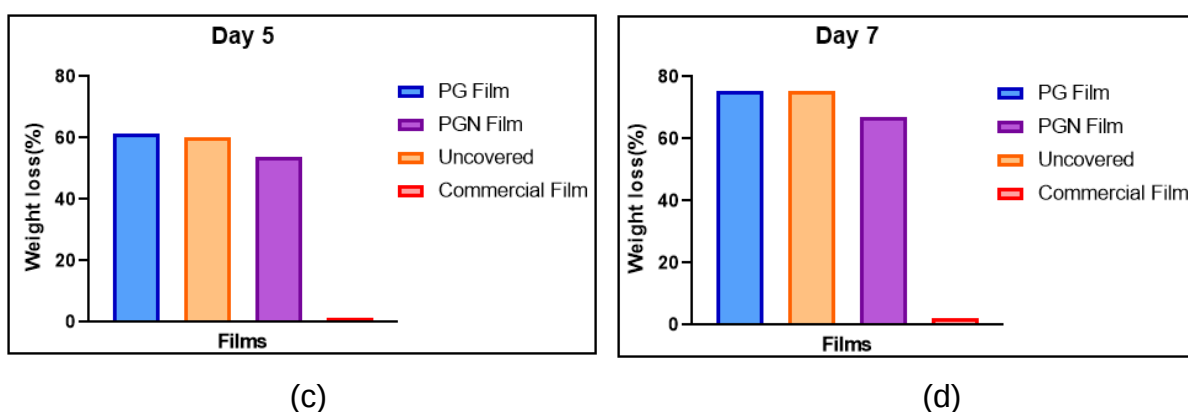


Fig 5.35: Weight loss percentage of corn: (a) Day 1 - weight loss percentage of corn, (b) Day 3 - weight loss percentage of corn, (c) Day 5 - weight loss percentage of corn and (d) Day 7 - weight loss percentage of corn

The commercial film has an excellent conservation capacity, but it has another leading disadvantage too. Since the plastic incorporated film couldn't exchange air between the corn and the environment, the respiratory gas of corn (carbon dioxide) got trapped inside the microenvironment. This led to the formation of blisters in the corn due to the trapped heat and gases, and made it unfit for consumption. This also denatured the natural properties of the corn, and might have also led to plastic infusion into the food samples. The uncovered corn sample suffered severe fungal attacks, and the infection was visible to the naked eye. The corn covered with the Pectogel biowrap was devoid of any heat exchange problems, but had black fungal spots which had infected the corn as the film could not survive against the fungi due to the lack of antimicrobial properties. The Pectogel nanobiowrap had the best results of not producing blisters on the corn's surface, thus ensuring fair air permeability and was devoid of any fungal contaminations or bacterial infusions. The Pectogel nanobiowrap acted as an excellent mechanical and anti-microbial barrier against the potent environmental threats to perishable foods.



Fig 5.36: First and final day of uncovered corn



Fig 5.37: First and final day of corn wrapped with commercial film



Fig 5.38: First and final day of corn wrapped with Pectogel biowrap



Fig 5.39: First and final day of corn wrapped with Pectogel nanobiowrap

5.9 ANTIBACTERIAL ACTIVITY

The film incorporated with the selenium nanoparticles had a higher capacity to prevent the bacteria from forming the biofilm. The PG film also had a considerably good antibacterial activity, probably due to the presence of active antimicrobial

compounds in the biopolymers. Gelatin, which is a byproduct of collagen, has antimicrobial peptides and amino acids like proline and glycine that have been demonstrated to stop the growth of fungus and bacteria. Plant cell walls are rich in pectin, a complex polysaccharide that has antibacterial properties like galacturonic acid, which has inhibitory effects on a variety of bacteria and fungus. Antimicrobial substances found in starch, a polymer of carbohydrates, include α -amylase inhibitors that hinder the enzymatic activity of bacteria, and amylose-lipid complexes that possess antimicrobial effects against specific pathogens. To this arsenal of antimicrobial compounds, the nanoparticles act as an added advantage to tackle the food-spoiling microorganisms and helps us to extend the shelf life for longer periods. The plastic films available on the market cannot display this property, as they provide a suitable and habitable environment for the contaminating microorganisms, leading to easy spoilage and unhealthy packaging. The results obtained were documented (Ma et al., 2020).

Gram negative bacteria: While the control media with the inoculated cultures of *P. aeruginosa* had an optical density value of 1.04, the PG film had a reduced value of 0.4 acting against the bacterial culture. The PGN film had the lowest optical density of 0.28 proving its antibacterial nature against the bacterium, exposing its combinatorial potential of antimicrobial compounds in the plant polymers and the active nanoparticles. The PGN film displayed its efficiency by bringing down the optical density of the film incubated bacterial culture by 73.04%.

Gram positive bacteria: Yet again, the film with the SeNP had greater antibacterial efficacy compared to its non-reinforced counterpart. The results are clearly evident from Figure 5.40, and this serves as standing evidence for the active preservation properties of the film and its ability to counter the dominant microbial species that can infuse food and cause diseases and infections in the human body. While the control media with the inoculated cultures of *S. aureus* had an optical density value of 1.15, the PG film had a reduced value of 0.42 acting against the bacterial culture. The PGN film proved its enhanced antimicrobial property by having the lowest optical density of 0.22, bringing about a drop of 80.87% in the optical density in the film incubated bacterial culture.

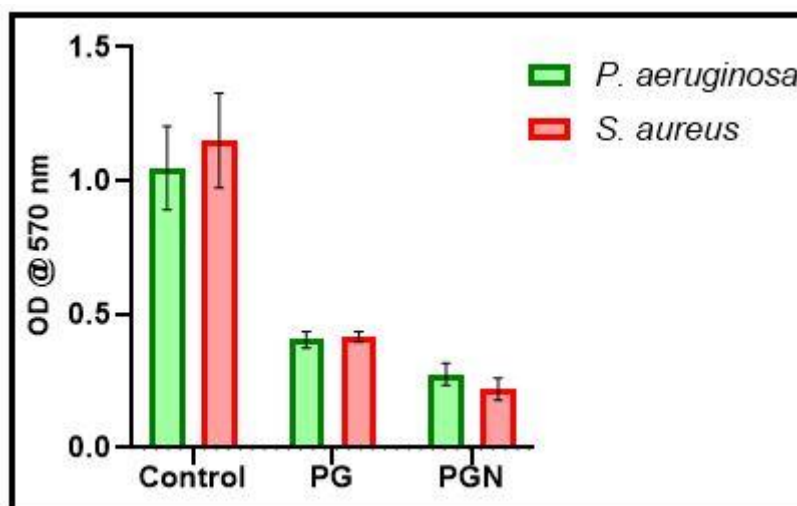


Figure 5.40: Antibacterial activity against *P. aeruginosa* & *S. aureus*

5.10 BIOCOMPATIBILITY ANALYSIS

The product film is incorporated with selenium nanoparticles, which can be toxic to humans on a greater scale (Badgar et al., 2021). The weight of the film prepared with the volumes of 0.5 mL, 0.25 mL and 0.125 mL was measured and the values are 18 mg, 9 mg and 4.5 mg respectively. The amount of film casting solution used to cover the subject – baby corn (*Zea mays. L*) was 25 mL. On cross calculations, the film casted with the help of 25 mL of film casting solution weighed 0.9 grams. By concluding with the calculations, if 1 Kg or 1000 grams of the solution holds 2000 mg of selenium nanoparticles. So, the film used to wrap the corn possesses 1.8 mg of selenium nanoparticles. If we assume that the entire amount of 1.8 mg of selenium nanoparticle infuses inside the baby corn, it falls well under the toxicity limits. The concept of biomagnification may also be nullified, as selenium is a micronutrient utilised by the human body. Among the proteinogenic amino acids, selenium (often referred to as the 21st amino acid) is distinct. It is the only amino acid that is synthesised on its tRNA across all domains of life, the only amino acid encoded by a UGA codon, and the only amino acid that contains the crucial dietary element selenium as a constitutive component. The 1.8 mg of selenium has a good chance of getting metabolized in the body, and get converted into selenocysteine and end up in a non-toxic cycle (Schmidt & Simonović, 2012).

6. SUMMARY AND CONCLUSION

The synthesised film was subjected to characterization studies, and the results were promising enough to reveal stable molecular binding, and the active nature of the selenium nanoparticles was also evident. The successful incorporation of the selenium nanoparticles was proven by the morphological colour change and absorbance spectroscopy. The physical characterization tests and the durability tests against moisture and water have also yielded positive results, proving the film's nature against moisture and thereby producing a standing statement for its shelf-life-increasing capacity. The water contact angle and the surface energy analysis were also in favour of the product, as it repelled water from its surface naturally, proving its hydrophilic nature. The results of the tensile strength analysis using the UTM stated that the film was durable against shear stress and had a greater capacity to withstand strain before tearing. The free radical scavenging assay was a testament to the film's capacity to increase the life-span of the food material packed inside as it consumed the food-spoiling free radicals at a fabulous rate. The results of the swelling assay also proved the water retention capacity of the film, as the film excelled by holding a good amount of water, thereby acting as a barrier between the moist environment and the food material packed inside. The degradation assays were carried out in an open environment to mimic the natural ecosystem, and the film was completely consumed by the wild microorganisms, stage by stage. This is an added advantage to the product, as it proves that it doesn't require any special processes to degrade, unlike its market competitors. The final stage and the purpose of the product were fulfilled when it was put into real-time product testing using baby corn (*Zea mays. L*). The film conserved the corn from losing its integrity and also protected it from the potent microorganisms prominent in the environment. The statistical data suggests the safety boundaries of the selenium nanoparticles and justifies their addition to enhance the fortified properties of the product. These results imply that the proposed novel biodegradable film has the capacity and potential to replace and overrule the plastic wraps present in the market to pack and preserve food on a healthier and more eco-friendly note. Furthermore, in vivo studies and product testing on a pilot scale are required for full-time market implementation of the product. The focus of the project falls under program outcome 7 (PO7), as it understands the impact of engineering/technological solutions in the society. The Pectogel Nanobiowrap stands

as a proof for the need of sustainable solutions to revive the environment to its pure state. The program specific outcome 1 (PSO1) also correlates with the project's goal of conceptualizing and implementing the solution of sustainable wraps to solve the problem of plastic solution. The project focus was formulated keeping in mind the sustainable development goals SDG 11 (sustainable cities and communities), SDG 12 (responsible consumption and production), SDG 13 (climate action), SDG 14 (life below water) and SDG 15 (life on land). The Pectogel nanobiowrap aims to fulfil these goals scripted by the United Nations to conserve nature.

7. REFERENCES

- Asfaw, W., Tafa, K., Heliyon, N. S., & 2023, undefined. (2023). Optimization of citron peel pectin and glycerol concentration in the production of edible film using response surface methodology. *Cell.ComWA Asfaw, KD Tafa, N SatheeshHeliyon, 2023•cell.Com*. <https://doi.org/10.1016/j.heliyon.2023.e13724>
- Atarés, L., & Chiralt, A. (2016). Essential oils as additives in biodegradable films and coatings for active food packaging. *Trends in Food Science & Technology*, 48, 51–62. <https://doi.org/10.1016/J.TIFS.2015.12.001>
- Azeredo, H. M. C., Rosa, M. F., & Mattoso, H. C. (2016). ARTICLE IN PRESS G Model Nanocellulose in bio-based food packaging applications. *Industrial Crops & Products*. <https://doi.org/10.1016/j.indcrop.2016.03.013>
- Azeredo, H. M. C., Rosa, M. F., & Mattoso, L. H. C. (2017). Nanocellulose in bio-based food packaging applications. *Industrial Crops and Products*, 97, 664–671. <https://doi.org/10.1016/J.INDCROP.2016.03.013>
- Badgar, K., Prokisch, J., Badgar, K., & Prokisch, J. (2021). Testing Toxicity and Antidote Effect of Selenium Nanoparticles with Paramecium caudatum. *Open Journal of Animal Sciences*, 11(4), 532–542. <https://doi.org/10.4236/OJAS.2021.114036>
- Barnes, D. K. A., Galgani, F., Thompson, R. C., & Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1526), 1985–1998. <https://doi.org/10.1098/RSTB.2008.0205>
- Bierhalz, A. C. K., Da Silva, M. A., & Kieckbusch, T. G. (2012). Natamycin release from alginate/pectin films for food packaging applications. *Journal of Food Engineering*, 110(1), 18–25. <https://doi.org/10.1016/J.JFOODENG.2011.12.016>
- Bourgeat-Lami, E., França, A. J. P. G., Chaparro, T. C., Silva, R. D., Dugas, P. Y., Alves, G. M., & Santos, A. M. (2016). Synthesis of polymer/silica hybrid latexes by surfactant-free RAFT-mediated emulsion polymerization. *Macromolecules*, 49(12), 4431–4440. <https://doi.org/10.1021/ACS.MACROMOL.6B00737>
- Caleb, O. J., Mahajan, P. V., Al-Said, F. A. J., & Opara, U. L. (2013). Modified Atmosphere Packaging Technology of Fresh and Fresh-cut Produce and the Microbial Consequences—A Review. *Food and Bioprocess Technology*, 6(2), 303. <https://doi.org/10.1007/S11947-012-0932-4>

- Chandran, R. R., Thomson, B. I., Natishah, A. J., Mary, J., & Nachiyar, V. (2023). Nanotechnology in Plastic Degradation. *Biosciences Biotechnology Research Asia*, 20(1), 53–68. <https://doi.org/10.13005/BBRA/3068>
- Clifford, A., D’Elia, A., Deering, J., Lee, B. E. J., Grandfield, K., & Zhitomirsky, I. (2020). Electrochemical Fabrication and Characterization of Pectin Hydrogel Composite Materials for Bone Tissue Repair. *ACS Applied Polymer Materials*, 2(8), 3390–3396. <https://doi.org/10.1021/acsapm.0c00480>
- D’amelia, R. P., Gentile, S., Nirode, W. F., & Huang, L. (2016). Quantitative analysis of copolymers and blends of polyvinyl acetate (PVAc) using Fourier transform infrared spectroscopy (FTIR) and elemental analysis (EA). *Article. Journal of chemical education RP D’Amelia, S Gentile, WF Nirode, L Huang World J. Chem. Educ*, 2016•*article. Journal of chemical education* ..., 4(2), 25–31. <https://doi.org/10.12691/wjce-4-2-1>
- Dutta, P. K., Ravikumar, M. N. V., & Dutta, J. (2002). Chitin and chitosan for versatile applications. *Journal of Macromolecular Science - Polymer Reviews*, 42(3), 307–354. <https://doi.org/10.1081/MC-120006451>
- Espitia, P. J. P., Soares, N. de F. F., Coimbra, J. S. dos R., de Andrade, N. J., Cruz, R. S., & Medeiros, E. A. A. (2012). Zinc Oxide Nanoparticles: Synthesis, Antimicrobial Activity and Food Packaging Applications. *Food and Bioprocess Technology*, 5(5), 1447–1464. <https://doi.org/10.1007/S11947-012-0797-6/METRICS>
- Figueroa-Lopez, K. J., Vicente, A. A., Reis, M. A. M., Torres-Giner, S., & Lagaron, J. M. (2019). Antimicrobial and Antioxidant Performance of Various Essential Oils and Natural Extracts and Their Incorporation into Biowaste Derived Poly(3-hydroxybutyrate-co-3-hydroxyvalerate) Layers Made from Electrospun Ultrathin Fibers. *Nanomaterials 2019, Vol. 9, Page 144*, 9(2), 144. <https://doi.org/10.3390/NANO9020144>
- Filipović, N., Ušjak, D., Milenković, M. T., Zheng, K., Liverani, L., Boccaccini, A. R., & Stevanović, M. M. (2021). Comparative Study of the Antimicrobial Activity of Selenium Nanoparticles With Different Surface Chemistry and Structure. *Frontiers in Bioengineering and Biotechnology*, 8, 624621. <https://doi.org/10.3389/FBIOE.2020.624621/BIBTEX>
- Food Packaging Materials | Food Packaging Forum*. (n.d.). Retrieved March 25, 2024, from <https://www.foodpackagingforum.org/food-packaging-health/food->

packaging-materials

- Fullana, S. G., Ternet, H., Freche, M., Lacout, J. L., & Rodriguez, F. (2010). Controlled release properties and final macroporosity of a pectin microspheres-calcium phosphate composite bone cement. *Acta Biomaterialia*, 6(6), 2294–2300. <https://doi.org/10.1016/j.actbio.2009.11.019>
- Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances*, 3(7). https://doi.org/10.1126/SCIADV.1700782/SUPPL_FILE/1700782_SM.PDF
- India has a 26,000-tonne plastic waste problem | India News - Times of India*. (n.d.). Retrieved March 25, 2024, from <https://timesofindia.indiatimes.com/india/india-generates-26k-tonne-plastic-waste-everyday-40-remains-uncollected/articleshow/67646745.cms>
- Jayavardhini, B., Pravin, Y. R., Kumar, C., Murugesan, R., & Vedakumari, S. W. (2022). Graphene oxide impregnated sericin/collagen scaffolds – Fabrication and characterization. *Materials Letters*, 307(January 2021). <https://doi.org/10.1016/j.matlet.2021.131060>
- Kaniuk, Ł., & Stachewicz, U. (2021). Development and Advantages of Biodegradable PHA Polymers Based on Electrospun PHBV Fibers for Tissue Engineering and Other Biomedical Applications. *ACS Biomaterials Science & Engineering*, 7(12), 5339. <https://doi.org/10.1021/ACSBiomaterials.1C00757>
- Khan, B., Bilal Khan Niazi, M., Samin, G., & Jahan, Z. (2017). Thermoplastic Starch: A Possible Biodegradable Food Packaging Material—A Review. *Journal of Food Process Engineering*, 40(3). <https://doi.org/10.1111/JFPE.12447>
- Khubiev, O. M., Egorov, A. R., Kirichuk, A. A., Khrustalev, V. N., Tskhovrebov, A. G., & Kritchenkov, A. S. (2023). Chitosan-Based Antibacterial Films for Biomedical and Food Applications. *International Journal of Molecular Sciences*, 24(13), 24. <https://doi.org/10.3390/IJMS241310738>
- Kim, T. H., An, D. B., Oh, S. H., Kang, M. K., Song, H. H., & Lee, J. H. (2015). Creating stiffness gradient polyvinyl alcohol hydrogel using a simple gradual freezing-thawing method to investigate stem cell differentiation behaviors. *Biomaterials*, 40, 51–60. <https://doi.org/10.1016/J.Biomaterials.2014.11.017>
- Leceta, I., Guerrero, P., Ibarburu, I., Dueñas, M. T., & De La Caba, K. (2013). Characterization and antimicrobial analysis of chitosan-based films. *Journal of Food Engineering*, 116(4), 889–899.

<https://doi.org/10.1016/J.JFOODENG.2013.01.022>

Lee, B. Y., Kim, J. K., Kim, J. S., & Kim, Y. Y. (2009). Quantitative evaluation technique of Polyvinyl Alcohol (PVA) fiber dispersion in engineered cementitious composites. *Cement and Concrete Composites*, 31(6), 408–417.

<https://doi.org/10.1016/J.CEMCONCOMP.2009.04.002>

Li, D. qiang, Li, J., Dong, H. lin, Li, X., Zhang, J. qi, Ramaswamy, S., & Xu, F. (2021). Pectin in biomedical and drug delivery applications: A review. *International Journal of Biological Macromolecules*, 185(June), 49–65.

<https://doi.org/10.1016/j.ijbiomac.2021.06.088>

Liu, B. ;, Zhang, J. ;, Guo, H., Liu, B., Zhang, J., & Guo, H. (2022). Research Progress of Polyvinyl Alcohol Water-Resistant Film Materials. *Membranes* 2022, Vol. 12, Page 347, 12(3), 347. <https://doi.org/10.3390/MEMBRANES12030347>

Liu, S., Wu, Q., Sun, X., Yue, Y., Tubana, B., & Cheng, H. N. (2021). *Novel Alginate-Cellulose Nanofiber-Poly(vinyl alcohol) Hydrogels for Carrying and Delivering Nitrogen, Phosphorus and Potassium Chemicals* 2 3.

Liu, X., Chen, L., Dong, Q., Wang, Z., Zhang, D., He, J., Ye, Y., Zhou, J., Zhu, W., Hu, Z., Din, Z. ud, Ma, T., Ding, W., & Cai, J. (2022). Emerging starch composite nanofibrous films for food packaging: Facile construction, hydrophobic property, and antibacterial activity enhancement. *International Journal of Biological Macromolecules*, 222, 868–879.

<https://doi.org/10.1016/J.IJBIOMAC.2022.09.187>

Long, H., Bi, Y., Pu, L., Xu, W., Xue, H., Fu, G., & Prusky, D. (2022). Preparation of chitosan/ fennel seed essential oil/ starch sodium octenyl succinate composite films for apple fruit preservation. *LWT*, 167, 113826.

<https://doi.org/10.1016/J.LWT.2022.113826>

Lu, Y., Luo, Q., Chu, Y., Tao, N., Deng, S., Wang, L., & Li, L. (2022). Application of Gelatin in Food Packaging: A Review. *Polymers*, 14(3).

<https://doi.org/10.3390/POLYM14030436>

Ma, R., Wang, W., Yang, P., Wang, C., Guo, D., & Wang, K. (2020). In vitro antibacterial activity and cytocompatibility of magnesium-incorporated poly(lactide-co-glycolic acid) scaffolds. *BioMedical Engineering Online*, 19(1), 1–12. <https://doi.org/10.1186/S12938-020-0755-X/FIGURES/7>

Meijer, L. J. J., van Emmerik, T., van der Ent, R., Schmidt, C., & Lebreton, L. (2021). More than 1000 rivers account for 80% of global riverine plastic emissions into

- the ocean. *Science Advances*, 7(18). <https://doi.org/10.1126/SCIADV.AAZ5803>
- Mihalca, V., Kerezsi, A. D., Weber, A., Gruber-traub, C., Schmucker, J., Vodnar, D. C., Dulf, F. V., Socaci, S. A., Fărcaș, A., Mureșan, C. I., Suharoschi, R., & Pop, O. L. (2021). Protein-Based Films and Coatings for Food Industry Applications. *Polymers* 2021, Vol. 13, Page 769, 13(5), 769. <https://doi.org/10.3390/POLYM13050769>
- Nguyen, T. B. L., Min, Y. K., & Lee, B. T. (2015). Nanoparticle biphasic calcium phosphate loading on gelatin-pectin scaffold for improved bone regeneration. *Tissue Engineering - Part A*, 21(7–8), 1376–1387. <https://doi.org/10.1089/ten.tea.2014.0313>
- North, E. J., & Halden, R. U. (2013). Plastics and environmental health: The road ahead. *Reviews on Environmental Health*, 28(1), 1–8. <https://doi.org/10.1515/REVEH-2012-0030/HTML>
- Núñez-Flores, R., Giménez, B., Fernández-Martín, F., López-Caballero, M. E., Montero, M. P., & Gómez-Guillén, M. C. (2012). Role of lignosulphonate in properties of fish gelatin films. *Food Hydrocolloids*, 27(1), 60–71. <https://doi.org/10.1016/J.FOODHYD.2011.08.015>
- Othman, S. H. (2014). Bio-nanocomposite Materials for Food Packaging Applications: Types of Biopolymer and Nano-sized Filler. *Agriculture and Agricultural Science Procedia*, 2, 296–303. <https://doi.org/10.1016/J.AASPRO.2014.11.042>
- Patil, A. S., Waghmare, R. D., Pawar, S. P., Salunkhe, S. T., Kolekar, G. B., Sohn, D., & Gore, A. H. (2020). Photophysical insights of highly transparent, flexible and re-emissive PVA @ WTR-CDs composite thin films: A next generation food packaging material for UV blocking applications. *Journal of Photochemistry and Photobiology A: Chemistry*, 400, 112647. <https://doi.org/10.1016/J.JPHOTOCHEM.2020.112647>
- Pérez-Soto, E., Badillo-Solis, K. I., Cenobio-Galindo, A. de J., Ocampo-López, J., Ludeña-Urquiza, F. E., Reyes-Munguía, A., Pérez-Ríos, S. R., & Campos-Montiel, R. (2021). Coating of tomatoes (*Solanum lycopersicum* L.) employing nanoemulsions containing the bioactive compounds of cactus acid fruits: Quality and shelf life. *Processes*, 9(12). <https://doi.org/10.3390/PR9122173>
- Qin, Y. Y., Yang, J. Y., Lu, H. B., Wang, S. S., Yang, J., Yang, X. C., Chai, M., Li, L., & Cao, J. X. (2013). Effect of chitosan film incorporated with tea polyphenol on

- quality and shelf life of pork meat patties. *International Journal of Biological Macromolecules*, 61, 312–316. <https://doi.org/10.1016/J.IJBIOMAC.2013.07.018>
- Ramos, M., Valdés, A., Beltrán, A., & Garrigós, M. C. (2016). Gelatin-Based Films and Coatings for Food Packaging Applications. *Coatings 2016, Vol. 6, Page 41*, 6(4), 41. <https://doi.org/10.3390/COATINGS6040041>
- Rasmussen, M. K., Pedersen, J. N., & Marie, R. (2020). Size and surface charge characterization of nanoparticles with a salt gradient. *Nature Communications*, 11(1), 1–8. <https://doi.org/10.1038/s41467-020-15889-3>
- Samsudin, H., Auras, R., Mishra, D., Dolan, K., Burgess, G., Selke, S., & Soto-Valdez, H. (2017). *Migration of antioxidants from polylactic acid films: A parameter estimation 1 approach and an overview of the current mass transfer models*.
- Sans-Serramitjana, E., Obreque, M., Muñoz, F., Zaror, C., Mora, M. de L. L., Viñas, M., & Betancourt, P. (2023). Antimicrobial Activity of Selenium Nanoparticles (SeNPs) against Potentially Pathogenic Oral Microorganisms: A Scoping Review. *Pharmaceutics*, 15(9). <https://doi.org/10.3390/PHARMACEUTICS15092253/S1>
- Scarfato, P., Di Maio, L., Milana, M. R., Giamberardini, S., Denaro, M., & Incarnato, L. (2017). Performance properties, lactic acid specific migration and swelling by simulant of biodegradable poly(lactic acid)/nanoclay multilayer films for food packaging. *Food Additives and Contaminants - Part A Chemistry, Analysis, Control, Exposure and Risk Assessment*, 34(10), 1730–1742. <https://doi.org/10.1080/19440049.2017.1321786>
- Schmidt, R. L., & Simonović, M. (2012). Synthesis and decoding of selenocysteine and human health. *Croatian Medical Journal*, 53(6), 535. <https://doi.org/10.3325/CMJ.2012.53.535>
- Shahbaz, M., Akram, A., Mehak, A., Haq, E. ul, Fatima, N., Wareen, G., Fitriatin, B. N., Sayyed, R. Z., Ilyas, N., & Sabullah, M. K. (2023). Evaluation of Selenium Nanoparticles in Inducing Disease Resistance against Spot Blotch Disease and Promoting Growth in Wheat under Biotic Stress. *Plants*, 12(4). <https://doi.org/10.3390/PLANTS12040761/S1>
- Shen, Z., & Kamdem, D. P. (2015). Development and characterization of biodegradable chitosan films containing two essential oils. *International Journal of Biological Macromolecules*, 74, 289–296.

- <https://doi.org/10.1016/J.IJBIOMAC.2014.11.046>
- Shoeibi, S., & Mashreghi, M. (2017). Biosynthesis of selenium nanoparticles using *Enterococcus faecalis* and evaluation of their antibacterial activities. *Journal of Trace Elements in Medicine and Biology*, 39, 135–139.
<https://doi.org/10.1016/J.JTEMB.2016.09.003>
- Simon, N., Raubenheimer, K., Urho, N., Unger, S., Azoulay, D., Farrelly, T., Sousa, J., van Asselt, H., Carlini, G., Sekomo, C., Schulte, M. L., Busch, P. O., Wienrich, N., & Weiland, L. (2021). A binding global agreement to address the life cycle of plastics. *Science*, 373(6550), 43–47.
<https://doi.org/10.1126/SCIENCE.ABI9010>
- Soares, R. R., Carone, C., Einloft, S., Ligabue, R., & Monteiro, W. F. (2014). Synthesis and characterization of waterborne polyurethane/ZnO composites. *Polymer Bulletin*, 71(4), 829–838. <https://doi.org/10.1007/S00289-014-1095-4>
- Sowmiya, P., Dhas, T. S., Inbakandan, D., Mani, R., Natarajan, A., Dharani, G., Govindaraju, K., Kannan, M., Velu, K., & Kumar, C. M. V. (2023). Antagonistic activity of a novel chitosan-selenium nanoflower against common aquaculture pathogen *Aeromonas caviae*. *Aquaculture International*, 31(6), 3109–3123.
<https://doi.org/10.1007/S10499-023-01146-Z/METRICS>
- Sun, M., Wang, Y., Yao, L., Li, Y., Weng, Y., & Qiu, D. (2022). Fabrication and Characterization of Gelatin/Polyvinyl Alcohol Composite Scaffold. *Polymers*, 14(7). <https://doi.org/10.3390/POLYM14071400>
- Thompson, R. C., Swan, S. H., Moore, C. J., & Vom Saal, F. S. (2009). Our plastic age. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1526), 1973–1976. <https://doi.org/10.1098/RSTB.2009.0054>
- Weiss, L., Ludwig, W., Heussner, S., Canals, M., Ghiglione, J. F., Estournel, C., Constant, M., & Kerhervé, P. (2021). The missing ocean plastic sink: Gone with the rivers. *Science*, 373(6550), 107–111.
<https://doi.org/10.1126/SCIENCE.ABE0290>
- Welch, K., Cai, Y., Biomaterials, M. S.-J. of F., & 2012, undefined. (n.d.). A method for quantitative determination of biofilm viability. *Mdpi.Com*. Retrieved March 26, 2024, from <https://www.mdpi.com/2079-4983/3/2/418>
- Wright, S. L., & Kelly, F. J. (2017). Plastic and Human Health: A Micro Issue? *Environmental Science and Technology*, 51(12), 6634–6647.
https://doi.org/10.1021/ACS.EST.7B00423/SUPPL_FILE/ES7B00423_SI_001.P

DF

- Xiao, X., Teng, F., Shi, C., Chen, J., Wu, S., Wang, B., Meng, X., Essiet Imeh, A., & Li, W. (2022). Polymeric nanoparticles—Promising carriers for cancer therapy. *Frontiers in Bioengineering and Biotechnology*, 10. <https://doi.org/10.3389/FBIOE.2022.1024143>
- Yuan, Q., Xiao, R., Afolabi, M., Bomma, M., & Xiao, Z. (2023). Evaluation of Antibacterial Activity of Selenium Nanoparticles against Food-Borne Pathogens. *Microorganisms*, 11(6), 1519. <https://doi.org/10.3390/MICROORGANISMS11061519/S1>
- Zareie, Z., Tabatabaei Yazdi, F., & Mortazavi, S. A. (2020). Development and characterization of antioxidant and antimicrobial edible films based on chitosan and gamma-aminobutyric acid-rich fermented soy protein. *Carbohydrate Polymers*, 244. <https://doi.org/10.1016/J.CARBPOL.2020.116491>
- Zhang, N., Liu, X., Yu, L., Shanks, R., Petinaks, E., & Liu, H. (2013). Phase composition and interface of starch–gelatin blends studied by synchrotron FTIR micro-spectroscopy. *Carbohydrate Polymers*, 95(2), 649–653. <https://doi.org/10.1016/J.CARBPOL.2013.03.045>
- Zolfi, M., Khodaiyan, F., Mousavi, M., & Hashemi, M. (2014). Development and characterization of the kefiran-whey protein isolate-TiO₂ nanocomposite films. *International Journal of Biological Macromolecules*, 65, 340–345. <https://doi.org/10.1016/J.IJBIOMAC.2014.01.010>

8. ANNEXURE

PUBLICATION

The project work has been presented at the “11th International Conference on the Integration of Science and Technology for Sustainable Development 2024 (ICIST 2024)” in the form of an oral presentation and has won the **First place**.



Abstract Book: The 11th International Conference on the Integration of Science and Technology for Sustainable Development 2024 organized by Sathyabama Institute of Science and Technology, Tamil Nadu, India during 1-3, February 2024 (*ISBN: 978-93-83409-84-6*)

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Plastics are considered to be the greatest invention of mankind. However, the chemical structure of most of the synthetic polymers renders them resistant to many natural processes of degradation and as a result these polymers have destroyed the environment by contaminating land, water and the ecosystem around us. Polymers used for food packaging contributes to nearly 35 % of the total plastic accumulation in the environment. In this study, we investigated the fabrication of a novel biodegradable nano biowrap from plant based polymers for food packaging applications. The pectin biowrap is enriched with selenium nanoparticles, which improves the structural integrity and the antimicrobial properties of the wrap. The biowrap had increased opacity, swelling percentage with a comparatively lower moisture content. The biowrap was also subjected to real time testing with corn and grapes, in a week's time for weight loss percentage and study the morphological changes. The degradation assays were carried out in soil and water and visual data sets were promising enough to prove the biodegradable nature of the film. The DPPH radical scavenging activity assay proved that the film had 94.6 % of scavenging activity which is high enough to counter the free radicals that cause oxidation to spoil the food during the packaging process. Thus, these biowraps have the capacity to replace the conventional plastic wraps in the industry and help to preserve the foods in a sustainable and efficient manner.

Keywords: Pollution, Biopolymers, Food Packaging, Pectin, Antimicrobial.

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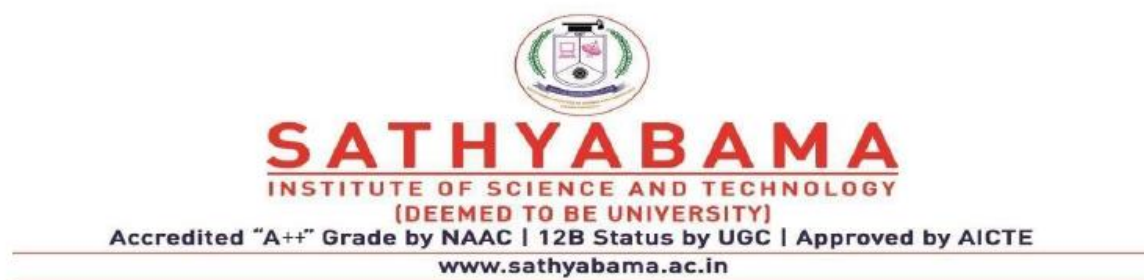
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Title of the Thesis: Fabrication of Nano-Selenium Incorporated Biodegradable Food Packaging Film

Internal Guide Name: Ms. E. Jancy Mary

External Guide Name: Dr. T Stalin Dhas

PO / PSO / PEO / SDG	Justification
PO7	Product built to replace plastic food packaging films
PSO1	Conceptualization and implementation of a novel solution to save the environment
SDG11	Helping to build sustainable cities and communities
SDG12	Helps humanity to perform responsible consumption and production
SDG13	Helps to control and evade climate change
SDG14	Supporting healthier life below water
SDG15	Supporting healthier life on land