



Recent trends of biodegradable food packing polymer films

A. Geetha Bhavani*, Jayanand, Varun K Sharma, Shailesh Solanki and Prathiba Teotia

Department of Chemistry, School of Sciences, Noida International University Research & Innovation Centre, Noida International University, Gautama Buddha Nagar, Greater Noida-2013086, U.P, India

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ABSTRACT

For a better understanding of food packaging polymers and potential hazards they currently pose on public health. Through the use of an extensive literature review, key problems are identified with current food packaging plastics including leaching of toxic chemicals into food as well as food plastic's economical and environmental impact. Research and independent studies concerning consumer acquisitions and availability of the different types of polymers were then conducted and showed the direct impact on these issues of biodegradability and contamination on the average consumer. Ultimately, a general outline for a national recycling program is proposed in order to address some issues regarding environmental and economical impact as well as increase awareness of issues with current food packaging plastics.

1. Introduction

Packing a food and food products is mere process of shipping safely, prolonged self-life as well as buttresses from bacterial contamination and package must be biodegradable. Packing industry mainly modify polymers, glass, and paper materials to store, protect, and preserve food from indulging and destruction^[1,2]. The contemporary methods for packaging food are petroleum-based, synthetic materials that provide minimal barrier properties with excellent mechanical support^[3,4]. The petroleum supplies are weakening the profusion of non-biodegradable plastics in landfills across the country, the need for environmentally friendly, cheaper, and more effective methods of packaging are required to extend shelf life and preserve the quality of the food while also improving the barrier and mechanical properties^[5,1]. Current technologies aim to reduce productions cost and proficient way to package their goods to preserve the freshness and reliability of the food packing. Though this method is efficient, advances in technology have allowed for far greater advantages in food packaging while maintaining a low price for businesses^[6]. With growing concern for the environment, Biodegradable polymers are scrutinised for food packaging as a prime concern due to proven degradability and environment friendly^[7-10]. The plastics have an increasingly negative impact on the earth due to a lack of biodegradability and poor recycling practices, leading to an ever increasing need for a solution that is effective and efficient. It is the goal of this project to understand the food packaging industry, materials and processes used, and potential hazards it poses while understand societal awareness of the effect food packaging has on the product itself as well as on the environment. In order to fully understand food packaging plastics and the food packaging industry, research must be conducted into current processing

methods and materials. By obtaining a base of knowledge of current practices, information on problems involving functionality properties of food packaging plastics as well as their economical and environmental impact can be sought and explained.

The many industrial plastics, the food wrapping industry encompasses virtually a fifth of the net revenue of the plastic business with the use of polystyrene (PS), polyvinyl chloride (PVC), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyethylene terephthalate (PET), polypropylene (PP), are the key constituents of common food packaging plastics^[11]. Each plastic constituents is labelled for its exceptional properties.



Currently Dr. A. Geetha Bhavani is Associate Professor & Head, Department of Chemistry, School of Sciences. She received Ph.D. degree in 2008 on Heterogeneous Catalysis for petroleum industry applications. She joined in Pohang University of Science and Technology, South Korea as Postdoctoral Fellow in the field of synthesis of Novel porous catalytic solids, Reaction conversion process and isolation of

the intermediates structures and transport properties of porous solid catalysts, Photo-catalytic hydrogen production as a means to produce hydrogen, Development of New Catalysts for CO₂ Reduction and Eco-friendly Production from Chemical Stocks. She holds international patent and with high impact international publication.

* Corresponding author. Tel.: +91-8826699428; e-mail: geetha.bhavani@niu.edu.in, gitabhavanai_19@yahoo.co.in

Advanced Scientific Research



Professor (Dr.) Jayanand received Ph.D. from Jawaharlal Nehru University, New Delhi and currently as Director & Registrar at Noida International University. Prof. Jayanad has researching in different areas like biophysics, biomaterials, bio-electromagnetics, bioinstrumentation, electro-magneto-therapy, spinal cord injury and osteoporosis.

Dr. Varun Kumar Sharma is a one of the active researcher and youngest HOD of NIU who take cares the Department of Biotechnology and Microbiology as a Head, under the School of Sciences. He received his Ph.D. degree in Molecular Oncology from the University of Padova, Padova, Italy, PDF from INSERM, Paris, France. Prior to that, He has worked as research fellow at the CSIR-Centre for Cellular and



Molecular Biology (CCMB), Hyderabad, India. He is continuing his research in molecular Cancer biology, Immunology, Biochemistry, Epigenetics, Infection biology, epidemiology and other biomedical area. He is invited member of several scientific committee and active reviewer of many publication agencies, such as current science, PLoS ONE, Virus diseases and others.



Dr. Shailesh Solanki is Associate professor and Head of the Department Agriculture and Environment. She has received her Ph.D. from Dr. Bhim Rao Ambedker University, UP India in 2013. Her field of research field waste water treatment, Effects of water pollution on life of aquatic, environmental biotechnology focusing on isolation and characterization of microbes capable of degrading

all types of wastes thus contributing in environmental protection and eco-efficient industrial waste degradation. In field of Agriculture interesting area study of hydroponic plants and medicinal value plants.

Dr. Pratibha Teotia is the Head, Department of Biotechnology, Noida International University her Ph.D. is on Topic "Insilico Identification and Optimization of drug target sites in *Cryptosporidium parvum*. Her research area is Bioinformatics which is being used for drug development and targeting which involves statistics, computer sciences, and



engineering to collect and analyze complex biological data. To make this simpler, Bioinformatics makes use of in-silico analysis using mathematical algorithms and predictions based on extrapolation.

PET and PVC shows virtuous features of tensile strength, transparent and melts very easily, to prepare cold beverages containers, which prerequisite a strong material to resist chemical interactions and low cost^[12]. PVC has a stretching abilities to extrude into sheets. HDPE is castoff for where clarity is not obligatory like containers used for milk packing, where a strong material is also needed. Since HDPE is cheaper to buy as raw material and process, it is used when clarity is not as great a factor^[13,14]. LDPE has large stretch capacity compared with PET, PVC and HDPE, which is used for food rapping bags because of excellent barrier properties and economic^[15]. PP has high strength properties is used in rigid containers like baby bottles and cups and bowls and slightly expensive than other plastics materials^[16]. PS is utilised in Styrofoam food containers like cups, meat and egg trays that need an inflexible form or heat resistance^[17].

Beside of many uses of different types of plastics materials must guards the food to increase shelf-life to store freshness and both mechanical and barrier properties to prevent damage. The mechanical properties are pertinent to how strong the material is and what kind of support and strength it will have, the tensile strength is the most commonly looked at aspect of a material since it will indicate the materials resistance to stress and strain. To avoid decay of food from packed containers are mainly depends on barrier properties, water transfer and oxygen are the most important aspects^[18]. Only few report are discussed on packaging problems such as biodegradability, prevent or warn of impurities, or preservation of the food^[19,6].

2. Concerns on present food packaging plastics

Though existing practices are active, there are still many issues of plastics and food interactions with and without heat, reusability^[20,21]. In addition, these issues are not properly addressed caused environmental damage due to common disposal methods and poor recycling policies^[22,23].

2.1 Material-food interactions

Existing packaging plastics are used for several years, but few short coming are exposed by additives within materials to leak into the food material-food interactions may to contamination for longer hours. This toxicity leads to harmful disorders due to leaching of barrier and mechanical properties^[25-28]. The barrier and mechanical properties may change due to heating and UV exposer will loosen the matrix^[24]. As previously discussed, additive to incorporate into matrix of a polymer, will allow the molecular structure of the plastic to alter to improve the mechanical strength of the plastic material^[6]. These additives, are typically inert and nontoxic and bound in the matrix of the polymer, can interrelate with food in large doses and harmful. Usually, most of the additives are effortlessly solvable and able to latch on fats and oils are leads toxicity. Though this delinquent is not commonly seen in PET or HDPE, PP and PVC are used in wrapping that can be heated under microwave and resists leaching chemicals. One study found leaching of PVC chemicals and additives with change in temperature. Though the study did not test food specifically, it found that when PVC polymers reached temperatures greater than 100°C, chemicals would leach from the plastic^[29]. Another study found additives leaching into water from PS cups along with styrene particles which are toxic^[30]. The group found that when hot water was poured into PS cups, styrene chemicals and additives would leach from the cup into the water in unsafe amounts.

Few investigations conducted on the reuse of plastic containers. Schmid's group found that when PET bottles are

reused and sanitized using solar water disinfection, exposure to UV for 6-9 hours while filled with water, the plastic leaches additives^[31]. Though additives may help obtain some mechanical and barrier properties that are necessary for food packaging, they can also be dangerous if they interact with food and leach harmful chemicals. Through microwaving and heating common food packaging polymers, dangerous toxins can leach from the plastics into food and be hazardous^[28].

It is important then to have a method for measuring additive leaching. This, however, is difficult due to measurement of leaching and the various values for diffusivity that are calculated^[5]. Studies have found variations in diffusivity on the order of two times the magnitude in LDPE^[32,33] and ten times in PET^[34].

3. Biodegradable polymers

With the growing need for an environmentally friendly alternative to current food plastic packaging, development in the area of biodegradable polymers has shown some potential. These polymers are made of natural composites of materials such as starch-based polymers, Poly(lactic acid) (PLA), or other naturally occurring substances and are partly or completely biodegradable which may prove useful for food packaging^[35]. However, there are still issues with biodegradable polymers such as a decrease mechanical function and more complex and difficult processing techniques that make these polymers less functionally useful and more expensive in terms of processing. If these difficulties can be addressed, biodegradable polymers may be the solution to the environmental problem that current food packaging plastics pose.

3.1 Starch-based polymers

Starch-based polymers are usually comprised of a mixture of starch additives and the petroleum-based polymers. Due to the relatively cheap cost of starch additives and its availability, this technique is cost effective and enhances currently used food packaging polymers^[35]. Using this additive can provide some biodegradation at a faster rate as well as provides strengthening properties from the starch additive itself^[36]. Fang's group showed that increased percentages of starch-based additive, when combined with polymers such as PE and PS, showed improved strain curves when force was applied. Though the study focused mostly on film based processing and mechanical function, it did show positive results toward the stability of such polymers.

These starch-based polymers can also be thermally processed and can undergo extrusion, injection molding, compression, and film casting. Fang's group processed techniques that can be used on starch-based materials as well as phase transitions during processing. They also tested processing properties of the starch-based polymers by observing effects of water, glycerol, citric acid and other plasticizers and additives^[37]. His group showed that after processing, there was some loss in mechanical function due to temperature changes during processing that needed to be controlled and mechanical function of the polymers was based largely on the processing technique and control of moisture within each stage, as an increase in moisture greatly affected the mechanical function in the end stage of processing.

Several other studies also found control and control of heat and moisture during processing^[38]. The besides difficulties with processing, another issue is that, when combined with petroleum-based polymers, they are not completely biodegradable. Though starch-based polymers may offer a solution, its limitations in processing and loss of mechanical functions due to heat make it a less than ideal candidate for food packaging applications.

3.2 Poly(lactic acid): PLA

PLA is a common natural polymer used in various applications ranging from biomaterials to food packaging. PLA is comprised of lactic acid molecules, which is a natural occurring molecule found in the human body. It is easily broken down and biodegradable into lactic acid which can be metabolized by micro-organisms to water and carbon monoxide^[39]. PLA can be made from a variety of renewable resources such as sugar, potato starch or corn starch and processing produces a highly transparent material with a high molecular weight and resistance to water solubility^[40].

PLA can also be cross-linked in order to provide more mechanical stability and strength. Yang's group tested both the thermal and mechanical properties with varying degrees of crosslinking in order to determine its effect. Another major disadvantage of PLA is that when exposed to high humidity conditions, it begins to break down and loss its mechanical integrity and thus must be process and kept in a controlled environment^[36]. Despite these issues, PLA could be a promising polymer that may prove to be economically beneficial as well as environmentally safe.

3.3 Films (polylactic acid and polyethylene terephthalate)

Two flexible films were considered as coating substrates, polyethylene terephthalate (PET) and polylactic acid (PLA). The former is a thermoplastic polymer of the polyester family, commonly used in the food packaging field for different purposes, such as liquids container, thermoforming applications, as a layer for flexible packaging solutions. Figure 1 and Figure 2 shows the molecular structure of this polymer. The latter is an aliphatic polyester and is a sustainable alternative to petrochemical-derived products, since its production is a multistep process which starts from the production of lactic acid. Lactic acid is the basic monomer obtained from renewable resources (carbohydrates, such as corn or starch) by fermentation.

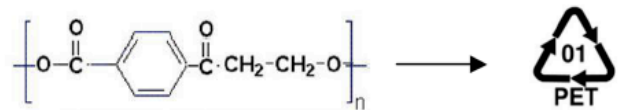


Figure 1 Molecular structure and plastic identification code of PET.

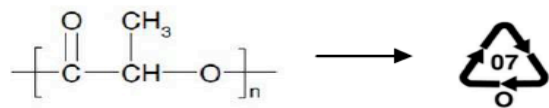


Figure 2 Chemical structure of PLA and plastic identification code

3.4 Gelatins films

Gelatin is a biodegradable polymer that can be obtained from porcine, bovine, or fish skins though due to religious, health, and social reasons, most studies are now being conducted on fish as well as fish skins be a common waste product and readily available^[11]. Studies have found that the molecular weight and amino acid composition of fish gelatins directly correlates to their mechanical and barrier properties^[41-44]. Muyonga investigated the effect of molecular weight and amino acid composition on the mechanical properties of fish gelatin and found that with a higher proportion of low molecular weight amino acids lowered the tensile strength of the gelatin and made it more difficult to process^[45]. By using amino acids that were similar in composition, to determine that the variation in molecular weight had direct effect on the mechanical properties

of the gelatin. By choosing gelatins with higher molecular weight amino acids, the group found that mechanical properties could be manipulated.

The other major issue with gelatins is their lack of barrier properties necessary for food packaging materials. In order to address this issue, a study was conducted add clay composites as a filler additive to gelatin in order to make them less permeable^[11]. The study found that with increased amounts of clay additive (9% was the most additive added in the study), both tensile strength properties and barrier properties increased. The study found a 75% decrease in oxygen and water permeability through the gelatin with the addition of the largest amount of clay additive.

Other types of additives could include chitosan, which is obtained from the chitin in the exoskeleton of several invertebrates^[47]. It is biodegradable, known to have antimicrobial characteristics, and also has film-forming capabilities^[48]. Chitosan is most commonly used as an additive in combination with other material to enhance mechanical and barrier properties. The chitosan was added to fish gelatin in varying amounts using glycerol as a solution to mix in the chitosan and found that mechanical strength decreased. An attempt to add chitosan without glycerol and found mechanical and barrier properties increase. Stress strain curves showed a 20% increase in strength while barrier properties increased by 50%^[49]. Though various kinds of additives may be added into gelatins, there are still issues that have arisen. Besides insufficient mechanical and barrier properties without additives, a study have been done as to the leaching properties of fish gelatin and possible negative effects of food-polymer interactions^[50]. Other issues involve insufficient raw materials, as the type of fish skin used effects the amino acids within the gelatin and in return effect both the mechanical and barrier properties. It may also be difficult to find skins from the same type of fish in large quantities on a consistent basis. Variable quality of fish skin and other factors such as odor, color, and viscosity of fish gelatin may all negatively affect the gelatin strength and are difficult to control. These varying factors make fish gelatin a difficult product to mass produce on a scale necessary for food packaging materials and therefore may not be suitable as a biodegradable material for this industry.

3.5 Oil-based polymers

Two petrol-based polymers were considered as coating materials, to make a comparison with the performance of the final biocoated films, Polyvinyl alcohol (PVOH) and Oxaqua.

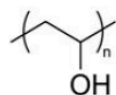


Figure 3 Chemical structure of PVOH

3.6 Adhesion promoter

Another polymer was considered with the aim to provide an improved adhesion of coating on the substrates, in particular on PLA. It is the water-based primer "P" as a polymer dispersion 50 wt %. Pullulan was considered as the only component of the new antifog coating. The substrate for coating deposition was a corona-treated low-density polyethylene. With the aim to provide an improved adhesion of coating on the LDPE film, a primer solution was used LDPE layers were loaded with non-ionic aliphatic OH-functional additives belonging to the polyglycerol esters family.

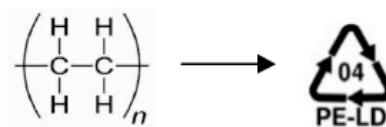


Figure 4 Molecular structure and plastic identification code of LDPE.

3.7 Additives to Plastics

Additives in packaging materials are typically used to strengthen the mechanical or barrier properties of plastics. Additives can range in a variety of materials from silicon to wood flour, each having its own unique purpose and use^[21]. In some cases an additive is chosen in order to lower the cost of a polymer while retaining its mechanical properties or another additive can be added in order to alter barrier properties and may slightly increase cost. The choice of which additive is needed all depends on what is demanded of the end product polymer.

Additives are usually combined with polymers in a matrix form, integrating the polymer and additive together^[25]. The molecular structure of the polymer is altered so that the additive is incorporated within the very structure of the plastic, altering the properties depending on additive is included. This allows uniform strengthening of the material as well as replacing some volume that would otherwise be filled with polymer, which can often lead to a less expensive product^[26]. Though there are many different types of compounds and chemicals that can be added to plastic, it is important to denote the categories they fall under. These groupings help to categories how they will modify the polymer^[26]. Though not all additives are used for food packaging plastics, the categories below show the types of additives that may be used.

3.8 Fillers

Fillers are usually added to polymers in order to lower cost. Fillers tend to maintain barrier and mechanical properties while filling the polymer with a relatively inexpensive molecule, reducing polymer volume and cost. Though it is not the purpose to enhance any properties of the polymer, some fillers do enhance tensile and compressive strength, toughness, abrasion resistance, and dimensional and thermal stability. A variety of materials can be added to accomplish these criteria including silica flour and sand, carbon black, limestone, talc, and other synthetic polymers^[24].

3.9 Plasticizers

This type of additive is used to strengthen flexibility, ductility, and toughness of polymers while also reducing hardness and stiffness^[23]. Plasticizers work by decreasing the strength and amount of the intermolecular forces in the material^[27]. These additives are usually liquids that have low molecular weights and vapor pressures. Plasticizers are usually used in polymers that are brittle at room temperature and lower the glass transition temperature of the polymer so that the plastic can be used in applications requiring some pliability and ductility as well, such as plastic wrap. Common plasticizers include Bis(2-ethylhexyl) phthalate (DEHP) and Bis(n-butyl) phthalate (DBP) both used in plastic wraps.

3.10 Stabilizers

Stabilizers are meant to prevent deterioration of mechanical properties due to such things as UV light and oxygenation^[28]. This is accomplished by combining an additive to absorb either UV light or oxygen. An additive can also be added to repair

damage that has already been caused, though this process is often more complicated and expensive. The most common of the stabilizers is carbon black. Even with the use of additives, there are still issues involving mechanical properties, material-food interaction and lack of environmentally sound practices that impact society greatly. Though there is a pursuit for an economical, environmentally friendly, and functional solution, it is important to understand the components of each problem first.

4. Environmental impact: disposal of food packaging materials

Many current food packaging plastics are not biodegradable, leading to an increasingly large problem for the environment. Though there are many recycling programs across the nation, billions of tons of plastic end up in landfills causing a strain on our resources as well as our environment due to leaching and a lack of volume control. Though there is currently no economically sound way to solve this problem, a reduction in plastic use or alteration in material may help to lessen the overwhelming issue^[28].

This however does not minimize plastic consumption from food packaging since recycled plastics cannot be used unless it meets specific government standards costing more money to produce such containers (FDA 2006). Due to the lack of a nationwide recycling program and resources to start one, various states have their own recycling programs and therefore only accept certain plastics (regardless of resin numbers), which make it inconvenient and confusing to the everyday consumer as to which plastics are recyclable^[42]. Not only this, but recycling is often inconvenient away from home and few public facilities have separate containers for recycling plastics, making it harder to recycle plastics outside of the common household.

5. Nanomaterial's as a food packing materials

Nanomaterials are increasingly being used in the food packaging industry due to the range of advanced functional properties they can bring to packaging materials. Nanotechnology-enabled food packaging can generally be divided into three main categories^[51,52].

Improved packaging - whereby nanomaterials are mixed into the polymer matrix to improve the gas barrier properties, as well as temperature and humidity resistance of the packaging.

Active packaging - illustrated by the use of nanomaterials to interact directly with the food or the environment to allow better protection of the product. For example, silver nanoparticles and silver coatings can provide anti-microbial properties, with other materials being used as oxygen or UV scavengers; and

Intelligent/smart packaging - designed for sensing biochemical or microbial changes in the food, for example detecting specific pathogens developing in the food, or specific gases from food spoiling. Some "smart" packaging has also been developed to be used as a tracing device for food safety or to avoid counterfeit.

Most of the plastic are composed of organic polymers. Most these polymers are based on carbon chains with oxygen, sulphur or nitrogen. The backbone of the polymer chain of plastic is the large number of linking, repeated units together. The structure of the side chains influences the properties of the polymer chain. Most of the plastics also contain inorganic or organic compounds as additives. The amount of additives blended in the composition may range from zero percentage to more than 50%. Additives or fillers improve the performance and also reduce the production

costs. Many plastics contain these fillers which are inert in nature and are inexpensive materials making the products cheaper, toxic and many disadvantages of using. Research and Development activities in the area of food bio-packaging have intensified over the last decade but the scientific studies on these materials are still very much in their infancy. The following biodegradable polymer-nanomaterial composites are well practiced:

5.1 Biodegradable polymer-nanomaterial composites as nanoparticle reinforced materials

These are polymers reinforced with nanoparticles to provide a composite material with enhanced properties. Also termed as 'nanocomposites', these are reinforced with small quantities (typically up to 5% by weight) of nanoparticles. Such reinforcement can radically modify the properties and performance of a polymer. The composites developed so far include a variety of thermoplastic, thermoset and elastomer polymers, and biodegradable polymers such as potato starch and polylactic acid^[53]. Nanocomposite films have also been developed for improving mechanical and barrier properties of plastic films or polymers against permeation of gases and moisture to increase the shelf life of packaged food products [54]. Barrier plastic coatings using embedded nanocrystals have also been developed for use on the inner plastic lining of cans. This technology is also used in plastic beer bottles to increase the shelf life by preventing the migration of oxygen.

5.2 Polymer nanocomposites incorporating clay nanoparticles

These are among the first nanocomposites to emerge on the market as improved materials for packaging (including food packaging). The nanoclay mineral used in these nanocomposites is montmorillonite (also termed as bentonite), which is a natural clay commonly obtained from volcanic ash/ rocks. Nanoclay has a natural nano-scaled layer structure that restricts the permeation of gases. Substantial improvements in gas barrier properties of polymer composites containing nanoclay have been claimed^[55]. This has led to the development of nanoclay-polymer composites for potential use in a variety of food packaging applications, such as processed meats, cheese, confectionery, cereals, boil-in-the-bag foods, as well as in extrusion-coating applications for fruit juices and dairy products, or co-extrusion processes for the manufacture of bottles for beer and carbonated drinks.

Nanoclay-polymer composites are made from a thermoset or thermoplastic polymer. The polymers used for nanocomposites are polyamides (PA), nylons, polyolefins, polystyrene (PS), ethylene-vinylacetate (EVA) copolymer, epoxy resins, polyurethane, polyimides and polyethyleneterephthalate (PET). Other additives used in polymer nanocomposites include Polyhedral Oligomeric Silsesquioxane (POSS). The POSS-Nanoclay is a relatively new hybrid based on the silsesquioxane-cage structures, one of the smallest forms of silica also known as molecular silica, the physical forms of which can be liquid, wax or crystalline solid^[53].

5.3 Polymer nanocomposites incorporating metal (oxide) nanoparticles

Polymer nanocomposites developed for 'Active' packaging are based on the antimicrobial action of metal or metal oxide nanoparticles. Other improvements in polymer performance through incorporation of metal(oxide) nanoparticles include abrasion resistance, UV absorption, and strength. Some nanomaterials have been used to develop active packaging that can absorb oxygen and therefore keep food fresh. Other applications include UV absorbers (e.g. nano-titanium dioxide) to prevent UV-degradation in plastics such as PS, PE, PVC. The

commercially important nanoparticulate materials in this respect are metals such as silver (Ag), gold (Au), zinc oxide (ZnO), and metal oxides such as silica (SiO₂), titanium dioxide (TiO₂), alumina (Al₂O₃) and iron oxides (Fe₃O₄, Fe₂O₃). Polymer composites incorporating titanium nitride (TiN) have also been developed for rigidity and strength of the packaging objects.

Utilising the antimicrobial action of nanosilver, a number of 'active' FCMs have been developed that are claimed to preserve the food within the materials longer by inhibiting the growth of microorganisms. Antimicrobial properties of other nanoparticles, such as zinc oxide and magnesium oxide, have recently been discovered at University of Leeds^[56]. It is hoped that nano forms of zinc oxide and magnesium oxide may provide a more affordable and safe food packaging solutions in the future.

5.4 Coatings incorporating nanoparticles

Coatings incorporating nanoparticles have been used to develop antimicrobial, scratch-resistant, anti-reflective, or corrosion-resistant surfaces^[56,57]. These coatings contain nanoparticulate form of a metal or a metal oxide, or a film resin containing nanoparticles. Nano-coatings may also be applied in a multi-layer deposition process, which is referred to as layer-by-layer (LBL) or electrostatic self-assembly (ESA) coating.

5.5 Biodegradable polymer nanocomposites

This is an emerging area of R&D with potential application of nanotechnology to improve properties of biodegradable polymers. For example, starch based polymers have poor moisture barrier properties due to their hydrophilic nature, and inferior mechanical properties compared to plastic films. The incorporation of nanoclay in starch polymers has been reported to improve moisture barrier and mechanical properties^[57]. Similarly, poly lactic acid (PLA) is a biodegradable thermoplastic polymer that has a high mechanical strength, but low thermal stability and low water vapour and gas barrier properties compared to plastic polymers. The incorporation of 5% (w/w) of montmorillonite or microcrystalline cellulose into PLA has been reported to improve tensile modulus and yield strength in the case of montmorillonite, but only marginal improvement in yield strength in the case of microcrystalline cellulose. A reduction in the oxygen permeability has also been reported in the case of nanoclay-PLA nanocomposite, but not in the case of microcrystalline cellulose-PLA composite.

6. Oxygen barrier properties

The oxygen barrier properties of PET and PLA can quantify the influence of the external relative humidity conditions on the barrier properties of coated films according to the standard method -ASTM F2622-08. Oxygen Transmission Rate indicated as the most suitable unit for heterogeneous packaging materials (e.g., multilayer and coated films), that is, whenever a linear relationship between permeability and thickness is not maintained. The starting from the bare substrate, the observed results are typical for a medium-barrier film are noticed that the decrease of permeability from 0% to 80% RH it is due to an occupancy of the free volume by water molecules that start to compete with the oxygen ones, bringing to a reduction of the gas solubility. The application of biopolymer coatings brought to an almost totally reduction of permeability at least in anhydrous conditions, except for gelatin. A good barrier is maintained till 60% of relative humidity, then the permeability increases exponentially. Pectins revealed the higher barrier at 0% RH, followed by chitosan, pullulan and finally gelatin. At 80% RH, the scenario changes oppositely (except for pullulan): films with

pectins lost their barrier capacity, while PLA+gelatin even shows a barrier capacity. As for pullulan is concerned, it revealed the lowest OTR values at 80% RH, similarly to PVOH at the same thermo-hygro-metric conditions.

It is reasonable to explain the trends observed on the basis of the physio-chemical characteristics of the biopolymers used. It is well known that the chemical groups in polymers are one of the main factors affecting permeability. In this respect, it is well known that all biopolymers, especially polysaccharides, have a high hydrophilic character, basically due to the high number of –OH groups. It is well known that these groups, (together with other groups such as amino groups), are responsible for the barrier performance of materials, due to the formation of hydrogen bonds. However, not only the chemical groups are responsible for the barrier performances of a film. Other factors are related for example to the crystallinity, chain stiffness, orientation, free volume. Pectins, for example, have a more crystalline structure than other biopolymers, together with a rigid and compact organization owing to the linear structure given by D-galacturonic acid (GalA) units (from a few hundred to about 1000 saccharide) joined together by α -1,4 glycosidic linkages in a chain-like configuration. In turn, chains arrange relative to each other through extensive hydrogen bonding. Eventually, such physicochemical organization could be the reason for the good barrier performances they maintain up 60% relative humidity condition. However, as the relative humidity increases, the physical structure of biopolymers starts changing due to the interaction of water molecules with the polar hydroxyl groups along the biopolymer backbone. Ultimately, this leads to an increase in the mobility of oxygen molecules in the polymer bulk phase. Therefore, whereas at 40% RH biopolymers generally retain their structure, at approximately 60% RH the vapour tension is significantly high insomuch as water molecules hinder the establishment of inter- and intra-molecular hydrogen bonds. This phenomenon is even marked for biopolymers that can establish less intra-molecular hydrogen bonds, such as chitosan and, to a minor extent, gelatin.

Gelatin in particular, due to its hydrophobic aminoacids (leucine, valine, phenylalanine, isoleucine and methionine), does not totally lose its barrier capacity at 80% RH, as it happens, conversely, for pectins. The gelatin performance can be useful in food packaging application where a total barrier is not required, but where improving the barrier properties of some highly permeable substrates (e.g., PLA) is a sought-after requirement to prolong the shelf-life of vegetables products. As for chitosan, it is important to note that at 60% RH the OTR value has a higher increase than the other biopolymers, and this can be ascribed to the non-polar impurities present in even the highest-quality commercial samples. It is the presence of apolar components that reduce the film's oxygen barrier, because they hinder the formation of intramolecular hydrogen bonds.

Among all the matrices analyzed, pullulan appears as the most intriguing polymer, because despite its high hydrophilicity, it resembles the synthetic coating performances, revealing itself as a potential substitute of petroleum-derived polymers. This behavior has been attributed to its unique pattern, in which the presence of α -(1-6) linkages interrupt what would be a linear amylose chain. This feature confers flexibility and other characteristics lacking in many other polysaccharides.

7. Degradation of Polymers

Similar various definitions of Biodegradable & degradable plastic have also been proposed as per ASTM D-6400:

Biodegradable plastic: A degradable plastic in which the degradation results from the action of naturally occurring microorganisms such as bacteria, fungi and algae (ASTM D-6400-99). Fig. 1 clear shows various degradation process of polymer films.

Compostable Plastic: A plastic that undergoes degradation by biological processes during composting to yield CO₂, water, inorganic compounds and biomass at a rate consistent with other known compostable materials and leave no visible, distinguishable or toxic residue.

Photodegradable/ Oxodegradable Plastics: Photodegradable /Oxodegradable plastics disintegrate into small pieces when exposed to sunlight (manufacturers add a sun-sensitive component to the plastic to trigger degradation). But sustainability requires that a degradable material should break down completely by natural processes so that the basic building blocks can be used again by nature to make a new life form. Plastics made from petrochemicals are not a product of nature and cannot be broken down by natural processes. Therefore, despite how small the pieces of plastic may become, they are not and cannot be biodegradable.



Fig. 5. Various stages of biodegradability of poly films

Though there are a variety of biodegradable polymers available, the aforementioned fields are leaders in developing safe and useful biodegradable food packaging plastics. Though there are still issues with each, research is still being done to use these polymers in a variety of fields and may largely impact the food packaging industry in the future.

8. Conclusion

The ultimate goal was to increase awareness of potential hazards in current food packaging practices as well as address issues involving environmental and economical impact of the food packaging industry. Through a literature review, issues with food-material interactions, environmental damage, economical effect and degradation were identified. In all, a generalize solution was purposed as well as initial objectives and possible constraints. In addition, the combination of such kind of biopolymer coatings with a bio-based substrate such as PLA can be a promising way to see a fully bio-based packaging with enhanced features, reducing the amount of plastics on the market. In particular, the final oxygen barrier properties of the films improved without worsening their optical appearance and these improvements can be attributed to the chemo-physical characteristics of the biopolymers used. Though there are various aspects of a nationwide program that need to be worked out, the purposed solution may be the initial step in lessening the

environmental impact that food packaging plastics and the average consumer have on the world.

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