DEVELOPMENT AND EVALUATION OF POTATO WASTE BASED BIODEGRADABLE FILM FOR FOOD PACKAGING

by

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TAVANUR-679573, MALAPPURAM
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PROJECT REPORT

Submitted in partial fulfilment of the requirements for the degree of

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
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DECLARATION

We hereby declare that this project report entitled "**DEVELOPMENT AND EVALUATION OF POTATO WASTE BASED BIODEGRADABLE FILM FOR FOOD PACKAGING**" is a bonafide record of project work done by us during the course of project and that the report has not previously formed the basis for the award to us of any degree, diploma, associate ship, fellowship or other similar title of any other University or society.

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CERTIFICATE

Certified that this project report entitled “**DEVELOPMENT AND EVALUATION OF POTATO WASTE BASED BIODEGRADABLE FILM FOR FOOD PACKAGING**” is a record of project work done jointly under our guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other University or society.

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SYMBOLS AND ABBREVIATIONS

Symbols	Abbreviations
-	Subtract
%	Per cent
/	Per
+	Add
=	Equal to
×	Multiply
a	Red/green colour value, dimensionless
A	Absorbance
ABTS	2,2'-Azinobis (3-ethylbenzothiazoline-6-sulfonic acid)
ASTM	American Society for Testing and Materials
ATR	Attenuated total reflectance
b	Yellow colour value, dimensionless
BHA	Butylated hydroxyanisole
BHT	Butylated hydroxytoluene
BPF	British plastics federation
c	Chroma
Ch	Chitosan
CIE	International Commission on Illumination
cm	Centimetre
CO_2	Carbon dioxide
DA	Degree of acetylation
DDA	Degree of deacetylation
DESs	Deep eutectic solvents
DPPH	2,2-Diphenyl-1-picrylhydrazyl
DTG	Derivative thermogravimetry
EBA	Elongation at break

et al,.	And other
FFS	Film forming solutions
Fig.	Figure
FT-IR	Fourier transform infrared
g	Gram
GSM	Grams per Square Meter
h	Hour
h	Hue
H_2SO_4	Sulphuric acid
HBAs	Hydrogen bond acceptors
HBD	Hydrogen bond donor
ie.	That is
ILs	Ionic liquids
kg	Kilogram
kg/cm^2	Kilogram per centimetre square
L	Bright/Dark colour, dimensionless (Hunter colorimeter
m	Metre
mg	Milligram
min	Minute
ml	Millilitre
mm	Millimetre
MoEF&CC	Ministry of Environment, Forest and Climate Change of India
MPa	Megapascal
MT	Metric tonne
N	Newton
NaOH	Sodium hydroxide
nm	Nanometers
NSP	Non starch polysaccharide
PCB	Polychlorinated biphenyls
PHA	Polyhydroxyalkanoates

PHB	Poly hydroxyl butyrate
PLA	Polylactic acid
PP	Potato peel
PPP	Potato peel powder
PPW	Potato peel waste
RGB	Red green blue
rpm	Revolutions per minute
Rs.	Rupees
s	Second
SEM	Scanning electron microscope
Tg	Glass transition temperature
TGA	Thermogravimetric analysis
TS	Tensile strength
UK	United Kingdom
USA	United States of America
uv	Ultraviolet
viz	Namely
Wb	Wet basis
YI	Yellow index
ΔE	Total colour difference

DEDICATED TO NATURE

INTRODUCTION

CHAPTER I

INTRODUCTION

Food packaging serves three main purposes for consumers-it contains food, shields it from outside influences and harm and provides ingredient and nutritional information. Three secondary purposes that are becoming more and more important are traceability, ease and tamper indication. Food packaging aims to cost-effectively confine food while meeting consumer and business demands, preserving food safety and reducing environmental impact.A food product's shelf life is largely determined by the design and construction of its packaging. During distribution and storage, product quality and freshness are preserved with the appropriate choice of packing materials and methods. Glass, paper and paperboards, plastics, metals (aluminum, foils and laminates, tinplate and tin-free steel) and foils have all historically been utilized in food packaging. Furthermore, a greater range of plastics in both rigid and flexible forms has been introduced (Marsh and Bugusu, 2007).Because of affordability, durability and lightweight, plastics are a more valuable material than metals, papers and other materials. As a result, they are employed in nearly all industrial fields. In 2015, about 300 million tons of plastic were used worldwide. Plastic garbage is everywhere in the world, even in the oceans. Furthermore, there are several drawbacks to the plastics business that are associated with both environmental and economic issues (Arikan and Bilgen, 2019). Very long-time decomposition is the main disadvantage of these materials. While only 21% of them are recycled and burned, 79% of them are rejected, which damages the environment. Plastic debris buildup in landfills and oceans can contaminate the ecosystem. Their breakdown products may be added to the marine food chain (Panou and Karabagias, 2023).

The main strategies available for the management of plastic waste are incineration, recycling and landfill. The treatment of waste plastics has become a serious problem because of the difficulty of ensuring reclaimed land and burning by incineration which creates more environmental pollution, as well as the release of dioxin when plastics are burned, which poses a health risk (Jansson *et al*., 2006).The replacement of petroleum-based plastic materials with biodegradable ones has been the subject of increased research in recent years to address the issues brought on by plastic waste. Biological components, such as proteins and their derivatives, which are naturally occurring and renewable, are typically used to make biodegradable films.

When a packaging material comes into touch with soil, water, or air, it doesn't disrupt the environment's balance. This is known as biodegradable packaging. It applies to both food and non-food products. Biodegradable plastic packaging is a kind that breaks down naturally over time. It is composed of readily available natural elements. Starch, cellulose, chitin, chitosan and other materials are typically utilized in the production of biodegradable films (Laksanawati *et al*., 2024).The majority of these items have a relatively limited-service life and wind up in landfills, packaging films and containers constructed of natural biopolymers are particularly appealing due to their biodegradability. Biodegradable films composed of natural and renewable resources including starch, animal and vegetable proteins, lipids and resins are becoming more and more popular. According to recent studies, using films made entirely of materials (such as starch, protein, lipids and fibers) enhances their mechanical and barrier qualities. The natural interactions between the starch, protein and lipids that take place during the drying of the casting suspension give flour-based films their unique properties (Pelissari *et al*., 2013).Biodegradable films are prepared from plant materials especially starch.It is used in many industrial areas, including paper, corrugated boards, biofuels, pharmaceuticals, textiles and especially the food industry. However, many companies have already started using starch for the production of bioplastics (Arikan and Bilgen, 2019).

The benefits of starch for plastic are its availability, biodegradability, renewability, affordability and thermal stability. The main plasticizer for starch is water, which is why starch dissolves in water with ease. Naturally, starch has low mechanical characteristics and is brittle, making it difficult to convert into plastic and having a low film-forming capability.In nature, starch exhibits thermoplasticity and is a biodegradable polysaccharide that is produced in large quantities at minimal consumption. Despite its endless supply, starch appears to be the most affordable raw material for biodegradable polymers. A variety of starches, including those from potatoes, barley, wheat, tapioca and rice, have been investigated as possible film-forming agents. It is now the most promising substitute material for traditional plastics into specific market niches (Olagundoye and Morayo, 2022).Potato (Solanum tuberosum L.) is one of the main horticultural products grown worldwide, a member of the Solanaceae family. It is regarded as essential as a food crop and has been developed since its introduction in the early seventeenth century. After China, which produces 69.06 million MT of potatoes, India is the second-largest producer, with an estimated 34.4 million MT. Roughly 11.26% of the world's total potato production is produced in India. The method for casting sets up biodegradable packaging film made of potato starch (Hirpara *et al*., 2021).

After rice, wheat and maize, potatoes are the fourth most important crop worldwide. Every year, millions of tons of potato peel (also known as potato peel, PP) trash are generated, which causes issues with handling and storage. Cropland composting or ruminant animal feed production are the conventional management approaches for removing PP pollutants from the environment. In addition, PP is a good source of biodegradable polymers, with low levels of protein (2.56 g/100 g) and carbs (12 g/100 g) (Xie *et al*., 2020).Potato peeling is typically the first preprocessing stage before processing, producing enormous amounts of potato peel waste (PPW) annually, mostly due to the type of peeling technique used. Since such horticultural waste ranges from 15% to 40% (70 and 140 thousand tons) of initial product mass, PPW as a value by-product is a major global concern. The huge amounts of PPW produced by industrial potato processing require careful management to be used going forward as a sustainable value-added commodity.

Due to its extremely fibrous character, PPW is not recommended for ingestion by non-ruminants, nonetheless, it does offer economic value assistance and has shown to be one of the most exceptional raw materials for use in the production of edible packaging. Huge amounts of phyto-constituents, including cellulose, fermentable sugars, hemicellulose, starch, nonstarch polysaccharides (NSP), lignin, polyphenols, protein and lipids, are present in low-cost PPW by-products, which makes them an invaluable source of natural antioxidants, antimicrobials, dietary fiber, biopolymers and other materials for the innovative and sustainable development of biodegradable, edible products (Mishra and Poonia, 2022).

Film performance, spreadability and the thickness and homogeneity of the liquid coating layer can all be impacted by the rheological characteristics of biopolymer solutions (García *et al*., 2014). Incorporating different combinations of plasticizers such as gelatin, glycerol and chitosan can significantly enhance the quality of packaging.

Long-term reduction of plastic waste and food waste can be achieved through the use of this novel approach in the creation of bioplastics. Because bioplastic is biodegradable, it is a promising sign that pollution can be addressed. Furthermore, bioplastic may be able to take the place of petroleum-based plastic products. Thus, the most cost-effective substitute for solid waste management in Malaysia is bioplastic (Kasmuri and Zait, 2018).

There are several difficulties in getting rid of the massive amounts of trash produced by food packaging made of petrochemicals. As such, investigating other choices is becoming increasingly important. The utilization of bio-based materials, which are completely biodegradable and have advantages over manufactured biopolymers, must be given top priority. These materials are a good replacement for synthetic polymers.

In response to these challenges, a study was conducted to develop and assess biodegradable packaging films using potato peel as the primary material, aiming to achieve the following objectives:

i) To standardize film forming solution for the preparation of potato peel based biodegradable film
ii) To develop a potato peel based biodegradable film and its evaluation
iii) To study the shelf-life of sealed food product in biodegradable packaging material

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with the literature reviews on plastic, classification of plastic and its disposal. It also reviews the development of biodegradable composite films, including their testing, biodegradability and shelf-life studies.

2.1 PLASTICS

It is somewhat challenging to acknowledge the significant role that plastics now play in our daily lives. These materials are ones that we always appear to be familiar with and often take for granted because they are present in everything we do daily, including the food that is wrapped, the chair that we sit on, the pen we use to write with and the clothes we wear.

Plastic is described as a material that has a large molecular weight organic compound as a key element. Long carbon chain polymers are another definition for it. Long-chain molecules are created when carbon atoms are joined in chains.

Polymers' molecular structure completely governs their material behavior. This holds for all polymers, both those made artificially and those that are found in nature (known as "bio-polymers"), such as cellulose-based materials, natural rubber, ivory and amber (Brinkmann *et al*., 2006).

2.1.1 Properties of Plastics and Their Application

There is no doubt that one of the most important properties of plastics is corrosion resistance. It makes plastic ideal for the production of packaging materials, bottles, or building and insulation materials. Bags, disposable dishes, insulating tapes, protective films and many other daily-use products are made from plastic. Another very important feature of plastics is their plasticity. This property warranted their recognition of, among others, manufacturers in the packaging, plumbing, clothing, food, pharmaceutical, construction and many other industries.

2.1.2 Classification of Plastics

Materials including fiberglass, textile fibers, paper, silica and sawdust are added during the manufacturing process to generate certain qualities and lower production costs. Chemical additives are mostly used to reinforce and increase the flexibility of polymers, whereas pigments are used to give plastics colour. The key characteristics of plastics are their flexibility, stiffness, elasticity and strength. It also exhibits strong resistance to thermal, electrical and acoustic qualities. The three main categories of plastics are elastomers, thermoplastics and thermo stables (Robertson, 2012).

2.1.2.1 Thermosetting plastics

The phrase "thermosetting plastics" refers to a class of polymers that solidify when heated to a liquid condition. We call the process of solidification "curing." All of the tiny molecules combine chemically to form a single, massive network molecule during the curing process. As a result, they are known as network polymers, which sets them apart from linear polymers (thermoplastics). Before molding, the structure of thermosetting plastics is extremely similar to that of thermoplastics and resembles a chain (Alauddin *et al*., 1995)

2.1.2.2 Thermoplastic

No matter how often the process is performed, thermoplastics always soften when exposed to heat and solidify when cooled. They may be formed numerous times by heating and cooling them in succession. They resemble rubbery liquids when melted and they are glassy or somewhat crystalline when solid.

2.1.2.3 Elastomer

These polymers may regain their original shape even after being stretched to extreme limits because they are chemically linked together to form a final structure that is slightly cross-linked. The lengthy molecules that comprise an elastomeric substance are normally coiled randomly. That being said, when force is applied, the molecules align themselves with the direction of the pull. The molecules instantly return to their typical compact, random configuration after being released. Elastomers include things like neoprene, polyurethanes, polybutadiene and natural rubber (Rajesh, 2014)

2.1.3 Problems Associated with Plastics

Because of their stubborn nature and resistance to biodegradation, plastics pose a significant environmental burden. When discarded plastic stays in its current state for an extended period, it poses a serious risk to human health, wildlife, plants and the environment. Plastic has a significant impact on human society because of its adaptability and variety of uses. The growing pace of plastic waste creation combined with the lack of suitable technologies for management, treatment and disposal presents a significant challenge. According to BPF (2012) India produces approximately 16% more plastic annually than China, which produces almost 10% more plastic garbage annually and the UK produces 2.5 percent more plastic waste annually. Given that India has the fastest-growing plastic market, solid waste management, notably that of plastic garbage, is a concern in many of the country's largest cities.

Large cities like Kolkata, Mumbai, Bangalore and Delhi are thus very vulnerable to the accumulation of solid trash. India alone produces 15,000 tons of plastic waste per day, of which 9,000 tons are collected and processed further, leaving the remaining 6,000 tons of waste uncollected, according to the Ministry of Environment, Forest and Climate Change (MoEF&CC), 2016 (Plastic Waste Management Rules, 2016). The leftover garbage is either emptied into the sea or disposed of in landfills (Moharir and Kumar, 2019).

2.1.4 Management of Plastic Wastes

Management of plastic waste is an important this in our society for many methods are available.

2.1.4.1 Landfilling

Plastics make up about 10% of household garbage and are primarily disposed of in landfills. Although landfilling is the most widely used conventional waste management method in many nations, a significant issue is the lack of landfill space. Well-managed landfills can minimize environmental pollution and public health hazards, but disintegrating plastic residues and additives have the potential to contaminate soil and groundwater and remain in the environment for an extended period (Alabi *et al*., 2019).

2.1.4.2 Plastic incineration

Incineration is one way to dispose of plastic garbage instead of clogging landfills, but there are rising worries about potentially dangerous chemicals being released into the atmosphere during the process. For example, the burning of plastics releases furans, dioxins and polychlorinated biphenyls (PCBs) into the environment and plastic waste fumes emit halogenated additives and polyvinyl chloride. Compared to recycling and landfilling, plastic incineration is used less often for waste management because of the possible environmental harm it poses (Alabi *et al*., 2019).

2.1.4.3 Recycling of plastics

Plastic recycling is the process of turning recovered plastic trash or scraps into goods that can be used. Since most plastics are not biodegradable in the natural world, reducing waste emissions and managing and recycling the wastes that occur is essential. One of the main initiatives being undertaken globally to reduce the 8 million tonnes of plastic garbage that enter the ocean each year is recycling plastics. Due to their low density and low value, plastic recycling is frequently more difficult than recycling metal, which is more profitable. This is comparable to the low value of recycling glass

Recycling can be divided into four main categories: primary recycling, which entails mechanically repurposing plastics into a new product with equivalent properties; secondary recycling, which entails mechanically repurposing plastics into a product with lower properties; and tertiary recycling, which entails recovering the chemical components of the plastics (Alabi *et al*., 2019).

2.1.5 Recommendations for Reduction and Control of Plastic Waste

The usage and disposal of plastic items in modern civilization are not sustainable, endangering human health, ecosystems and economies. The detrimental impacts of plastic pollution have been tried to be lessened by current cleanup techniques, but they are unable to keep up with the growing amount of plastic that is entering the environment.

Thus, minimizing inputs of plastic to the environment must be emphasized through a global multidisciplinary strategy. An Integrated trash Management System can help minimize mismanaged trash, a significant land-based source of plastic pollution, by improving the life-cycle of plastics, particularly in terms of manufacturing, consumption and disposal.

Regulation of plastic production and consumption, eco-design, increasing demand for recycled plastics, reducing plastic use, using renewable energy for recycling, extended producer responsibility over waste, improvements to waste collection systems, prioritizing recycling, using bio-based and biodegradable plastics and improving e-waste's recyclability are the ten recommendations for stakeholders looking to reduce plastic pollution (Prata *et al*., 2019).

2.2 BIODEGRADABLE PLASTICS

Biodegradable packaging is a type of plastic packaging made with natural materials whose availability is unlimited and can be degraded by microorganisms and weather. Materials that are generally used for the manufacture of biodegradable films are starch, cellulose, chitin, chitosan and others (Laksanawati *et al.*, 2024). Biodegradable plastics are generally derived from either replenishable agricultural feed stocks or marine food processing industry wastes such as starch, proteins of animal and vegetable origin, fats and resins. Therefore, it capitalizes on natural resource conservation with eco-friendly and safe atmosphere. Moreover, by biodegradation and composting process, they can convert into fertilizer and soil conditioner, which facilitates better yield to crops. Different types of biodegradable biopolymers are used for numerous packaging purposes. According to their source, there are three groups of natural biodegradable polymers:

- Biomass products such as starches and lignocellulosic products.
- Polymers obtained by extraction of microorganisms such as polyhydroxyalkanoates (PHAs).
- Polymers synthesized from renewable materials such as polylactides (PLA).

2.2.1 Polysaccharide Based Films

The formation of biodegradable films is carried out due to the interaction between polymers (i.e., polysaccharides, lipids and proteins) and polysaccharides are the most widely used biopolymers for biodegradable films due to their accessibility. The main natural sources of polysaccharides are plants (e.g., cellulose, starch and pectin), animals (e.g., chitin, chitosan and hyaluronic acid), algae (e.g., alginate, agar and carrageenan), fungi (e.g., glucans and pullans) and bacteria (e.g., dextran, xanthan and gellan) (Díaz-Montes, 2022).

With cellulose being the most commonly utilized polymer, plant polysaccharides account for more than 50% of reports on biodegradable films. This makes sense as it's the most prevalent polysaccharide found in nature, it's cheap and it can be made with easy techniques like alkaline hydrolysis. The most commonly utilized animal polysaccharides for the production of biodegradable films are chitosan and chitin, which make up around 30% of the material. The process of extracting these polysaccharides involves demineralization, deproteination and distillation of leftovers from crustacean shells. Because of their cationic properties, these animal polysaccharides have antibacterial action, which makes them valuable. On the other hand, about 11% of the natural polymers that have been documented as being used to create biodegradable films are polysaccharides found in algae. Alginate stands out because its extraction is traditionally carried out from brown algae using hydrolysis acid–alkaline. Less than 10% of the rest of the studies report biodegradable films based on fungi and bacteria. This is because bacteria and fungi need strictly controlled conditions of temperature, substrate and exposure times so that the production yield is high. However, the production of a polysaccharide by fermentation or by culture cannot be compared with the extraction yield of a polysaccharide from a plant or an animal (Díaz-Montes, 2022).

2.2.2 Lipid Based Films

Waxes, fatty acids, resins and neutral lipids are the most commonly used lipid compounds for the fabrication of edible films and coatings. A liquid lipid offers less resistance to gas and vapor transmission than a solid lipid. Lipid-based edible films can also apply to cereals, chocolates, dairy products, confectionery products, frozen products, fish, poultry meat and dried products (Devi *et al*., 2024).

Lipids are grouped into three primary categories: simple, derived and compound lipids. Simple lipids are further subcategorized into fats and oils, along with waxes. Compound lipids, on the other hand, are divided into two classes: phospholipids and glycolipids. The third category of lipids, derived lipids, is intricately classified into steroids, terpenes and carotenoids. Among these, simple lipids, particularly fats and oils, play a prominent role in food and nutritional processes. Oils and fats, composed mainly of triglycerides, are widely prevalent lipids in various food sources, both from animals and plants (Zubair *et al*., 2021).

Lipids, known for their economical and abundant presence in nature, are extensively used in edible films and coatings. In addition, lipids minimize moisture loss and packaging costs while imparting a glossy finish to food products, enhancing their visual appeal. Several studies have investigated the addition of lipids to the biopolymer film matrices to change various hydrocolloid film properties. A composite transglutaminase gelatin film containing beeswax exhibited higher moisture resistance and tensile strength compared to the film without a lipid component. Lipid materials like edible fatty acids or waxes are incorporated into the hydrophilic biopolymer to prepare edible films with flexibility, hydrophobicity and cohesion. Edible coatings composed of lipids act as effective barriers against moisture and, to some degree, oxygen, thus preserving food quality. Lipid-based coatings are used for numerous applications, including food, agricultural and pharmaceutical applications. On the other hand, lipid coatings quickly oxidize and provide a lipid flavour that detracts from the food's sensory qualities and appeal (Devi *et al*., 2024).

2.2.3 Polyester-Based Films

The family of polyesters known as polyhydroxyalkanoate (PHA) includes renewable, biodegradable, biocompatible and optically active materials. They serve as an energy and carbon store resource and are synthesized in intracellular form by a variety of bacterial species. Selecting distinct bacterial strains and substrates for the biopolyester synthesis can regulate the specific monomer composition, which is one of the determinants of the final PHA-material's characteristics. Numerous bacteria have accumulated poly hydroxyl butyrate (PHB), a thermoplastic biopolyester, as a carbon and energy reserve. Because of its remarkable stereochemical regularity, it becomes brittle with age as a result of gradual crystallization. By using grafting to incorporate co-monomers, this has been resolved.

For instance, the addition of particular ingredients to the growing medium results in the production of copolymers of PHB with 3-hydroxyvalerate. Even though this method enhances PHB's qualities, it is not economical because the copolymer is more expensive, its toxicity reduces manufacturing yields and its presence alters the kinetics of PHB crystallization, resulting in longer processing cycle durations. However, PHB can be toughened by the annealing process by conditioning in an oven, which expands its potential applications. PHB's hydrophobic character contributes to its strong moisture and scent barrier qualities (Rajesh, 2014).

2.2.4 Protein – Based Films

Thin layers of edible or nonedible proteins can be used as protein-based films or coatings on food or other surfaces. There may be certain drawbacks of biodegradable materials, such as the low mechanical strength and water barrier qualities. The qualities of coatings or films based on proteins can be enhanced using a variety of formation techniques. Films and coatings prepared using protein could also be utilized as a carrier to deliver antioxidant- and antimicrobial-rich formulations.

Protein is one of the important macromolecules that exist in natural resources in two different forms (globular or fibrous). Globular protein has good solubility in water as well as aqueous solutions of salts and acid bases. Fibrous protein is considered as water insoluble and plays a vital role in providing structural support. Both forms of protein are important for sustaining the routine functioning within the body of living organisms. The physical and chemical features of protein depend on the concentration of amino acid residues and their amendment in polymer chains. Collagen (fibrous) is widely being utilized in the synthesis of edible films. The characteristic features of films prepared from protein of different sources (mung bean, corn zein, gelatin, wheat gluten, whey protein, soy and gelatin) have been well documented. Protein-based films prepared from different sources are presented (Purewal *et al*., 2023).

Protein-based films and coatings offer a sustainable and versatile solution for various industries. Their diverse applications in food packaging, biomedical and pharmaceutical fields, agriculture, personal care products, environmental settings and smart packaging demonstrate their potential to revolutionize multiple sectors. Ongoing research and development efforts continue to enhance the properties, functionality and application potential of edible coatings and films, further solidifying their position as an environmentally friendly alternative to conventional packaging materials.

2.3 PLASTICIZERS

A plasticizer is a chemical that adds softness and flexibility to another material. Plasticizers are used to reduce brittleness produced by intermolecular pressures and facilitate film removal from the forming support. Adding plasticizer reduces intermolecular pressures along polymer chains, improving flexibility, extensibility, toughness and rip resistance of the film. However, a high crosslink density in the polymer is necessary for effective barrier characteristics. Plasticizer reduces intermolecular pressures, softens the film structure and enhances chain mobility and spacing. Adding plasticizer can enhance gas or water vapour diffusion coefficients while decreasing film cohesion, tensile strength and glass transition temperature (Tg) (Guilbert, 1986; McHugh *et al*., 1994).

To prevent early separation during film drying, the plasticizer should be compatible with the polymer and easily soluble in the solvent. In other words, effective plasticizers should be most similar to the structure of the polymers plasticize. Biodegradable films often employ polyols (e.g., glycerol, sorbitol and polyethylene glycol), lipids and derivatives as plasticizers (Guilbert, 1986).

Plasticizers often employed include polyols such propylene glycol, glycerol, sorbitol, polyethylene glycol, oligosaccharides and water. Water, a common natural diluent, may either plasticize or anti-plasticize films based on its absorption into the matrix (Chang et al., 2000). According to Krochta (2002), the relative humidity of the surrounding environment has a significant impact on film moisture content and characteristics. Plasticizers can alter the barrier characteristics of films, leading to increased permeability to gases or fragrance compounds, decreased water attraction and decreased tensile strength (Sothornvit and Krochta 2000; Mali *et al*., 2006).

Starch sheet is brittle and weak, resulting in poor mechanical qualities. Glycerol and sorbitol are commonly employed as plasticizers due to their stability and edible properties. The use of plasticizers makes the brittle films more flexible, but less strong (Chandra and Rustgi, 1998).

2.3.1 Gelatin

The capacity of gelatin to create films, its high functional qualities and its usage as an exterior barrier to shield food from drying out and being exposed to light and oxygen have all been the subject of much research. Although gelatin films have good mechanical qualities, it has been discovered that they are moisture-sensitive and have inadequate water vapor barrier qualities. When added to high moisture food products, this has the unintended consequence of causing films to dissolve, bloat, or disintegrate when they come into contact with water (Suderman *et al*., 2018).

2.3.2 Glycerol

According to the results obtained by Maurizio *et al*., 2007, Mass ratios between the polymers and the glycerol effectively control the plasticizing impact of the glycerol. The molecular structure of the polysaccharides used in blends has a significant impact on their properties. Specifically, high molecular weight and high guluronate residue content represent the ideal balance of microstructural properties that enable glycerol molecules to become entangled in specific binding sites of the polymeric network, while lower molecular weight and higher mannuronate residue content result in a flexible, linear three-dimensional arrangement that hardly interacts with the added plasticizer; in fact, only at high glycerol concentrations is it possible to observe a slight interaction of the glycerol itself with the intermolecular binding sites.

2.3.3 Chitosan

One of the most intriguing biopolymers derived from natural sources is chitosan. Apart from its biocompatibility attributes, chitosan's bacterio- and fungi-static qualities are highly beneficial for the preservation of food. It is a polymer that is produced when chitin is deacetylated. Chitosan typically has a degree of deacetylation (DDA) ranging from 70% to 95%, while chitin often has a DDA of 5% to 15%. The solubility in common solvents of chitin molecules is dependent on their degree of acetylation (DA) and crystallinity. Chitosan becomes soluble in aqueous acid solutions by reducing its acetylation level, which guarantees the existence of free amino groups that are easily protonated in an acidic environment with the intermolecular binding sites (Marino *et al*., 2010).

2.3.4 Water

Water is a crucial plasticizer in biological systems, including foods, due to its ability to form hydrogen bonds with polymeric chains. This interaction significantly impacts the physical properties of biopolymers, such as their relaxation behavior, ultimately influencing the texture and stability of food products (Fundo *et al*., 2015)

2.3.5 Deep Eutectic Solvents (DESs)

Deep eutectic solvents (DESs) are increasingly used as sustainable plasticizers for polysaccharide-based films. Unlike ionic liquids, DESs are mixtures of a quaternary ammonium salt and a hydrogen bond donor (HBD), or complexes of Lewis or Bronsted acidic HBDs and basic hydrogen bond acceptors (HBAs). DESs have shown superior performance compared to traditional plasticizers for chitosan, starch and cellulose. They enhance the flexibility and reduce the fragility of chitosan films, improving their mechanical stability. However, highly hydrophilic DESs, like choline chloride—malonic acid, increase water vapor transmission rates, making them unsuitable for food packaging applications (Shamshina *et al*., 2024).

2.4 POTATO WASTE BASED BIODEGRADABLE PLASTICS

Low-value agricultural byproducts, such as PPs, can assist lower the existing high costs of industrial bioplastic products by serving as a viable source of biopolymers (Gune *et al*., 2021; Sen and Baidurah, 2021).

Potato peels contain a number of interesting compounds from the point of view of nutritional and pharmacological activity. Potato wastes (peels) are abundant in polysaccharides. They are mostly made up of starch (30-85%), but they also contain other cell wall polymers such as fibers (24-65%) and proteins (6-18%) (Danila *et al*., 2021).

Starch is a natural polymer that can replace petroleum-based alternatives in several uses, including food packaging. It is synthesized intracellularly in semicrystalline granules made up of two hydrocolloids: linear amylose and branching amylopectin. Potato starches often exhibit B-type crystallinity, with amylopectin branches organized in a tridimensional structure with a hexagonal unit cell containing 12 glucose units and two double helices. This structure can be broken by heating an aqueous starch suspension, a process known as gelatinization. This causes the starch to swell and create a thick paste by destroying the majority of its intermolecular hydrogen bonds. This method is frequently employed in the creation of starch-bioplastics. (Danila *et al*., 2021).

2.5 POTATO PEEL POWDER

Potato, belonging to Solanaceae family, referred as fourth leading crop after rice, wheat and maize, constitutes major part in human diet all around the world. Prior to processing of potatoes, the initial preprocessing step is usually peeling of potatoes resulting in huge quantities of potato peel waste (PPW) every year, which mainly depends on the employed peeling method (Arapoglou et al. 2009). PPW as zero value by-product is a matter of serious concern round the world as such horticultural waste ranges from 15% to 40% (70 and 140 thousand tons) of initial product mass Such big amounts of PPW obtained after industrial potato processing need to be given proper attention for its management and further utilization as sustainable value-added product (Sepelev and Galoburda 2015). Although PPW is not suitable for consumption among non-ruminants due to highly fibrous nature, PPW has economic value assistances and proved to be one of the most remarkable raw materials for its usage in edible packaging developments (Mishra and Poonia, 2022).

Potato is the fourth main crop consumed worldwide and is an important constituent in the human diet. Consequently, potato is widely used in food-processing industries. However, these industries generate massive amounts of potato peel (PP) as a by-product, which is usually considered waste and is discarded. Interestingly, recent research suggests that PP is a valuable source of bioactive compounds, which can be converted into value-added products. In addition to being used as dietary fiber or medicine, the value-added products obtained by the fermentation of PP have multiple uses, including their use as adsorbents, biocomposites and packaging materials. These products can also be used in energy production, biopolymer film development, corrosion inhibition and the synthesis of cellulose nanocrystals. The biorefinery approach for PP will increase the value of this waste by producing an array of value-added products and reducing extensive waste generation (Pathak *et al*., 2018).

Table 2.1 Chemical composition of potato peel waste

Parameters	Dry weight (%)
Moisture	6.78 ± 0.22
Reducing sugar	0.32 ± 013
Starch	48.46 ± 1.88
Protein	15.21 ± 0.82
Fat	0.52 ± 0.09
Ash	7.23 ± 0.21
Fiber	26.52 ± 0.23

Source: Khawla *et al*., 2014

2.5.1 Peel waste in potato processing

On an industrial scale, potato products (e.g., potato fries, potato chips, mashed sweet potatoes) generate between 3 and 5% of waste (peel). The losses (%) caused by potato peeling ranged between 15% and 40%, depending on the peeling method (i.e., steam peeling, alkali peeling, or abrasion). Typical potato processing plants generate from 6 to 10% of potato peel waste during the peeling process and 15% of waste is caused by defect removal, trimming and cutting. Potato peels contain fiber between 9.7 and 68% of their total weight. Potato peel has a protein content of 18%, ash content of 6% on a dry weight basis and produces 63% of fiber on a dry weight basis by manual peeling (Tlay *et al.*, 2023).

2.5.2 Nutritional value and chemical composition of potato peels

Potato peel (PP) powder is a varied and nutrient-rich byproduct contingent upon various factors such as farming practices and genotype. Research by Jeddou et al. (2017) demonstrates how different potato peel genotypes differ in their metabolites. With 69–88 g/100 g dry weight (dw), carbohydrates are one of the main macronutrients in PP. A substantial amount (30–52% dw) of these carbohydrates comprises starch. Additionally, PP has a high dietary fiber content, which has been linked to benefits like lowered cholesterol, better diabetes control (soluble fiber) and intestinal health regulation (insoluble fiber).

Research findings on the total dietary fiber content range from 19.59% to 51% dw (Kumari *et al.*, 2017). PP has low concentrations of soluble sugars, usually between 0.9 and 1.0% dw, with glucose being the most prevalent kind. PP's monosaccharide composition differs among genotypes; in certain types, glucose predominates (Jeddou *et al.*, 2016).

High water-holding and fat-binding capabilities have been observed in water-soluble polysaccharides derived from polypropylene by physicochemical studies (Jeddou *et al.*, 2016). These polysaccharides undergo enzymatic hydrolysis to yield oligosaccharides with foaming and emulsion properties. With quantities varying from 2 to 17 g/100 g dry weight across studies, protein is the second most abundant macronutrient in PP. Additionally present are free and essential amino acids, which enhance the nutritional profile of PP (Choi *et al.*, 2016).

PP has a usually low-fat content; some studies report as little as 2.6 g/100 g dw or insignificant quantities. Other components of PP include quinic acid and ascorbic acid, which have been linked to potential health advantages including antioxidant and diabetic management (Wu *et al*., 2012).

All things considered, PP is a great additive to increase the nutritional content of foods because it is a rich source of nutritious components, including dietary fiber and protein. However, using PP efficiently requires careful attention because of compositional changes caused by environmental factors and genotype.

2.5.3 Phytochemicals in potato peels

2.5.3.1 Phenolic compounds

Potato peels (PP) are a rich source of phenolic compounds, which are known for their antibacterial and antioxidant capabilities among other health benefits. Compared to potato flesh, peels (PP) can have up to 10 times the amount of phenolic compounds. Certain chemicals, such as vanillin, caffeic acid and chlorogenic acid, are more prevalent in the peel (Wu *et al*., 2012).

Among the main phenolic chemicals included in PP are caffeic acid and its isomers, as well as chlorogenic acid. Different potato cultivars can range greatly in their phenolic chemical composition, with chlorogenic acid being the most common molecule in the majority of studies (Riciputi *et al*., 2018). PP also contains flavonoids, p-coumaric acid and ferulic acid, among other phenolic components (Sampaio *et al*., 2020).

The phenolic concentration of PP is mostly determined by the extraction techniques used. When compared to conventional approaches, techniques like ultrasound and microwave-assisted extraction have demonstrated better efficiency in recovering phenolic chemicals (Kumari *et al*., 2017). The extraction efficiency is also influenced by temperature, duration of extraction and solvent selection.

PP contains anthocyanins as well, which give purple and red-fleshed potatoes their colours. These substances support PP's antibacterial and antioxidant qualities in addition to other phenolics. PP from coloured potato types is suitable for natural food colouring and preservation applications because they contain larger levels of anthocyanins than meat (Sampaio *et al*.,2020).

In conclusion, because of its antioxidant and antibacterial qualities, PP is a valuable source of phenolic compounds, such as caffeic acid, anthocyanins and chlorogenic acid, which may find use in food colouring, preservation and health-promoting products (Sampaio *et al*., 2020).

2.5.3.2 Glycoalkaloids

Glycoalkaloids, namely α-solanine and α-chaconine, are found in potato peels (PP) and act as natural defenses against pests and diseases. At concentrations under 1-2 mg/kg of body weight, these chemicals are deemed safe for human consumption, even though they can be harmful in large doses. Glycoalkaloid levels in commercial potato cultivars are generally less than 10 mg/100 g fresh weight, with a maximum limit of 20 mg/100 g fresh weight recommended (Sampaio *et al*., 2020).

According to recent studies, glycoalkaloids in PP may have positive health benefits on humans, including antibacterial, anticancer, anti-inflammatory and anti-obesity capabilities. α-chaconine is more bioactive than α-solanine and is frequently the main glycoalkaloid in PP. Glycoalkaloid content of PP in potatoes that were grown organically versus non-organically. They discovered that the glycoalkaloid content of organically cultivated gold and Russet kinds was higher than that of non-organic samples, whereas the red variety showed the opposite trend. In a similar vein, different potato cultivars have varied glycoalkaloid levels (Sampaio *et al*., 2020).

2.5.4 Bioactive properties

2.5.4.1 Antioxidant activity

Potato peel (PP) extracts have been shown in numerous studies to possess antioxidant properties. In lab settings, these extracts can scavenge free radicals and reactive oxygen species. Numerous tests, including DPPH radical-scavenging capability, reducing power, β-carotene bleaching inhibition, ABTS radical scavenging, lipid peroxidation inhibition and iron ion chelation, have been used to evaluate these activities (Jeddou *et al*., 2018). According to some research (Wu *et al*., 2012), PP extracts had noticeably stronger antioxidant activity than meat extracts.

For example, Jeddou *et al*., (2018) obtained encouraging findings in a variety of tests when examining the antioxidant potential of low molecular weight oligosaccharides made from PP waste. These oligosaccharides have the potential to be natural food additive antioxidants since they demonstrated antioxidant activity that was comparable to that of synthetic antioxidants like BHA and BHT (Sampaio *et al*., 2020).

2.5.4.2 Antibacterial and antiviral activities

Numerous research has shown that potato peel (PP) extracts have strong antiviral and antibacterial properties. Antitrichomonad activity of PP powders from several potato cultivars against pathogenic trichomonad strains. Furthermore, studies conducted and demonstrated the antibacterial activity of PP extracts against Salmonella Typhimurium and Escherichia coli (Sampaio *et al*., 2020).

2.5.4.3 Anti-obesity and anti-diabetic properties

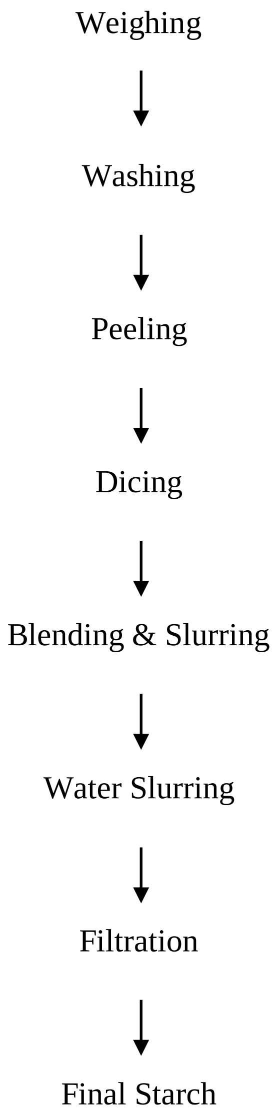
The possible anti-obesity and antidiabetic effects of PP have been studied. It lowers postprandial glucose levels and α-glucosidase inhibitors are a promising treatment option for type 2 diabetes. The methanolic extract had encouraging α-glucosidase inhibitory action, suggesting that it could help with type 2 diabetes management (Sampaio *et al*., 2020).

2.5.5 Preparation of potato peel powder

2.5.5.1 Extraction of starch from Potato tubers:

Water medium was chosen for the extraction because it was observed that the extraction rate was enhanced as compared to alkali extraction. With alkali medium, the extraction of starch from potato is decreased as compared to other tubers such as the family of Colossi which includes the cocoyam.

Fig 2.1. Production of potato peel powder



Source: Gangurde, S.B. (2023) 'Production of Biodegradable Plastic from Potato Starch', *International Journal of Science and Research*, 12(2).

2.5.5.2 Preparation of potato peel powder

Potato tubers were washed with plain water and peeled manually. The percentage of peels obtained was on average 13% of the tuber weight. The peels were dried using a hot air-drying oven at 60°C for 12 hours to constant moisture. After drying, the dried peels were ground using a mill, then sieved through a fine sieve (60 mesh) to obtain a fine homogeneous powder and stored in opaque sealed containers in a cool dry place until the time of manufacture and testing (Tlay *et al*., 2023).

2.6 ADVANTAGES AND DISADVANTAGES OF BIOPLASTICS

The future of biodegradable plastics shows great potential.

2.6.1 Advantages of Bioplastics

2.6.1.2 Lower carbon footprint

It should be noted that whether or not a bioplastic permanently stores the carbon that the developing plant removes from the air will have a significant impact on the plastic's carbon footprint. The carbon dioxide that plants absorb during photosynthesis is sequestered by plastic derived from biological sources. If the resultant bioplastic breaks down into water and CO_2, this sequestration is undone. However, the CO_2 is permanently stored in a bioplastic that is designed to resemble polyethylene or other conventional plastics. The CO_2 that was originally extracted from the environment is still sequestered even after the plastic is recycled numerous times (Chen *et al*., 2014).

2.6.1.2 Independence

Unlike conventional plastics, which are derived from petroleum, bioplastic is created from renewable resources, such as corn, sugarcane, soy and other plant sources (Yu *et al*., 2008).

2.6.1.3 Energy efficiency

Compared to traditional plastics, less energy is used in production. Conversely, only 4% of the oil used worldwide annually is used to make plastics. The production of plastics is more vulnerable to price fluctuations when there is a shortage of oil (Chen *et al*., 2014).

2.6.1.4 Eco-safety

In addition, bioplastic emits no poisons and produces fewer greenhouse emissions. According to studies by Yu *et al*., (2008) and Chen *et al*., (2014), bioplastics unmistakably help achieve the objective of reducing greenhouse gas emissions, since each kilogram of resin produced releases just 0.49 kg of CO_2. In comparison to equivalent petrochemical competitors that emit 2–3 kg CO_2, this represents an 80% reduction in potential global warming. Nevertheless, there could be issues with using bioplastics (Arikan *et al.,* 2015).

2.6.2 Disadvantages of Bioplastics

2.6.2.1 High costs

The cost of bioplastics is reportedly twice as high as that of traditional plastics. However, it is anticipated that if cost-cutting measures are put in place, there will be a greater volume of large-scale industrial manufacturing of bioplastics, which will become more prevalent (Arikan *et al*., 2015).

2.6.2.2 Recycling problems

Issues with recyclingIf bioplastic material is not isolated from regular plastics, it could potentially compromise the recycling process. For instance, bioplastics cannot be separated when using infrared radiation in a waste separation system and the plastics being separated may become contaminated with bioplastics (Arikan *et al*., 2015).

2.6.2.3 Reducing raw materials

Reducing raw material reserves could be possible with bioplastics made from renewable resources. Furthermore, the exploitation of food by-products is a contemporary trend aimed at reducing energy consumption during the manufacturing of bioplastics, mitigating potential rivalry with agricultural resources for food and providing additional sources of raw materials (Arikan *et al*., 2015).

2.6.2.4 Misunderstanding of terms

It can be confusing to refer to bioplastic as compostable. Like organic food waste, not all bioplastics can be composted at home. Most bioplastics need to undergo an industrial composting process, which isn't offered by all composting sites. Additionally, several businesses are misrepresenting bioplastics and related terminology to make their products appear more appealing on the market. Manufacturers utilize phrases like "environmentally friendly," "non-toxic," and "degradable/ degradable" to deceive consumers who lack knowledge (Arikan *et al*., 2015).

2.6.2.5 Lack of Legislation

By 2018, it's expected that approximately 6.7 million tons of bioplastics will be produced. However, many nations continue to lack laws or regulations about their production, use, or disposal of garbage (Arikan *et al*., 2015).

2.7 TESTING

2.7.1 Testing of potato peel powder

2.7.1.1 Moisture content

The hot air oven method was used to assess the sample's moisture content. A hot air oven was used to precisely weigh and dry a sample weighing between 5 and 10 g at 70 degrees Celsius. Until a consistent weight was reached, the drying process was maintained. The percentage of moisture content was stated (Rajesh, 2014).

$$\text{Moisture content (\% wb)} = \frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}} \times 100$$

2.7.1.2 Colour

The colour changes in potato peel powder throughout the production of the biodegradable film were measured using the Hunter Lab colour flex meter. It measures the amount of energy reflected from the sample across the visible spectrum by gathering light. The meter uses mathematical models and filters based on "standard observer curves" to calculate the luminance ('L') value, which ranges from 0 (black) to 100 (white), as well as the red-green ('a') and yellow-blue ('b') components. Ceramic calibration tiles in black and white were used to establish standardization. To report the 'L', 'a' and 'b' values for daylight colour, data from three replicates per sample were averaged (Rajesh, 2014).

2.7.1.3 Estimation of amylose and amylopectin

The method recommended by Hoover and Ratnayake (2002) and Juliano (1981) was used to determine the amylose content. After weighing about 100 mg of the samples, 1 ml of 99% ethanol and 9 ml of 1N sodium hydroxide (NaOH) were added to a 100 ml volumetric flask. After that, the contents of the flask were well combined and covered with foil or parafilm. To gelatinize the starch, the mixture was cooked for ten minutes in a boiling water bath; the timer was set to begin at that point. The samples were heated, cooled and then thoroughly shaken to restore their original volume using distilled water (Rajesh, 2014).

A volumetric flask with a capacity of 100 ml was pipetted with a part of the mixture, approximately 5 ml. Following the addition of 1 ml of 1N acetic acid and 2 ml of iodine solution, the flask was filled with distilled water. At a wavelength of 620 nm, the absorbance (A) was measured with a spectrophotometer. One milliliter of ethanol, nine millilitres of sodium hydroxide and one milliliter of boiling and volume-driven distilled water made up the blank solution, which was utilized to standardize the spectrophotometer. Before the spectrophotometer reading, acetic acid and iodine were also applied to this blank solution. Next, the absorbance values and the standardization data from the blank solution were used to compute the amylose content (Rajesh, 2014).

2.7.1.4 Estimation of starch

To eliminate sugars, the material (0.1–0.5 g) was homogenized in heated 80% ethanol. Following centrifugation, the residue was cleaned with anthrone reagent and hot 80% ethanol until no colour remained. A water bath was used to dry the cleaned residue. The residue was then mixed with 5 ml of water and 6.5 ml of 52% perchloric acid and it was stored at 0°C for 20 minutes to facilitate extraction. Following centrifugation, the supernatant was gathered, combined from multiple extractions and poured into a 100 ml container (Rajesh, 2014).

A pipetted portion of the supernatant (0.1 ml) was diluted with 1 ml of distilled water for analysis. Water-filled tubes containing different volumes (0.2, 0.4, 0.6, 0.8 and 1 ml) of the supernatant were used to prepare the standards. Each tube received four millilitres of the anthrone reagent, which was then heated for eight minutes in a boiling water bath. After the tubes were quickly cooled, the green to dark green colour intensity was measured at 630 nm. A standard graph was used to measure the glucose level and a factor of 0.9 was applied to determine the starch content (Rajesh, 2014).

2.7.1.5 Estimation of total proteins

The Kjeldahl method was used for protein measurement. During digestion, H_2SO_4 transformed the nitrogen in proteins and organic materials to ammonium sulfate. After being released during steam distillation, ammonia was collected in a solution of boric acid and titrated against standard acid. The nitrogen concentration of the sample was computed using the formula that 1 millilitre of 0.1 N acid is equal to 1.401 mg N.

A carefully measured 100 mg sample with 1-3 mg of nitrogen was put into a 30 ml digestion flask and broken down using 2 ml of concentrated H_2SO_4, 80 ± 10 mg of mercuric oxide and 1.9 ± 0.1 g of potassium sulfate. Because the sample size was bigger, more H_2SO_4 (0.1 ml per 10 mg dry material) was added.

After adding boiling chips, the mixture was further broken down until it was colourless. The solution was moved to the distillation equipment after cooling and being diluted with distilled water free of ammonia. An aliquot was used for distillation after the digest was adjusted to a specified volume for samples with a high nitrogen content. To collect ammonia during distillation, a 100 ml conical flask containing a mixed indicator and a boric acid solution was put. After adding 10 millilitres of sodium hydroxide solution to the test solution, ammonia was found in the distillate. As the endpoint, the collected ammonia was titrated against standard acid until a violet tint appeared. To find the protein content, a blank was made and deducted from the sample titration volume (Rajesh., 2014).

2.7.1.6 Estimation of total fats

Total fat was calculated using Ranganna's (1986) methodology. To ensure uniform solvent distribution during extraction, a piece of filter paper was folded to retain the PPP. Another paper was then wrapped around it like a thimble. Finally, cotton wool was placed on top. After the sample was put into the soxhlet extraction device, it was gently heated for six hours and extracted using 150 drops of petroleum ether per minute. The extraction flask was disassembled and the ether evaporated on a steam or water bath until no odor was detected when the flask had cooled. After cooling and being cleared of any debris or moisture, the flask was weighed. Until a steady weight was reached, this drying procedure was repeated (Rajesh., 2014).

2.7.2 Testing of biodegradable film

2.7.2.1 Surface Morphology

A Hitachi Co., Ltd., Japan model SU1510 scanning electron microscope (SEM) was used to study the films' surface and transversal sections. Film samples were sputter-coated with gold under vacuum, carbon conductive adhesive tape was used to mount them on aluminum stubs and they were cryo-fractured in liquid nitrogen before being seen. The SEM was run at 500× and 1000× magnifications at a 5 kV acceleration voltage (Liu *et al*., 2022).

2.7.2.2 FTIR Spectroscopy

Utilizing a Nicolet IS50 FT-IR spectrometer from Thermo Nicolet Corporation in the USA, FTIR spectra of film samples were acquired. Film samples were examined using an ATR-FTIR spectrometer in the absorbance mode. After 32 scans, spectra were obtained with air serving as the background and in the wavenumber range of 4000–500 cm^{-1} at a resolution of 4 cm^{-1} (Liu *et al.*, 2022).

2.7.2.3 Colour Parameters and Barrier Properties

A Minolta colourimeter from Kyoto, Japan was used to measure the colour parameters (L*, a* and b*). Five readings were taken at random intervals while the films were positioned on a regular white plate. Based on colour data, the hue angle (h*), chroma (C*), yellowness index (YI) and total colour difference (ΔE) were computed. Transmittance spectra were acquired between 200 and 800 nm and the transparency and UV barrier qualities were assessed using the transmittances at 280 nm (T280) and 660 nm (T660) (Liu *et al.*, 2022).

2.7.2.4 Thickness and mechanical properties

A spiral micrometer from Mitoyo Corporation in Japan was used to measure the thickness of the film and the TA-XT Plus texture analyser (TA XT Plus, UK) was used to determine the mechanical properties by ASTM D882 standards. After cutting film samples into strips (20 mm × 70 mm), they were put on a sample fixture with the cross-head speed and initial clamping distance adjusted. Using the given formulas, tensile strength (TS) and elongation at break (EBA) were computed. TS is the maximum force applied to pull the sample divided by the film sample's cross-sectional area and EBA is the elongation at break about the samples' initial grip-strength length (Liu *et al.*, 2022).

2.7.2.5 Solubility in water (WS)

WS is the ratio of the weight of the soluble substance to the weight of the film. After drying, the films were divided into squares measuring 2 cm by 2 cm and weighed. The dehydrated films were then placed in distilled water at 25 °C for 24 hours. To achieve a constant weight, the films were then dried for the entire night at 105 °C.

The following formula was used to determine the samples water solubility:

$$\text{WS (\%)} = \frac{W1 - W2}{W1} \times 100\%$$

Where W_1 means the initial weight of the film and W_2 means the weight of the film after drying. Each sample was measured three times (Liu *et al.*, 2022).

2.7.2.6 Thermodynamic evaluation

Thermogravimetric analysis of the composite films thermal stability was done using a TGA 5500, manufactured by TA Instruments in the United States. Three milligrams of film fragments were placed in an aluminium container. As a guide, an empty aluminium container was employed. The specimens were heated between 25 and 600 ◦C, heating at a rate of 10°C/min in an environment of nitrogen. Additionally, thermogravimetric analysis (TGA) was used to measure the shift in the samples' masses. By utilizing a technique called derivative thermogravimetry (DTG), which involves separating the mass-temperature profiles, the rate of mass loss of the samples with temperature during heating was determined (Liu *et al*., 2022).

2.7.2.7 Opacity

The percentage (%) of the bioplastic film opacity was calculated based on their light transmittance, which was measured using a double beam Ultra Violet – Japanese-made Visible Spectrometer, Model 1800, with a wavelength of 600 nm. The empty colourimetric cup served as the control and the film samples were cut into 4 x 1 cm2 and adhered to one side of the cup. Three measurements of the films relative opacity were made and the result was computed using the following formula:

$$\% \text{ Opacity} = \frac{A600}{X}\text{ nm}$$

Where X is the film thickness (nm) and A600nm is the absorbance at 600nm (Olagundoye *et al*., 2022).

2.7.2.8 Biodegradability of the Bioplastics

The biodegradability of the samples was assessed using the soil burial method. Every sample has a size of 2 ×2 cm^2 was weighed (W_1) and then buried 10 cm below in the ground. For twelve days, this test was conducted at room temperature (26–28°C) with 80–85% humidity. After being removed from the soil, the samples were washed, dried for 24 hours at 26–28°C and then weighed (W_2) every three days. The following equation was used to calculate the bioplastic decrease percentage:

$$\% \text{ Loss of weight} = \frac{W1 - W2}{W1} \text{ X } 100$$

Where W_1 is the samples' initial weight and W_2 is their weight following the deterioration period (Olagundoye *et al*., 2022).

2.8 Storage Studies of Food Products Packed in Biodegradable Packaging

The primary causes of quality deterioration in food products are due to microbiological growth, physiological deterioration and biochemical changes, which lead to undesired colour changes, off-flavour and firmness loss. The composition of storage gases, environmental condition and product factors are the major factors that control the biological and biochemical activities (Zagory and Kader, 1988). There are various methods for retarding respiration and biochemical activities during storage, the more successful method being modified atmosphere packaging (MAP) (Zagory and Kader 1988).

Modified atmosphere packaging involves the use of polymeric film with a specific permeability to O_2, CO_2 and water vapour. Depletion of O_2 and elevation of CO_2 within the package can be achieved passively by respiration or actively by flushing a desired mixture of gases into the package (Zagory and Kader 1988; Ballantyne *et al*., 1988). The level of gas composition achieved depends on the permeability of the packaging film and the rate of respiration of the vegetable materials.

The application of a biodegradable film as barrier between fruits and vegetables and their surroundings is becoming an increasingly important venture because consumers demand of hygienic and sanitary products. Modified atmosphere packaging (MAP) has been used to extend the shelf-life of fruits and vegetables and is considered to be an effective method in preventing microbial and insect contamination (Cliffe *et al*., 2005).

The effect of Modified Atmosphere Packaging (MAP) with biodegradable films on preserving sweet cherry fruit quality during cold storage was studied by Giacalone and Chiabrando, (2013). Results showed that the use of biodegradable films was useful to preserve quality of cherries through a delay in the changes in colour and the losses of firmness and acidity. Biodegradable film characterized by a high permeability to CO_2 and high barrier to O_2 provided the best results in terms of colour, acidity and firmness. With respect to anthocyanins contents, phenolic contents and total antioxidant capacity, differences existed among the three treatments but was not detected any negative effect due to biodegradable films. The effects of polylactic acid (PLA) based biodegradable film packaging on the microbial and physicochemical quality of green peppers (Capsicum annuum L.) were compared to the effects of low-density polyethylene (LDPE) film packaging and perforated LDPE film packaging. Results indicated that the physicochemical properties of colour, hardness, ascorbic acid concentration and microbial levels (total aerobic bacteria and moulds and yeasts) did not show remarkable changes during storage period. The biodegradable film with higher water vapour permeability can be used to maintain the quality and sanitary conditions (protection from microbial and insect contamination) of freshly harvested green peppers in modified atmosphere packaging (Koide and John, 2011). Broccoli florets were stored in zein films at refrigeration temperatures. Broccoli florets maintained their original firmness and colour after 6 days of refrigerated storage. Low CO_2 permeability of laminated-and-coated films contributed to quickly establish high CO_2 atmospheres that retarded respiration early in the storage period thus preventing oxygen depletion. Microscopic examination revealed that refrigerated storage affected dimensional stability of zein films. They became soft and soggy except for films laminated and coated with tung oil, which remained structurally unchanged and maintained their appearance and dimensional stability (Rakotonirainy et al., 2001).

MATERIALS AND METHODS

CHAPTER III

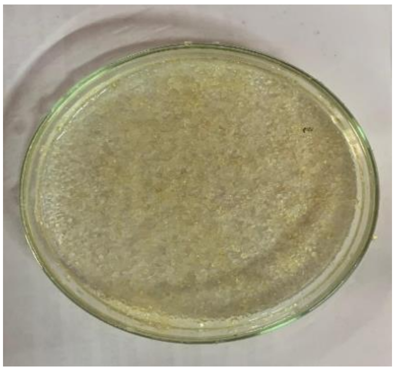
MATERIALS AND METHODS

This chapter discusses the experimental setup and methods used to create biodegradable film from potato peel powder. The techniques for the determination of mechanical, structural, barrier and textural characteristics of biodegradable film are covered. The shelf-life studies of food product packed under the optimized biodegradable packaging are also included in this chapter.

3.1. RAW MATERIALS

The film-forming component for creating a continuous biodegradable film matrix was prepared using potato peel starch powder. The necessary amount of potato peels was collected from the KCAET Ladies Hostel. Film-forming solutions (FFS) were prepared, incorporating low molecular weight chitosan (Ch) sourced from M/s marine hydrocolloids. Other ingredients like glycerol, gelatin and citric acid were procured from M/s chemind, Thrissur. Film-forming moulds were purchased through online from M/s 53 Arts.

(a) Potato Peel



(b) Gelatin

(c) Citric Acid

(d) Chitosan

(e) Glycerol

Plate 3.1 Raw materials for the preparation of biodegradable packaging

3.2 PHYSICAL PROPERTIES OF POTATO PEEL

3.2.1 Estimation of Moisture Content

Infrared moisture meter determines the moisture contents of samples by emitting infrared radiation on the sample surface. The moisture content is determined based on the interaction between the infrared radiation and the sample. Before starting the actual measurement, the infrared moisture meter needs to be calibrated. Then prepare the sample and it should be finely ground or homogenized to ensure consistent results. After that, turn on the infrared moisture meter and allow it to warm up as per the manufacture instructions. Make sure the instrument is clean and free from any contaminants that could affect the accuracy of the measurements. Place the prepared sample in the sample holder or container provided by the moisture meter. Ensure that the sample is spread evenly and covers the measurement area completely. Then activate the moisture meter to initiate the measurement process. The moisture meter will display the moisture content value (wet basis) on its screen digitally. Repeat measurements to ensure accuracy and precision.

Plate 3.2 Infrared moisture analyser

3.2.2 Estimation of Water Activity

Water activity (a_w) is the amount of free moisture available for chemical and biological reactions. Water activity meter works on the principle of measuring the relative humidity at head space, when liquid phase water in the sample reaching equilibrium with the vapour phase water in the headspace. The water activity of potato peel was observed with a water activity meter (Model: Aqua Lab, Decagon Devices Inc., Pullman, USA) as shown in Plate 3.3. The sample was filled in cup which was provided along with water activity meter. The drawer knob was first turned to OPEN position and opened the sample port by pulling the handle. The sample was then placed in sample port and sealed the chamber and 45 turned the knob to READ position. The water activity of the sample was shown in the display screen with respect to atmospheric temperature.

Plate 3.3 Water activity meter

3.3 PREPARATION OF STARCH POWDER FROM POTATO PEEL

Potato peels were collected from a variety of sources, including restaurants, food processing plants and hostels. The potato peels were washed properly to remove dust and other foreign materials. The surface moisture was removed using a cotton cloth. It was then pulverized using a grinder into a fine paste. The starch was extracted by adding water to the paste. The solution was kept overnight and the starch was separated by decantation process. The wet starch was then subjected to drying using the heat pump dryer in food processing lab. The drying temperature was set to 70^0C.and sample were kept for 5 hours. The dried sample at moisture content 10%(wb) was pulverised, sieved and packed in polypropylene packets till further studies.

Collection

↓

Cleaning

↓

Pulverizing

↓

Settling

↓

Decantation and Starch extraction

↓

Drying

↓

Powdering

↓

Sieving and Storage

Fig 3.1. Flow chart for the preparation of potato peel powder

(a) Cleaning

(b) Grinding

(c)Settling

(d) Decantation and starch extraction **(e)Drying** **(f) Sieving**

Plate 3.4 Preparation of potato peel powder

3.4 TESTING OF POTATO PEEL POWDER

3.4.1. Estimation of Amylose and Amylopectin

The method that Hoover and Ratnayake (2002) and Juliano (1981) approved was used to determine the amylose content. A 100 ml volumetric flask containing approximately 100 mg of the samples was carefully filled with 1 ml of 99 percent ethanol and 9 ml of 1N-sodium hydroxide (NaOH). The flask's mouth was sealed with foil or parafilm and the contents were thoroughly combined. To gelatinize the starch, the samples were cooked for 10 minutes in a boiling water bath (the timing was begun when boiling starts). After being taken out of the water bath, the samples were let to cool. After that, distilled water was added until it reached the full capacity and it was thoroughly shaken. The liquid was then pipetted into a second 100 ml volumetric flask, using around 5 ml of it. After adding 2 ml of iodine solution and 1 N of acetic acid (1.0 ml), the container was filled up to the top with distilled water. Next, using a spectrophotometer set to 620 nm wavelength, absorbance (A) was measured. The blank was filled with one millilitre of ethanol, nine millilitres of sodium hydroxide, heated and then topped off with distilled water. The spectrophotometer was calibrated at 620 nm by pipetting around 5 ml into a 100 ml volumetric flask, to which 1 ml of 1N acetic acid and 2 ml of iodine solution were added and the flask was then filled to the mark.

The amylose content was calculated as:

Amylose (%) = 61.20 (A) ………… (i)

Where, A = Absorbance value.

Amylopectin (%) = 100 – Amylose ………… (ii)

Plate 3.5 Spectrophotometer

3.4.2. Estimation of Starch

We estimated the amount of starch using the technique outlined by Ranganna (1986). To eliminate sugars, the material (0.1–0.5 g) was homogenized in heated 80% ethanol. After centrifuging, the residue was kept. The residue was repeatedly cleaned using hot, 80 percent ethanol until the anthrone reagent did not produce any colour. To dry, the residue was spread out over a water bath. It was filled with five millilitres of water and 6.5 millilitres of 52% perchloric acid. It was then left to extract for 20 minutes at 0°C. After then, the supernatant was preserved by centrifugation. The procedure was repeated, the supernatant was pooled and 100 millilitres was produced. After pipetting out the 0.1 ml of supernatant, distilled water was added to bring the volume up to 1 ml. To prepare the standards, 0.2, 0.4, 0.6, 0.8 and 1 millilitre of water were added to each tube. Each tube received four millilitres of anthrone reagent, which was cooked in a boiling water bath for eight minutes. It quickly cooled and about 630 nm, the colour changed from green to dark green. The usual graph was used to determine the glucose content. By multiplying the glucose content by 0.9, the starch content was found.

Starch content (%) = glucose content x 0.9 ………… (iii)

Plate 3.6 Estimation of starch

3.4.3. Estimation of total Fat Content

Total fat content is estimated using a Soxhlet apparatus. Begin by preparing the sample for fat extraction. Ensure that the sample is representative and accurately weighed according to the required amount for analysis. The sample's weight typically ranges from 1 to 5 grams, depending on the expected fat content and the capacity of the Soxhlet apparatus being used. Choose an appropriate solvent for fat extraction. Commonly used solvents include petroleum ether, hexane, or a mixture of these solvents. The choice of solvent depends on the type of fat to be extracted and the solubility characteristics of the sample. Set up the Soxhlet apparatus according to the manufacturer's instructions. The apparatus consists of a round-bottom flask, a Soxhlet extraction chamber, a condenser and a heating source such as a heating mantle or hot plate. Place the accurately weighed sample into the extraction chamber of the Soxhlet apparatus. Add a suitable volume of the selected solvent to the round-bottom flask. Ensure that the solvent level is below the top of the thimble in the extraction chamber. Start the extraction process by heating the solvent in the round-bottom flask. The solvent vaporizes and rises through the Soxhlet extraction chamber, carrying fat from the sample with it. The fat-solvent mixture condenses in the condenser and drips back into the round-bottom flask. The Soxhlet apparatus operates in a continuous extraction cycle. As the solvent refluxes back into the extraction chamber, it continuously extracts fat from the sample. This cycle repeats several times, ensuring thorough extraction of fat from the sample. The extraction process continues until the fat content in the solvent reaches equilibrium, indicating that most of the fat has been extracted from the sample. This typically takes several hours, depending on the fat content of the sample and the efficiency of the Soxhlet apparatus.

Plate 3.7 Soxhlet apparatus

After the extraction is complete, remove the round-bottom flask from the Soxhlet apparatus. Evaporate the solvent from the fat-solvent mixture using a rotary evaporator or a similar evaporation method. Once the solvent is evaporated, the remaining fat is dried to remove any residual moisture. Finally, weigh the extracted fat to determine its mass. The total fat content in the sample is calculated as a percentage based on the weight of the extracted fat and the initial weight of the sample.

The formula for calculating fat content is typically:

$$\text{Fat content (\%)} = \frac{\text{Weight of extracted fat}}{\text{Weight of sample}} \times 100 \quad \text{………… (iv)}$$

3.4.4 Estimation of Colour

Using a colourimeter (Lovibond hand held spectrocolorimeter) to estimate the colour of potato peel powder requires a simple yet accurate process to identify colour features. Make the potato peel powder sample first. To get reliable colour measurements, make sure the sample is uniform and finely powdered. As directed by the manufacturer, set up the colourimeter. This entails turning on the instrument, choosing the proper colour scheme (such CIELAB or RGB) and calibrating the apparatus with a calibration standard or a common white reference tile. Select the colour space that best meets the needs of your analysis. Because it offers values for lightness (L*), the red-green axis (a*) and the yellow-blue axis (b*), CIELAB (L*a*b*) is frequently used for colour measurements.

This is because it provides comprehensive colour information. To guarantee precise colour measurements, do a colourimeter calibration procedure. This entails confirming that, in accordance with the chosen colour space, the instrument accurately interprets colour values. Put a tiny quantity of the prepared potato peel powder sample in the colourimeter's cuvette or sample holder. Make sure the sample is dispersed evenly and completely covers the measurement area.

Using the colourimeter, determine the sample of potato peel powder's colour. Depending on the colour space that is chosen, the device will output numerical values that correspond to colour properties.

Plate 3.8 Hand-held spectrocolorimeter

3.4.5 Estimation of Moisture Content

The moisture content of the PPP was determined using an infrared moisture analyzer, using the procedure outlined in Section 3.2.1.

3.4.6 Estimation of Water Activity

The water activity of the PPP was determined using a water activity meter, using the procedure outlined in Section 3.2.2.

3.5 DEVELOPMENT OF BIODEGRADABLE PACKAGING

3.5.1 Experimental Design

Biodegradable plastic films were prepared using different PPP concentrations (3, 4 and 5 %) and a combination of plasticizers (glycerol + chitosan, chitosan + gelatin and glycerol + gelatin) as shown in table 3.1,3.2 and 3.3. PPP solution was prepared by dissolving PPP (3, 4 and 5% w/w) in water. A combination of plasticizers was then added to the prepared solution. The solution was heated and stirred using a hot plate at 70°C for twenty minutes to induce gelatinization. The film-forming solution was then cooled to ambient temperature.

Table 3.1 Concentrations of chitosan-glycerol film-forming solution

Sl No.	Sample	Starch (g)	Gelatin (g)	Chitosan (g)	Glycerol (ml)
1	A1	6	-	1.5	1.5
2	A2	8	-	1.5	1.5
3	A3	10	-	1.5	1.5

Table 3.2 Concentrations of gelatin-glycerol film-forming solution

Sl No.	Sample	Starch (g)	Gelatin (g)	Chitosan (g)	Glycerol (ml)
1	B1	6	1.5	-	1.5
2	B2	8	1.5	-	1.5
3	B3	10	1.5	-	1.5

Table 3.3 Concentrations of gelatin-chitosan film-forming solution

Sl No.	Sample	Starch (g)	Gelatin (g)	Chitosan (g)	Glycerol (ml)
1	C1	6	1.5	1.5	-
2	C2	8	1.5	1.5	-
3	C3	10	1.5	1.5	-

3.5.2 Preparation of Biodegradable Packaging Film

The prepared film-forming solution of 55 g was measured and poured into an 8 x 8-inch silicon mould, then manually spread to achieve uniform thickness. The mould was placed on a vibrating surface to eliminate undesired air bubbles. Subsequently, it was shade-dried at an average atmospheric temperature of 35°C for a duration of 2 days.

3.6 TESTING OF BIODEGRADABLE FILM

3.6.1. Colour

Hand-held Spectrocolorimeter (Model:Lovibond LC100) was used for the measurement of colour values of the developed biodegradable film. The colour of the film was expressed in terms of L, a, b values as described in section 3.4.4.

3.6.2. Tensile Strength and Elongation Percentage

The tensile strength and elongation percentage of the films were determined using a Digital Tensile Testing Machine (Model: AMT-2BE A.S.I Sales pvt. ltd.). The studies were conducted at room temperature (32.2°C) and 56% relative humidity. Film specimen of dimension 100 x 50 mm was fastened to a moving grip on one side and a stationary grip on the other. Sandpaper was used to line the grips to avoid slipping. The film was stretched until it broke to continue the elongation. The test crosshead speed was 0.1 mm/s and the initial grasp spacing was 30 mm. For every type of film, a minimum of three samples were used and the mean value was reported. Peak force (N) divided by initial cross-sectional area (m^2) yielded the tensile strength (MPa) result. The lengthening of the film was expressed as a percentage increase over its initial length.

Plate 3.9 Digital tensile testing machine

3.6.3 Solubility and Swelling Index

The technique outlined by Alves *et al*. (2011), was used to calculate the solubility and swelling index of the film. 30 mm × 30 mm dried film pieces were cut and they were left in 50 ml of distilled water for 24 hours. The dried film's initial weight was recorded (W1). The extra water was drained off after 24 hours and the swollen weight (W2) was measured once more.

Next, the degree of swelling was ascertained as follows:

$$\text{Swelling Index (\%)} = \frac{W2-W1}{W1} \text{ x } 100 \text{ ………… (v)}$$

Following soaking, the remaining film pieces were dried once more at 60°C to a constant weight and the solubility was determined by measuring the drop in their dry weight. At least two duplicates of each sample were examined.

$$\text{Solubility (\%)} = \frac{\text{(Initial dry weight} - \text{final dry weight)}}{\text{Initial dry weight}} \text{ x } 100 \text{ ………… (vi)}$$

Plate 3.10 Solubility and swelling index of biodegradable film

3.6.4 Cobb's Test

The Cobb Sizing Tester measures the volume of water that paper, cardboard, corrugated fiber board and paperboard absorb in a predetermined amount of time under uniform settings. The water absorptiveness is used to analyse its size, porosity and other properties.

Cut a piece of PP film sample into a circle that is larger than the instrument's diameter. Using a computerized weighing balance, weigh the sample. Then, the sample should be placed between the rubber cushion and the cylinder for support. Using the screw, manually tighten the sample.

After clamping, make sure the sample is not crushed and then turn the cylinder back to its original position. Once the sample is clamped, fill the cylinder with 100 or 250 ml of water to the test-specific marker. Set the stopwatch for a time duration of 30 minutes. Remove the water from the cylinder and remove the sample when 30 minutes are over. With the aid of a hand roller, empty an excessive amount of water by moving forward and backward once by keeping the film inside a blotting paper. Weigh the sample once more using a digital scale. Subtract the sample weight before testing from the sample weight following testing to find the Cobb Value

Plate 3.11 Cobb tester

3.6.5 Grammage

Gram per square meter (GSM) value is the unit to measure the weight of the paper. Cut a sample of the biodegradable packaging material to a precise and standardized size, usually a specific area such as 100 cm² or 1 m². Accurately weigh the sample using a precision balance to determine its mass in grams. Calculate the grammage by dividing the weight of the sample (in grams) by its area (in square meters).

$$\text{Grammage } (g/cm^2) = \frac{\text{Weight of the sample}}{\text{Area of the sample}} \quad \ldots\ldots\ldots\ldots \text{(vii)}$$

3.6.6 Thickness

Thickness of biodegradable film was measured using digital micrometer. A micrometer provides highly accurate measurements, making it an essential tool in material analysis.

Plate 3.12 Micrometer

3.6.6 Bursting strength

Bursting strength is a key parameter used to measure the strength and durability of materials, particularly paper, paperboard and packaging materials, including biodegradable options. It indicates the material's ability to withstand pressure or force applied uniformly over a specific area before rupturing or bursting. Cut a specimen of the material to the required size, ensuring it is free from creases, folds, or defects. Place the sample securely in the testing apparatus (Bursting strength tester). The material is clamped in place to ensure it remains flat and stable during the test. A rubber diaphragm is pressurized with hydraulic or pneumatic force to apply pressure to the sample. The pressure is increased steadily and uniformly. The pressure is applied until the sample bursts. The maximum pressure recorded at the point of bursting is noted as the bursting strength.

Plate 3.13 Bursting strength tester

3.7 EVALUATION OF SEALABILITY OF BIODEGRADABLE PACKAGING FILMS

Pouch size of 12 mm x 8 mm was prepared from optimized packaging film. The sealing properties of these pouches were then inspected to assess their effectiveness.

Plate 3.14 Sealing machine

3.8 BIODEGRADABILITY STUDIES USING SOIL BURIAL TEST

Biodegradable plastics are those that break down due to the activity of naturally occurring microorganisms including fungi, bacteria and algae. To evaluate the biodegradability of biodegradable film, a soil burial test was performed. The test was performed according to the method published by Thakore *et al*. (2001). Samples of soil were taken from the KCAET farm and put into a tray. A sample of normal plastic and PP film was divided into 10 x 10 mm pieces and buried 5 cm below the ground. A plastic film of same dimensions is also buried along with the biodegradable films for reference. Following the placement of the soil in the lab, water was sprayed on it at regular intervals to keep it moist. There was a hole in the bottom of the pot where the extra water was emptied. After carefully removing the sample from the dirt and giving it a gentle wash with distilled water to remove soil from the film, the deterioration of the samples was measured at regular intervals of ten days. The sample was sun-dried until its weight remained constant. The sample's weight loss over time was used to calculate the pace at which the soil burial test degraded. By tracking the film's weight reduction over time, the soil burial test was examined. The weight loss was determined for every seven days from the starting day and was calculated using equation given below:

$$\text{Weight loss (\%)} = \frac{W1-W2}{W1} \text{ x } 100 \text{ ………… (viii)}$$

Where, W_1 - Initial weight of film

W_2 – Final weight of film

Plate 3.15 Biodegradability test in soil

3.9 PACKAGING AND STORAGE STUDIES OF SELECTED FOOD PRODUCT USING OPTIMISED BIODEGRADABLE FILM

For the storage study, biodegradable films with the best combination of properties were selected to evaluate their effectiveness. Dehydrated pepper was chosen as the test material for this investigation. The pepper was packed in the developed biodegradable pouches and its shelf life was monitored and analyzed over a defined period. To provide a benchmark for comparison, a parallel study was conducted using conventional polypropylene pouches. This allowed for a direct comparison of the shelf life and preservation capabilities of the biodegradable pouches versus the traditional polypropylene pouches. The stored sample was kept for 45 days and the quality analysis of the stored sample *viz.* moisture content and water activity were evaluated every 15 days interval.

Plate 3.16 Effect of biodegradable packaging on quality attributes of stored product during

3.9.1 Quality Attributes of Stored Product packed inside biodegradable pouch

3.9.1.1 Moisture Content

The moisture content of dehydrated pepper was determined using an infrared moisture analyzer, following the procedure outlined in section 3.2.1.

3.9.1.2 Water Activity

The water activity of dehydrated pepper was determined using a water activity meter, following the procedure outlined in section 3.2.2.

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with the results obtained on characteristics of potato peel and potato peel powder, development of biodegradable packaging film, properties of potato peel powder based biodegradable film, biodegradability studies of the film and storage studies of food product stored in the developed biodegradable film.

4.1. CHARACTERISTICS OF POTATO PEEL AND POTATO PEEL POWDER

The composition of potato peel (PP) and potato peel powder (PPP) is presented in Table 4.1.

Table 4.1 Characteristics of potato peel and potato peel powder

Sl No.	Particulars	Potato peel	Potato peel powder
1.	Moisture Content (% wb)	81	10.83
2.	Water Activity	0.96	0.693
3.	Starch (%)	-	30
4.	Lipids (%)	-	0.9
5.	Amylose (% starch)	-	34.9
6.	Amylopectin (% starch)	-	65.1
7.	Colour value, L	-	80.56
8.	Colour value, a	-	1.2
9.	Colour value, b	-	5.3
10.	Colour value, c	-	5.4
11.	Colour value, h	-	77

Potato peel (PP) had an initial moisture content of 81 per cent (wb) and water activity of 0.96per cent. Potato peel powder (PPP) was light yellow in colour. It had an initial moisture content of 10.83 per cent (wb) and water activity of 0.693 per cent. The starch and lipids were 30 and 0.9 per cent, respectively. PPP has low starch content compared to Potato Flour but could be an alternative for film forming applications. The amylose content and amylopectin value of PPP were 34.9 and 65.1 per cent of its starch content. The L, a, b, c and h values of PPP was 80.56, 1.2, 5.3, 5.4 and 77, respectively. The flour has a very light colour (almost white), with a slight yellowish tint and a hint of red. The colour is not very saturated, indicating a soft, subtle hue rather than a vibrant one.

4.2. DEVELOPMENT OF BIODEGRADABLE FILM

Biodegradable film was prepared using potato peel powder using the procedure explained in section 3.5. The concentration of film forming solution was optimized based on properties of the developed film. The combination of film forming solution were furnished in table 4.2.

Table 4.2 Treatments selected for the production of biodegradable film

Sample Name	Description
A1	3% w/v starch, chitosan (1.5g)-glycerol(1.5ml)
A2	4% w/v starch, chitosan (1.5g)-glycerol(1.5ml)
A3	5% w/v starch, chitosan (1.5g)-glycerol(1.5ml)
B1	3% w/v starch, gelatin (1.5g)-glycerol(1.5ml)
B2	4% w/v starch, gelatin (1.5g)-glycerol(1.5ml)
B3	5% w/v starch, gelatin (1.5g)-glycerol(1.5ml)
C1	3% w/v starch, chitosan (1.5g)- gelatin (1.5g)
C2	4% w/v starch, chitosan (1.5g)- gelatin (1.5g)
C3	5% w/v starch, chitosan (1.5g)- gelatin(1.5g)

4.3 STANDARDIZATION OF FILM FORMING SOLUTION FOR THE PREPARATION OF BIODEGRADABLE PACKAGING

Nine treatments were selected in this study. The optimization of process parameters was done based on the quality evaluation of the biodegradable packaging film.

4.3.1 Effect of Potato Peel Powder and Plasticizer Combination on Colour Values of the Developed Biodegradable Film

The colour values of biodegradable films made of different PPP and plasticizer concentrations are presented in Table 4.3.

Table 4.3 Colour Values of Biodegradable Film

A1					**A2**					**A3**				
L	**a**	**b**	**c**	**h**	**L**	**a**	**b**	**c**	**h**	**L**	**a**	**b**	**c**	**h**
77.6	5.8	-0.4	4.3	325	78.9	4.8	0	4.8	359.8	79	4.6	0.2	5.2	362
B1					**B2**					**B3**				
L	**a**	**b**	**c**	**h**	**L**	**a**	**b**	**c**	**h**	**L**	**a**	**b**	**c**	**h**
81.5	5.3	-6.3	8.2	310	80.7	4.8	-0.3	4.8	356.7	80	5.1	0.4	4.6	361.2
C1					**C2**					**C3**				
L	**a**	**b**	**c**	**h**	**L**	**a**	**b**	**c**	**h**	**L**	**a**	**b**	**c**	**h**
79.2	5.1	-0.1	6.5	332	76.2	5.3	-0.9	6.9	349.1	75	5.2	5.1	7.3	344.4

The L, a and b values for each treatment were found to be similar; however, the L value decreases with an increase in PPP concentration. The highest L value of 81.5 was found in the sample B1 (3% w/v starch, gelatin-glycerol) for a 3 per cent PPP concentration with a plasticizer combination of gelatin and glycerol, indicating that this sheet is closer to white.

4.3.2 Effect of Potato Peel Powder and Plasticizer Combination on Tensile Strength and Elongation Percentage of Developed Biodegradable Film

Tensile strength and elongation of biodegradable films made of different PPP and plasticizer concentrations are presented in Table 4.4

Table 4.4 Tensile strength and elongation percentage of biodegradable film

Sample	Tensile strength (MPa)	Elongation (%)
A1	3.2	21
A2	3.5	25
A3	4.5	30

B1	3.0	17
B2	3.1	19
B3	3.3	20
C1	4.1	32
C2	4.7	35
C3	5.5	38

The effect of PPP and plasticizer combinations on tensile strength and elongation percentage were shown in Fig.4.1 and Fig.4.2, respectively.

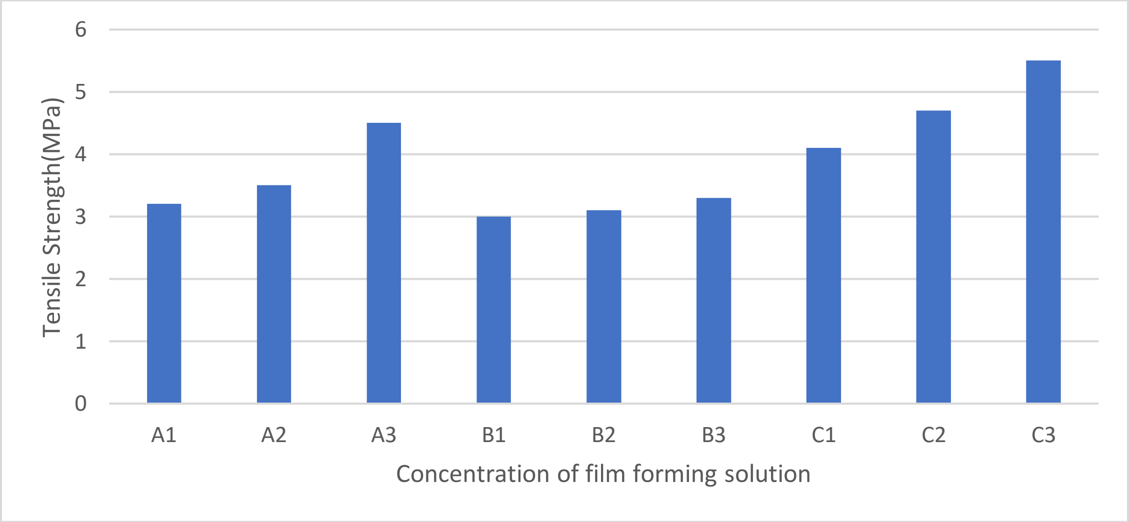


Fig 4.1. Effect of PPP and plasticizer concentrations on tensile strength of film

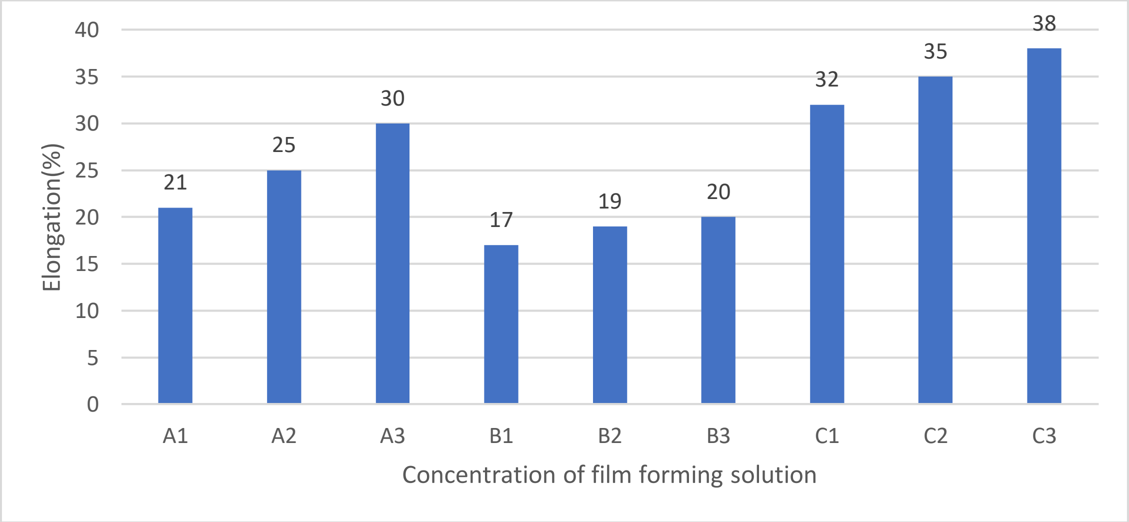


Fig 4.2. Effect of PPP and plasticizer concentrations on elongation percentage of film

The tensile strength of glycerol and chitosan films at 3,4 and 5 per cent PPP concentration were 3.2,3.5 and 4.5, respectively. Similarly, the elongation at break for these films were 21,25 and 30 mm, respectively. The tensile strength of gelatin and glycerol films at 3,4 and 5 per cent PPP concentration were 3.0,3.1 and 3.3, respectively. Similarly, the elongation at break for these films were 17,19 and 20 mm, respectively. The tensile strength of gelatin and chitosan films at 3,4 and 5 per cent PPP concentration were 4.1,4.7 and 5.5, respectively. Similarly, the elongation at break for these films were 32,35 and 38 mm, respectively.

The tensile strength and elongation increased with the increasing percentage concentration of starch. Additionally, the combinations with chitosan provided better tensile strength and elongation. Among these combinations, 5 per cent PPP concentration, chitosan (1.5g) and gelatin (1.5g) exhibited the highest tensile strength and elongation.

The combination of chitosan and gelatin often results in biodegradable films with high tensile strength due to their unique properties and interactions. Chitosan, derived from chitin, provides structural integrity and reinforcement to the film matrix due to its strong hydrogen bonding capabilities and crystalline structure. Gelatin, derived from collagen, contributes to film flexibility and cohesion through its ability to form crosslinks and interact with chitosan, enhancing the overall mechanical properties of the film (Flórez *et al*., 2022)

4.3.3 Effect of Potato Peel Powder and Plasticizer Concentrations on Solubility and Swelling Index of Film

Solubility and swelling index of biodegradable films made of different PPP and plasticizer concentrations are presented in Table 4.5.

Table 4.5 Solubility and swelling index of biodegradable film

Sample	Solubility	Swelling Index
A2	76.6	163
A3	68.6	115
B2	94	466
B3	85.8	236
C2	88	215

C3	88.7	375

The water solubility and swelling index of biodegradable films having different PPP and plasticizer concentrations are presented in Fig.4.3 and Fig 4.4, respectively.

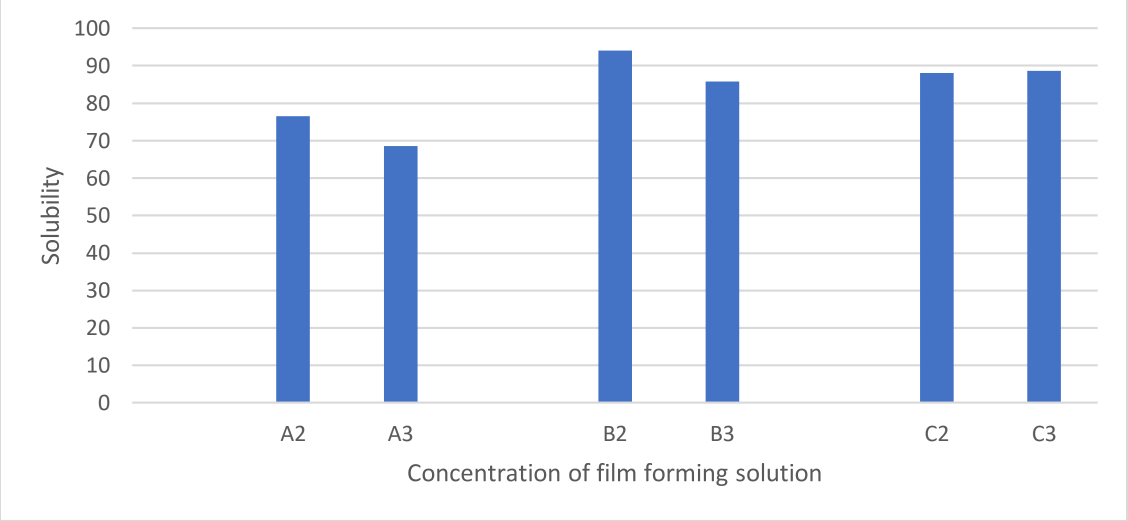


Fig 4.3 Effect of PPP and plasticizer concentrations on solubility of film

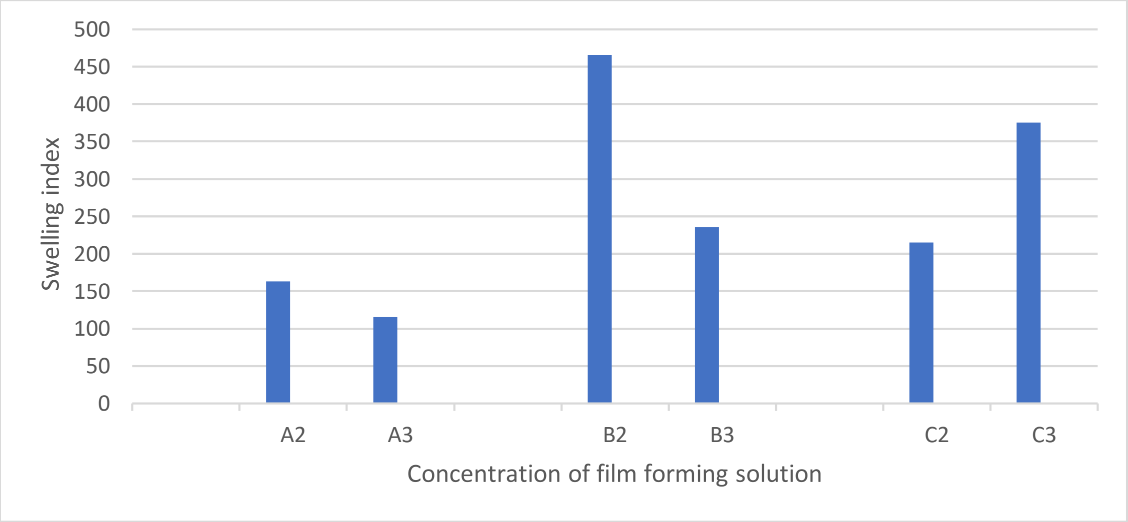


Fig 4.4 Effect of PPP and plasticizer concentrations on swelling index of film

The solubility of glycerol and chitosan films at 4 and 5 per cent PPP concentration were 76.6 and 68.6, respectively. Similarly, the swelling index for these films were 163 and 115, respectively. The solubility of gelatin and glycerol films at 4 and 5 per cent PPP concentration were 94 and 85.8, respectively. Similarly, the swelling index for these films were 466 and 236, respectively. The solubility of gelatin and chitosan films at 4 and 5 per cent PPP concentration were 88 and 88.7, respectively. Similarly swelling index for these films were 215 and 375, respectively. The lowest value of solubility and swelling index was obtained for 5 per cent PPP, chitosan and glycerol.

The reduced solubility and swelling index of films containing glycerol-chitosan plasticizer combinations can be attributed to the plasticizing effect of glycerol, which modifies the polymer structure and limits water uptake. Glycerol acts as a plasticizer by disrupting the intermolecular forces within the polymer matrix, increasing flexibility and reducing the mobility of polymer chains. This decreased mobility reduces the ability of water molecules to penetrate and swell the film, resulting in lower solubility and swelling index (Chillo *et al*.,2008)

4.3.4 Effect of Potato Peel Powder and Plasticizer Concentrations on Water Absorbance of Film

Cobb Index of biodegradable films made of different PPP and plasticizer concentrations are presented in Table 4.6.

Table 4.6 Cobb Index of biodegradable film

Sample	Cobb Index
A2	799.4
A3	811.5
B2	712.0
B3	883.9
C2	873.1
C3	980.0

The gelatin-chitosan combination demonstrates the highest water absorbance, with the Cobb Index reaching 980.0 at 5% PPP concentration. This indicates that films made from this combination absorb more water compared to the other combinations. The cobb index value ranges from 712 to 980.

The reduced water absorbance in chitosan films with glycerol plasticizer combinations can be attributed to the plasticizing effect of glycerol. Glycerol enhances the flexibility of the polymer matrix, reducing the free volume available for water absorption. This decreased water absorption is often observed due to the formation of hydrogen bonds between glycerol and chitosan molecules, which restricts the entry of water molecules into the film structure (Chillo *et al*., 2008).

4.3.5 Effect of Potato Peel Powder and Plasticizer Concentrations on Grammage of Film

The GSM values of biodegradable films made of different PPP and plasticizer concentrations are presented in Table 4.7.

Table 4.7 GSM Values of biodegradable film

Sample	Weight(g)	Area(cm^2)	GSM
A1	2.32	100	0.023
A2	2.69	100	0.026
A3	3.76	100	0.037
B1	2.65	100	0.026
B2	2.80	100	0.028
B3	3.92	100	0.039
C1	2.54	100	0.025
C2	2.73	100	0.027
C3	3.80	100	0.038

The grammage values have not shown significant differences among the sample combinations. From the table it is observed that grammage value increases with an increase in PPP concentration. The combination of glycerol and gelatin shows a small increase in the value of grammage. The values obtained for this combination with 3 per cent, 4 per cent and 5 per cent PPP concentration were 0.025, 0.027 and 0.038, respectively. This may be due to the inherent properties of gelatin and the plasticizing effect of glycerol. Similarly, the grammage for the plasticizer combination of glycerol and chitosan with per cent, 4 per cent and 5 per cent PPP concentration were 0.023, 0.026 and 0.037, respectively and the combination of gelatin and chitosan with 3 per cent, 4 per cent and 5 per cent PPP concentration were 0.026, 0.028 and 0.039, respectively.

4.3.6 Effect of Potato Peel Powder and Plasticizer Concentrations on Thickness of Film

The thickness of biodegradable films made of different PPP and plasticizer concentrations are presented in Table 4.8.

Table 4.8 Thickness of biodegradable film

Sample	Thickness (mm)
A1	0.184
A2	0.233
A3	0.267
B1	0.254
B2	0.269
B3	0.293
C1	0.197
C2	0.238
C3	0.259

The thickness of the film increases with an increase in PPP concentrations. When using a plasticizer combination of glycerol and gelatin, the measured values of thickness were 0.256, 0.269 and 0.293 for 3 per cent, 4 per cent and 5 per cent PPP concentrations, respectively. Similarly, the combination of glycerol and chitosan resulted in thickness values of 0.184, 0.233 and 0.267 for the same PPP concentrations. For the combination of gelatin and chitosan, the thickness values were 0.254, 0.269 and 0.293 at 3 per cent, 4 per cent and 5 per cent PPP concentrations, respectively.

4.3.7 Effect of Potato Peel Powder and Plasticizer Concentrations on Bursting Strength of Film

The Bursting Strength of biodegradable films made of different PPP and plasticizer concentrations are presented in Table 4.9.

Table 4.9 Bursting strength of biodegradable film

Sample	Bursting Strength (kg/cm^2)
A2	8.7
A3	9.1
B2	7.5
B3	8.0
C2	7.7
C3	8.9

The Bursting Strength of biodegradable films having different PPP and plasticizer concentrations are presented in Fig.4.5.

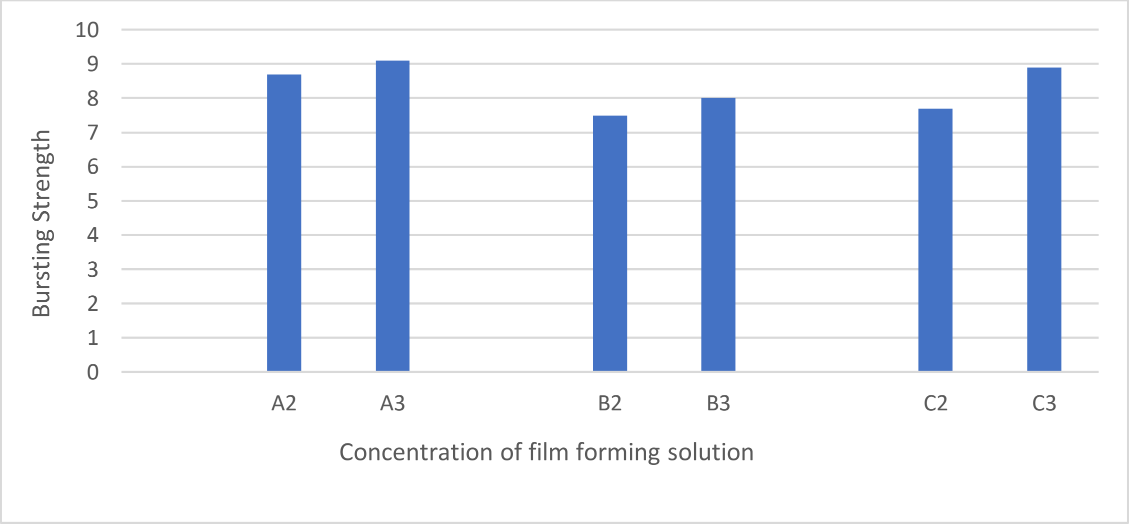


Fig 4.5 Effect of PPP and plasticizer concentrations on bursting strength of film

The bursting strength increases with the rise in PPP concentration. The plasticizer combination of glycerol and chitosan exhibits a high bursting strength, with values of 8.7 and 9.1 for 4 per cent and 5 per cent PPP concentrations, respectively. The combination of gelatin and chitosan also demonstrates a strong bursting strength, measuring 7.7 and 8.9 for the same PPP concentrations. For the combination of gelatin and glycerol, the bursting strength was found to be 7.5 and 8.0. Combinations A1, B1 and C1 were omitted from this study due to lower bursting strength value.

The higher bursting strength of gelatin-chitosan combination can be due to their intermolecular interaction and synergistic effects. Gelatin and chitosan have complementary properties that can enhance the mechanical strength of films when combined. Gelatin contributes flexibility and elasticity, while chitosan provides strength and rigidity. The combination of these properties can lead to films with improved mechanical performance, including higher bursting strength.

4.4 SEALABILITY STUDY OF BIODEGRADABLE FILM

The samples were subjected to sealability test. Out of 9 combinations chitosan-glycerol combination with 5 % w/v starch exhibit good sealability compared to other combinations.

4.5 OPTIMIZATION OF PROCESS PARAMETERS

Based on the physical and mechanical properties, chitosan combinations (chitosan-glycerol,chitosan-gelatin) showed promising results. Additionally, when considering sealability, the chitosan-glycerol combination produced the best result. Therefore, out of the three combinations (chitosan-glycerol, chitosan-gelatin and glycerol-gelatin), the chitosan-glycerol combination was only be considered for further studies.

4.5 TEST FOR BIODEGRADABILITY

The biodegradability studies of PPP films were estimated using soil burial method and the details are presented in the following table

Table 4.10 Weight of PPP film under soil burial test

Type of film	**Weight (g)**			
	Initial	**After 10 days**	**After 20 days**	**After 30 days**
Plastic	0.98	0.98	0.98	0.98
Biodegradable	2.38	1.80	0.70	0.24

Table 4.11 Weight loss percentage of PPP film under soil burial test

Type of film	**Percentage weight loss (%)**		
	After 10 days	**After 20 days**	**After 30 days**
Plastic	0	0	0
Biodegradable	24	71	90

The percentage weight loss of biodegradable films during 10, 20 and 30 days were 24, 71, 90 per cent, respectively. It was observed from the table that the samples continuously degrade with an increase in the length of time. However, the reference plastic sample had not shown any decrease in their weight during the same time interval.

4.6 SHELF-LIFE STUDIES OF PRODUCT STORED UNDER POTATO PEEL POWDER BASED BIODEGRADABLE PACKAGING

The moisture content and water activity of packed pepper were estimated using infra-red moisture analyser and water activity meter, respectively and the details were presented in the following table.

Table 4.12 Comparison of shelf life of food product stored under biodegradable and polypropylene pouches

Parameters	**0 days**		**15 days**		**30 days**		**45 days**	
	BP*	**CPP****	**BP***	**CPP****	**BP***	**CPP****	**BP***	**CPP****
Moisture content	5.4	5.4	6.1	5.4	7.4	5.8	8.8	6.1
Water activity	0.6	0.6	0.72	0.62	0.78	0.66	0.83	0.68

*Biodegradable Pouches ** Conventional Polypropylene Pouches

Over the course of 45 days, the moisture content of dehydrated pepper stored in biodegradable pouches increased from 5.4% to 8.8%. In contrast, the moisture content of pepper stored in conventional polypropylene pouches increased from 5.4% to 6.1%. Similarly, the water activity of the pepper in biodegradable pouches rose from 0.6 to 0.83, whereas in conventional polypropylene pouches it increased from 0.6 to 0.68.

SUMMARY AND CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSIONS

The majority of packaging materials used today are made of petrochemicals, which take hundreds of years to break down. Burning plastic materials releases dioxin, which is harmful to people's health. Furthermore, the harmful monomers connected to plastic materials have been connected to cancer and other fatal illnesses. These restrictions made it possible for an environmentally benign substance to replace plastics made of petroleum. Renewably supplied agricultural feedstocks, animal sources, trash from the marine food processing industry, or microbiological sources are the sources of biodegradable polymers. Biodegradable materials decompose to produce environmentally favourable products like carbon dioxide, water and high-quality compost in addition to renewable raw ingredients.

Prior to the development of biodegradable film, the properties of the raw material were determined. Colour characteristics, percentage of starch, fat content, moisture content, water activity, amylose and amylopectin were determined using standard procedures. Film forming solutions (FFS) were prepared using different PPP concentrations and plasticizer combinations. Chitosan, glycerol and gelatin were used as plasticizers. FFS were prepared and 55 g of it was poured into 8x8 -inch silicone moulds and dried under the shade at an ambient atmospheric temperature of 30° C for a span of 2 days. The dried film sample were then peeled off from the mould.

The films thus formed was tested for their colour, thickness, tensile strength and elongation, water absorption (using Cobb’s test), solubility and swelling index, bursting strength, grammage and sealability. Process parameter of FFS was optimized based on the quality attributes of the biodegradable film. Optimized sample was only considered for further study like biodegradability of developed film. Shelf-life study of product packed under biodegradable packaging was done for a duration of 45 days.

The results of the experiments are summarized as follows:

Potato peel (PP) had an initial moisture content of 21 per cent (wb) and a water activity of 0.96 per cent. The developed potato peel powder (PPP) was white in colour. It had an initial moisture content of 10.83 per cent (wb) and a water activity of 0.693 per cent. The starch and lipid contents were 30 and 0.9 per cent, respectively. The amylose content and amylopectin value of PPP were 34.9 and 65.1 per cent of its starch content.

The L, a, b, c and h values of PPP were 80.56, 1.2, 5.3, 5.4 and 77, respectively. The L value 80.56 indicates a lighter colour (white).

Nine treatments were selected for the study. The process parameters were optimized based on film quality. Colour values of biodegradable films ‘L’, ‘a’ and ‘b’ did not show large variations. However, the transparency decreased with the increase in PPP concentrations.

As the PPP concentration increased, the tensile strength values increased. Similarly, the plasticizer combinations with chitosan showed an increase in tensile strength. The tensile strength values and elongation percentage of the developed film ranges from 3.0-5.5 MPa and 17-38 per cent, respectively. The tensile strength was higher for the plasticizer combination of chitosan with gelatin. The tensile strength for chitosan and gelatin combination for 3, 4 and 5 per cent PPP concentration was 4.1, 4.7 and 5.5 MPa, respectively. Similarly, the elongation percentage for the above combination is found to be 32, 35 and 38 per cent, respectively.

The thickness of the film increased with an increase in PPP concentrations. The thickness of the biodegradable film ranges from 0.184-0.293 mm. The plasticizer combination of glycerol and gelatin showed an increase in the measured values of thickness. The value obtained for the above combination with 3, 4 and 5 per cent PPP concentration were 0.256, 0.269 and 0.293, respectively.

The gelatin-chitosan combination demonstrates the highest water absorbance, with the Cobb Index reaching 980.0 at 5% PPP concentration. This indicates that films made from this combination absorb more water compared to the other combinations. The cobb index value ranges from 712 to 980. Overall, the gelatin-chitosan combination has the highest Cobb Index, making it the most effective for high water absorbance applications, while the glycerol-chitosan combination, with the lowest values, is preferable for applications requiring lower water absorbance.

The solubility of film ranges from 68.6 to 94 and swelling index ranges from 115 to 466. The ideal low value of solubility and swelling index was obtained for 4 and 5 per cent PPP with plasticizer combination of chitosan and glycerol. Their solubility for 4 and 5 per cent PPP concentration were 76.6 and 68.6, respectively. Similarly, the swelling index for these films was 163 and 115, respectively. The data for tensile strength of 3 per cent of PPP concentration is not obtained due to the sticking nature of the film.

The bursting strength increased with an increase in PPP concentration. The bursting index ranges from 7.5 to 9.1. The plasticizer combination of glycerol and chitosan had a high bursting index. The bursting index of the above combination with 4 and 5 per cent PPP concentration were 8.7 and 9.1, respectively. The data for tensile strength of 3 per cent of PPP concentration was not obtained due to the sticking nature of the film.

The grammage values did not show large variations in grammage values and it ranged from 0.023 to 0.039. However, the grammage value increased with an increase in PPP concentration. The combination of glycerol and gelatin showed a small increase in the value of grammage. The value obtained for the above combination with 3, 4 and 5 per cent PPP concentration were 0.025, 0.027 and 0.038, respectively. This could be due to the inherent properties of gelatin and the plasticizing effect of glycerol.

Based on the physical and mechanical properties, both chitosan combinations showed results. However, considering sealability, the chitosan-glycerol combination produced the best result. Therefore, out of the three combinations, the chitosan-glycerol combination was only considered for further studies.

The biodegradability of the prepared PPP film was monitored and found that under suitable moisture, soil condition and other external factors, the packaging film took 30 days for 90 per cent degradation.

Shelf-life study was conducted on dehydrated black pepper and was observed that the moisture content and water activity of black pepper stored in biodegradable pouches increased from 5.4% to 8.8 % and 0.6 to 0.83, respectively. However, moisture content and water activity of conventional polypropylene pouches showed a slight increase from 5.4% to 6.1% and 0.6 to 0.68, respectively.

SUGGESTIONS FOR FUTURE WORK

Non-polar and hydrophobic compounds and waxes offer a sheen that improves the visual appeal of objects while acting as an effective barrier against moisture migration. The quality of biocomposite films can be improved by using edible wax, such as carnauba and bee wax, which can decrease the permeability of the films to water vapour on their surface.

Nano clay can be added to biopolymer to create nano bio-composites. Owing to its distinct atomic structure and substantial surface area, nano clay has the potential to greatly enhance the mechanical, thermal and barrier qualities of composite films.

While the casting film technique works well in laboratories, it is not practical for use in large-scale manufacturing. To create bio film, it takes several stages, such as combining the polymer with a solvent and then letting the solvent evaporate. The polymer is swiftly changed into the appropriate substance during the extrusion process. For large-scale manufacture, bio composite film can be produced using the extrusion technique. Bio-composite polymers can be manipulated by injection, blow and extrusion moulding techniques to create trays and containers.

REFERENCES

CHAPTER VI

REFERENCES

Alabi, O.A., Ologbonjaye, K.I., Awosolu, O. and Alalade, O.E., 2019. Public and environmental health effects of plastic wastes disposal: a review. *J Toxicol Risk Assess*, *5*(021), pp.1-13.

Alauddin, M.B.A.D.C.U., Choudhury, I.A., El Baradie, M.A. and Hashmi, M.S.J., 1995. Plastics and their machining: a review. *J. of Mater Processing Technol.*, *54*(1-4), pp.40-46.

Alves, V.D., Ferreira, A.R., Costa, N., Freitas, F., Reis, M.A. and Coelhoso, I.M., 2011. Characterization of biodegradable films from the extracellular polysaccharide produced by Pseudomonas oleovorans grown on glycerol byproduct. *Carbohyd. polymers*, *83*(4), pp.1582-1590.

Arikan, E.B. and Bilgen, H.D., 2019. Production of bioplastic from potato peel waste and investigation of its biodegradability. *Int. Advanced Researches and Eng. J.*, *3*(2), pp.93-97.

Arikan, E.B. and Ozsoy, H.D., 2015. A review: investigation of bioplastics. *J. Civ. Eng. Arch*, *9*(1), pp.188-192.

Ballantyne, A., R. Stark and J. D. Selman. 1988. Modified Atmosphere Packaging of Shredded Lettuce. *Int. J. Food Sci. and Tech.* 23:267-274.

Brinkmann, S., Oberbach, K., Baur, E., Schmachtenberg, E. and Osswald, T.A., 2006. International Plastics Handbook. *Hanser; Carl Hanser Verlag GmbH & Co., KG: Munich, Germany*.

British Plastics Federation (2012) *Sustainability in the Plastics Industry*. London: British Plastics Federation.

Chandra, R. and Rustgi, R. 1998. Biodegradable polymers. *Prog. in Polym. Sci.* 23(7):1273-1335.

Chang, Y. P., P. B. Cheah and C. C. J. Seow. 2000. Starch films reinforced with mineral clay. *Food Sci*. 65: pp-1–7.

Chen, Y.J., 2014. Bioplastics and their role in achieving global sustainability. *J. of Chem. and Pharma. Res.*, *6*(1), pp.226-231.

Chillo, S., Flores, S., Mastromatteo, M., Conte, A., Gerschenson, L. and Del Nobile, M.A., 2008. Influence of glycerol and chitosan on tapioca starch-based edible film properties. *J. of Food Eng.*, 88(2), pp.159-168.

Choi, S.H., Kozukue, N., Kim, H.J. and Friedman, M., 2016. Analysis of protein amino acids, non-protein amino acids and metabolites, dietary protein, glucose, fructose, sucrose, phenolic and flavonoid content and antioxidative properties of potato tubers, peels and cortexes (pulps). *J. of Food Composition and Analysis*, *50*, pp.77-87.

Cliffe-Byrnes, Valerie and O. B. David. 2005. Effects of chlorine treatment and packaging on the quality and shelf-life of modified atmosphere (MA) packaged coleslaw mix. *Food Control* 16(8): 707-716.

Danila, M., Paul, U. C. and Athanassiou, A., 2021. Bio-based plastic films prepared from potato peels using mild acid hydrolysis followed by plasticization with a polyglycerol. *Food Packaging and Shelf Life*, *29*, p.100707.

Devi, L.S., Jaiswal, A.K. and Jaiswal, S., 2024. Lipid incorporated biopolymer based edible films and coatings in food packaging: A review. *Current Research in Food Sci.*, p.100720.

Díaz-Montes, E., 2022. Polysaccharide-based biodegradable films: An alternative in food packaging. *Polysaccharide*s, 3(4), pp.761-775.

Flórez, M., Guerra-Rodríguez, E., Cazón, P. and Vázquez, M., 2022. Chitosan for food packaging: Recent advances in active and intelligent films. *Food Hydrocolloids*, 124, p.107328.

García, N. L., L. Ribba, A. Dufresne, M. I. Aranguren and S. Goyanes, S. 2009. Physico-Mechanical Properties of Biodegradable Starch Nanocomposites. *Macromolecular Mater. and Eng*. 294(3):169-177.

Giacalone, G. and V. Chiabrando. 2013. Modified atmosphere packaging of sweet cherries with biodegradable films. *Int. Food Res. J.* 20(3): 1263-1268.

Guilbert, S. 1986. Technology and application of edible protective films. *Food packaging and preservation*. Elsevier Applied Science, London, UK.

Gune, R., Sawant, A. and Joglekar, N. 2021. Formation of bio-based polymer (poly-lactic acid) from potato Peel waste and blending with chitosan extracted from Fish scales. *Int*. *J*. *of Res*. *in Eng*., *Sci*. and *Manag*. 4: pp-13-18

Hirpara, N.J., Dabhi, M.N. and Rathod, P.J., 2021. Development of potato starch based biodegradable packaging film. *J. Food Process. Technol.*, *12*, pp.529-541

Jansson, A., L. Järnström, P. Rättö. and F. Thuvander. 2006. Physical and swelling properties of spray-dried powders made from starch and poly(vinyl alcohol). *Starch.*58:632-641

Jeddou, K.B., Bouaziz, F., Zouari-Ellouzi, S., Chaari, F., Ellouz-Chaabouni, S., Ellouz-Ghorbel, R. and Nouri-Ellouz, O., 2017. Improvement of texture and sensory properties of cakes by addition of potato peel powder with high levels of dietary fiber and protein. *Food Chem.*, *217*, pp.668-677.

Jeddou, K.B., Chaari, F., Maktouf, S., Nouri-Ellouz, O., Helbert, C.B. and Ghorbel, R.E., 2016. Structural, functional and antioxidant properties of water-soluble polysaccharides from potato peels. *Food Chem.*, *205*, pp.97-105.

Kasmuri, N. and Zait, M.S.A., 2018. Enhancement of bio-plastic using eggshells and chitosan on potato starch based. *Int. J. Eng. Technol.*, *7*, pp.110-115.

Khawla, B.J., Sameh, M., Imen, G., Donyes, F., Dhouha, G., Raoudha, E.G. and Oumèma, N.E., 2014. Potato peel as feedstock for bioethanol production: A comparison of acidic and enzymatic hydrolysis. *Industrial Crops and Products*, *52*, pp.144-149.

Koide, Shoji, and S. John. 2007. Microbial and quality evaluation of green peppers stored in biodegradable film packaging. *Food control* 18.(9): 1121-1125.

Krochta, J. M. 2002. *Protein-based Films and Coatings* . CRC Press, Boca Raton.

Kumari, B., Tiwari, B.K., Hossain, M.B., Rai, D.K. and Brunton, N.P., 2017. Ultrasound-assisted extraction of polyphenols from potato peels: profiling and kinetic modeling. *Int. J. of Food Sci. & Technol.*, *52*(6), pp.1432-1439.

Laksanawati, T.A., Khirzin, M.H., Meidayanti, K., Kusherawati, P.A., Kusuma, H.S., Darmokoesoemo, H. and Iqbal, M., 2024. Prediction of Shelf Life and Sensory Qualities of Beef Meatball with Biodegradable Taro Starch-Duck Bone Gelatin Packaging at Different Storage Temperatures. *Applied Food Res.*, p.100402.

Laksanawati, T.A., Khirzin, M.H., Meidayanti, K., Kusherawati, P.A., Kusuma, H.S., Darmokoesoemo, H. and Iqbal, M., 2024. Prediction of Shelf Life and Sensory Qualities of Beef Meatball with Biodegradable Taro Starch-Duck Bone Gelatin Packaging at Different Storage Temperatures. *Applied Food Res.*, p.100402.

Liu, Y., Liu, M., Zhang, L., Cao, W., Wang, H., Chen, G. and Wang, S., 2022. Preparation and properties of biodegradable films made of cationic potato-peel starch and loaded with curcumin. *Food Hydrocolloids*, *130*, p.107690.

Mali, S., M. V. E. Grossmann, M. A. García, M. N. Martino and N. E. Zaritsky. 2006. Effects of controlled storage on thermal, mechanical and barrier properties of Plasticized films from different starch sources. *J. of Food Eng*., 75: pp-453-460.

Marino, L., Filomena, P., Pasqualina, M., Giovanna, G. B. 2010. Study of the combined effect of both clay and glycerol plasticizer on the properties of chitosan films. *Carbohyd*. *Polym*. 82: pp-291-298

Marsh, K. and Bugusu, B., 2007. Food packaging—roles, materials and environmental issues. *J. of food sci.*, *72*(3), pp.R39-R55.

Maurizio, A., Emilia, D. P., Barbara, I., Giuseppe, I., Mario, M., Gabriella, S. 2007. Addition of glycerol plasticizer to seaweeds derived alginates: Influence of microstructure on chemical–physical properties. *Carbohyd*. *Polym*. 69: pp-503-511

McHugh, T. H., J. F. Aujard and J. M. Krochta. 1994. Plasticized whey protein edible films: water vapor permeability properties. *J. of Food Sci*. 59: pp-416-419.

Mishra, P. and Poonia, A., 2022. Potato Waste-Based Packaging Edibles: A Sustainable Approach for Food Preservation. *Edible Food Packaging: Applications, Innovations and Sustainability* (pp. 149-156). Singapore: Springer Nature Singapore..

Moharir, R.V. and Kumar, S., 2019. Challenges associated with plastic waste disposal and allied microbial routes for its effective degradation: A comprehensive review. *J. of Cleaner Prod.*, *208*, pp.65-76.

Moshood, T.D., Nawanir, G., Mahmud, F., Mohamad, F., Ahmad, M.H. and Abdulghani, A., 2022. Biodegradable plastic applications towards sustainability: A recent innovations in the green product. *Cleaner Eng. and Technol.*, *6*, p.100404.

Olagundoye, A.A. and Morayo, A.O., 2022. Characterization of Potato Peel Starch-based Bioplastic Reinforced with Banana Pseudostem Cellulose for Packaging Applications. *Int. J. of Innovative Sci. and Res. Technol.*, *7*(4).

Panou, A. and Karabagias, I.K., 2023. Biodegradable packaging materials for foods preservation: sources, advantages, limitations and future perspectives. *Coatings*, *13*(7), p.1176.

Pathak, P.D., Mandavgane, S.A., Puranik, N.M., Jambhulkar, S.J. and Kulkarni, B.D., 2018. Valorization of potato peel: a biorefinery approach. *Critical Reviews in Biotechnol.*, *38*(2), pp.218-230.

Prata, J.C., Silva, A.L.P., Da Costa, J.P., Mouneyrac, C., Walker, T.R., Duarte, A.C. and Rocha-Santos, T., 2019. Solutions and integrated strategies for the control and mitigation of plastic and microplastic pollution. *Int. J. of environ. res.and public health*, *16*(13), p.2411.

Purewal, S.S., Kaur, A., Bangar, S.P., Singh, P. and Singh, H., 2023. Protein-Based Films and Coatings: An Innovative Approach. *Coatings*, *14*(1), p.32.

Rajesh, G.K., 2014. Development and testing of banana flour based Biodegradable film and its suitability for storage of selected food products.Ph.D. Thesis, Tamil Nadu Agricultural University, Coimbatore.pp.23-53.

Rakotonirainy, A. M., Q. Wang, and G. W. Padua. 2001. Evaluation of zein films as modified atmosphere packaging for fresh broccoli. *J. of food sci*. 66(8): 1108-1111

Robertson, G. L .2012. *Food packaging: principles and practice*. CRC press.

Sampaio, S.L., Petropoulos, S.A., Alexopoulos, A., Heleno, S.A., Santos-Buelga, C., Barros, L. and Ferreira, I.C., 2020. Potato peels as sources of functional compounds for the food industry: A review. *Trends in Food Science & Technology*, *103*, pp.118-129.

Sen, K.Y. and Baidurah, S. 2021. Renewable biomass feedstocks for production of sustainable biodegradable polymer. *Curr. Opinion in Green and Sustain. Chem*. 27: pp- 100412.

Sothornvit, R. and J. M. Krochta. 2000a. Water vapor permeability and solubility of films from hydrolyzed whey protein. *J. of Food Sci*. 65(4): pp-700-705.

Suderman, N., Isa, M. I. N., Sarbona, N. M. 2018. The effect of plasticizers on the functional properties of biodegradable gelatin-based film: A review. *Food Biosci*. 24: pp-111-114

Thakore, I. M., S. Desai, B. D. Sarawade and S. Devi. 2001. Studies on biodegradability, morphology and thermomechanical properties of LDPE/modified starch blends. *Eur. Polym.* J 37(1), 151–160

Tlay, R.H., Abdul-Abbas, S.J., El-Maksoud, A.A.A., Altemimi, A.B. and Abedelmaksoud, T.G., 2023. Functional biscuits enriched with potato peel powder: Physical, chemical, rheological and antioxidant properties. *Food Syst.*, *6*(1), pp.53-63.

Wu, Z.G., Xu, H.Y., Ma, Q., Cao, Y., Ma, J.N. and Ma, C.M., 2012. Isolation, identification and quantification of unsaturated fatty acids, amides, phenolic compounds and glycoalkaloids from potato peel. *Food Chem.*, *135*(4), pp.2425-2429.

Xie, Y., Niu, X., Yang, J., Fan, R., Shi, J., Ullah, N., Feng, X. and Chen, L., 2020. Active biodegradable films based on the whole potato peel incorporated with bacterial cellulose and curcumin. *Int. J. of Biological Macromolecules*, *150*, pp.480-491.

Yu, J. and Chen, L.X., 2008. The greenhouse gas emissions and fossil energy requirement of bioplastics from cradle to gate of a biomass refinery. *Environ. Sci. & Technol.*, *42*(18), pp.6961-6966.

Zagory, D. and A. A. Kader. 1988. Modified atmosphere packaging of fresh produce. *Food technol.* 42(9): 70-77.

Zubair, M., Pradhan, R.A., Arshad, M., Ullah, A., 2021. Recent advances in lipid derived bio-based materials for food packaging applications. *Macromolecular. Mater. Eng.* 306 (7), 2000799

ABSTRACT

DEVELOPMENT AND EVALUATION OF POTATO WASTE BASED BIODEGRADABLE FILM FOR FOOD PACKAGING

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ABSTRACT OF THESIS

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ABSTRACT

Plastics have become a necessary component of our contemporary lifestyle and are used widely in a variety of industries. Of them, the packaging industry is the one that uses plastics the most. However, the disposal of plastic and allied wastes poses a serious threat to the environment. Therefore, researches has been done to create biodegradable polymers from renewable and natural resources, such as starch, proteins derived from plants and animals, lipids and resins, to lower the risk to the environment and increase the degradability of plastic wastes. In the experiment, biodegradable packaging films were prepared from potato peel power (PPP). Moisture content and water activity of potato peel (PP) and colour characteristics, lipids, amylose and amylopectin content, starch, moisture content and water activity of the PPP were analyzed. The films for the test were prepared from 3, 4 and 5% PPP concentrations and different plasticizer combinations *viz.* gelatin-glycerol, chitosan-glycerol and gelatin-chitosan and were dried at atmospheric temperature for two days. Based on preliminary studies, nine treatments were selected and the quality parameters selected were colour, thickness, tensile strength, water absorption, solubility and swelling index, bursting strength, grammage and biodegradability. The samples have not shown much deviation in colour, thickness and grammage. Glycerol and chitosan combination at larger concentrations showed moderate water absorbance, low solubility and swelling index and high bursting strength, whereas, gelatin and chitosan combination showed high tensile strength. Based on previous results and sealability studies, the glycerol-chitosan combination was optimized and it was only selected for further studies. From biodegradability studies, it was understood that 30 days were taken for 90% degradation. Storage study of dehydrated black pepper under biodegradable packaging material was conducted for 45 days. Polypropylene pouch was selected as control sample. From the study, it was observed that the moisture content and water activity of dehydrated pepper packed under biodegradable and polypropylene pouches were increased from 5.4% to 8.8%, 5.4-6.1% and 0.6-0.83, 0.6 to 0.68, respectively. In conclusion, the biodegradability of potato peel starch film presents a promising solution to the pressing environmental challenges posed by conventional plastic packaging. Derived from an abundant agricultural byproduct, these films offer a sustainable alternative for waste reduction and thus, fostering a healthier planet.