BIOPLASTICS USED IN RENEWABLE PACKAGING IN THE FOOD INDUSTRY[1*]

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ABSTRACT

Food waste from different sources is an environmental burden. In food technology, plastics and polymers are an alternative option for food packaging, food preservation and preservation, and recycling of food waste. Today, almost all plastics are produced synthetically and have much better properties than naturally occurring plastics. The raw materials of all modern plastics are petroleum and natural gas. Due to the non-degradable properties of these raw materials, it is supported to reduce the cost of production in plastics by offering an environmentalist approach option. In this review, for polymers such as polyhydroxy alkanoates (PHA) Poly (3-hydroxybutyrate) (PHB), Polylactic acid, Polylactide aliphatic copolymer (CPLA), Polycaprolactone (PCL), polyhydroxy-co-3-butyrate-co-3-valerate (PHBV) focuses on available technologies for polymers. Fermentation technologies based on pure and mixed cultures are of particular importance in the preparation of raw materials (prepared from food waste) for true bioplastic production. In this study, alternative methods are provided for the evaluation of food wastes, their economical/technical approaches meeting the expectations and applicability, and the reduction of waste by solving food wastes (FW) with environmentally friendly renewable polymer packages.

Keywords: *Bioplastics, Polymers, Polyhydroxy Alkanoate (PHA), Food Waste (FW)*

INTRODUCTION

Bioplastics are perishable materials whose raw materials are composed of renewable raw materials. Bioplastics are alternatives compatible with sustainable nature **[1].** Plastics are biodegradable; It is sustainable as raw material and can be obtained from oil **[2].** The United Nations Food and Agriculture Organization (FAO) has defined food waste as "food losses in quality and quantity throughout the supply chain process that takes place during the production, post-harvest and processing stages". Food losses that occur at the end of this chain become defined as "food waste (FW)", which is dependent on consumer behavior, purchasing intent and retailer marketing strategy **[3].** Due to the use of plastics in a wide variety

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of applications, plastic waste production has increased 200 times in the last 60 years worldwide. Bioplastics are preferred because they reuse less energy and less waste for plastic waste reuse **[4, 5].**

Poly-hydroxy alkanoates (PHA) as active ingredients for bioplastics can be produced to prevent the use of excess carbon-nitrogen, oxygen or phosphorus **[5]**. PHA are biodegradable polyesters of various hydroxy-alkanoates **[6].** Economic, ethical, environmental and engineering studies can be supported with sustainable PHA production. Instead of fossil sources, biomass such as starch, cellulose, wood and sugar can be used for plastic production. Their use is also among common methods for a sustainable environment **[7].** The use of cost-effective biodegradable natural biopolymers such as rice husk, wheat straw and corn ground can be expanded **[8].** Synthetic polymer production is an environmental burden **[9].** The conventional petro-polymer average energy requirement of the bioplastics to be produced is lower in terms of global warming rates (47 MJ kg^{-1} compared to 67 MJ kg^{-1}) **[10, 11].** In many ways, bioplastics are a good alternative to replace petroleum-based plastics **[12, 13].**

Recycling methods are preferred for reuse of plastic waste. Manual or automatic devices should be used before recycling plastics. Subsequently, large amounts of used plastic are needed to use other regimes such as combustion, pyrolysis, hydrogenation, gasification and thermal cracking **[13].**

In the use of recycled materials or using renewable resources, two strategic methods are used, namely directives and dependence on fossil resources, to reduce CO_2 **[14].** The role of bio-based sugar and lipids are very important in the food packaging industry to increase sustainability **[15, 16, 17].** However, large-scale use of PHBV in packaging may result in fragility and thermal instability **[18, 19, 20].**

BIOPLASTICS THAT CAN BE USED IN FOOD PACKAGING

Food waste occurs at all stages including post-production sustainable supply chain, shopping and consumption **[21].** According to the researches, an average of 90 million tons of food waste is produced by the European Union in a year. Some of this data (38%) originates from the food production sectors **[22].** The shelf life of the products is related to the durability of the packaging. The mechanical and/or barrier properties of the packaging material must remain stable and can be operated without any problem until destroyed during storage. The material should then be efficiently biodegradable. The most important variables to control the stability of the biologically based packaging material are proper water activity, pH, oxygen, nutrients, temperature and storage time. The disadvantage of biodegradable starch-based films is their hydrophilic character, which leads to low stability when exposed to different environmental conditions. Therefore, moist foods must have limited storage times **[23].** Polyalkanoate use in the food industry should be widely preferred in beverage bottles, coated cardboard milk cartons, glasses, fast food packages **[24].** In some bioplastic grades, in terms of cost and performance in their production, PHA and polylactides are usually easily processed into films, with greater efficiency than standard plastics, but are more costly than synthetic analogues **[25].**

Films made from proteins and carbohydrates are oxygen-tolerant due to tightly packed, regular hydrogen bonded network structures **[26].** The results of a PE film containing a normal polyethylene (PE) film and 6% corn starch were evaluated in the packaging of broccoli, bread and minced meat stored under normal time and temperature conditions. They discovered that the addition of starch (0±28%) in polyethylene films does not impair the thermal permeability and does not accelerate microbial growth in minced meat. Another study found that when fresh mushrooms were covered with gluten film and stored at 10 ° C for 5-6 days, a modified atmosphere with 2-3% CO_2 and 2-3% O_2 developed during the storage period **[27].** In addition, chitosan (14.5% by weight) cellulose (48.3%) and polycaprolactone [glycerol (36.2%) and protein (1.0%)] were synthesized as packaging materials for the storage of fresh vegetables **[28].** It showed that minced meat improved reddish surface color by matching with samples.

Polyhydroxy alkanoates (PHA)

Poly-hydroxy alkanoates (PHA) are polyesters of various hydroxy-alkanoates. Over 100 are defined as units of different monomers. PHA has the lowest molecular weight and is one of the most common polymers in nature. Its biodegradability has been demonstrated compared to conventional plastics **[29, 30].** Unique features of PHA are considered to be good oxygen barrier, water vapor barrier, oil/odor barrier. Such superior physico-chemical properties of PHA promote its use in a variety of fields, including food packaging. In addition, medical applications are used in different fields, including energy and fine chemicals **[31].** It is determined that global PHA production from commercial producers reached 2.05 million tons in 2017. Food products preferred in the PHA industry are sugarcane and vegetable oils. The current industrial costs of PHA production are 5-10 times higher than that of petroleum polymer derivatives **[29].** PHA production is one of the most preferred methods among alternative raw materials for the search for large-scale (compared to traditional raw materials) cost-effective raw materials **[32, 33].** Figure 1 shows the PHA biosynthesis scheme.

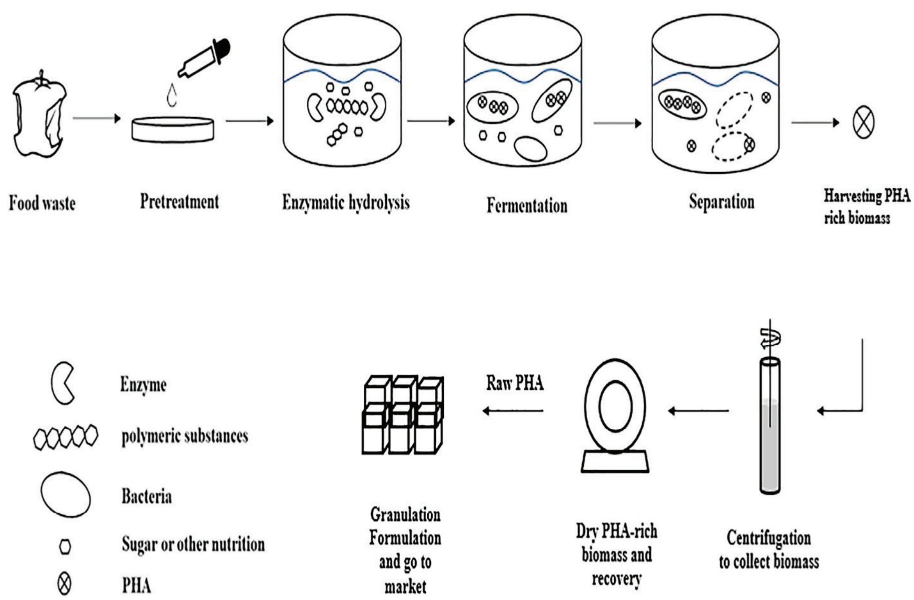

Figure 1. PHA biosynthesis scheme **[4].**

Table 1. Characteristics of food wastes with high usability in PHA production.

Type of food waste	Potential materials	Properties	References
Consumed and used cooking oils	tail oil, margarine oil, extra virgin olive oil seed	High lipid (oil) content can be converted to biodiesel (fatty acid methyl esters: FAMEs)	**[34]**
Animal wastes	Blood, fats, large intestine rumen residues	High nitrogen content or high levels of BOD and COD	**[35]**
Organic plant waste	Fruits, vegetables, herbs, plants, greens prina	These fractions consist of important sources of sugar, lipids, carbohydrates, and mineral acids. Provided water, soluble sugar and celluloseSuccinic acid production	**[36, 37]**
Domestic waste	waste meal, peanut and walnut shell	High protein, starch, fat and fatty acids content	**[38]**

Table 1 describes some of the old methods for producing PHA, as well as their errors and benefits. In particular, as a result of 145 article reviews published after 2010, current information on valuation techniques for FW has been summarized, focusing on PHA production.

Table 2. Advantages and disadvantages of some commonly used PHA production methods **[36]**

Production method	Advantages	Disadvantages
Production with pure bacterial cultures	These single isolates may have the ability to produce and biologically improve PHA.	Sterilization is needed to ensure efficient production
	Great potential to reduce PHA production cost	Sometimes the production process may require substrates such as pretreatment or physicochemical or biological hydrolysis.
Production by substrate hydrolysis	Many substrates can be suitable for production	Usually several steps and / or solvents are required to prepare the hydrolysates of the substrate.
	It can be an effective method for the use of various substrates that are normally difficult to use	Since it requires a separate hydrolysis step before production, it can be a time consuming method

PHB (poly-hydroxy butyrate)

The polymeric material properties of PHAs are considered a good alternative for petroleum-derived synthetic plastics. Another emerging application of PHA is enantiomeric pure 3-hydroxybutyric acid (3-HB), which acts as an intermediate for the synthesis of many chiral drugs **[39].** High production costs are biodegradable of PHAs. This is one of the main factors that limit its broader use. Improvement in PHA production strategies may result in lower costs, which enables wider use of PHA in daily life **[40].** This has created a worldwide interest in the efficient production of PHB at low cost by new microorganisms. PHB can also be synthesized from sugars and fatty acids by de novo fatty acid biosynthesis and oxidation pathways **[41, 42]**. The three most unique features of PHB are (I) 100% water resistance, (II) 100% biodegradability, (III) thermoplastic processing ability. It can be easily processed in standard industrial plastic plants, and it is highly fragmented with its water resistance and soil contact.

PLA (polylactic acid)

Polylactic acid (PLA) is the polymer with the highest potential for commercial large-scale production of renewable packaging materials. PLA materials have a good water vapor barrier and also have relatively low gas permeability. There may be agricultural resources such as raw materials, corn or wheat, and alternatively agricultural waste products such as whey or green juice can be used **[43].** They are the most promising and versatile biopolymers. Sugar, which is a renewable resource that is biodegradable easily, is its raw material. PLA is the controlled depolymerization of lactic acid monomer from sugar fermentation **[44].** It can be recycled in terms of transparency, molecular weight, processability, high resolution. PLA is water absorbent, thereby providing hydrolysis and splitting of ester linkages that are automatically catalyzed by carboxylic acid end groups. It is easily processed with thermoform, which is the real technology in the packaging of foods. This material is currently used for short shelf life products in food packaging application.

The PLA components were examined by extraction tests under which the polymer samples were exposed to food simulating solvents under the temperature/time conditions that the foods would be exposed to while in contact with the PLA. In the samples examined, acid and oil formation was observed in foods. It has been concluded that lactic acid (dimers, trimers, etc.) represents very small and safe amounts **[15].**

Aliphatic polyesters

Biodegradable aliphatic polyesters are similar to PE and PP polymers in terms of their other properties except mechanical properties. These polymers are formed by the polycondensation reaction of glycol and aliphatic dicarboxylic acid obtained from renewable raw materials. They are odorless and can be used for beverage bottles. They can biodegrade in 2 months, giving carbon dioxide and water in soil and water **[15].**

CPLA (Polylactide aliphatic copolymer)

Polylactide aliphatic copolymer (CPLA) is a mixture between aliphatic polyesters, such as dicarboxylic acid orglycol, with hard (like PS) and soft flexible (such as PP) properties, depending on the amount of aliphatic polyester in the mixture with renewable sources. It can be easily processed up to 200 ^{o}C. The amount of carbon dioxide produced during heating combustion does not produce toxic substances, nearly half of that produced from commercial polymers such as PE and PP. It dissolves completely after 12 months in the natural environment and starts to deteriorate in 5 to 6 months. Food waste begins to decompose after 2 weeks **[15].**

PCLA (Polycaprolactone)

Polycaprolactone (PCL) is a completely biodegradable polymer resulting from the polymerization of non-renewable raw materials such as crude oil. Chemical resistance against liquids such as water, oil and chlorine is strong. Due to its low melting point, it is a thermoplastic polymer that is easy to process and has a very short degradation time. It is not possible to apply it in food applications. However, by combining with materials such as starch, biodegradable material can be obtained which can be broken down at low cost **[15].**

Starch-based polymers

Depending on the percentage of starch and other ingredients such as additives (coloring additives, flame retardant additives), the properties of these materials are variable. Starch, consumed by the microbial effect, speeds up the breakdown of the polymer chain by producing pores in weakening materials. This processing time is quite long, but if the mixture is blended with starch, the processing time can be accelerated by 60%. Starch can also be transformed into foamy material using water vapor by replacing the polystyrene foam as packaging material. It can be pressed on trays or disposable dishes, consumed by the microbial medium in about 10 days, giving only water and carbon dioxide as a by-product **[15].**

PHBV

Polyhydroxy-co-3-butyrate-co-3-valerate (PHBV) is an aliphatic polyester produced by bacterial fermentation of sugars and lipids**.** Biodegradability can be thermally processed through the ease of processing, injection molding, extrusion, low moisture permeability, and acceptable mechanical properties**.** However, large-scale use of PHBV in packaging is limited by its fragility, thermal instability, and narrow processing window**.** Table 3 shows comparisons between some common plastics and bioplastics **[45].** Figure 2 shows ways to convert energy from biomass **[4].**

Table 3. Comparison between some common plastics and bioplastics **[45].**

Polymer	**Moisture permeability**	**Oxygen permeability**	**Mechanical properties**
Cellulose	High- medium	high	high
Cellulose acetate	medium	high	medium
Starch	high	Low	high
polylactate	medium	high	high
Low density polyethylene	Low	high	medium
Polystyrene	high	high	Low-medium

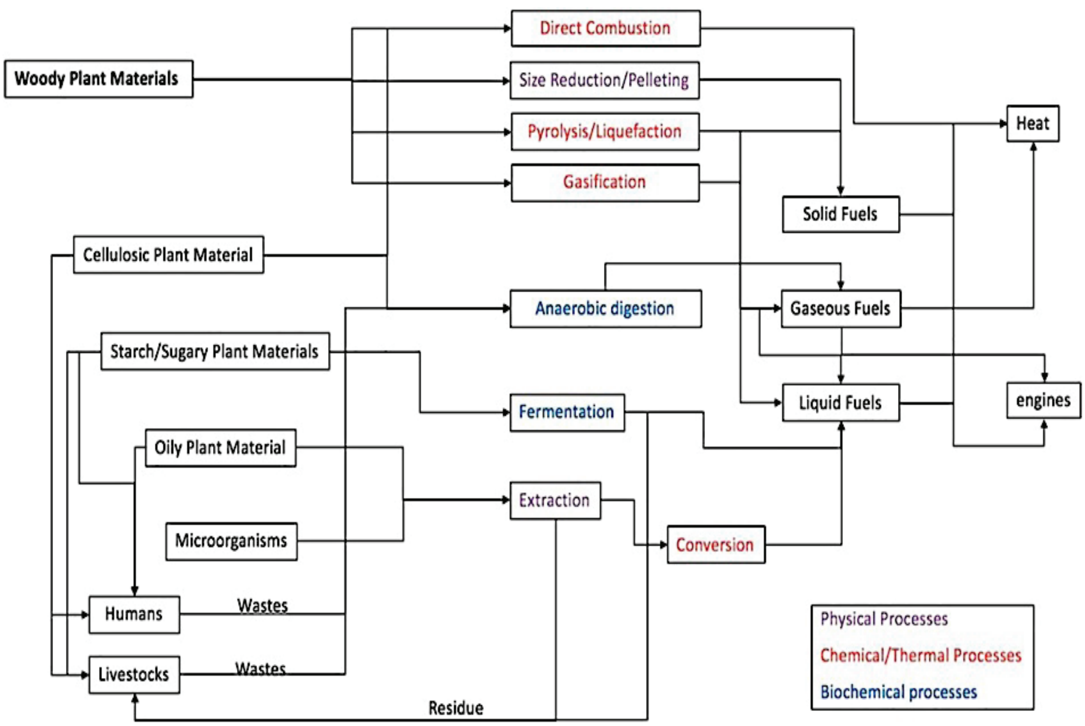

Figure 2. Ways to convert energy from biomass **[4]**.

CONCLUSION

Bioplastics, which are natural polymeric materials that have been widely developed in the last two decades, have become one of the most active areas of research due to their biocompatibility and biodegradability. Generally, it can be applied as a solvent in bioplastics, packaging industries, spray, device materials, electronics, agricultural products and various chemical environments. Bioplastic production is an essential strategy in terms of economic and environmental burden aimed at linking biotechnology processes, maximizing the use of food waste and increasing the potential income of the entire bioprocess chain. The production of consumed food wastes, environmental problems caused by wastes (eg air pollution and CO_2 gas emissions) need to be reduced. It should also be used as a commercial packaging for the applicability of long shelf life in foods. For all these reasons, this review showed that FW has the potential for important environmental problems for bioplastic production. In addition, based on additive/mixed culture and fermentation technologies, PHA, Poly (3-hydroxybutyrate) (PHB), Polylactic acid (PLA), Polylactide aliphatic copolymer (CPLA), Polycaprolactone (PCL), polyhydroxy-co-3-butyrate-co It focuses on the use of -3-valerate (PHBV) polymers. As a result of all these data, it was concluded that PHA production may be a more suitable technology item for FW production.

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