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Food packaging Bio-based plastics: Properties, Renewable Biomass resources, Synthesis, and Applications

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Abstract. The current trend in food packaging technology necessitates the development of novel packaging materials in order to extend the shelf life of food and reduce spoliation. To preserve the food product, the construction material of the packaging played a key role. In the emerging field of food packaging technology, using biobased plastics for food packaging shown a comparative advantage. At this moment, bioplastics have shown measurable benefits and are receiving more and more attention from business organizations, political figures, scientific communities, and in the whole public. This was as a result of looking for new plastic profiles brands. Besides, the environmental impact(ecological concerns) of convective materials, the depletion of natural resources specifically the petrochemical, and consumer concerns have necessitated alternative bio-based food packaging items. Therefore, the aim of this study was to review the properties of food packaging materials such as thermal, mechanical, barrier, surface, antimicrobial, optical, and environmental, as well as their synthesis type and applications. The cellulose and starch components of the common agricultural wastes for the synthesis of biopolymers were elaborated. In addition to that, different microalgae species were justified in the manufacturing of bio-based plastics. This review article also included examples of sustainable filler and reinforcement materials used in the food packaging industry. Therefore, this review work contributes to opening up the entire body of scientific knowledge on bio-based plastics used for food packaging and helps to develop important results for further investigation.

Keywords: renewable biomass resources, bio-based plastics, properties, food packaging application.

Introduction

Current issues with food packaging materials are different perspectives depending on their utility and operation. Environmental concerns such as the impact of petrochemical plastics, non-biodegradability, non-recyclability, and well disposal methods are current art of research [1]. Plastic waste released worldwide exceeds 400 million tons per year and their non-sustainability and non-recyclability are the current issues. In addition, expects the production rate of plastic waste is expected to increase fourfold in 2050 [1]. Additionally, plastic wastes used for agriculture purposes such as pesticide containers, shading nets, and mulching materials are incremented globally [2, 3].The second phase concerns food packaging materials to which consumers pertain. The ultimate goal and concern of the current food industry are shelf life and packaging-related issues of materials. Therefore, new bio-based packaging plastics are the main issue for this type of industry. It follows a clean, sustainable chain, good quality, and biodegradability as the needs and criteria of the global food production industries in the application environment. Furthermore, low ecological impact, low fetter, easy fit, high economic value, and recyclability can be achieved by compostable or degradable bio-based plastics [4].

Furthermore, the sustainability and recyclability of food packaging materials can be generated by manufacturing bio-based plastics and polymers. Current methods for synthesizing bio-based plastics are classified into two routes. The first phase generates bio-based precursors from starch, cellulose, and agro-wastes [5], and polylactic acid (PLA) and polyhydroxyalkanoates (PHA) are synthesized from renewable materials by gram-positive and gram-negative bacteria[6]. The second phase of bio-based polymers and plastics is manufactured from non-biodegradable plastics through modification techniques. Antioxidants can be utilized to change the structure of non-biodegradable polymers, and the rate of photo-oxidation biodegradability can also be improved by adding pro-oxidant additives that are exposed to ultraviolet light. So, different agro-wastes used as sources of biobased are investigated, such as horticultural plants, sugarcane bagasse, cotton stalk, rice husks, wheat straw, onion peels, carrot tops, and lemon peel [2]. Indeed, the materials that are used as containers, handled, transported, and used for disposal

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as waste after usage are called packaging. Packaging is a critical technique in the food processing industry for keeping food quality and safety while also protecting the food, presenting food, and preventing food degradation by physical, chemical, or biological contamination. Food packaging materials must have excellent quality and full safety standards and should meet the requirements of the government's regulations and policies [7]. The gap in food packaging materials currently research articles have a limitation in comparative representation of microalge, agricultural wastes, and agricultural crops (generally agricultural fresh products), a lack of full information about the bio-plastic properties, and a lack of a well-developed synthesis scheme. By selecting excellent fillers and methodology that have a low cost of production and are comfortable for customers, filling this gap helps to develop novel food packaging bio-plastic materials with excellent properties.

The goal of this review study was to examine previously published work on bio-based polymers critically, as well as to suggest research gaps and future directions. Furthermore, the goal of this review was to go through the features of food packaging materials, renewable biomass resources, bio-based plastics synthesis, application, limitations, and future possibilities. For background information on bio-based plastics, researchers should read this review paper, which contains an important synopsis of the research on bio-based plastics. Besides, the reference list in this review article can be utilized to locate other articles on bio-based plastic, making it an excellent beginning point for a research study.

1.1 Properties of food packaging materials

Food packaging bio-based materials must have chemical, mechanical, and long shelf life, safety, protection of food loss, and biological protection. The materials used in the development of food packaging are influenced by the use of the package. The selection of food packaging materials is highly dependent on the nature of the food to be packed, the type of design, and shelf-life [7]. Several vital factors must be considered when selecting the packaging materials. The manufacturer or engineer should consider the following primary criteria for choosing materials for food packaging operations: These are economic value, properties, method of manufacturing, end product properties, design type, and market values (needs). The best food packaging material must have excellent properties such as suitable optical properties, good thermal properties, good surface properties, excellent antimicrobial characteristics, good mechanical properties, low barrier properties, and environmental friendliness, which presented in figure 1 [8].

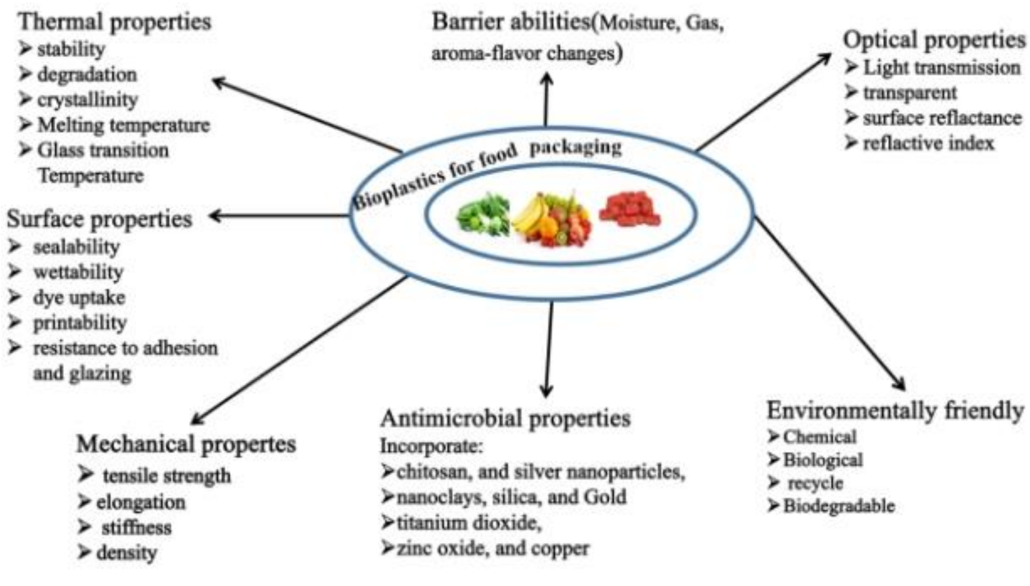

Figure 1. Properties: Bio-plastic of food packaging/Свойства: Пластик пищевой упаковки

1.2 Barrier properties

Food packaging materials are chosen based on their mechanical, thermal, and barrier qualities. The main properties of barriers in packaging are aroma, gas, grease, and vapor, such as water and oxygen. The material should be non-permeable to these barriers[9]. Likewise, the food packaging materials act as good resistance for vapors and gases, protective layers for food, and act as excellent resistance for vapors, grease, and moisture from the external spaces. Furthermore, maintaining the quality and shelf-life of food by providing enough barriers is the ultimate aim of food packaging materials (both conventional and biobased materials). Rancidity (unpleasant taste and smell) of food is caused by a lack of excellent barriers such as grease, moisture, or gas barrier properties. The oxidation of fats, as well as the oxidation of oil, occurs by hydration with water and oxidation with oxygen, and this reaction is called rancidity[10]. In addition to gases, grease, and moisture, the aroma properties are also some of the barriers in food packaging. When the packaging bio-based materials have poor or weak aroma protection or barrier, aroma scalping occurs. This enhanced flavor changes through the food aroma diffusing out or the environmental aroma effect. The barrier properties such as gas, grease, aroma, and moisture in food packaging can be improved through nanotechnology integration and improvement techniques. Due to very low production costs in large-scale operations, nano-based composites have great potential to modify and improve the constraint/barrier properties of food packaging materials. The packaging bio-based materials' chemical sustainability and recyclability, showing off while maintaining the desired mechanical and barrier properties, has been elaborated [11].

1.3 Surface properties

The chemical composition and combination of bio-based materials can be customized to be biodegradable films, which are integrated with the optical, mechanical, water transmission rate, and surface properties of the films. Food packaging bio-based polymers with surface properties such as sealability, wettability, dye uptake, printability, and resistance to adhesion and glazing for food surfaces are crucial elements for maintaining the shelf life of products while ensuring excellent quality appearance[12]. In addition, the bio-compatibility of bio-based polymers and plastics depends on the polarity, wettability, modification of the surface, and surface roughness[13].

1.4 Antimicrobial properties

Food safety is one of the basic human rights issues. Without food safety, food is blemished by insects, pathogens, and microbial cells, and it is not good for a human being to consume because it causes illness if consumed. Hence, the prioritized goals of the food industry for end-users/consumers are food safety and food quality. Antimicrobial packaging materials should be combined with antimicrobial treatments to protect foods from germs[14]. By killing and decreasing microbial cell growth, the function of antimicrobial agents can greatly contribute to food preservation and confirm food safety to consumers by killing and decreasing microbial cell growth. Organic and inorganic nano composites are the most effective antibacterial nano materials. These include copper, nano-tubes, cellulose fibers, nano clays, zinc oxide, gold, chitosan, silver nano-particles, and silica [15].

1.5 Environmentally friendly

The packaging materials generated from cellulose, starch, protein, microalgae, and agro-waste should be biodegradable and benign. Currently, the sustainability and green economy of biobased materials is a major concern. Polymers produced during the treatment can be catalyzed by microbial enzymes. Microbes may totally break down environmentally beneficial bioplastics in a fair amount of time and under certain conditions [16].

2 **Bio-polymers/plastics**Non-biodegradable and Biodegradable polymers

Due to the diversity, properties, and sources of bio-based polymers, their applications are currently increasing. Classifications of plastics and polymers are grouped into (i) petroleum-based and biodegradable, (ii) bio-based and non-biodegradable, and (iii) bio-based and biodegradable. Except for poly (Ɛ-caprolactone) (PCL), polybutylene adipate terephthalate (PBAT), and poly (butylene succinate) (PBS), all traditional petroleum-based polymers are generally non-biodegradable [17]. Renewable biomass resources (animals, plants, and microorganisms) are a source of bio-based polymers. Production of Bio-plastics from renewable biomass resources includes plants, microorganisms, and animals have been elaborated. Bio-based polymers can either be directly derived from renewable monomers (e.g., PLA) or produced by microorganisms (e.g., PHAs). The unique characteristics of biodegradable plastics and polymers are that they are ecologically benign (biocompatible and biodegradable). According to figure 2, biopolymers, which are divided into chemical synthesis methods, bacterial synthesis methods, biopolymer blends, and renewable sources, were developed based on the intended product and available ingredients. Non-biodegradable and biodegradable polymers are the two types of polymers. Non-biodegradable polymers are synthesized by chemical methods, but biodegradable polymers are synthesized by microbial, bio-polymer blending, and chemical techniques of production [18]. Chemical synthesis generates two types of end products: convectional and biobased. Polyethylene, Polypropylene, high-density polyethylene, low-density polyethylene, polyethylene terephatalate are generated using the conventional method of synthesis. Next, the PHAs, Bacterial cellulose, and polybutylene succinate are synthesis using the microbial technique. Additionally, the starch blends and polyester blends are synthesized using bio-polymer blending methodology, but cellulose nitrate, polybutylene adipate-co-terephathalate (PBAT), polybutylene succinate, polycaprolactone, and polyvinyl alcohol are produced using a chemical route [16].

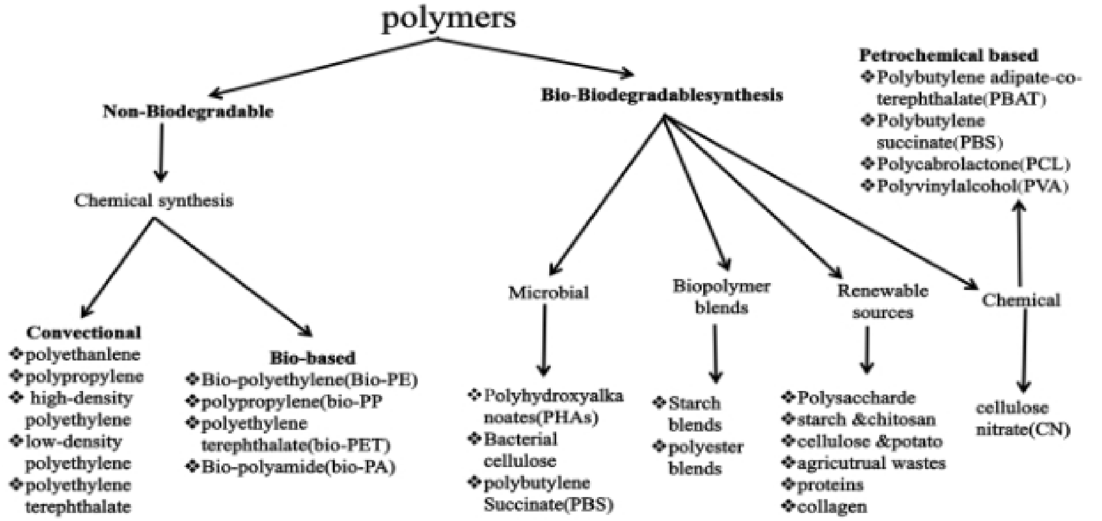

Figure 2. Sources, biodegradability, classification of production, and components of Bio-polymer materials/Источники, биоразлагаемость, классификация производства и компоненты био полимерных материалов

The application of bio-based polymers in the construction, medical, electronic, agricultural, and food sectors depends on the physical properties of the materials. The key criterion for selection in construction are physical attributes such tensile strength, high tensile strength, and yield strength, but for food application, the percentage (%) elongation of the bio-based polymer gives the highest property for utility and operation. In accordance with table 1, the physical properties of the selected polymers are presented. Starch, PLA, Poly-L-lactide (l-PLA), Poly-D, L-lactide (dl-PLA), PHB, poly (glycolic acid) (PGA), and PCL have different properties [48]. PHB and PGA have the highest Young's modulus and tensile strength. However, they have the lowest percentage of elongation at break [17]. Bio-polymers with the highest densities have high mechanical strength. Therefore, for food packaging, starch and PCL are the best-selected materials because of their highest elongation at break.

Table 1.

Distinct varieties of bio-polymer physical characteristics

property	Kind of biopolymer						
	Starch	PLA	l-PLA	dl-PLA	PHB	PGA	PCL
Melting Temperature [°C]	-	150	170	-	168	220	58
Density [kg/m^{3}]	1.11	1210	1240	1250	1180	1500	1110
Glass Transition Temperature [°C]	-	45	55	50	5	35	-65
Young's Modulus [MPa]	0.125	0.35	2.7	1	3.5	6	0.21
Tensile strength [MPa]	5	21	15.5	27.6	40	60	20.7
Elongation [%]	31	2.5	3	2	5	1.5	300

3 Sources of bioplastics/polymersCellulose

Cellulose is the first abundant source of biopolymer on the earth, and algae, microbial cells (fungi and bacteria), plants, and animals are sources of cellulose. It's a syndiotactic homopolymer made up of D-anhydroglucopyranose units connected by b-glycosidic linkages [19]. Cellulose materials' properties and sources depend on the polymerization degree of the structure of the cellulose. As a result, cellulose chains have massive hydrogen bonding, such as intra-molecular and inter-molecular bonds, and a group of glucose units with a large number of hydroxyl groups (Figure 3). The cellulose chain's main structure can be divided into amorphous and crystalline portions. This enhances the high stiffness, strength, durability, and bio-compatibility of the cellulose structure [19,20]. The hydrophilicity, biodegradability, and chirality properties of cellulose depend on the three hydroxyl groups and reactivity. The hydroxyl groups assist the chemical alteration of cellulose through reaction pathways in order to develop cellulose derivatives for food packaging applications. The reaction mechanisms for chemical fictionalization for altered properties are grouped into cyanoethylation, etherication, hydroxypropylation, and carboxymethylation. A method of synthesis and substituent is used for the cellulose derivatives classification criteria items. Additionally, cotton (90%) and wood (50%) are the main sources of cellulose materials.

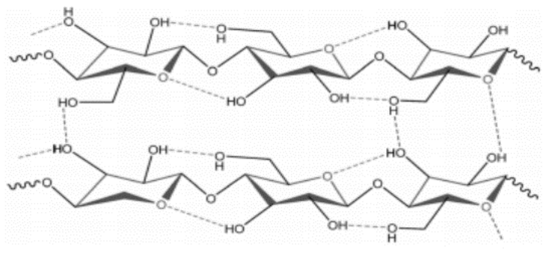

Figure 3. Molecular structure of cellulose linked by hydrogen bonds/Молекулярная структура целлюлозы, связанной водородными связями

The nature of the raw materials and the end product's application influence the biobased polymer's manufacturing process. According to figure 4, the production process of different biobased polymers through microbial fermentation systems has been presented. Renewable resources such as starch-based and cellulosic materials are used as raw materials for bio-polymer synthesis [22]. Corn, cassava, potato, wheat flour, sugar cane, and sugar beet are the most commonly utilized bio-polymers [23]. Pretreatment, chemical/enzyme hydrolysis, fermentation, purification, and polymerization are the crucial steps for biobased polymers [22]. The function of pretreatment is to remove the cover part of the raw materials, exposing the starch or sugar to the enzyme. Next, the pretreated materials are hydrolyzed by chemical or enzymatic methods. Hydrolysis is responsible for the production of simple sugars. Continuously, the glucose unit is fermented using a positive or negative bacterial cell fermentation scheme. The end product of fermentation is lactic acid. It can be used as an input for different bio-polymer products. After fermentation, the lactic acid is dehydrated, filtration, purification, and polymerization, PLA, biobased polyethylene terephthalate (Bio-PeT), polytrimethylene terephthalate (PTT), Polyamide (PA6), Poly (butylene succinate-co-butylene adipate) (PBSA), PHB, and bio-polyethylene (Bio-PE) are generated [57].

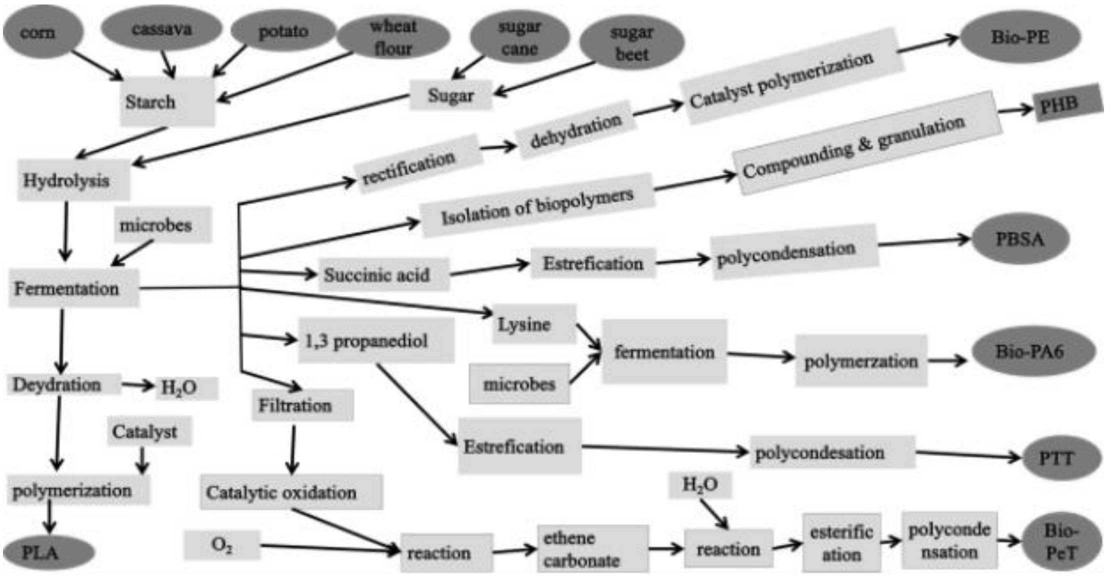

Figure 4. The manufacturing method for bio-based polymers/Способ производства биополимеров

The resultant properties of cellulose interaction in the composites of cellulose-based composites depend on the nature of the material, type of processing, compositions, and additives (figure 5) [24]. There are numerous advantages to using cellulose fibers and derivatives as a filler. The advantages of composites of cellulose fiber/high-density polyethylene and cellulose lyocell fibers/PLA are that they improve thermal and mechanical properties and have unexpectedly high biodegradability and significantly high mechanical characteristics [25]. Significantly, the cellulose fiber/polystyrene and cellulose acetate butyrate composites have the advantage of increased flexural storage modulus, processing speed, increased tensile properties, biodegradability, dimensional stability, and fiber compatibility. Further, the cellulose particles/chitosan composite has a good filler by enhancing the mechanical properties and adsorption capacities of the chitosan film [26]. The functions of cellulose-based composites as matrix are cellulose/MMT clay composite films, cellulose paper/carbon nanotube, carboxymethyl cellulose/ carbon fiber composites, cellulose acetate/ hydroxyapatite mineral composites, and methylcellulose/ keratin hydrolysate composite membranes. The function of cellulose/MMT clay composite films and cellulose paper/carbon nanotube in matrix form are high-strength cellulose composite films with excellent antibacterial activities. The resulting matrix is highly flexible, mechanically tough, thermally stable, and suitable for biotechnological applications and has uniform electrical conductivity [27]. Furthermore, the function of carboxymethyl cellulose/carbon fibers and cellulose acetate/hydroxyapatite mineral composites, cellulose gives functional composites a great potential in sensing elements in paper electronics and a useful application of pollutants absorption resulting from a cellulosic polymer's uniform and good ductility. HPA and the cellulose polymer have strong interactions. Indeed, by integrating the protein and polysaccharides of agricultural waste-based biopolymers in food packaging applications, the function of methylcellulose/keratin hydrolysate composite membranes increases the mechanical and thermal properties [28].

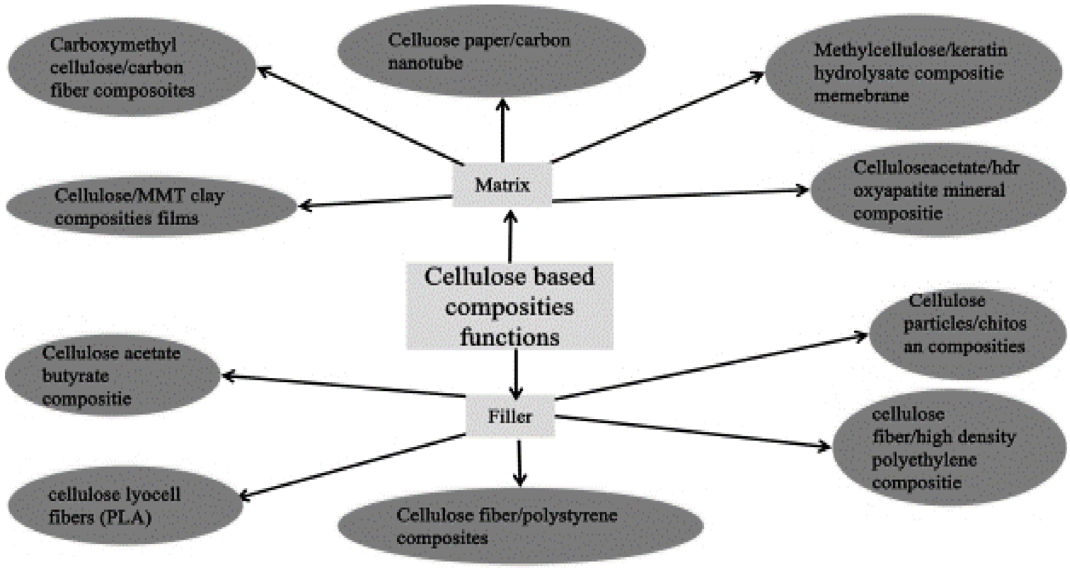

Figure 5. The function of common types of cellulose-based composites/Функция распространенных типов композитов на основе целлюлозы

3.2 Starch sources

Starch is found in plant cell granules that have crystalline (containing amylose linear chains and amylopectin branching points) and amorphous (mainly composed of long amylopectin side chains) structures. According to figure 6, it has two main combined branches of homo-polymers. They're termed amylose and amylopectin, respectively. Amylose is a linearly organized polymer of D-glucose monomers, and amylopectin is a – D-(1-4)-glucan, which has – D(1–6) linkages at the branch point [29]. The main sources of starch from biomass resources are rice, corn, yam root, potato, cassava, wheat, and tapioca. The ratios of starch branches (amylose/amylopectin) depend on the source of plant materials, that is, between 10% to 20% of amylose and 80 to 90% of amylopectin. Starch is easily diffused in water because of its characteristics. Whether it is cold or hot. At high temperatures, starch forms a gel after cooling. The de-structure(plasticize) of starch can be enhanced by the integration of molecules (concentration between 15–30wt%) that interact via hydrogen bonding. Those interacted molecules are sorbitol, glycerol, and water. They can greatly improve the barrier and mechanical properties of the materials. This thermoplastic starch (TPS) is ideal for making foams and solid molded bio-based materials because of its high temperature and pressure resistance properties. However, because of retrogradation, they become brittle over time. Starch-based materials are also biodegradable, meaning they decompose under the control of microorganisms, fungi cells, temperature, light, water, pressure, and oxygen [30]. Different sources of starch materials and production processes, as well as the products, are presented in figure 4.

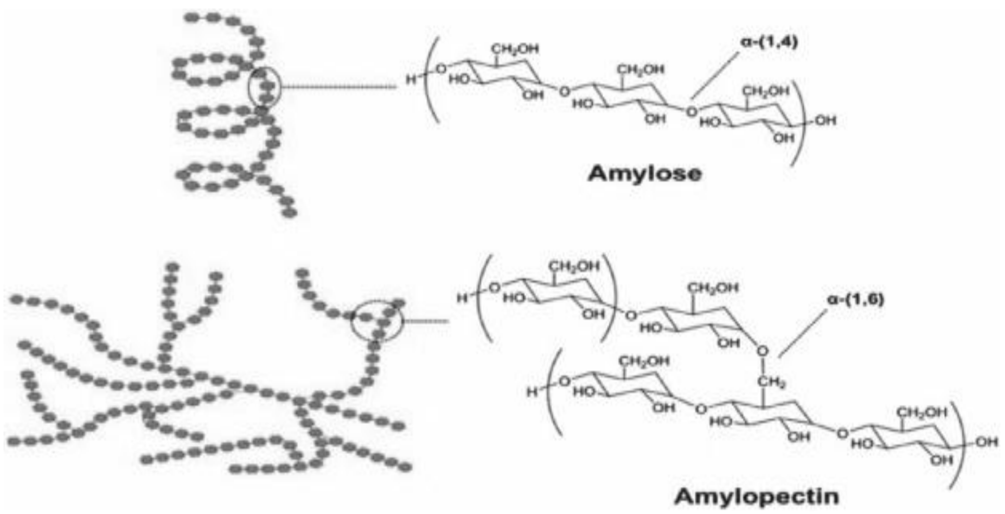

Figure 6. Graphical representation of Amylose and Amylopectin branches/Графическое изображение ветвей амилозы и амилопектина

3.3 Algae sources

Currently, the best and promising alternative inputs for Biobased polymers due to the rate of high growth and non-competition with food are algae. Heretofore, the generation and characterization of bio-based plastics from microalgae materials are evaluated [31]. It can be used as raw material directly or indirectly (extraction of PHBs and starch) for the synthesis of bioplastics. The different routes also incorporated for production such as melt mixing, twin-screw extrusion, hot/compression molding, injection molding, or solvent casting are used for the blend of microalgae with others [32]. The better bio-based plastic behavior (Chlorella) with different species and the better blending properties (Spirulina) type of microalgae have been examined more than other microalgae's. Besides, extraction of bio-based plastics from *Chlorella pyrenoidosa* was justified bio-based plastic and *Chlorella sorokiniana*-derived starch granules [33]. Using as additive of polyvinyl alcohol for salt-rich *Spirulina* sp. residues were produced different bio-based plastic films. Cyanobacteria such as *Chlorogloea fritschii species* also investigated for the source of bioplastics, *Calothrix scytonemicola* and *Neochloris oleoabundans*, residual *Nannochloropsis* after oil extraction [34], and *Nannocloropsis gaditana* [35]. Likewise, for starch synthesis and its derivatives of biobased plastic generation, ten green microalgae were selected as raw materials. The most promising (*C. reinhardtii* 11–32A) microalgae were responded for starch generating an excellent plasticize incorporated with glycerol at 120 °C [36]. Bioplastics are made from microalgae found in wastewater treatment plants. Consortium microalgae were propagated using nutrients, light, CO_2, and water and harvested from water bodies, and hybrid with a plasticizer(glycerol) for the synthesis of bioplastics. Currently, the biomass of microalgae was combined with petroleum materials for the synthesis of new composites. According to figure 7, the microalgae biomass used for the production of Polyhydroxy butyrate (PHB) through bioreactor is presented and feasible with aid of bacteria microbial cells. The production process of the polyhydroxy butyrate (PHB) consists of upstream, fermentation, and downstream parts. In the upstream such as the cultivation of microalgae, harvesting, and drying is proceeding to the next step(hydrolysis). The dissolution of biomass into individual components is known as hydrolysis. After hydrolysis, the bacterial cells fermentation was performed and given the polyhydroxy butyrate (PHB). The aquatic plants such as See weeds and macroalgae are rich in polysaccharides also used as promising biomass sources for bio-based plastics in addition to microalgae. Likewise, recently for the production of bioplastics aided polyethylene glycol as plasticizer the whole red macroalga *Kappaphycus alvarezii* as input material was explored for food packaging applications [37].

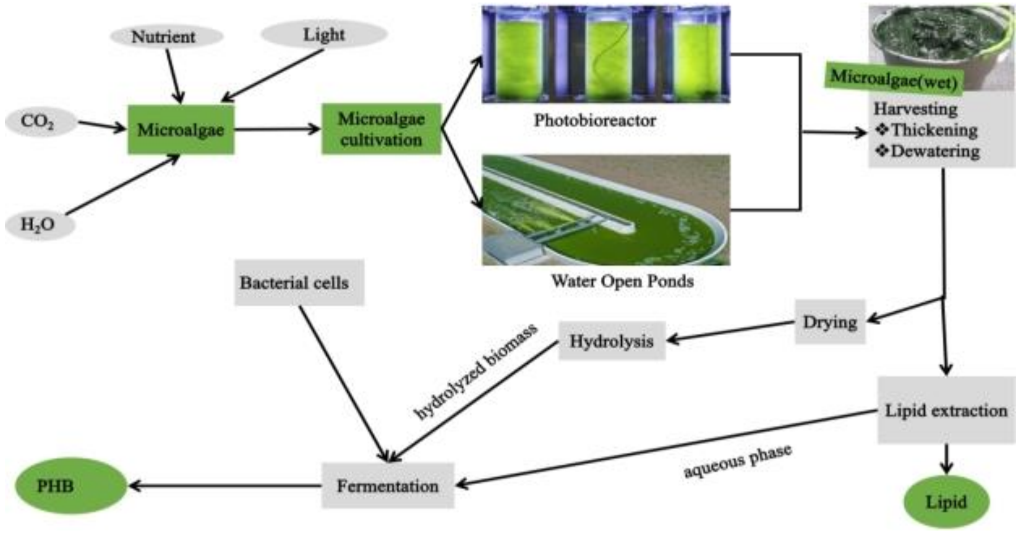

Figure 7. A synthesis scheme of Polyhydroxy butyrate from microalgae/Схема синтеза полигидроксибутирата из микроводорослей

3.4 Agricultural sources

Today, agricultural wastes are the best solution for reducing carbon footprint and environmental concerns used for the synthesis of bio-based polymers. The PCL, PBAT, and PBSA are biodegradable bio-based Polymers as well as carbon chains are susceptible to enzymatic degradation [38]. Groups of butyl rubber, PLAs, CA, polyols, Bio-based counterpart of bio-PET, PA6, and PHAs polymers are commercially procurable [39]. Chain branches PHAs polymers are classified into short, medium, and long [39]. The strength, stiffness, brittleness, and degree of crystallinity and depend on the length of chains, and the chains types predict the utility in commercial applications. The low chain of the length of bio-based polymers are brittle, less elastic modulus, however medium-chain of the length of bio-polymers have low crystalline and flexibility (longer elongation). But, the bio-polymers generated from medium agricultural wastes resources are not resistant to high-temperature operations [38].

The main criteria for selection and use of agricultural wastes for biobased plastics are such as food security, bio-availability selection, the complexity of development scheme, starch, and lignocellulosic contents, and end-product properties and eco-friendly. The cellulose content of the agricultural wastes is critical-stage for producing high-strength polymer. According to table 2 the cellulose concentration (% w/w) of hemp, banana pseudo stem, cotton stalks are highest compared to wheat straw, soya stalks, and coir. The tradeoff in the synthesis of bio-based polymers depends on the content of the cellulose and the eco-friendly (biodegradability) are explained from the Experimental data. Plant cellulose enhances high mechanical strength, but it takes time to degrade by microbes. The biodegradability of cellulose plant polymers has now been determined. The successful replacement of plant cellulose by bacterial cellulose was reported in some studies[40]. The crucial limiting reactants(factors) for the selection of precursors from agriculture waste are cellulose and starch contents.

Table 2.

Ordinary agricultural wastes: chemical compositions

Agricultural waste	Chemical composition (%w/w)					Reference
	Cellulose (%)	Lignin (%)	Hemicellulose (%)	Ash (%)	Total Solids (%)	
Banana pseudo stem	41.45	10.46	23.37	12.4	-	[41]
Hemp	75	15	3	-	-	[42]
Wheat straw	32.9	8.9	24.0	6.7	95.6	[43]
Cotton stalks	58.5	21.5	21.9	11	-	[44]
Rice straw	39.2	36.1	23.5	12.4	98.62	
Sunflower stalks	42.1	13.4	29.7	11.17	-	
sawdust	45.1	24.2	28.1	1.2	98.54	
Soya stalks	34.5	19.8	24.8	10.39	-	
Oat straw	39.4	17.5	27.1	10.39	-	
Coir	36–43	41–45	0.15–0.25	-	-	
Oil palm	47.91	24.45	19.06	-	-	

Bio-based polymers derived from agricultural waste offer a variety of properties. The agro-wastes cellulose content predicts the strength of the polymer, but the thickness of the Bio-based polymer film depends on starch content. The optimum thickness of polymer films is approximately from 0.099 up to 0.1599 mm and correlated with the starch content of agricultural wastes due to the presence of amylose and amylopectin compounds [45]. Excellent mechanical properties of biopolymers are synthesized from thick films than thin films of agro-wastes. Hence, the starch content of ago-waste materials is the first criteria used as a precursor, and micro-algae such as *Scenedesmus sp* and *Chlorella variabilis* have low precursors for the synthesis of bio-degradable polymers than *Chlamydomonas reinhardtii* micro-algae. The yield of starch depends on the Incubation time, type of the micro-algae, and agricultural precursors. For instance, at 800 h of incubation, the highest yield of starch was produced through *Chlamydomonas reinhardtii* microalgae species. The preference for species with a high starch content comes at the expense of the rate at which the culture grows. A larger cellulose concentration, on the other hand, increases mechanical strength while slowing biodegradation. The general scheme of bio-based plastics from selective agricultural and food wastes is presented in figure 8 [46].

Compared to the agricultural crops (fresh materials) the advantage and disadvantage of the microalgae and agricultural (organic) wastes are elaborated according figure 9.

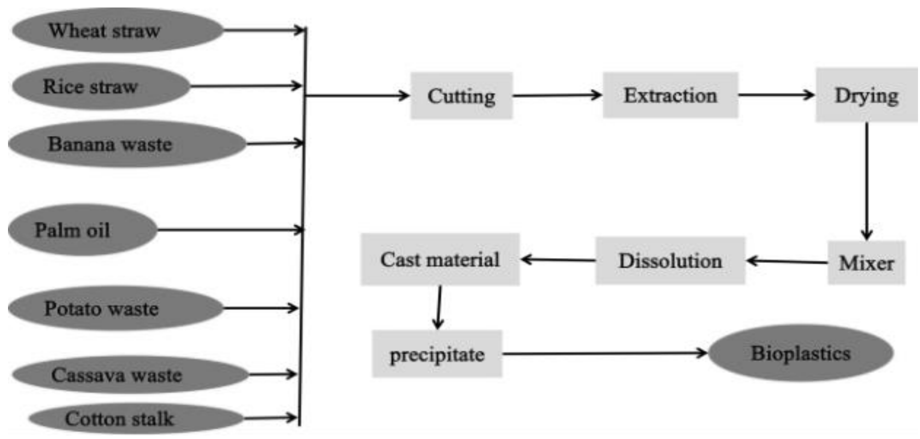

Figure 8. Scheme of Bio-based plastics from selective agricultural and food wastes/Схема производства пластиков на биооснове из селективных сельскохозяйственных и пищевых отходов

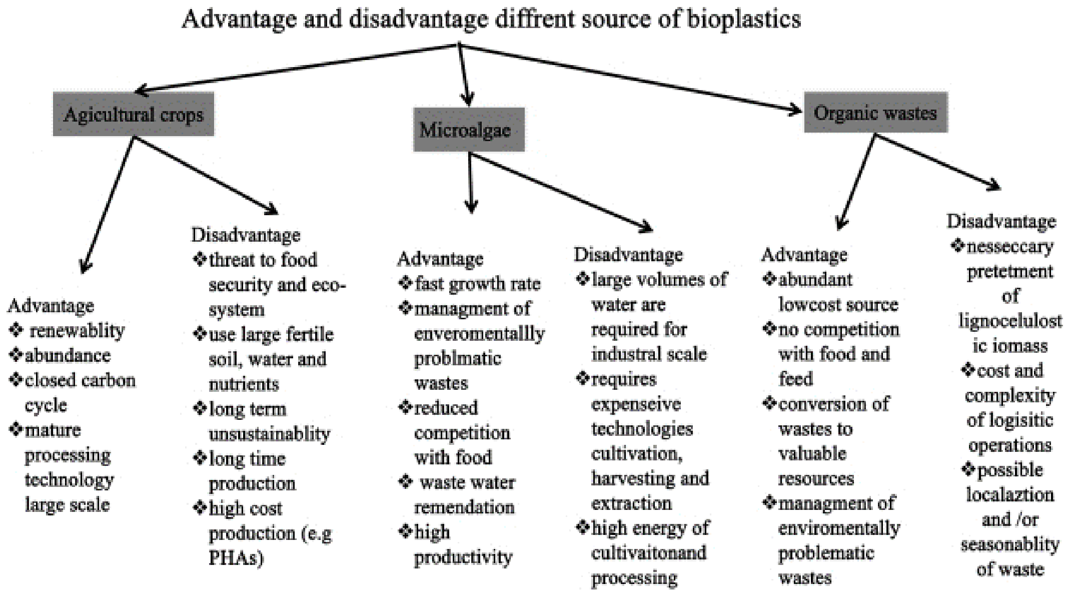

Figure 9. Different Biomass resources for Bioplastics: its advantages and disadvantages/Различные ресурсы биомассы для биопластиков: их преимущества и недостатки

3.5 Application in Food Packaging

Bio-based polymers are increasingly being used in food packaging around the world. The selection of agricultural wastes, algae, and renewable biomass resources for food packaging depends on their sustainability such as cost, social impact, environmental impact, and properties of the materials. Among them, corn starch, PLA, coffee grounds-PBAT composites, blueberry agro-industrial waste, sugar palm nano-fibrillated cellulose, cellulose-based bio-polymers are the most effective [47].The low tensile strength and low mechanical properties of bio-based plastics are not the only criteria for food packaging applications. In food packaging application, the data following in Table 3 shows that PLA and cellulose acetate have a good substitution for conventional plastics such as polyethylene and polypropylene other than PHA, PBAT, PEF, and PTT [48]. The un-blended biobased polymers having a high rate of water permeability, high rate of biodegradability, and poor mechanical properties are haven't impact in food packaging sectors. The mechanical and physical properties of biofilms produced from agro-wastes can be modified by incorporating nano-fibrillated cellulose (SPNFCs) materials. Adding 0.1 to 1.0 wt% concentration of SPNFCs showed a significant change in the properties of sugar palm Biofilms. The chitosan, PLA, and lignocellulosic composites are the main reinforces and fillers for materials synthesized from agricultural wastes such as coffee grounds having hydrophobicity properties in the food packaging applications. The limitation with starch and blueberry agro-wastes Bio-films can be improved through the photo-bleaching techniques [47].

Table 3.

Comparison between petrochemical and bio-based polymers properties

material		Glass transition Temperature (°C)	Melting temperature (°C)	Elongation at break (%)	Tensile strength (MPa)
Plant-based	Cellulose acetate	110	230	25	90
	Corn starch	112	-	9	40
	polylactides	55	165	2–7	59
	Polyhydroxyalkanoates	12–13	100–173	1–800	15–50
	PB AT	-29	110	800	22
	Polyethylene Furanoate	85	211	3–4	35–67
	PTT	50	228	160	49
Petrochemical	Polyethylene	-125	110–130	100	15–30
	Polypropylene	-13	176	400	36
	Polyethylene terephthalate	72	265	20	86
	polystyrene	100	-	1–5	30–60
	Polyvinyl chloride	-18	200	35	52

The best bio-based plastic that is greatly applicable in food packaging is PLA. According to table 4, the application of PLA in coffee, beverage, dairy drinks, potato chips, bread, fresh salads, fresh-cut fruits, vegetables, and organic poultry are published in different countries [49]. Organic tomatoes and milk chocolate food products are packed with starch-based polymers. The application of cellulose-based polymers in food packaging is for the packing of organic pasta, kiwi, potato chips, and sweets products. The utilize of agro-wastes in food packaging application depend on the mechanical and thermal properties of the bio-based polymers.

Table 4.

The most common uses of bioplastics in the food sector

	Application	Bio-polymer	Company/user
PLA	Coffee and other beverages	Cardboard and cups with PLA coating	KLM
	Beverages	Cups made with PLA	Musburger (JP)
	Fresh salads	Bowls made with PLA	McDonald's
	Carbonated water, juices, and dairy drinks	Bottles cups made with PLA	Biota, noble
	Fresh cut fruits, vegetables, bakery goods	Trays and packs made with PLA	Asda(retailer)
	Organic pretzels, potato chips	Bags made with PLA	Snyder's of Hanover, PepsiCo's Frito-lay
	Bread	Paper bags with PLA window	Delhaize (retailer)
	Organic poultry	bowls made with PLA, absorb pads	Delhaize (retailer)
Starch-based	Milk chocolate	Corn starch trays	Cadbury food group, Marks and Spencer
	Organic tomatoes	Packaging based on Corn	Iper supermarkets (Italy), Coop in Italy
Cellulose-based	Kiwi	Bio-based trays wrapped whit cellulose film	Wal-Mar
	Potato chips	Metalized cellulose film	Boulder Canyon
	Organic pasta	Cellulose-based packaging	Birkel
	Sweets	Metalized cellulose film	Quality street, Thorn ton

3.6 Challenges of materials for food packaging

The cost of manufacture and non-biodegradability are the key challenges facing bio-based polymers in present research and development. According to table 5, the cost bio-based plastics are slightly expensive than convectional/petrochemical plastics [50]. The average cost of manufacturing for starch, polylactic acid (PLA), and starch blends biopolymers from renewable biomass/plants are up to 1. 1,1, and 2euro per kg respectively, but for petrochemical plastics, the cost of production is 1.865, 1.855, 1.455, 2.2, and 1.755 euro per kg for PVC, PP, PE, PS, and PET and three-layer co-extruded film (3L) respectively[51]. However, averagely upto12.02, and 8.00 € per kg of Cellulose esters/ethers (CEs) and PHA are required costs of manufacturing respectively. As a result, bio-based polymers (PHA and CEs) have a greater manufacturing cost than conventional plastics. All in one, in terms of economical visibility/dimensions starch, PLA, and starch/polymer blends are greatly suitable than PHA and Cellulose Esters for replacing the petrochemical. Nevertheless, the higher cost of PHA and Cellulose esters are compensated through bio-based properties such as tensile strength, density, elongation at break, and heating temperature, and the glass transition temperature. The cost factors and biodegradability of bio-based plastics can be resolved through research and development and modifying or manufacturing of new bio-based materials.

Table 5.

Cost comparison of selective bio-based and petrol-chemical plastics

Source	Materials	Price(€/kg)
Renewable natural resources	starch	0.2–2.0
	Starch/polymer blends	2.0–4.0
	Cellulose esters/ethers (CEs)	4.0–20.04
	Polylactic acid (PLA)	0–2.0
	Lignocellulose fiber (LCF)	0.4–1.2
	Polyhydroxyalkanoates (PHA)	4.0–12.02
Convectional based	Polyvinylchloride (PVC)	1.71–2.02
	Polypropylene (PP)	1.71–2.0
	Polyethylene (PE)	1.31–1.6
	Polystyrene (PS)	2.0–2.4
	polyethylene terephthalate (PET)	1.71–1.8

Conclusions

In this review, the biomass resources such as cellulose, starch, micro-algae, and agricultural wastes production to bio-based polymers are selected to elaborate on the synthesis, properties, yields, and application in food packaging areas. The PLA, PCL, and starch blend polymers in food packaging applications have great attention for replacing petrochemical plastics such as polyethylene and polypropylene because they have similar elongation at break, biodegradability, and economic positive. Despite the fact that the PHA and PHBA have low moisture and oxygen permeability and good mechanical qualities, their synthesis method is expensive. Among the agricultural wastes, hemp, banana pseudo steam, and cotton stalks are good sources of bio-based plastics compared to wheat straw, soya stalks, sunflower stalks, sawdust, oat straw, and coir, because they have the highest cellulose concentration. Chitosan, PLA, and lignocellulosic composites are the main reinforcements and fillers for materials synthesized from agricultural wastes having hydrophobic properties in food packaging applications. Furthermore, researchers and academicians can design novel food packaging applications by developing, re-configuring, blending with low-cost polymers, and nano-biotechnology integration systems of bio-based plastics from cellulosic, starch component of agro-wastes, and microalgae with low-cost fillers, sustainable and reinforcers.

References

1 Hong L.G., Yuhana N.Y., Zawawi E.Z.E. Review of bioplastics as food packaging materials. AIMS Materials Science. 2021. vol. 8. no. 2. pp. 166-184. doi: 10.3934/matersci.2021012

2 Ayorova Ya.O., Voronina M.S. processing food waste to create biodegradable packaging. News of the Far Eastern Federal University. Economics and Management. 2021. vol. 100. no. 4. pp. 87–97. (in Russian).

3 Chan J.X., Wong J.F., Hassan A., Zakaria Z. Bioplastics from agricultural waste, Biopolymers and Biocomposites from Agro-Waste for Packaging Applications. Food packaging. 2021. pp. 223–263.

4 Jabeen N., Majid I., Nayik G. A. Bioplastics and food packaging: A review. Cogent Food & Agriculture. 2015. no. 1. no. 1. pp. 1117749.

5 Zhang B., Qiao D., Zhao S., Lin Q. et al. Starch-based food matrices containing protein: Recent understanding of morphology, structure, and properties. Trends in Food Science & Technology. 2021. vol. 114. pp. 212-231. doi: 10.1016/j.tifs.2021.05.033

6 Venkatesh S., Mahboob S., Govindarajan M., Al-Ghanim K.A. et al. Microbial degradation of plastics: Sustainable approach to tackling environmental threats facing big cities of the future. Journal of King Saud University-Science. 2021. vol. 33. pp. 101362. doi: 10.1016/j.jksus.2021.101362

7 Tsang Y.F., Kumar V., Samadar P., Yang Y. et al. Production of bioplastic through food waste valorization. Environment international. 2019. vol. 127. pp. 625-644. doi: 10.1016/j.envint.2019.03.076

8 Kudryakova G.Kh., Kuznetsova L.S., Shevchenko E.G., Ivanova T.V. Biodegradable packaging in the food industry. Food industry. 2006. no. 7. (in Russian).

9 Nazrin A. et al. Water barrier and mechanical properties of sugar palm crystalline nanocellulose reinforced thermoplastic sugar palm starch (TPS)/poly (lactic acid)(PLA) blend bionanocomposites. Nanotechnology Reviews. 2021. vol. 10. no. 1. pp. 431-442. doi: 10.1515/ntrev-2021-0033

10 Minh N.P., Pham T., van Hung L., Thuan N.T. et al. Effectiveness of Pouzolzia zeylanica, Curcuma longa, Piper nigrum, Capsicum annum to stability of dried salted tilapia during storage. Journal of Pharmaceutical Sciences and Research. 2019. vol. 11.pp. 1469–1473.

11 Briassoulis D., Pikasi A., Hiskakis M. Recirculation potential of post-consumer/industrial bio-based plastics through mechanical recycling-Techno-economic sustainability criteria and indicators. Polymer Degradation and Stability. 2021. vol. 183. pp. 109217. doi: 10.1016/j.polymdegradstab.2020.109217

12 Tyuftin A.A., Kerry J.P. Review of surface treatment methods for polyamide films for potential application as smart packaging materials: surface structure, antimicrobial and spectral properties. Food Packaging and Shelf life. 2020. vol. 24. pp. 100475. doi: 10.1016/j.fpsl.2020.100475

13 Sionkowska A., Płanecka A. Surface properties of thin films based on the mixtures of chitosan and silk fibroin. Journal of Molecular Liquids. 2013. vol. 186. pp. 157-162. doi: 10.1016/j.molliq.2013.07.008

14 Orlova E.S., Al-Suhaimi S.A., Rebezov M.B. Assessment of antioxidant and antimicrobial activity of plant bioactive compounds as natural preservatives. Agrarian Science. 2023. vol. 1. no. 8. pp. 143-150. (in Russian).

15 Omerović N., Djisalov M., Živojević K., Mladenović M. et al. Antimicrobial nanoparticles and biodegradable polymer composites for active food packaging applications. Comprehensive Reviews in Food Science and Food Safety. 2021. vol. 20. no. 3. pp. 2428-2454. doi: 10.1111/1541-4337.12727

16 Moshood T.D. et al. Sustainability of biodegradable plastics: New problem or solution to solve the global plastic pollution? Current Research in Green and Sustainable Chemistry. 2022. vol. 5. pp. 100273. doi: 10.1016/j.crgsc.2022.100273

17 Al-Jahwari F.S., Pervez T. The Potential of Environmental-Friendly Biopolymers as an Alternative to Conventional Petroleum-Based Polymers. Encyclopedia of Renewable and Sustainable Materials. 2020. vol. 5. pp. 200–206. doi: 10.1016/j.crgsc.2022.100273

18 Nduko J.M., Taguchi S. Microbial Production of Biodegradable Lactate-Based Polymers and Oligomeric Building Blocks From Renewable and Waste Resources. Frontiers in Bioengineering and Biotechnology. 2021. V. 8. P. 618077. doi: 10.3389/fbioe.2020.618077

19 Cao L., Gong Z., Xu C., Chen Y. Mechanical strong and recyclable rubber nanocomposites with sustainable cellulose nanocrystals and interfacial exchangeable bonds. ACS Sustainable Chemistry & Engineering. 2021. vol. 9. no. 28. pp. 9409-9417.

20 Li C., Ju B., Zhang S. Construction of a new green vitrimer material: introducing dynamic covalent bond into carboxymethyl cellulose. Cellulose. 2021. vol. 28. pp. 2879-2888.

21 Mukherjee S., Mukherjee G. Bacterial cellulose production from industrial waste and its applications. Plant Cell Biotechnol. Mol. Biol. 2021. vol. 22. pp. 104–113.

22 Pinto L., Bonifacio M.A., de Giglio E., Santovito E. et al. Biopolymer hybrid materials: Development, characterization, and food packaging applications. 2021. vol. 28. pp. 100676. doi: 10.1016/j.fpsl.2021.100676

23 Shafqat A., Tahir A., Khan W.U., Mahmood A. et al. Production and characterization of rice starch and corn starch based biodegradable bioplastic using various plasticizers and natural reinforcing fillers. Cellulose Chemistry and Technology. 2021. vol. 55. pp. 867-881.

24 Shaghaleh H., Xu X., Wang S. Current progress in production of biopolymeric materials based on cellulose, cellulose nanofibers, and cellulose derivatives. RSC Advances. 2018. vol. 8. no. 2. pp. 825-842. doi: 10.1039/C7RA11157F

25 Vorawongsagul S., Pratumpong P., Pechyen C. Preparation and foaming behavior of poly (lactic acid)/poly (butylene succinate)/cellulose fiber composite for hot cups packaging application. Food Packaging and Shelf Life. 2021. vol. 27. pp. 100608. doi: 10.1016/j.fpsl.2020.100608

26 Zahiri Oghani F., Tahvildari K., Nozari M. Novel antibacterial food packaging based on chitosan loaded ZnO nano particles prepared by green synthesis from Nettle leaf extract. Journal of Inorganic and Organometallic Polymers and Materials. 2021. vol. 31. pp. 43-54.

27 Yotprayoonsak P., Virtanen J., Kangas V., Promarak V. Facile fabrication of flexible and conductive cellulose paper from aqueous carbon nanotube/hemicellulose compound. Synthetic Metals. 2021. vol. 271. pp. 116646. doi: 10.1016/j.synthmet.2020.116646

28 Liebeck B.M., Hidalgo N., Roth G., Popescu C. et al. Synthesis and characterization of methyl cellulose/keratin hydrolysate composite membranes. Polymers. 2017. vol. 9. no. 3. pp. 91. doi: 10.3390/polym9030091

29 Reichert C.L., Bugnicourt E., Coltelli M.B., Cinelli P. et al. Bio-based packaging: Materials, modifications, industrial applications and sustainability. Polymers. 2020. vol. 12. no. 7. pp. 1558. doi: 10.3390/polym12071558

30 Lackner M., Ivanič F., Kováčová M., Chodák I. Mechanical properties and structure of mixtures of poly(butylene-adipate-co-terephthalate) (PBAT) with thermoplastic starch (TPS). International Journal of Biobased Plastics. 2021. vol. 3. no. 1. pp. 126-138.

31 Madadi R., Maljaee H., Serafim L.S., Ventura S.P. Microalgae as contributors to produce biopolymers. Marine Drugs. 2021. vol. 19. no. 8. pp. 466. doi: 10.3390/md19080466

32 Onen Cinar S., Chong Z.K., Kucuker M.A., Wieczorek N. et al. Bioplastic production from microalgae: a review. International journal of environmental research and public health. 2020. vol. 17. №. 11. pp. 3842.

33 Sunday N.F. Microplastics: Holistic overview of source, identification, interaction, health and environmental implications and strategies of abatement. Acta Chemica Malaysia. 2020. vol. 5. no. 1. pp. 18-23.

34 Gallego R., Bueno M., Chourio A.M., Ibáñez E. et al. Use of high and ultra-high pressure based-processes for the effective recovery of bioactive compounds from Nannochloropsis oceanica microalgae. The Journal of Supercritical Fluids. 2021. vol. 167. pp. 105039. doi: 10.1016/j.supflu.2020.105039

35 Sánchez-Bayo A., Rodríguez R., Morales V., Nasirian N. et al. Hydrothermal liquefaction of microalga using metal oxide catalyst. Processes. 2019. vol. 8. no. 1. pp. 15.

36 Alshehri W.A., Khalel A., Elbanna K., Ahmad I. et al. Bio-plastic Films Production from Feather Waste Degradation by Keratinolytic Bacteria Bacillus cereus. J Pure Appl Microbiol. 2021. The Author (s) 2021. Open Access. This article is distributed under the terms of the Creative Commons Attribution. 2021. vol. 4.

37 Ng J.S., Kiew P.L., Lam M.K., Yeoh W.M. et al. Preliminary evaluation of the properties and biodegradability of glycerol- and sorbitol-plasticized potato-based bioplastics. International Journal of Environmental Science and Technology. 2022. pp. 1-10.

38 Soares R.M.D., Siqueira N.M., Prabhakaram M.P., Ramakrishna S. Electrospinning and electrospray of bio-based and natural polymers for biomaterials development. Materials Science and Engineering: C. 2018. vol. 92. pp. 969-982. doi: 10.1016/j.msec.2018.08.004

39 Li M., Ma Y., Zhang X., Zhang L. et al. Tailor-Made Polyhydroxyalkanoates by Reconstructing Pseudomonas Entomophila. Advanced Materials. 2021. vol. 33. no. 41. pp. 2102766. doi: 10.1002/adma.202102766

40 Xie Y., Niu,X., Yang J., Fan R. et al. Active biodegradable films based on the whole potato peel incorporated with bacterial cellulose and curcumin. International Journal of Biological Macromolecules. 2020. vol. 150. pp. 480-491. doi: 10.1016/j.ijbiomac.2020.01.291

41 Melesse E.Y., Bedru T.K., Meshesha B.T. Production and Characterization of Pulp from Banana Pseudo Stem for Paper Making Via Soda Anthraquinone Pulping Process. International Journal of Engineering Research in Africa. 2022. vol. 58. pp. 63-76. doi: 10.4028/www.scientific.net/JERA.58.63

42 Loiacono S., Crini G., Martel B., Chanet G. et al. Simultaneous removal of Cd, Co, Cu, Mn, Ni, and Zn from synthetic solutions on a hemp-based felt. II. Chemical modification. Journal of applied polymer science. 2017. vol. 134. no. 32. pp. 45138. doi: 10.1002/app.45138

43 Pallem C. Utilization of wheat straw for the production of L-asparaginase in solid-state fermentation. J. Exp. Biol. Agric. Sci. 2019. vol. 7. no. 1. pp. 51-56.

44 Maraveas C. Production of sustainable and biodegradable polymers from agricultural waste. Polymers. 2020. vol. 12. no. 5. pp. 1127. doi: 10.3390/polym12051127

45 Santana R.F., Bonomo R.C.F., Gandolfi O.R.R., Rodrigues L.B. et al. Characterization of starch-based bioplastics from jackfruit seed plasticized with glycerol. Journal of food science and technology. 2018. vol. 55. pp. 278-286.

46 Ramadhan M.O., Handayani M.N. The potential of food waste as bioplastic material to promote environmental sustainability: A review. IOP Conference Series: Materials Science and Engineering. IOP Publishing, 2020. vol. 980. no. 1. pp. 012082. doi: 10.1088/1757-899X/980/1/012082

47 Luchese C.L., Sperotto N., Spada J.C., Tessaro I.C. Effect of blueberry agro-industrial waste addition to corn starch-based films for the production of a pH-indicator film. International journal of biological macromolecules. 2017. vol. 104. pp. 11-18. doi: 10.1016/j.ijbiomac.2017.05.149

48 Bárcena A., Graciano C., Luca T., Guiamet J.J. et al. Shade cloths and polyethylene covers have opposite effects on tipburn development in greenhouse grown lettuce. Scientia Horticulturae. 2019. vol. 249. pp. 93-99. doi: 10.1016/j.scienta.2019.01.023

49 Coppola G., Gaudio M.T., Lopresto C.G., Calabro V. et al. Bioplastic from renewable biomass: a facile solution for a greener environment. Earth systems and environment. 2021. vol. 5. pp. 231-251.

50 Maraveas C. Environmental sustainability of greenhouse covering materials. Sustainability. 2019. vol. 11. no. 21. pp. 6129.

51 Baxevanou C., Fidaros D., Bartzanas T., Kittas C. Yearly numerical evaluation of greenhouse cover materials. Computers and electronics in agriculture. 2018. vol. 149. pp. 54-70. doi: 10.1016/j.compag.2017.12.006

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Биопластик: свойства, возобновляемые ресурсы биомассы, синтез и применение

Аннотация. Современные тенденции в технологии упаковки пищевых продуктов обуславливают необходимость разработки новых упаковочных материалов с целью продления срока хранения продуктов питания и уменьшения их порчи. Для сохранения пищевого продукта, конструкционный материал упаковки играет ключевую роль. В развивающейся области технологии упаковки пищевых продуктов, использование биобазных пластиков для упаковки пищевых продуктов показало сравнительное преимущество. На данный момент, биопластики показали измеримые преимущества и получают все больше внимания со стороны деловых организаций, политических деятелей, научных сообществ, и в целом общественности. Это стало результатом поиска новых марок пластиковых профилей. Кроме того, воздействие на окружающую среду (экологические проблемы) конвективных материалов, истощение природных ресурсов, в частности, нефтехимических, и озабоченность потребителей вызвали необходимость в альтернативных средствах упаковки пищевых продуктов на биооснове. Поэтому целью данного исследования был обзор свойств упаковочных материалов для пищевых продуктов, таких как тепловые, механические, барьерные, поверхностные, антимикробные, оптические и экологические, а также их тип синтеза и применение. Были разработаны компоненты целлюлозы и крахмала из распространенных сельскохозяйственных отходов для синтеза биополимеров. Кроме того, различные виды микроводорослей были обоснованы в производстве пластмасс на биооснове. В данной обзорной статье также приведены примеры устойчивых наполнителей и армирующих материалов, используемых в индустрии пищевой упаковки. Таким образом, данная обзорная работа способствует раскрытию всего объема научных знаний о пластиках на биооснове, используемых для упаковки пищевых продуктов, и помогает получить важные результаты для дальнейших исследований.

Ключевые слова: возобновляемые источники биомассы, пластики на основе биоматериалов, свойства, применение в пищевой упаковке.

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