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(Review Article)

Plant derived Starch for the Production of Biodegradable Plastic

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Abstract

Petroleum-based plastics have hazardous effect on the environment. The non-degradability of conventional plastics has led to the filling of landfill sites, raising water, land pollution, and rapid depletion of fossil resources. One promising solution is the production of starch-blended biodegradable polymers. These polymers are produced from renewable resources such as corn, potato, cassava, jackfruit, rice, wheat, barley and sorghum and have the potential to be biodegradable or compostable. Starch, the main component of these materials, is derived from plants, making it a renewable resource. Starch is a potential biological polymer due to its intrinsic biodegradability, availability, and annual renewability. Glycerol was used as a plasticizer, and it was reported that the addition of citric acid would improve the solubility of starch. In general a combination of starch, vinegar, glycerol and water is used for the preparation of thin films. Glycerol, a a plasticizer increase the polymer's elongation and enhance processibility by lowering the melting and softening points and viscosity of the melts. However, starch, as a natural component, can introduce challenges in maintaining the structural integrity and durability of the resulting polymer blend. Another concern is the sensitivity of the starch-blended biodegradable polymers to environmental conditions. These materials often exhibit susceptibility to moisture, leading to potential issues of water absorption and subsequent degradation. In near future, there might be a solution for this problems, and starch based bio-plastic can be utilized for the for the food packaging.

Keywords: Bioplastic; Corn; Cassava; Jackfruit; Potato; Polymers; Plastic; Glycerol; Plasticizer; Starch

1. Introduction

As synthetic or petroleum-based plastics create a severe environmental impact, it is very essential to produce eco-friendly bio-plastics to meet the needs of both the commercial and industrial sectors. Plastics are extensively used in

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every facet of our lives [1-13]. However, petroleum-based plastics have hazardous effect on the environment [1-13]. The extensive industrialization of polyethylene during the 1950s resulted in the mass production of petrochemical-derived plastics that remain widely used today[1-13]. However, the harmful environmental impact of these non-biodegradable plastics has become increasingly evident [1-13]. The non-degradability of conventional plastics has led to the filling of landfill sites, raising water and land pollution, and rapid depletion of fossil resources [1-13]. As a result, there is an urgent need to develop sustainable alternatives that can reduce the environmental impact of plastic waste [1-13]. The potential of biodegradable polymers, and in particular of polymers obtained from agro-resources, has been widely investigated during the last few years as alternatives to non-degradable polymers currently used in films production for food packaging[1-13, 61-62]. Studying starch-blended biodegradable polymers as a sustainable alternative to conventional plastics is crucial in addressing the detrimental environmental effects of non-degradable plastics[1-13]. Most of the synthetic products currently used are not degradable and their cost is rising steadily as they are produced from non-renewable resources such as oil [1-13]. Synthetic polymers or petrochemical-based plastics like polyamides (PA), nylon, polystyrene (PS), Teflon, polyethylene terephthalate (PET), polyethylene (PE) etc. have been widely used for food packaging applications due to their excellent thermal and rheological properties, lightweight, easy to manipulate, and install in a diverse range of applications, gas and water barrier properties, and cost[1-13, 61].

Plastics derived from petroleum are made from synthetic polymers [1-13]. Their utility includes but is definitely not limited to agriculture, aerospace, automobile, construction, sports, domestic, and households [1-13]. Studying starch-blended biodegradable polymers as a sustainable alternative to conventional plastics is crucial in addressing the detrimental environmental effects of non-degradable plastics [1-13]. Increase in population and industrial growth have resulted in the increased production of synthetic polymers and allied materials [1-13-25, 61]. Polyethylene more often used as carry bag and more is produced annually [1-13]. Non recyclable and synthetic polymeric materials are causing a serious concern in environmental related issues. In particular, the plastic bags which are discarded into the environment have become a menace [1-13]. Significant quantities of plastic have gathered in the natural environment and in landfills [1-13]. Wasted plastic also contaminates a wide range of natural terrestrial, freshwater and marine habitats[1-13]. There are accounts of inadvertent contamination of soils with small polymer fragments as a consequence of spreading sewage sludge, of fragments of plastic and glass contaminating compost prepared from municipal solid waste and of plastic being carried into streams, rivers and ultimately the sea with rain water and flood events [1-13]. Most polymers are buoyant in water, and since items of plastic debris such as cartons and bottles often trap air, substantial quantities of plastic debris accumulate on the sea surface and may also be washed ashore [1-13-50]. As a consequence, plastics represent a considerable proportion (50% - 80%) of shoreline debris [11]. Plastics contain phthalates, BPA, flame retardants, cadmium, lead and organo tins, all of which have been shown in animal studies to result in obesity [11]. In addition, the monomer used to manufacture PVC plastic, vinyl chloride, is a known carcinogen and exposure can cause angiosarcoma of the liver among factory workers [11].

One promising solution is the production of starch-blended biodegradable polymers [1-13-26, 51-61]. These polymers are produced from renewable resources such as corn, potato, cassava, jackfruit, rice and have the potential to be biodegradable or compostable [1-13-26, 51-60]. The production and consumption of non-biodegradable synthetic films are an extreme threat to the ecosystem. As a substitute for plastic, the use of biopolymers for food packaging can play a vital role in minimizing this problem. Biopolymers are considered an important raw material for packaging films because of their plentiful availability, cheap rate, and biodegradability [1-13-50]. Biopolymers can be natural or synthetic, of which the natural one is more eco-friendly compared to the synthetic one [1-13]. The compatibility between starch and other biopolymers, like polybutylene succinate (PBS), polylactic acid (PLA), and polyhydroxyalkanoates (PHAs) is being researched in several areas of food processing [1-13]. The environmental impact and sustainability aspects of starch-blended biodegradable polymers are addressed, emphasizing their renewable nature, reduced carbon footprint, and potential to mitigate plastic waste [1-13-50]. They offer a sustainable and eco-friendly alternative that can significantly reduce plastic waste and minimize the reliance on fossil resources [1-13].

2. Starch based Bioplastics

To prepare starch-based biopolymers various sources of starch such as corn, rice, wheat, potato, and cassava along with other starchy foods such as yams, peas, and lentils are used as raw materials [1-7]. Among the natural polymers, starch is assessed potential due to its large accessibility and comparatively low price [1-13-26, 51-61]. Decent film-forming ability, biocompatibility, and biodegradability features make this hydrocolloid biopolymer the most promising packaging material [1-13-19,51-60]. There has been an increasing interest in the production of bioplastics as the environmental pollution from conventional plastics is increasingly evident [1-13]. Bio-plastics can also be biobased (originated from renewable materials) and biodegradable (that can be back to nature) [1-13]. In terms of renewability and production, some of the most widely known bio-based plastics nowadays are polylactic acid (PLA), starch-based plastics, protein-based plastics, cellulose esters, polyhydroxyalkanoates (PHAs), and plant fibers [1-13]. Bio-plastics, manufactured from biomass, with or without modifications, such as starch, protein, and cellulose, are biodegradable and therefore gaining more and more attention [1-13]. Bio-plastics produce remarkably less greenhouse gas (carbon dioxide) emissions than traditional oil-based plastics over their lifetime [11-19]. Since the plants that biobased plastics are made from absorbed that same amount of greenhouse gas as they grew, there is no net increment in this gas. With such advantages, bioplastics have been studied a lot in the world, especially the production of bioplastics from starch [9].

Biodegradable plastics are made from starch, cellulose, chitosan, and protein extracted from renewable biomass [1-13-19, 61, 62]. The development of most bioplastic is assumed to reduce fossil fuel usage, and plastic waste, as well as carbon dioxide emissions [1-13]. The biodegradability characteristics of these plastics create a positive impact in society, and awareness of biodegradable packaging also attracts researchers and industries [1-13]. Decomposable plastics are widely used in a large variety of products where recycling of plastics is encouraged[1-13-19].

Cellulose, lignin, and starch are commonly available in nature. Cellulose is abundant in all plants, although some plants produce more than others. Lignin is typically found in wood, and starch is common in plants such as corn, potatoes, and wheat. Plants, wood, corn, potatoes, and wheat are all raw materials that are renewable, biodegradable and easily available [1-11]. Packaging materials with biodegradable plastic is more expensive than traditional petroleum based plastic. Packaging materials based on these natural materials may be a solution to help control the environmental pollution and resolve other problems posed by non-degradable synthetic polymers [1-13].

Bio-plastics have two-thirds less harmful greenhouse emissions, including carbon and sulphur oxides, during their production [1-13]. This means significantly less air pollution and less of an effect on global warming [4-13-50]. They do not release any toxic chemical and by-product during the breakdown and decay period [1-5-13]. Bioplastics degrade and breakdown into CO_2 water and biomass at the same rate as cellulose (paper) and these are absorbed back into the earth [1-13-50]. Biodegradable films based on starches from different botanical sources exhibited physicochemical and functional properties which were related with the starch characteristics [1-5-13]. There has been increased interest in the development of biodegradable films because the environmental damage from conventional plastic packaging is increasingly evident [1-5-13]. Bio-plastics are produced from 100% renewable raw material which, when discarded in conditions favourable to its decomposition, is rapidly integrated into nature as carbon dioxide, water and biomass [1-5-13-50]. Biodegradable plastics are produced from biopolymers extracted directly from biomass, with or without modification, such as starch, cellulose and proteins [1-5-13]. Among these, starch has presented potential for the production of biodegradable materials because is a low-cost raw material, easily available and renewable[1-5-13-50-61].

One of the primary advantages of biodegradable starch materials is their ability to decompose naturally, contributing to a reduced environmental impact [1-13]. Unlike traditional plastics, which persist in the environment for extended periods, starch-based materials break down into environmentally benign by-products, promoting sustainability [1-13]. Starch, the main component of these materials, is derived from plants, making it a renewable resource [1-13]. In contrast, some materials in the food industry rely on non-renewable resources, contributing to resource depletion and environmental degradation [1-13]. Starch-based materials generally have a lower carbon footprint than certain conventional plastics[1-13]. The production of conventional plastics often involves energy-intensive processes and the use of fossil fuels, which contribute to greenhouse gas (GHG) emissions[1-13]. Plant-derived starch-based materials can offer a more environmentally friendly alternative [1-13].

3. Plant derived Starch

Starch, which is an inexpensive biodegradable polymer produced in abundance from many renewable sources is one of the most promising candidates for fabrication of bio-plastics [1-4-9-13-26, 51-60]. Starch-based biodegradable plastics are water-sensitive, have high water vapour permeability and generally provide films with mechanical properties unsuitable for many applications, which has hindered the expansion of their use and justifies the need to make modifications to improve their properties [9]. Biodegradable plastic properties can be improved mainly by using mixtures of starch with other synthetic polymers and chemical and physical modifications [1-13-19].

Starch based bioplastics are developed from wheat, corn, rice, potatoes, barley and sorghum [1-13-26]. Natural starch exhibits a pronounced macromolecular structure which is suitable for bio-plastic synthesis [1-4-13-26, 51-60]. The native starch can be transformed to thermoplastic starch (TPS) by several methods which destroy its semi crystalline granular structure [1-4-13-26, 51-60]. The transformation of granular starch into thermoplastic starch (TPS) is influenced by the processing conditions such as temperature and plasticizer content [1-4-19]. Water is the most commonly used plasticizer in starch processing but it results in poor mechanical strength such as brittleness due to recrystallization [1-13]. Therefore, other non-volatile plasticizers that are used in synthesis of starch based materials include polyhydric alcohols such as glycerol, glucose, ethylene glycol and amides such as urea formamide, acetamide, etc. [1-4]. Starch, which is an inexpensive biodegradable polymer produced in abundance from many renewable sources is one of the most promising candidates for fabrication of bio-plastics [1-4-13-26, 51-60].

Pure starch is white in color. The starch powder does not possess any specific taste or odor[1-4-13-19-26, 51-60]. Furthermore, pure starch cannot be dissolved in cold water or alcohol. It is non-toxic, biologically absorbable, and semi-permeable to carbon dioxide[1-4-13]. The linear and helical amylose and the branched amylopectin are the two types of molecules present in starch [1-4-13]. The amylose content may vary from 20 to 25%, while the amylopectin content varies from 75 to 80% by weight, depending on the type of plant. Amylopectin is a far greater molecule than amylose[1-4-13-19]. If heated, starch would become soluble in water, and the grains swell and burst. Due to this, the semi-crystalline arrangement is also lost, and the minor amylose particles begin percolating out of the granule, forming a network[1-4-13]. This network compresses water and increases the mixture's viscosity. This procedure is known as starch gelatinization, and amylose shows an imperative part through the initial stages of corn starch gelatinization [1-4-13]. While heating, the starch becomes a paste and the viscosity is also increased[1-4-13]. High amylose starch is a smart reserve for use as an obstruction in packing materials[1-4-13-26]. Due to the low price, renewability, and having decent mechanical properties, it was used to produce decomposable films to partly or else completely substitute the plastic polymers[1-4-13-26, 51-60].

Starch is recognized as one of the good biopolymers with high promise because it can biodegrade, is renewable and abundant, and is very economical [9-13-26, 51-60]. However, the utilization and effectiveness of starch are dependent on its precise structure and composition [9-13-26, 51-60]. Starch is now commonly used in a variety of sectors, including food, agriculture, engineering, packaging, and medicine [9-13]. As a form of stored energy, many plants synthesize starch as a natural, regenerative, and biodegradable polysaccharide [9]. The second-most prevalent organic compound in nature is starch, which is used by plants as their main stored carbohydrate[1-4-13]. Cereal grains are one of the main sources of starch and can be isolated, along with certain roots, tubers, fruit stones, and rhizomes [9]. The extraction of starch is done using easy and affordable techniques[1-4-13]. Washing, grinding, extraction, decantation, and drying are the primary steps in the wet extraction of starch granules [9-13-26, 51-60].

The dynamical structure of starch is made up of the macro-molecule's amylopectin and amylose[9]. Amylopectin, the main part, has a branching structure with an unbranched main branch consisting of units of glucose linked by α-(1,4) links and the branch chain created through α-(1,6) units linked [9]. Amylose is a linear biopolymer composed of glucose units linked byα-(1,4) glycosidic linkage [1-4-13]. Double helices that give starch granules their crystallinity are made up of a small chain of amylopectin with a polymerization degree greater than 10 [9-13-26, 51-60]. Amylose is detected in the amorphous portion of granules as biomolecules randomly dispersed between amylopectin molecules, it is thought that the crystalline area of the starch molecule was created by cross-linking amylopectin side chains [9]. Based on the amylose/amylopectin ratio, starches can be divided into three categories: "waxy" starches have amylose contents of less than 5%, "regular" starches have amylose contents of 20–30%, and starches with "high amylose" have amylose concentrations of at least 40% [9-13]. The amylose content in cereal, tuber, and pulse starch ranges from 15 to 33%, 15–30%, and 25–50%, respectively [9]. While tubers and roots have little to no lipids, cereals' amylose content is supplemented by lipids that include amylose [9]. Any bio-plastic's particular physio-chemical characteristics, which analyze what bio-plastic is appropriate for, influence its utility. Previous studies have established the viability of bio-plastics on starch-based food packaging materials and as marketing bags[9-13-26, 51-60]. They have also shown the fixed use and applicability of many types of starch bio-plastic in agriculture, shopping bags, domestic utensils, disposable, medicine, and even the automobile factory [1-4-13]. A study on the application of bioplastics in agriculture demonstrated the feasibility of starch-based bioplastics for the controlled release of fertilizer and modification[9, 61].

Amylose accounts for 5–35% of most occurring starch and has a substantial impact on starch properties [9]. Amylose content in waxy starches can vary from less than 1% to more than 70% [9], and these are composed of a straight chain of glucose units (500–2000 units) [45]. Even though amylose includes different branch connections, it behaves as straight polymers with connected repeated units in stretchable chains [9]. High amylose starch is more thermally stable and may result in a more stable amylose-lipid combination[1-4-13]. Physical interaction influences thermal characteristics and gel formation [9]. Furthermore, unlike other sugars, amylose can crystallize either freely or in the addition of complex compounds [9]. The amount of amylose in a product has a substantial effect on its starch paste and gel properties [1-4-13]. On a commercial basis, alterations in the amylose of starch could benefit food and industrial uses significantly [9]. The low amylose content of starch in cooked food generates stickier pastes than ordinary starch and is suitable for a variety of uses in industries [9]. Amylopectin, which makes about 70–80% of starch, is one of nature's biggest molecules because of its considerable units of glucose and essential functional properties. Its molecular makeup is more intricate than that of amylose and consists of approximately 1,000,000 substantially branched glucose units [1-4-13]. The starch properties, which differ significantly depending on botanical sources, are one of the crucial components in the chain of amylopectin length distribution [9]. Each of the three groups—A, B, and C—that make up the chains of amylopectin has its characteristics and functions [9]. The A chains are the smallest because they only connect to the amylopectin molecule via one α-(1 6) link. [9].

Starch is a potential biological polymer due to its intrinsic biodegradability, availability, and annual renewability [9-13-26, 51-60]. Although roots, cereals, tubers, and legumes can also be the origin of starch, plants are primary sources of this substance for example, Banana, Sorghum, Elephant foot yam, Rice, Potato, Tuber, Wheat, Cassava, Corn, Tapioca, Peas, Lentils, Faba beans,] Sweet potato, Arrowroot, and jackfruit [9-13-26, 51-60]. It's interesting to note that prior research has shown that starch has both linear and branching microstructures[1-4-13]. It is viewed as a heterogeneous material as a result[1-4-13]. While the branched composition is known as amylopectin (a starch with a branched polysaccharide chain with a non-crystallizable form), the unbranched structure is known as amylose (a highly crystalline form made up of straight polysaccharide chains) [9-13-26, 51-60]. It is well known that wasted and underutilized by-products contain carbohydrates, lipids, and proteins, which are the important building areas for the preparation of collagen, gelatine, enzymes, and different bioactive components[1-4-13]. This means that the products obtained from extraction have the application to be a raw material for medicines, nutraceuticals, functional food, food additives, and, more importantly, bio-packaging products[1-4-13]. Bio-plastic is produced from organic materials or natural such as lipids, polysaccharides, and proteins. Cellulose, chitin, starch, and lignin are popular polysaccharides utilized in the production of biological plastics, whereas casein, gelatin, and gluten are examples of natural proteins, as well as plant oils and unsaturated fats [9-13-26, 51-60].

Approximately 50% of the bio-plastics used commercially are prepared from starch[1-4-13]. The production of starch-based bio-plastics is simple, and they are widely used for packaging applications [8,9]. The tensile properties of starch are suitable for the production of packing materials, and glycerol is added into the starch as a plasticizer[1-4-13]. The required characteristics of the bioplastics are achieved by fine-tuning the quantities of the additives. For trade applications, the starch-based plastics are regularly mixed with eco-friendly polyesters[1-4-13]. Most green plants produce this polysaccharide as an energy store. Human diets also consist of this carbohydrate, and it is contained in enormous volumes in primary foods, including rice, cassava, maize (corn), wheat, and potatoes[1-4-13]. Among them, the most important starch is cassava starch, which contains more than 80% starch in dry mass. Starch is a carbohydrate that contains a great amount of glucose units, combined through glycosidic links[1-4-13]. For the residents of tropical regions, cassava starch is the third most essential nutrition source[1-4-13]. A biodegradable polymer from cassava starch for various applications was developed with different surface treatments. The various physical, mechanical, and thermal properties were addressed [1-4-13].

Researchers prepared sugar starch-based bioplastic film for packaging applications with various reinforcements [1-4-13]. Starch based bioplastics are developed from wheat, corn, rice, potatoes, barley and sorghum[1-4-13]. Bioplastics, made from biological materials represent an effective solution to this problem. Starch based bioplastics account for the major portion of the bioplastic market. In the manufacture of starch-based thermoplastics, plasticizers are added to the polymer matrix to enhance its flexibility[1-4-13].

Several starch-based bio-plastics were already developed by researchers [1]. However, most of them were produced from food grains such as corn, potato, casava, rice, and so on[1-2-13]. Around 50% of the bio-plastics are made from starch as they have several advantages like better tensile strength, biodegradability, ease of manufacturing [1]. Pure starch is available in white color. It does not have any explicit taste or smell, is biologically absorbable, non-toxic, semi-permeable to carbon dioxide, and insoluble in cold water or alcohol. Mainly starch consists of two types of molecules namely amylose and amylopectin [1-13]. Based on the nature of the plant, the amylose composition would differ from 20 to 25% and the amylopectin content varies from 75 to 80% by weight. Amylopectin is a larger molecule than amylose[1-4-13]. When the starch is heated starch gelatinization takes place and it becomes a paste, soluble in water and the viscosity is also increased [1]. Starch-based Bioplastics were produced from cassava peel reinforced with microcrystalline cellulose (MCC). Sorbitol was used as a plasticizer[1-4-13]. The mechanical properties were improved by adding the MCC and sorbitol. This would be a good substitute for the existing plastic materials [1-13].

Thus, the use of alternative botanical sources may be an important strategy to improve the properties of starch-based biodegradable plastics. Among these sources, the jackfruit seed. Song et al. (2018) [6] produced starch films using corn and wheat starch. They addressed the effect of essential oil and surfactant on the physical and antimicrobial properties of corn and wheat starch films[6] The properties of cassava starch-based bioplastics reinforced by nano clay were investigated and the X-ray diffraction (XRD), tensile test, moisture content test, water absorption, and biodegradability test were conducted experimentally [1-6]. The results revealed that the addition of nano clay would improve tensile strength. Abdullah et al. [1-7] have extracted starch from sweet potatoes. They added glycerol to produce bioplastics and the mechanical properties were investigated. They reported that the Bioplastics with the highest sweet potato starch and glycerol ratio showed the best physical, mechanical, and biodegradability properties. They attained the highest tensile strength of 2.57 MPa with a density of 1.66 g/cm3. The composite bioplastics by synthesized TiO2 nanoparticles with corn starch were proposed for packaging industries [1-7]. The composite bioplastics were prepared using starch, vinegar, glycerol, and TiO2 and it was concluded that the tensile strength of the bioplastics was increased and elongation is decreased by adding TiO2. In another study, cassava starch-based bioplastics by applying a two-step melt-blending extrusion has been reported [1-7]. The thermoplastic starch (TPS) was prepared with the addition of Glycerol and nano-SiO_2 with the starch in the first step. The addition of Polybutylene adipate-co-terephthalate (PBAT) in the second step was used to increase the mechanical properties. Cassava starch was added with xanthan, gellan, or pullulan gums to produce cassava starch-based films to reduce moisture absorption and enhance film strength. The Xanthan gum increased the tensile strength of the starch films but did not minimize the water absorption capacity and water vapor permeability [1-7].

Increasing concerns about environmental sustainability and plastic pollution are reflected in the interest in starch-blended biodegradable polymers as substitutes for traditional petroleum-based plastics [1-4-13]. The processability and mechanical qualities of materials based on starch are being improved by researchers by using a variety of blending processes, such as physical blending and chemical modification[1-4-13]. Furthermore, the compatibility of starch with other biopolymers makes applications in the food processing industry and other sectors possible[1-4-13].Starch-blended biodegradable polymers' effects on the environment and sustainability have been discussed, with a focus on their capacity for regrowth and low carbon footprint[1-4-13]. These substances could reduce plastic waste and help create a more sustainable future. The study investigated how the blends' mechanical strength, thermal [1-4-13].

4. Glycerol: Plasticizer

Glycerol was used as a plasticizer, and it was reported that the addition of citric acid would improve the solubility of starch [1-4-13]. Plasticizers are molecules with low molecular weight and volatility, which reduce intermolecular interactions by coupling between the polymer chains and increasing their mobility, reducing the glass transition temperature, melt viscosity, modulus of elasticity, as well as fragility of films [1-4-13]. Plasticizers as polymer additives serve to decrease the intermolecular forces between the polymer chains, resulting in a softened and flexible polymeric matrix [1-4-13]. They increase the polymer's elongation and enhance processibility by lowering the melting and softening points and viscosity of the melts [1-4-13]. Glycerol is a classical starch plasticizer is perhaps the thermoplastic starch's most commonly investigated and utilized plasticizer[1-4-13]. This is due to its low price, non-toxicity for human food and biomedical applications, and relatively high boiling point [1-4-13]. Furthermore, the hydrolysis or conversion of lipids (triglycerides) to fatty acids for the biodiesel industry produces glycerol as a by-product [1-13]. This presents an opportunity to improve the economics of both the biodiesel industry and the bioplastics industry[1-13].

The International Union of Pure and Applied Chemistry (IUPAC) defines plasticizer as a "substance or material incorporated in a material (usually a plastic or an elastomer) to increase its flexibility, workability or distensibility" [1-4]. Taking into consideration that effective plasticization is dependent on chemical structure of the plasticizer, its compatibility and miscibility with the polymer, molecular weight and concentration of plasticizer, different polymers require different plasticizers [1-4-13]. Gujar et al. [3] investigated the effect of glycerol on the mechanical and moisture absorption properties of corn-starch-based bioplastics [3]. They developed different bio-plastics by varying the amount of glycerol and determined the tensile strength density, and moisture content[3]. They concluded that the tensile strength and moisture content were decreased whereas the density was increased with an increase in the amount of glycerol [3]. Another study reported the preparation of starch films from cassava, corn, potato, and yam [1-4]. The effects of plasticizers namely glycerol and sucrose on the mechanical properties of the film were investigated at six different levels[1-4]. The results proved that glycerol would provide better results than sucrose due to its hygroscopic or hydrophilic nature [3]. One of the study reported the chemical, mechanical, and thermal properties of starch derived from potato and yam [1-4]. Another study also studied the morphology and thermal and mechanical properties of cornstarch-based bioplastics produced by extrusion [3]. They used chitosan as a plasticizer[1-4]. Edhirej et al. [2] prepared a cassava bagasse and sugar palm fiber hybrid composite using casting technique with cassava starch as matrix and fructose as a plasticizer [2]. Cassava starch/Cassava bagasse composite film was prepared by the addition of different loadings of sugar palm fiber (2, 4, 6, and 8% w/w of dry starch) and found that the sugar palm fiber appreciably prejudiced the physical properties and increased the thickness and to decrease the density, water content, water solubility, and water absorption[1-4]. Santana et al. (2018) [5] have investigated the performance of bio-plastics using jack fruit starch. Glycerol was the plasticizer [5]. The tensile strength, percent elongation, and young's modulus were calculated [5]. The results revealed that the jack fruit starch could be used to produce films with opacity and relatively high mechanical stability[5].

The hydrogen links between polymers of starch are broken and replaced by the plasticizer, allowing the chains of polymers to move freely [9]. When starch and plasticizer interact, the plasticizer molecules enter the starch granules, reducing the force of contact and improving the tensile characteristics of the end product [9]. Between 70% and 90% of the mixture contains starch, which is completely biodegradable [1-2-13].

5. Acid Citric

The adhesion between glycerol, water, citric acid, and starch in thermoplastic starch is strengthened by the supplementation of citric acid [1-2-13]. Citric acid can create stronger hydrogen bonding interactions with starch than glycerol. Hence, citric acid can effectually inhibit starch recrystallization (i.e., retrogradation), due to its strong hydrogen bonding interaction with starch [1-2-13]. Rheological investigations demonstrated that citric acid can clearly reduce the shear viscosity and improve the fluidity of thermoplastic starch [1-2-13]. Citric acid can also enhance the elongation of glycerol-plasticized thermoplastic starch and improve its water resistance at high relative humidity, but reduce the tensile stress [1-2-13]. Citric acid and glycerol are utilized to enhance the flexibility and fluidity of the material to which they are supplemented. Furthermore, citric acid is a potential cross-linking agent under low-cost, nontoxic conditions[1-2-13].

6. Baking Soda

Baking soda, also known as sodium bicarbonate ($NaHCO_3$), scientifically, is one of the preservatives and plasticizer additives as the same as sodium metabisulfite ($Na_2S_2O_5$), glycerol, and sorbitol [1-2-13]. These additions strengthen bioplastics and make them more durable [1-2-13].

7. Following are the few examples of starch based Bio-plastic thin films were produced and characterized.

1) *Prosopis juliflora* is an invasive plant species available in the hot region [1]. It is widely used as fuel wood in many developing countries such as India [1]. Marichelvam et al., (2022) [1] has reported the development of sustainable bioplastics from the extracted starch from *Prosopis juliflora*[1]. The test results revealed that the proposed starch-based bioplastics would be a better alternative material to be used in packaging industries[1]. Further, the usage of *Prosopis juliflora* would also reduce the environmental impact significantly [1]. This study examined the effect of glycerol as plasticizer on the mechanical and moisture absorption properties of starch-based bioplastics [1]. Varying amount of glycerol was used to produce bioplastics and then their tensile strength, density and moisture content were determined [1]. It was observed that, there is a decreasing trend in tensile strength and moisture content with increase in the amount of glycerol, whereas, this trend gets inverted in case of density [1].

Extraction of starch and biofilm Production

Prosopis juliflora plant located at Poolavurani, Virudhunagar district, Tamilnadu, India and wood was prepared [1]. The growth of Prosopis juliflora would affect biodiversity and reduce the groundwater level. *Prosopis juliflora* tree wood was converted into sawdust [1]. The sawdust was stirred with distilled water and heated at 60 °C [1]. About 50 g of wood powder was mixed with 600 ml of distilled water in a 1-L flask [1]. The flask was kept in the water bath and heated at 60 °C with constant stirring provided by a magnetic stirrer [1]. This process was continued for 3 h until the water is siphoned off [1]. The above process was repeated 3 to 4 times until the extract failed to give the tannin reaction with ferrous ammonium sulphate solution[1]. The tannin reaction confirms the presence of starch in the wood powder[1]. The final extract was allowed to dry to get the starch [1]. The materials used for preparing bioplastic films are gelatin, glycerol, PJS, citric acid, and distilled water[1]. Glycerol is the solvent or the plasticizer that plasticizes the added starch and other materials to produce the bio-plastics film [1]. Gelatin and citric acid also act as plasticizers [1]. The composition of materials is varied, and six different samples are prepared [1]. he weight of PJS remains constant for all the samples[1]. The weights of the gelatin, citric acid, and glycerol are increased, and 100 g of distilled water is used[1]. Gelatin, glycerol, PJS, citric acid, and distilled water are mixed thoroughly using a magnetic stirrer [1]. The mixture was allowed to mix at a constant speed of 180 rpm for 10 min[1]. After mixing, the solution is transferred to the hot plate which is maintained at 100 °C [1]. Then, the solution is heated for 10–15 min until a gel-like substance appears [1]. The gel is removed from the beaker and poured onto the Teflon glass plate and is spread uniformly to get uniform thickness [1]. The glass plate is dried for 3–4 days and then the plastic film is separated from the Teflon glass plate[1]. In this work, starch is extracted from the *Prosopis juliflora* and mixed with glycerol, citric acid, gelatin, and distilled water at different ratios to produce the bio-plastics films [1]. Various tests are conducted to evaluate the properties of PJS films [1]. The tensile strength of PJS film is found to be 5.81 MPa which is much better than many other starch-based films addressed in the literature [1]. The statistical results revealed that the film thickness, water-solubility, water contact angle, and biodegradability properties of PJS are also impressive [1]. The average thickness of the PJS film is 260 µm[1]. Hence, it is inferred that the PJS film could be used for packaging applications[1]. It would be an interesting future scope of this work is to investigate the biodegradability of the PJS films under different environmental conditions [1].

2) **Jackfruit (*Artocarpus heterophyllus*)** is a species of tree belonging to the *Moraceae* family, widely found throughout many tropical and subtropical regions such as India, China, Pakistan, Nepal, Sri Lanka, Bangladesh, and in many parts of Southeast Asia [5]. The jackfruit is composed of rind, edible yellow flesh, procarp and, seeds which represent 8–15% of the fruit weight [5]. Up to 500 seeds can be found in a single fruit, corresponding to approximately 15% of its total weight and are fairly rich in starch and protein [5]. The jackfruit seeds were selected as a source for starch because of their large availability, low price or even free, and high starch capacity [5]. According to Sanata et al., (2018) [5], for the extraction of starch, Jackfruit seeds were ground in an industrial blender in sodium bi-sulfite solution [0.2% (w/v) in SO_2] until the powder was very fine[5]. The crushed mass was filtered through cotton cloth. The starch suspension obtained was decanted for 30 min at room temperature, washed several times with sodium bisulfite solution, and centrifuged at 900 g for 5 min at 25^o C [5]. After centrifugation, the supernatant was discarded and two types of solid material were obtained: the first, a light brown color mucilage, was discarded, and the second was collected as starch [5]. The starch was dried in a tray dryer with air circulation at a temperature of 45^o C to constant mass[5]. Bioplastics were prepared using the casting technique[5]. Jackfruit starch at concentrations of 2, 3, 4, 5 and 6% w/w, and glycerol PA as a plasticizer at the concentrations of 20, 30, 40, 50 and 60 g/100 g of starch were dissolved in 200 mL of distilled water [5]. The suspension was heated to 95 ^{o} C under stirring on a magnetic hot plate for 5 min [5]. After the heat treatment, the film-forming solution was shaken in a 40 kHz ultrasonic bath for 20 min, then poured into acrylic rays and dried in an oven with air-circulation and air renewal at 55 ^{o} C, for 15 h [5]. After this time, the trays with bioplastic were stored in hermetically sealed containers for 48 h with saturated sodium bromide (NaBr) solution at 58% relative humidity [5]. The starch and glycerol concentrations ranged from 2 to 6% w/w and 20 to 60 g/100 g starch, respectively[5]. Bioplastics were obtained by the casting method and characterized in terms of color, mechanical properties, solubility, water vapor permeability (WVP), morphology and free energy of the hydrophobic interaction [5]. The results of the study by Sonata et al., (2018) [5] reported that jackfruit starch can be used to develop films, with low opacity, moderate WVP and relatively high mechanical stability, by using glycerol in the gelatinized starch dispersions [5].

3) The raw **jackfruit** seed has a very pungent odor and hard outer shell and then needs to be deseeded for both the hard shell and the brown spermoderm [8]. The deseeded seeds were then washed [8]. The rotten seeds were discarded while the good seeds were overnight soaked for latex removal[8]. After that, the overnight soaked jackfruit seeds were washed using pure water [8]. Clean jackfruit seeds were then ground to obtain a slurry[8]. The slurry was filtered through a filter cloth to obtain a crude starch suspension while the sediment was discarded[8]. The filtrate was precipitated overnight for settlement and latex and minerals removad [8]. The supernatant was removed, and the crude starch was washed with distilled water[8]. This step was reproduced three times, and the starch cake was then dried naturally or by an oven [8]. When using the sun-drying method, starch could be discolored and became contaminated, forming a thin light brown layer[8]. Instead, the starch suspension was dried at 45^{o}C for 24 hours in an oven dryer[8]. It should be added that the proposed starch extraction process is simple and easy to implement [8]. It does not include a centrifugation step as in, soaking in 2% NaOH and slicing as in, or cutting with the size of 1 cm2 approximately before crushing [8]. Bioplastics are prepared by mixing starch with glycerol with different starch : glycerol ratios by mass (2.5 : 1; 2.75 : 1; 3.0 : 1; and 3.5 : 1) [8]. The plasticization process was carried out by putting the liquid mixture with the ingredients in a given ratio above a heated magnetic stirrer at a temperature of 95oC [8]. The mixture was stirred with a magnetic stir bar[8]. When the temperature is higher, the process will go faster; however, when the temperature is too high, the mixture can be thermally decomposed before being completely converted into bioplastic [8]. After the mixture turned completely clear and thick, stop stirring[8]. The plastic mixture was poured into trays covered with PE film[8]. Without PE film coating, the bio-plastic would stick to the tray and be cracked when drying [8]. After that, the viscous liquid bioplastic was flattened on a tray and then transferred to an oven at 55°C and dried for 15 hours until the weight was constant[8]. It is worth noting that the drying time can be shorter or longer depending on the thickness of the viscous bioplastic layer [8].

4) **Sweet potato** (*Ipomea batatas*) is a tropical starchy tuber crop and abundantly grown in Malaysia, India, and China[10]. Starch is a major component of this root approximately 50–80% of its dry weight [10]. This high starch content in sweet potato provides its good film-forming ability to produce biodegradable food packaging films that can replace petroleum-based films and promote sustainability[10]. However, similar to other starches, sweet potato starch (SPS) has unconvincing mechanical and barrier properties than the commercial plastics and required some modification[10]. After cleaning with tap water, fresh sweet potatoes were peeled and cut into pieces with around 3 mm thickness[10]. The cuts were then macerated adding 1:1.5 (w/w) distilled water in a blender at full speed (10,000 rpm) [10]. Muslin cloth was used to filter the residues. The starch filtrate was kept undisturbed in a chiller (6 ± 2 ^{o}C) to settle for 3–4 h[10]. The supernatant was poured out and the starch layer at the bottom of the beaker was resuspended in distilled water[10]. The mixture was taken in the centrifuge tubes and centrifuged at 9000 rpm for 3 min[10]. The supernatant was discarded and distilled water was added again to proceed with the centrifugation[10]. This process was continued until white starch sediment was obtained[10]. The sediment starch was dried overnight in a convection oven at 50 °C[10]. The dried starch was cooled to ambient temperature (28 ± 2 °C) and ground using a laboratory-scale grinder into powder[10]. The powder was sieved through 100-micrometer mesh sieve size and packaged in polyethylene bags, sealed, and stored in a chiller at 4 °C [10]. The SPP films with different loadings of anthocyanin (SPS CA 0%, SPS CA 1%, SPS CA 1.5%, and SPS CA 2%) were obtained by adding 4 g of starch powder to 100 mL of distilled water in a beaker and the mixture was heated and stirred using a hot plate[10]. After it reaches 40 °C, 25% of glycerol (v/w) was added to the mixture[10]. The mixture was stirred and heated at around 85 °C until gelatinization occurs for about 20 to 30 min[10]. When the solution was cooled to below 40 °C, different loadings of anthocyanin powder (0%, 1%, 1.5%, and 2% (w/v)) were added accordingly and mixed properly for 10–15 min using the magnetic stirrer[10]. Then the solution was sonicated for 10 min to remove air bubbles[10]. After cooling down the formulation was poured (35 mL) into the petri dish with a diameter of 140 mm and left for drying on a flat table for 2 days at 26 ± 2 °C [10]. The steps were repeated to prepare SPS/SPP films with anthocyanin where the SPS and SPP powder was added in the ratio of 6:4[10]. The results of this study signify that the CA-associated SPS and SPS/SPP films have the potential to be used as pH indicator package to monitor the freshness or spoilage of food products to ensure their quality and safety[10]. Two categories of the film (i) SPS and (ii) SPS/SPP, were fabricated via solvent casting technique, incorporating different concentrations of commercial purple sweet potato anthocyanin (CA) at 0%, 1%, 1.5%, and 2% (w/v) and the physicochemical, mechanical, thermal, and morphological properties of the films were investigated[10]. The thickness, water solubility, and swelling degree of the films increased with the increment of CA, whereas there were no significant changes in the water content (WC) of the films[10]. Water vapor permeability (WVP) was decreased for SPS films while statistically similar for SPS/SPP films [10].The addition of CA reduced the tensile strength (TS) and tensile modulus (TM) yet increased the elongation at break (EaB) of the films as compared to films without CA[10]. The FTIR results confirmed the immobilization of anthocyanin into the film[10]. Furthermore, the CA-associated films showed a remarkable color response when subjected to pH buffers (pH 1 to 12) and successfully monitored chicken freshness[10]. The fastest color migration was observed in acidic conditions when the films were immersed into aqueous, acidic, low fat, and fatty food simulants[10].The findings of this work demonstrated that the developed pH indicator films have the potential to be implemented as smart packaging to monitor food freshness and quality for safe consumption[10].

5) Starch has demonstrated the potential to produce biodegradable materials because it is a cheap raw material that is readily available and renewable [12]. Also, it contains both branched and liner polymers such as amylopectin and amylose, respectively[12]. Due to its double helical crystallographic structure, starch can endure extreme heat and shear [12]. Hence, with the use of alternative plant-based resources, it is possible to enhance the qualities of starch-based biodegradable polymers[12]. In this study by Anitha et al., (2024) [12] starch-rich vegetable crop plants like cassava and sweet potato have been exploited for the preparation of bioplastics[12]. The starch content of tapioca and sweet potato is 17% and 43.5%, respectively [12]. Both plants have high amylose content (17–43.5%) and a high gelatinization temperature (69–80%), minimal fat content, increased temperature as well as pulp viscosity, and reduced pulp breakage compared to the gels made from other starches [12].

The sweet potato and cassava starch were added with 3 volumes of water to its weight and broken down into small pieces to obtain a slurry [12]. The extract was then passed through a muslin cloth and then filtered, and it was dried to obtain a fine powder[12]. A 5% cassava and sweet potato starch (w/v) was prepared; this was then mixed with a magnetic stirrer at 900 rpm for 5 min[12]. Different concentrations of glycerol were then added to this mixture (1.5%, 2%, 2.5%, 3%), and after that, the mixtures were swirled once more for five minutes at 900 rpm[12]. It was then heated to a temperature of 80 ◦C for 45 min[12]. The solution was then cooled and poured into a mold, then placed at ambient temperature (27 ◦C–30 °C) until fully dry, after which it was dried for 24 h at 50 °C in the oven [12]. The final thicknesses of the manufactured bioplastic films were measured using a digital micrometer (Ocean Digital Micrometer 0–25 mm, India, with the least count of 0.001 mm) [12].

6) First, 100 g corn was washed and boiled with water for an hour. More corn was ground in a mortar with 100 mL purified water [13]. The mixture was filtered and the remaining solid mass was put into the mortar [13]. Experiments were repeated for five times and more starch was obtained[13]. The blend was allowed to settle in the beaker for 5 min. Then, 100 mL of purified water was added and was agitated softly[13]. The water was removed after repeating the above process 3–4 times and the starch, white in color[13]. About 40 g of starch was obtained from 100 g of corn. In this similar manner, rice starch was also extracted[13]. In rice and corn starch-based TPS, glycerol is used as plasticizer, due to its better mechanical properties and good water solubility, ranging from 18 to 25%, though it can increase up to 36% [13]. It was shown that the glycerol concentration would not affect the glass transition temperatures[13]. TPS film was prepared according to the following procedure: The starch, glycerol, gelatin, and citric acid were added to 100 mL distilled water in various ratios [13]. The mixture was stirred at a rate of 180 rpm for 10 min [13]. Then the mixture was heated on a hot plate at 100 °C, and manual stirring was done for 70 min, continuously [13]. It was then poured onto a Teflon-coated glass plate and spread uniformly. It took 3–4 days for the mixture to dry out and the cast film was removed[13]. Then, five samples were prepared for different compositions of corn and rice starch [13]. The results showed that the samples prepared from the corn and rice starches have better biodegradability than the existing plastic materials[13]. The citric acid addition improves the shelf-life of the material and improves the mechanical properties[13]. The average thickness of the bio-plastics is 0.25 mm (250 microns) [13]. The average moisture content is 13.2% [13]. The solubility in water is 11.9%[13]. The biodegradability of the sample is 48.7%, and it is achieved in 15 days. The maximum tensile strength of the bio-plastics is found to be 12.5 MPa[13]. From the above test results, it can be concluded that bio-plastics can be used as packing materials and can be used as an alternative to LDPE and HDPE plastic bags[13]. Due to the obtained properties of bio-plastic, it would be interesting to prepare polybags using this bioplastic with assumed lower cost[13].

7. Limitation of Starch based Bioplastic

According to Singh et al., (2024) [9], starch-blended biodegradable polymers hold immense promise in advancing eco-friendly innovations, their utilization has certain limitations that warrant careful consideration [9]. Understanding these constraints is crucial for effectively navigating the sustainable materials landscape [9]. One significant limitation revolves around the mechanical properties of the starch-blended biodegradable polymers[9]. Starch, as a natural component, can introduce challenges in maintaining the structural integrity and durability of the resulting polymer blend [9]. The mechanical strength of these materials may not always meet the rigorous requirements of certain applications such as packaging or durable goods manufacturing [9]. This limitation may restrict their widespread adoption in industries in which robustness and long-term durability are paramount [9]. Another concern is the sensitivity of the starch-blended biodegradable polymers to environmental conditions [9]. These materials often exhibit susceptibility to moisture, leading to potential issues of water absorption and subsequent degradation[9]. This moisture sensitivity can affect the performance and lifespan of products made from these polymers, particularly in humid climates or in applications where exposure to water is unavoidable [9]. The processing challenges associated with starch-blended biodegradable polymers also pose a set of limitations [9]. The incorporation of starch into polymer matrices can complicate the manufacturing process, requiring specialized equipment and optimized processing conditions [9]. Achieving consistent and reproducible results may be challenging, affecting the scalability and cost-effectiveness of production[9].

Singh et al., (2024) [9] are of the opinion that starch-based biodegradable polymers may help build acceptable food packaging in the future[9]. Starch retrogradation reduces mechanical characteristics [9]. Adding functional additives and biopolymers to films has been tried to tackle this problem[9]. Although some approaches must maintain film properties, high work remains to create films based on starch with the same barrier, optical, antimicrobial, and mechanical characteristics as a synthetic polymer[9]. Starch type, film formation temperature, duration, plasticizers, and others affect the functional qualities of starch-based eco-friendly material[9]. Future challenges include mass-producing starch-based materials using simple and rapid processes[9]. Improved starch-based materials are generally made in the lab. Future starch-based material manufacture will require economically effective processing technologies[9]. A starch-based biodegradable material composting system must also starch-based biodegradable material composting system must be established to ensure proper treatment and recycling to avoid environmental pollution[9]. This will increase the food industry's use of these materials, reduce fossil energy use, and improve environmental sustainability[9].

Starch biodegradable materials may exhibit inferior mechanical properties compared with conventional plastics [1-9]. This limitation can impact their suitability for applications where strength and durability are critical, such as packaging that requires resistance to tearing or puncture[9]. Starch-based materials can be susceptible to moisture, potentially affecting their performance and shelf life, particularly under humid conditions [9]. This sensitivity limits their application in situations where moisture resistance is essential, such as in packaging for frozen or refrigerated food items [9]. The Incorporation of starch into polymer matrices may require specialized processing equipment and conditions[9]. This complexity can increase manufacturing costs and pose challenges for companies seeking to transition from conventional materials to starch-based alternatives[9].

8. Conclusion

Petroleum derived plastics dominate the food packaging industry even today. These materials have brought a lot of convenience and attraction to agro, food and packaging industry. These materials also have brought along with them problems relating to the safe-disposal and renewability of these materials. Due to the growing concern over environmental problems of these materials, interest has shifted towards the development and promoting the use of "bio-plastics". Bio-plastic is a term used for sustainable packaging materials derived from renewable resources i.e. produced from agro/food sources, materials such as starch, cellulose, etc. and which are considered safe to be used

in food applications. Bio-plastics made from renewable materials may be spontaneously recycled through biochemical processes, eliminating the demand for fossil fuels and protecting the environment. Therefore, bioplastics are safe for the environment, generally biodegradable, and compatible with living things. Bioplastics are now crucial in many industrial uses, such as food packaging, horticulture, composting bags, and hygiene. Bioplastics are also used in the manufacture of consumer items for the electrical, structural, and biological industries.

Bio-plastics generally have lower carbon footprints compared to conventional plastics because the raw materials used for bio-plastics are sourced from plants that naturally absorb atmospheric carbon dioxide, resulting in a cyclical carbon process. Considering the complete life cycle of bio-plastics, which encompasses aspects such as the development and utilization of fertilizers and pesticides, harvesting and cultivation of crops, and movement of finished products and raw materials, among others, it is evident that bio-plastics do not have a carbon footprint of zero. The dependence on the depletion of fossil resources is still less with these polymers than it is with conventional plastics made of petroleum.

Starch-based polymers are the principal subject of studies on biodegradable packaging materials. Starch-based materials may have lower heat resistance than conventional plastics. This limitation restricts their use in applications that involve exposure to high temperatures, such as hot food packaging or microwaveable containers. While rapid biodegradation is environmentally beneficial, it can pose challenges for certain food packaging applications that require a longer shelf life. The rapid degradation of starch-based materials may not align with the expectations of extended shelf life in the food industry, impacting their practicality in specific contexts. The production costs of biodegradable starch materials may be higher than those of conventional plastics. Cost-effectiveness is a crucial consideration in the competitive food industry, where profit margins are often tight. The initial investment required to transition to starch-based materials may deter some businesses from adopting these alternatives. Starch-blended biodegradable polymers' effects on the environment and sustainability have been discussed, with a focus on their capacity for re-growth and low carbon footprint. These substances could reduce plastic waste and help create a more sustainable future.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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