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Utilization of Polylactic Acid (PLA) in Textile Food Packaging: A Review"

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Abstract

Food packaging is one of the most important aspects of modern life, it is unavoidable in various communities: manufacturers, shopkeepers, sellers, and consumers. In today's world, food packaging plays a crucial role in our everyday lives because it safeguards foods against contamination from outside sources and preserve food properties during the entire assigned shelf life. This role involves prevention of decay, extension of shelf life, and preservation of packaged food quality and protection. In the recent years, several researches on biodegradable materials to replace petroleum-based plastics in food packaging have been conducted. The demand of biodegradable packaging is increasing as it can be disposed of with minimal environmental impacts, but the industry is still in its early stages, owing to a scarcity of materials. This review paper dealing with some of the manufacturing challenges of environmentally sustainable food packaging products as an alternative to products derived from petroleum products. Where the study reviews the textile products used in the field of food packaging and the characteristics of these products. It also shows the great interest of the PLA in the field of food packaging industry, and this is due to the fact that it is environmentally friendly, biocompatibility and energy savings. This article reviews and discusses the physical, mechanical and biological properties of PLA fiber, Which allows to compare it with the properties of polyester fibers, and is it possible that PLA fibers be an alternative to it in the manufacture of woven food packages.

Keywords: Textile packaging, woven bags, Technical textiles, Polyolefin woven sacks, Jute sacks, PLA fiber, Biodegradable.

1.Introduction:

Packaging is a necessity for all kinds of food, so the food packaging industry is growing rapidly because of its vital functions related to packaged products [1,2] . Packaging plays an important role in saving food from contaminants, where packaging systems protect food products during transportation and storage period. Furthermore, the characteristic packaging attracts many categories of customers where it is not heavy, clarify the brand, production date and product and It has a distinctive design [2,3]. Packaging protects agricultural items from chemical and physical challenges in the climate, which helps to preserve their consistency. The innovations in the field of packaging technology are very important to meet customer demands, face the foodborne microbes, and preserve the quality and safety of food [3].

The food packaging industry has evolved over time as a result of the development of food industry and the need for new packaging materials to preserve the flavor of foods and maintain food moisture. Many products, including plastics were designed for use during World War II and later made their way into food packaging [4,5]. They have been developed to improve the quality of food products and allow them to be available at all times. Recently, many countries are interested in using new materials based on biodegradable materials as an alternatives to petroleum-based plastics [5].

Plastics are made up of polymers and a variety of chemicals such as colorants, stabilizers, additives, processing aids, etc. Petrochemical-based plastics materials such as polyethylene, polypropylene, polyvinyl chloride and polystyrene are the most used materials in packing due to their low cost and high performance [6,7]. However, these substances cause a high risk to the environment because they are not recyclable or degradable, therefore it is necessary to

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decrease their use in packing materials. Accordingly, increasing the environmental awareness leads to use environmentally friendly materials for packaging. Biopolymers generated from renewable materials are usually biodegradable as they are broken down into carbon dioxide and water by microorganisms. [7,8]. Bio-plastics are plastic materials produced from renewable biomass sources, such as vegetable fats and oils and can be blended to improve the functional properties of the final product [8].

2. Textile food packaging

Textile packaging is used for food products packing and it can be divided into woven, nonwoven, and knitted fabrics [9,10]Textile packaging materials can be divided based on natural source such as (hemp-flax-Jute) and on synthetic source such as (polyester-polyolefin). The main advantages of textile packages are that they are environmentally friendly due to their availability from nature without harmful effects of chemicals or toxins and they can be washed, reused, recycled, and can biodegrade, but it has poor gas and moisture barrier properties. As a result, they are commonly used for short-distance transportation where fruits and vegetables are transported in a short time before they are exposed to picking up smell or increased humidity.[10,11].

Textile packaging protects packaged products from chemical and physical agents such as light, heat, microorganisms, moisture and gaseous pollution.[11].The materials used in packaging food and consumer goods vary from heavyweight woven bags and sacks to lightweight nonwovens for sturdy papers. Textile packaging is a rapidly rising market that involves all textile packaging materials for commercial, agricultural, and other products. The demand for packaging materials is closely related to the economic growth, where the internal trade, import and export activities is increasing.The growing need for reusable packages and containers considers a real opportunity for textile packages [12,13].

2.1 Types of textile packaging:

Textile packages are considered a kind of technical textiles, which are used in packaging and subsequent transportation and categorized under packtech category including:

a) Nonwoven lightweight papers, tea bags, and other food and industrial commodity wrappings.
b) Fabric packaging could be knitted made of polyester, nonwoven, or woven, blends of polyester with viscose, acrylic fibers, or cotton.
c) Sacks and packs made of conventional jute, cotton or regular fiber [13].

Recently, there are textile packages made from new materials, as they can be designed to have exceptionally solid weaving mechanisms while being lightweight and more supportable than ordinary packaging materials. The resistance of textile packaging to burst, which it encounters during transportation and storage, can be measured and air, water and barrier permeability tests can also be carried out for these packages[14].The following products illustrate the use of textile fabrics in food packaging:-

1-Flexible Intermediate Bulk Containers (FIBC):-This kind of packages are used for granular goods and packing as foodstuffs, building materials, chemicals, minerals and etc, Figure 1. Furthermore, this packaging type has many advantages such as low weight for transport, low cost, good chemical and organic resistance, speed of packing and emptying, and loading and unloading time is reduced as a result of the ease of handling[15,16].

Figure 1. FIBC bags [18].

2- Polyolefin woven sacks and jute sacks: Polyolefin woven sacks are widely used in the packaging of fertilizers, thermoplastic raw materials, cement, food crops, salt, pesticides, fodder, and sugar Figure 2. The features of these type of packages are less seepage, higher power, humidity proof, light weight, long lasting (sturdy) and less expensive. For the agriculture sector, jute sacks are a traditional and environmentally friendly packaging option. It's used to package vegetables, onions, potatoes, and other farm products, Figure 3[16] .

Figure 2. Polyolefin woven sacks . **Figure 3**. Jute sacks.

3-Tea bags and food soaker pads: They are made from the cellulose fibers of the abaca tree, common in the Philippines as shown in Figure 4 [17,18]. To soak extra blood and moisture from food trays, soaker pads are used, as shown, in Figure 5, these pads prevent the product leaking onto or out of the packaging [18].

Figure 4. Tea Bag

Figure 5. Food soaker pads.

4- Leno Bags may be used to pack a variety of agricultural items such as onions, garlic, potatoes, carrots, ginger, oranges, and pineapples as are shown in Figure 6. Low weights, cost-effective nature, permeability allows air to travel through the bag, which helps to keep the food fresh, simplicity of handling and storage, reuse and recyclable, and suited for dry skin vegetables (Potato, Onion, Garlic etc.) are just few examples of their advantages[18]

Figure 6. Leno Bags [18]

3. Biodegradable polymers for food Packaging

Biopolymers (biomaterials) are polymers made from natural scources. Plant raw materials are used to make biopolymers. But recently biopolymers were extracted and manufactured from animal sources like chit in, Chitosan, Collagen and Keratin. Large chains of molecules that are too large and too closely attached to each other make it impossible for microorganisms to dissolve fossil polymers. On the contrary, the molecules in biopolymers manufactured from natural plant materials such as wheat, potato, or corn starch are readily microbiologically degradable. Air permeability, low temperature sealability, and abundance are all attributes of biopolymers [19-21]. Biopolymers have reduced the environmental impact of using plastic products, and lead towards green economy. Biodegradable packaging may be used for modified packaging of high-value brands and specialty merchandises such as organic foods. Moreover, pre-studies on the interaction of food components and biopolymers during processing and storage are needed. Blends of different biopolymers, such as starch-PLA blends, starch-PCL blends, and so on, are currently common in food packaging[20,21].

Recently, the manufacture of biodegradable packaging materials made from sustainable natural resources has gained significant government subsidies in EU countries, as well as several national and international organizations set up to help with this. Biodegradable packaging materials with similar functionalities to conventional oil-based plastic packaging have been developed thanks to technological advancements [21].

4. Eco-friendly biodegradable polymers classification:

The degree of biodegradation of polymers is affected by the surrounding environment such as; soil types, pH, humidity and the types of the microorganisms. Using the general term for biodegradable polymers may be misleading as these polymers are divided according to their properties [22,23] .

Biodegradation of biopolymers involves hydrolysis or enzymatic dissociation of the bonds in the polymer. Degradable polymers can be classified into several types according to the illustrated synthesis processes and sources shown in Figure 7**.** Environmentally degradable polymers are divided into natural and synthetics materials, as the natural materials are intobiomass products from agro-resources and micro-organisms products, while synthetics materials are divided into petrochemicals products and biotechnology products. Each of these classifications has its own characteristics in terms of polymer decomposition, where the tensile strength, color, and their shape may change under the influence of environmental factors such as light, heat, or chemicals. Biopolymers can be converted into various products for many uses, and are eventually disposed in different ways [23].

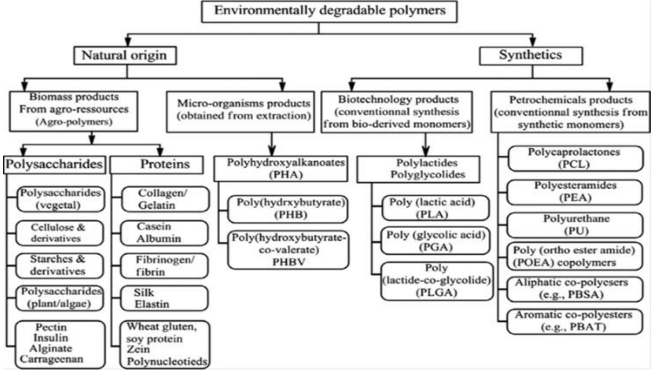


Figure 7. Classification of different biodegradable polymers [23].

5. Polylactic acid (PLA)

Polylactic Acid (PLA) is one of the most innovative widely developed materials. It is a thermoplastic and biodegradable polymer that is ideal for biological and medical implementation. Its chemical formula is $(C3H4O2)_n$ [24-26] . PLA was first used only in therapeutic applications including orthopedics, opioid carriers, facial fracture reconstruction, antimicrobial agents, and antitumor agents.[25,27]. Due to its mechanical property profile, thermoplastic processability, and biological characteristics, PLA is considered as one of the most successful biodegradable polymers. It can be made from natural resources including cassava, potato, corn, and sugarcane by fermentation. It has a significant market share in the ecofriendly polymer market, and it is one of the most promising potential growth candidates. PLA has been a common material for a variety of uses, including packaging, automotive, and biomedical applications. PLA is a biopolymer that has a variety of properties including strong clarity, glossy texture, high rigidity, and easy to process. In addition, PLA composites can be recycled as they are thermoplastic [26]. PLA is a natural ingredient plastic with a global supply of over 140,000 tons per year. It will assist consumers in realizing that high-performance materials can be manufactured using green materials that are better for the environment[27].

5.1 Synthesis of PLA

PLA can be made using a variety of polymerization techniques, including direct methods, poly-condensation, and ring-opening polymerization [28]. The cycle of PLA life begins with corn and sugar beets; biological processes utilize solar energy through photosynthesis, as shown in Figure 8. PLA has excellent properties such as biocompatibility (PLA should not produce toxic or carcinogenic effects), environmentally friendly (PLA is biodegradable, recyclable and compostable), savings in energy (PLA needs 25–55 % less energy to create) and processability (PLA has better thermal processibility). Raw material such as starch, extracted from corn or beet is converted into sugar by enzymatic hydrolysis. Later, these sugars are treated with bacteria to obtain lactic acid; the polymerization of lactic acid can then be carried [29].

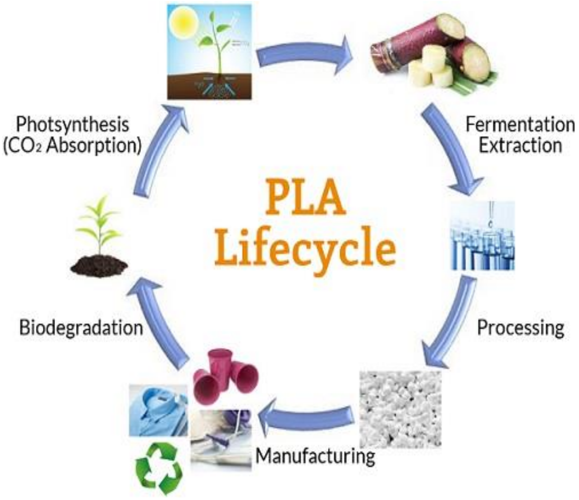


Figure 8. PLA life cycle.

PLA has a variable molecular weight and only high molecular weight polymer is used in the packaging industry.[30-32].Lactic acid is a popular chemical platform that can be made from green carbohydrates and is used to produce a broad range of products [31]. Lactic acid comes in three stereo chemical model poly (D-lactic acid), poly (L-lactic acid) and poly (lactic acid). The crystallinity of PLA is 37%, with melting temperature (Tm) ranging between 173 and 178ºC, with tensile modulus of 2.7–16 GPa and a glass transition temperature (Tg) between 50–65˚C. Time, temperature, impurities, and residual catalyst concentration exhibit a high effect on PLA degradation. PLA is made by either ring-opening polymerization of lactide or ring-closing polymerization of lactide as shown in Figure 9. PLA produces a combination of L-lactide, D-lactide, or meso-lactide under reduced strain. [32].

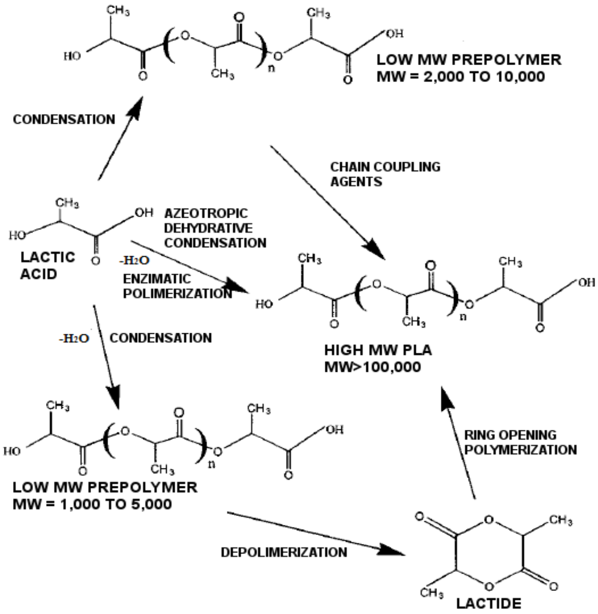


Figure 9. Synthesis route of polylactic acid [32].

5.2 PLA Properties

PLA exhibits a unique features, such as; good appearance, high mechanical strength, and low toxicity. PLA properties depends on its component, annealing time, and processing temperature. The degree of crystallization is important in determining the properties of PLA and also determines its appropriateness of any application, whereas its crystallization affects the material hardness, modulus, tensile strength, wrinkle, and melting points [33]. Special catalysts with isotactic and syndiotactic material and various enantiomeric units may be used to regulate the properties of PLA. PLA's physical and mechanical properties are influenced by its glass transition temperature and melting temperature. Tg and Tm are also critical physical parameters for forecasting PLA activity [34,35]. Alcohols such as methanol, ethanol and propylene glycol, lactic acid-based polymers do not dissolve in them. PLA crystals expand in three structural function to classify α, β, and γ forms. Different helix conformations and cell symmetries describe them, which evolve as a result of various thermal and/or mechanical treatments [35].

5.2.1 Physical Properties of PLA

Physical properties such as polymer density and melting temperature are very important. All Physical properties of PLA are shown in Table 1. For a desired shape or product, dimensions, volume, and weight specifications must be known [36-40]. Higher density values result in higher transmission costs, so density can be a critical design parameter. The percent of crystallinity is also important to be known because it has a high impact on the polymer's physical properties [37,40]. Polylactides' crystallization action is influenced by their thermal background, amount and type of additives and depends upon optical purity. PLA is a semi-crystalline polymer and has a low glass transition temperature of 45-60°C and a low melting temperature of 150–162°C [38].

5.2.2 Mechanical **Properties of PLA**

The mechanical properties of PLA polymers are comparable to those of conventional polymers such as polypropylene, polystyrene, and polyurethane [26] particularly when it refers to tensile strength which it means the force used to pull something, flexural strength which it means stress needed to start plastic deformation and Young's modulus which it means the ability to withstand elongation under strain or compression. Where higher mechanical properties are needed, semi-crystalline PLA is favored over amorphous PLA [39]. The mechanical properties of PLA include tensile features, modulus of elasticity, elongation at break, yield strength and tensile resistance all mechanical properties are shown in Table 1 [40].

Table 1. PLA Physical and mechanical properties [40]

Properties	**Values**
Polymer density	1.21–1.25 g/cm3
Tensile modulus	0.35–3.5 (GPa)
Ultimate strain	2.5–6 %
Specific tensile strength	16.8–48.0 Nm/g
Specific tensile modulus	0.28–2.80 kNm/g
Glass transition temperature	45–60°C
Melting temperature	150–162°C
Tensile strength	59 MPa
Elongation at break	7%
Modulus of elasticity	3750 Mpa
Yield strength	70 Mpa
Flexural strength	106 MPa
Unnotched izod impact	195 J/m
Notched izod impact	26 J/m
Vicat penetration	59°C
Heat deflection temperature	55°C

5.2.3 Rheological Properties

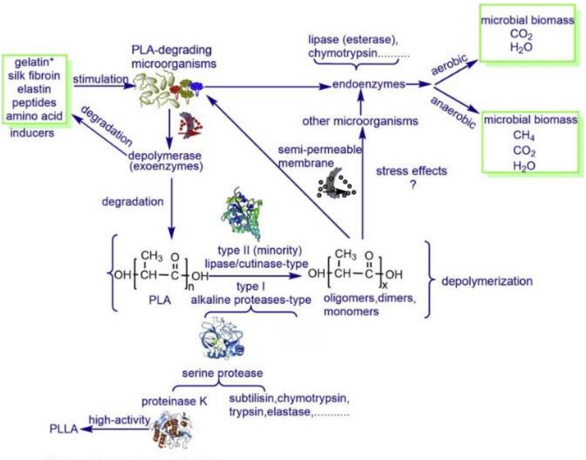
To evaluate the performance of thermoplastics during treatment processes the rheological properties are very important. As a result, understanding PLA melt rheology is essential in order to promote PLA processing since it displays pseudoplastic and non-Newtonian fluid behavior [41]. Its viscosity (flow resistance) can change based on the tension it is exposed to, according to its rheological properties. PLA viscosity reduces as stress is applied because it is a shear-thinning material [42].

5.2.4 Biodegradation of PLA

When the main chains or side chains of polymeric macromolecules are separated, mainly polymer degradation occurs. Thermal amplification, hydrolysis, and biological activity both contribute to polymer degradation in nature. The term "bio-based" refers to a substance that is made from biomass, meaning it is made of material that comes from living organisms, such as plants and animals. PLA is converted into raw materials such as water, carbon dioxide, and composite materials (Includes minerals and biomass like starch) [43-46] . Polymer degradation is performed by microorganisms in the environment with temperature is 60° and high humidity and it is present in the subsoil of the garden soil. A variety of conditions such as oxidation, photolysis, thermolysis, hydrolysis, biodegradation, or enzymatic hydrolysis affect polymer degradation [44]. PLA deterioration in soil takes a long time to begin to decompose , as soil tests have shown. For example, after 6 weeks in soil, no deterioration was observed on PLA sheets [45-49]. PLA is not only biodegradable, but it can also be recycled or incinerated. It may be hydrolyzed to lactic acid using steam or hot water, resulting in molecular recycling [46].

PLA in a compost environment can degrade into smaller particles (monomers) after 45-60 days at 50°C -60°C as it hydrolyses [47]. Microorganisms in the compost dissolve these smaller molecules into CO_2 and H_2O. The rate of decomposition decreases with increasing crystallization, PLA's crystalline part was found to be more resistant to deterioration than the amorphous part [48-52]. The biodegradability of the PLA depends on the environment to which it is exposed. Enzymes have more enabled role such as hydrolysis of polymers and a strong role in the degradation of polymers. The enzymatic hydrolysis process consists for aliphatic polyesters by two-step hydrolysis. Firstly, through the surface binding domain the enzyme is absorbed on the surface of the substrate, and secondly is the hydrolysis of the ester bond. Few studies of the fungal degradation of the PLA gene found in liquid cultures, only two filamentous fungi like Fusarium moniliform and

Penicillium roqueforti were able to assimilate DL-lactic [49]. Analyzing the PLA's biochemical biodegradation mechanisms is a critical step in discovering successful PLA biodegradation methods. Chemical hydrolysis and biodegradation are the primary biochemical pathways of PLA degradation in the natural soil microcosm [50]. Figure 10 shows a schematic diagram of the biochemical processes of PLA degradation. Microorganisms first excrete extracellular depolymerase of PLA, depolymerase production needs to be stimulated by certain inducers such as fibroin silk and elastin. In the stereochemical position of chiral carbon, most inducers have L-alanine units, which are identical to L-lactic acid units of PLA [51,52]. The ester bonds for PLA are attacked by depolymerase, which result in monomers production. Following that, low molecular weight molecules join microbial membranes and are decomposed by intercellular enzymes into water, carbon dioxide, or methane. Study of biochemical processes reveals that PLA biodegradation is influenced by the involvement of microorganisms as well as environmental factors such as PH, humidity, temperature, and oxygen, in which they affect the degree of degradation of PLA[52].



*the most frequently-used inducer

Figure 10. Schematic diagram of biochemical processes in PLA degradation [52].

5.2.5 Environmental Characteristics of PLA

PLA seems to be a commodity that is effective and environmentally friendly. It is still available as a raw material because it is made from natural materials. After the life cycle of polylactic acid is completed, its products can be converted into an effective fertilizer in the industrial fertilizer plant[53]. PLA can be made from maize, beets, and other crops, allowing for regional adaptation to different climates. PLA degradation under anaerobic conditions releases CO_2 and methane [54]. The use of crops for the processing of lactic acid rather than food is less important than suggested in a widely published critique. Therefore, it is important to have diverse sources for producing lactic acid, for example organic waste and cellulose. The amount of corn consumed in the manufacture of PLA fibers is less than 0.02 % of total world production, so there will be no food shortage [55].

5.3 PLA Applications

PLA offers a variety of industrial applications such as textiles, pharmaceuticals, food packaging and single-use products, so it is a versatile polymer. It is used in many medical applications because of its bioresorbable (referred to as bioresorbable or degradable polymers which can be safely absorbed by the body) and biocompatible properties in the human body. PLA is used in surgical implants as anchors, screws, pipes, pins, tubes, and as a mesh since it degrades into harmless lactic acid [56-61]. PLA is utilized as a feedstock material in desktop fused filament fabrication of 3D printers [57].Also it can be used as biodegradable packing material. Containers, drinking cups, sundae and salad cups, candy wrappers, lamination films, blister bags, and water bottles are also examples of packaging applications [58-61]. Compostable yard bags made of PLA are used to support state or national composting projects. Nonwoven fabrics and fibers, upholstery, plastic clothing, awnings, feminine grooming materials, and diapers are only a few examples of PLA's possible applications. It is their bio-compatibility and biodegradability that has opened the way for many applications and uses. Solvent and melt-spinning processes can be used to make fibers, which can then be drawn under various conditions to orient the macromolecules [59].PLA yarns can be made using a variety of technologies such as melt-. spinning technology and dry-spinning technology . These PLA yarns are used in the manufacture of textiles with high characteristics, the yarns have a high polarity that provide the properties necessary for the manufacture of absorbent towels [60]. PLA is a relatively new polymer and needs time to become an acceptable and an effective active packaging in the market. PLA antimicrobial packaging's creative strength has a significant effect on public wellbeing by resulting in cleaner and healthier wholesome packaged foods [61].

5.4 PLA Properties for Food Packaging Applications

Some of the most important required properties for food packaging materials are thermal, mechanical, chemical reactivity, optical, steam, and moisture barrier properties. One of the most difficult obstacles in the food packaging industry is packaging products with a short shelf life [62-74]. PLA, natural fillers and fibers from agricultural waste are used in sustainable packaging. Table 2 illustrates a comparison between the properties of common polymers used in food packaging and PLA properties [63].

Table 2. Comparison between the properties of common polymers used in food packaging and PLA properties [74].

Property/Polymer	**LDPE**	**PET**	**PP**	**PS**	**PLA**
Strength (MPa)	10-12	55-79	15-27	24-60	37-66
Elongation at Break (%)	300–500	15–165	100–600	1.6–2.5	0.5–9.2
Oxygen barrier (permeation at 30 ◦C[*10−10 cm^3 (STP)·cm/cm^2·S·cm Hg])	6.9	0.04	1.5	2.6	3.3
Moisture vapor transmission rate(g-mil/10in.2/24h)	1.0–1.5	2	0.5	10	18-22
Water absorbance (%)	0.005–0.015	0.1–0.2	0.01–0.1	0.01–0.4	3.1
Thermal properties [Glass Transition Temperature- Tg (◦C)]	110	73	20	90	55
Transparency (Clarity)	High	Excellent	Poor	Excellent	High
Carbon dioxide barrier (permeation)	28	0.2	5.3	10.5	10.2
Chemical resistance	good	good	good	good	good

LDPE: Low-density polyethylene , **PET**: Polyethylene terephthalate , **PP**: Polypropylene , **PS**: Polystyrene , **PLA**: Polylactic-acid

From the above-mentioned table, it can be found that the strength of PLA is the best when compared to other fibers except PET fibers. Strength is one of the mechanical properties that is required for food packages to contain what is inside and protect products from external forces. So, blending it with other biodegradable materials such as natural fibers can help to improve the resultant mechanical properties [64].
Good thermal properties protect products against thermal damage during the storage period. PLA has adequate thermal properties, allowing the storage of hot meals [65]. Synthetic fiber composites have better heat resistance because they have higher thermal stability [66-74]. A dangerous source of chronic disease is the transfer of organic and / or inorganic chemicals from packaging materials to food and can damage other properties such as mechanical properties and thus affect function. PLA-based materials can reduce exposure to this chemical migration [67]. Optical property is one of the preferred features in the packaging as it allows consumer to see the packed product, especially in meats, vegetables and sweets. High transparency and surface luster are characteristic of PLA as such it can easily show the packaged product [68-72]. One of the goals of sustainable packaging is to keep some gas compositions inside the package. Oxygen, phosphorus, and carbon dioxide make up these gas mixtures. The amount of oxygen is a crucial consideration because it aids in the oxidation process which results in fast food spoilage [70]. More crystallized biopolymers lead to an improvement in this property, so the use of PLA with higher crystallinity improves the gas barrier properties [71]. Air penetration must be controlled in the packaging materials to preserve product quality.

Biobased compounds have a lower moisture barrier than conventional compounds. Moisture barrier refers to the ability of a wrapping layer to prevent unwanted vapor from passing into it. Increased moisture barrier leads to the increases in the shelf life of food in the food packaging industry [72]. Blending PLA with natural fibers and fillers, increases the moisture barrier as moisture speeds up the biodegradation process of PLA.
Biopolymers' intrinsic ability to consume more water than fossil isotopes encourages the growth of bacteria and fungi, which contributes to rotting[73,74].The use of hydrophilic cellulose fiber fillers with poly-lactic increased water content and increased oxidation, which leads to food spoilage. Exposure to water means accelerated biodegradation, so the use of these materials is limited to a short period of time [74].

5.5 PLA Films in Food Packaging System

PLA is now a popular choice for food packaging as its thermal and mechanical properties compare to the more commonly used synthetic polymers, such as polystyrene and poly (ethylene terephthalate), but it is produced from renewable natural sources and is distinguished from petroleum products by its compostability, thermoplasticity and biodegradability.[75-80]. Active biodegradable films based on PLA and starch with practical and structural features of it were developed, in order to get materials have better properties to meet the requirements of food packaging by using two layers film method [76].Flexible films can be manufactured and polylactic acid extruded packages can be used as containers for yogurt, water and juice, lunch boxes and cups [77].PLA can be combined with minerals like silver, enzymes like lysozyme, and plant extracts like lemon in order to develop antimicrobial characteristics [78-80].Analyzes of the crystallization and glass transition behavior of elegant and plasticized semi-crystalline PLA films result in an increase in crystalline phase as well as a decrease in glass transition temperature (Tg) [79]. PLA has been developed for a variety of packaging applications, including food and beverage containers and cups. This innovation comprises flexible, oriented films, as well as extruded or thermoformed packaging. PLA films may be made using either double-blown bubble technique or casting, and their most significant feature is that they are transparent in order to get the acceptance of food product customers [80].

6. PLA fiber

6.1. Manufacturing of PLA fibers

The production of PLA yarn using melt spinning technique is similar to that used to produce other spun fibers such as polypropylene fibers or by spinning the solution that includes wet and dry spinning [81] . The manufacturing process of dry and wet spinning uses specific solvents that are toxic and difficult to recycle and are not environmentally friendly [82]. PLA is dissolved in appropriate solvent like chloroform for the wet spinning. From a spinneret immersed in the coagulation bath, the prepared solution is extruded into the coagulation bath. One or more coagulation baths are used for the PLA spinning. After the PLA fibers' are produced, the yarns are dried after spinning [83]. The procedure of wet spinning and equipment used is shown in Figure 11. When examining the wet spun PLA sutures it was found that the surfaces of fibers were discovered to be exceedingly uneven, with many holes of varying diameters and the tensile strength was very low [84] .

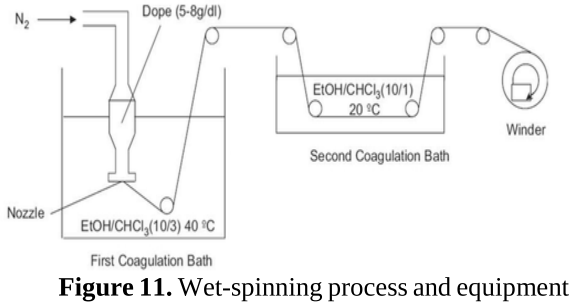


Figure 11. Wet-spinning process and equipment [84].

The PLA solution is extruded into a thermally insulated container with heated air in dry spinning as illustrated in Figure 12. A blend of excellent and poor solvents can also be employed to make PLA fiber and improve its tensile properties[85]. Winding speed, extrusion speed, spinning temperature, additives utilized, and hot drawing are all elements that impact the qualities of dry spun PLA fibers [86]. Rather of utilizing a solution, the PLA fibers were made utilizing non-solvents such as methanol, ethanol, or petroleum ether as vapor in the extrusion chamber [87]. The concentration of non-solvent vapor had a significant impact on the tensile strength, structure, and degradability of produced fibers [88].

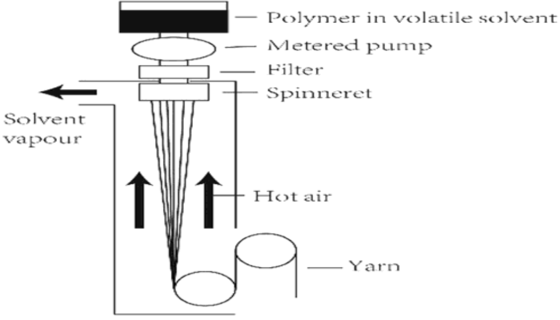


Figure 12. Dry-spinning process and equipment[84].

The most prevalent method for producing PLA filament is melt spinning. PLA can also be mixed with other polymers such as PBS(Polybutylene succinate), PHBV(polyhydroxy butyrate -CO- β-hydroxy valerate), or multifunctional particles [89-91]. Figure 13 shows the manufacturing process of melt spinning process. Under a variety of spinning settings, including processing temperature, extrusion speed, drawing speed, and hot drawing circumstances, the melt spinning of PLA fibers was investigated [90].The melt spinning method can also be used to produce PLA filament with unique functionality. High rotating speed results in filaments defects and breakages due to quite high viscosity of the PLA . In melt spinning the problem of degradation appears at high temperature. Melting spinning is expected to take place in one step instead of two to avoid filaments defects and breakage [91].

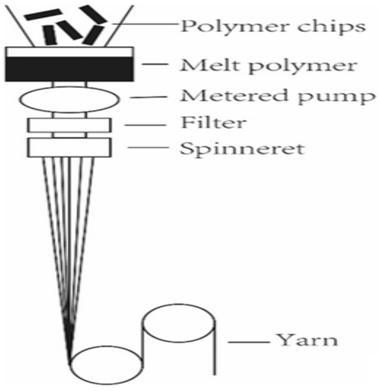


Figure 13. PLA melt spinning process [91].

6.2. Properties of PLA fibers

PLA fibers are made from a lactic acid polymer that contains at least 85 percent by weight of lactic acid ester units obtained from renewable sugars [92-94]. The properties of PLA fibers are presented in Table 3. PLA fibers have tensile strength similar to polyester fibers. The degradation process begins when the polylactic acid is subjected to high temperatures (60°C) and high humidity resulting in rapid degradation of fibers. PLA is also more flammable and less abrasion resistant, it is less heat resistant than polyester where Tg is as low as 55-60°C [93].PLA fibers can potentially be used as an environmentally and socially responsible alternative to conventional textile fibers in industrial and consumer garment applications.

Table 3. Properties of PLA fibers [94].

Tensile Strength (Tenacity)	Good[1]
Chemical Resistance	Fair[2]
Abrasion Resistance	Low
Absorbency	Low
Heat Resistance	Poor[3]
Resistance to Sunlight	Excellent
Elastic Recovery	Good
Flammability/Smoke	Burns (Low smoke)
Resilience	Good

[1] Higher than the most natural fibers (can be comparable to PET)
[2] Alkaline chemicals cause rapid loss in strength.
[3] PLA has a low TG of around 55 - 60°C

6.3. Applications of PLA fibers

PLA fibers are used either 100% or mixed with natural fibers such as cotton in many textile uses like active wear, outdoor furniture, automobile interior materials and single use products include diapers and wipes. Also they can be used in medical applications such as wound dressing as it is biodegradable and biocompatible [94]. Basic applications of PLA fiber are sportswear, underwear, streetwear, pillows, quilts, mattresses, hygiene products, wipes and agricultural applications such geo textiles. Different forms of staple fiber to composite materials can be produced from PLA as illustrated in Table 4 [95-98]. PLA can be blended with cotton, lyocell and wool, or on its own. Due to their excellent moisture management PLA textiles are ideal for sportswear manufacture [96]. Nonwoven fabric made from this material is non-toxic and odorless, and possess no risk to the human body, and have no harm to the human body, thus they are very safe. Microorganisms may totally dissolve PLA nonwoven fabric, releasing carbon dioxide and water and returning it to nature [97-99].

Table 4. Different forms of PLA [101].

Staple fiber	Knitted structure
Monofilament	Woven structure
Multifilament	Spun bonded nonwoven
Trilobal BCF	Needle punched nonwoven
Bicomponent fiber	Composite materials

In areas of technological importance, biodegradable textiles have aroused great interest. PLA fibers are appropriate for a variety of technical textile applications, particularly for performance applications and clothing due to their distinct polymeric properties. Among these properties are high resistance to ultraviolet light, low flammability and smoke generation, low moisture absorption and high wicking. PLA fibers have a low density, making them lighter than other fibers. PLA has a low index of refraction, which gives it excellent color qualities and low absorption of moisture, which provides advantages for clothing, sports products and performance [98-101]. The most important characteristic of polylactic in medical applications is its decomposition properties and biocompatibility with the human body. PLA threads have been tested in the laboratory for use in nerve regeneration in paralyzed individuals as well as in vivo ligament enhancement in rabbit subcutaneous tissue [99]. In food packaging and serviceware, in the last five years, the use of PLA is the most but as films, not as fibers. [100]. There are new trends to use PLA fibers for food packing in woven or nonwoven form. The nonwoven PLA fiber has been used in making tea spool packaging; it allows the tea flavor to steep in hot water due to the ability of the polymer to wick. The studies with PLA fiber in food packaging have been very limited [101].

6.4. Properties of Warp-Knitted Fabrics with PLA Multifilament

PLA as a commercial polymer presents textile makers distinct additional properties that have proven value in a wide range of textile applications such as nonwoven underwear fabrics, sanitary textiles [102-106]. PLA multifilament with totally different diameters was studied for its properties and warp-knitted materials with different coloring states were compared to review the impact of the material finishing method on properties. The PLA multifilament with 83.3 dtex/36 was designed to knit textiles with a material structure. The Knitted Fabric was colored by GS/red dye and the results showed sensible diffusibility, stable dispersion and linear molecules [103]. PLA multifilament's thermal shrinkage rate was compared to PET multifilament at various temperatures. Shrinkage rate of PLA more than PET at a similar temperature. With increasing temperature, the shrinking rate of PLA multifilament increased. This can be in the main thanks to the PLA content a lower Tg, which results in contraction when heated [104-106]. The mechanical properties of the warp-knitted fabric were evaluated before and after dyeing to determine its resistance to breakage and elongation. After dying, the breaking strength dropped by about 16 percent, while the elongation at break rose by around 67%. In general, PLA multifilament’s have mechanical qualities that are similar to PET multifilament’s. The results of PLA's hygroscopic properties tests revealed that the PLA multifilament has a higher moisture recovery compared to the PET multifilament**.** [105,106].When measuring the abrasion resistance of warp knitted fabrics, the undyed PLA fabric had several gaps after the rubbing test. However, the dyed fabric has only the same rubbing marks as the rubbing mark shape and no holes were found. The mechanical properties of PLA warp knitted fabrics are greatly influenced by the dyeing method. When dyeing and finishing, special attention should be paid to temperature control. High temperatures during the dyeing process affect the traction properties of PLA multifilament. The smooth texture, wear resistance, anti-pilling performance and application properties of the fabrics are improved [106].

7. Conclusion

In this paper, characteristics of textile food packaging a properties of PLA as (polymer and fiber) were reviewed. It was found that using biodegradable polymers will exploit the utilization of agricultural waste to alleviate the fossil fuel shortage, solve environmental issues involved when using petroleum-based plastics, as well as lead to a circular economy. These biodegradable composites can be biologically recycled and serve as a biological nutrient. An increase in the bioplastic applications can also realize employment growth in the sector and have cascading effects that could even lead to the development of rural areas where agricultural waste can be used as a sustainable input resource. The growing need for reusable packages and containers considers a real opportunity for textile packages, for its eco-friendly properties . It was realized that PLA is one of the environmentally friendly biodegradable polymers that has a promising future in the field of food packaging due to its properties that are similar to the plastic packaging materials currently in the market. Therefore, PLA fibers is an environmentally alternative to conventional textile fibers in food packaging applications especially it has mechanical properties comparable to PET.

Future research probably will be to design eco-friendly woven packages from polylactic fibres.

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