TRANSACTIONSNASTPHL
ISSN 0115-8848 (print)
ISSN 2815-2042 (online)
https://transactions.nast.ph/

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.6420

Physicochemical Properties of Bioplastics: A Review

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Citation
Sevilla FB III & Valdez R. 2026. Physicochemical properties of bioplastics: A review. Transactions NAST PHL 48: doi.org/10.57043/transnastphl.2026.6420

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ABSTRACT

Bioplastics are an environment-friendly alternative to petroleum-based plastics. However, the usefulness of these materials as a replacement to the conventional plastics is dependent on its physicochemical properties, such as mechanical strength, water resistance, and transparency. This paper presents a literature review of the physicochemical properties of bioplastics prepared from different sources. It also discusses the standard methods and equipment for the measurement of the chemical composition and physical properties of these materials. The mechanical, thermal and barrier properties and characteristics of bioplastics from terrestrial, marine and microbial sources were compiled from different sources, and compared with those of the fossil-based plastics. In general, the tensile strength of bioplastics was lower than the conventional plastics. However, some bioplastics, such as those derived from chitin, alginates, sago starch and kaong (*Arenga pinnata*) starch showed comparable mechanical properties to that of conventional plastics. The barrier properties of bioplastics were not as well studied as the mechanical properties, but are important for packaging applications. The cellulose-based and algae-based bioplastics had high barrier properties to water vapor, while the starch-based bioplastics had poor barrier properties to water vapor and oxygen.

Keywords: bioplastics; physicochemical properties; standard methods

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Abbreviations: accelerator mass spectroscopy (AMS); American Society for Testing and Measurement (ASTM); beta-ionization (BI); differential scanning calorimetry (DSC); dynamic mechanical analysis (DMA); European Committee for Standardization (CEN); glass transition temperature (Tg); International Organization for Standardization (ISO); isotope ratio mass spectrometry (IRMS); liquid scintillation counter (LSC); melting temperature (Tm); proportional scintillation counter (PSM) method; transmission of carbon dioxide gas (CO_2TR); transmission rate of water vapor (WVTR); ultimate tensile strength (UTS).

INTRODUCTION

Plastics have become part of everyday life. Described as a "material with a thousand uses", it has provided a versatile, durable, lightweight and cost-effective material in many consumer goods, household fixtures, package materials, medical and healthcare products, transportation parts, electrical and electronic gadgets (Pilapitaya et al. 2024). The annual global production amounted to 460 million tons in 2019, and is projected to triple this amount in 2060 (OECD 2022). About 99% of this output is produced from fossil fuel feedstock, contributing to the consumption of the limited stock of a non-renewable resource (CIEL 2019).

The massive production and consumption of plastics has presented a serious environmental threat. Most of the plastic products have limited usage lifetime, and the disposal of these materials poses a problem due to their durability and non-degradability. The slow degradation of plastic wastes, particularly single-use plastics, has led to their accumulation in the environment, choking landfills, leaking chemical additives into the terrestrial and aquatic ecosystems, and releasing fragmentation products into the atmosphere (Pilapitaya et al. 2024). Thermal treatment of plastic wastes, such as through incineration, released toxic gases into the atmosphere (Verma et al. 2018).

The urgency of the plastic pollution problem has raised global concerns and triggered the adoption of a global legally binding treaty among members of the United Nation to solve this problem (UNEP 2023). Among the actions to be implemented are the reduction in the usage of plastic, the re-use and recycling of plastic materials and the replacement of fossil-based plastics with sustainable alternatives. The promulgation of legislations and policies promote the adoption of these measures to control, if not eliminate, plastic pollution.

This paper presents bioplastics as an alternative material for the alleviation of the plastic pollution problem. It briefly discusses the different biological origin and the biodegradability of these materials, and focuses on their physicochemical characteristics. Published data on these properties were compiled and analyzed, together with the standard methods and equipment for their measurements.

BIOPLASTICS

Bioplastics have been introduced as an environment-friendly alternative to petroleum-based plastics. It includes "plastics based on renewable resources or plastics which are biodegradable and/or compostable" (Costa et al. 2023). The production of these substances from renewable biomass contributes to the conservation of limited natural resources, such as the fossil fuels. **These materials have the potential for a reduced carbon footprint, since they are produced from plant materials that sequester carbon dioxide during their growth.** The biodegradability of these materials decreases, if not eliminates, the energy requirement for waste management, since the decomposition process is facilitated by the enzymatic action of naturally occurring microorganisms.

The European Bioplastics Organization groups bioplastics into three types based on their origin and biodegradability: (1) polymers derived from biomass materials; (2) polymers produced by microorganism; and (3) polymers produced from renewable raw materials with the involvement of bio-intermediates (Costa et al. 2023). Figure 1 illustrates the classification of these biopolymers based on their sources and biodegradability.

The biomass raw materials for bioplastic productions could be of terrestrial origin, such as plants and agricultural wastes, or of aquatic origin, such as seaweeds or crustacean shells. These materials are renewable natural resources and contain biodegradable biomolecules, such as starch, cellulose, gelatin, chitosan, agar, carrageenan and alginates (Costa et al. 2023). These biopolymers are often blended with additives in order to improve their properties.

The bioplastics derived from microorganisms are actually products of the metabolism of microbial strains,

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

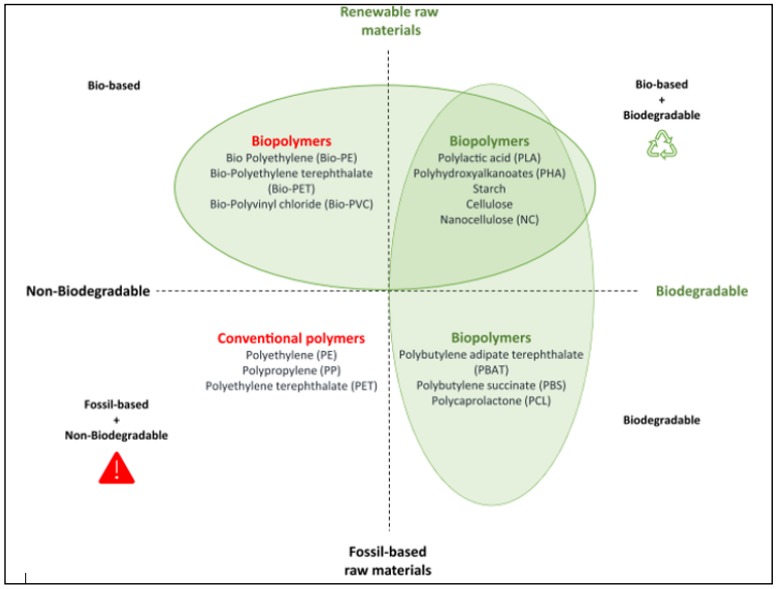

Figure 1. Classification of bioplastics (Adapted from Cinar et al. 2020).

such as *Bacillus* sp., *Azotobacter* sp., *Alcaligenes* sp. and *Pseudomonas* sp., as well as of algal strains, such as *Spirulina platensis*, *Nostoc muscorum* and *Synechococcus* sp. (Samadhiya et al. 2022). These materials include polylactic acid (PLA), polyhydroxybutyrate (PHB), and polycaprolactone (PCL), which are produced by culturing the microorganism in substrates containing carbon sources, such as sucrose, glucose, oleic acid, and propionic acid. These bioplastics are biodegradable either in an aquatic or in a soil environment (Coppola et al. 2021).

Some bioplastics are obtained from the polymerization of monomers derived from renewable biological resources, such as sugar cane, sugar beet, starch crops, and lignocellulose materials (Siracusa 2020). Monomers, such as ethylene and propylene, are produced from glucose extracted from the biological feedstock, and can be considered as bio-intermediates in the formation of their polymers. Similar to their petro-based analogue, these bioplastics are non-biodegradable.

PHYSICOCHEMICAL PROPERTIES

Bioplastics exhibit a range of physicochemical properties of bioplastics similar to the those of fossil-based plastics. These properties are greatly influenced by the large molecular mass of the polymer and by the repeating units (monomers) in the molecular framework. These properties determine the application of bioplastics.

Chemical composition. Being organic compounds, bioplastics are composed of carbon, hydrogen, oxygen, nitrogen and sulfur, similar to the conventional plastics. However, unlike the conventional plastics, the bio-based polymers contain the radioactive carbon-14 isotope, which is derived from the atmosphere and photosynthesis (Coppola et al. 2021). The carbon-14 content is the basis for the certification of bio-based bio-plastics through the EN16137 standard method in Europe, the ASTM 6866 standard method in the United States and the corresponding international standard ISO 16620-2 (European Bioplastic 2022). These methods are based on accelerator mass spectrometry, which measures the ratio of the three isotopes of carbon (C12, C13, and C14) in the graphite prepared from the sample (Funabashi et al. 2014).

The chemical nature of the bioplastic depends on its origin (Figure 2). It could be a polysaccharide, protein, lipid, or polyester, such as polyhydroxyalkanoates and polylactides. The chemical structure of bioplastics is identified through absorbance and fluorescence spectroscopic techniques, mass spectrometry, and nuclear magnetic resonance spectrometry (Censi et al. 2022).

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

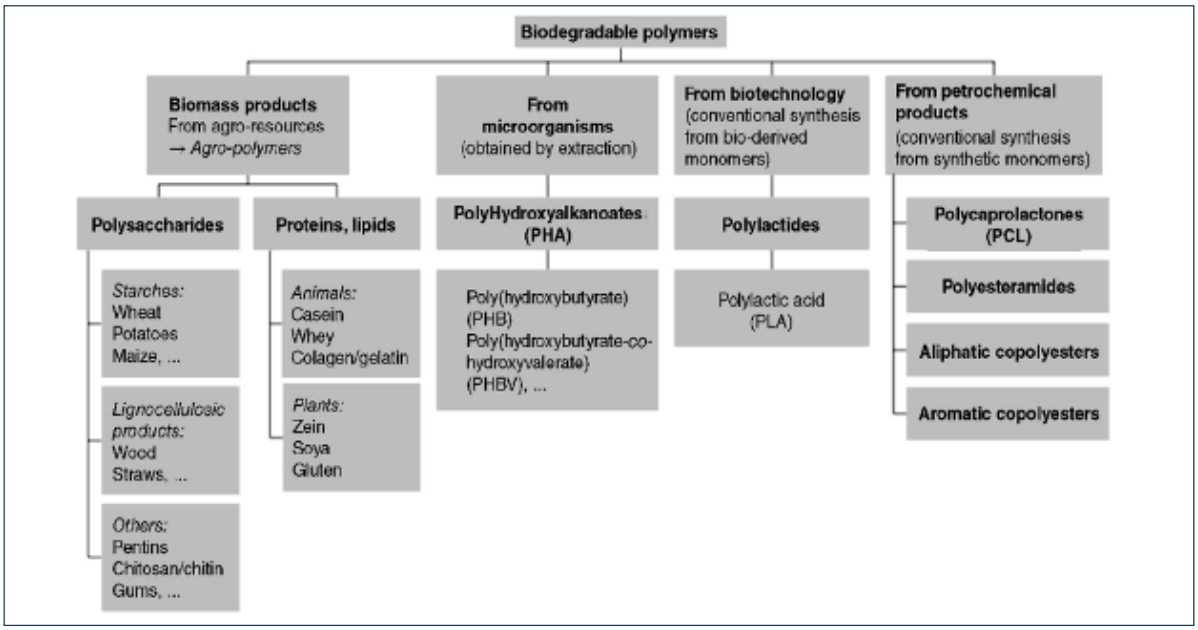

Figure 2. Chemical nature of bioplastics from different origins (From Coppola et al. 2021).

Physical properties. The important physical properties of bioplastics include molecular weight, density, molar volume and crystallinity. These properties are dependent on the molecular structure of the polymer and their intermolecular interaction. The crystallinity of the bioplastic is dependent on the regularity in the arrangement and the closeness of packing of the molecules in a bulk. Crystalline materials would have small molar volume and a high density. On the other hand, amorphous polymers involve a random arrangement of the molecules, and, consequently, a large molar volume and a low density. Crystallinity likewise influences the mechanical characteristics of plastics.

The density of solid plastics is measured using the displacement method and the density gradient technique (ASTM 2023). The displacement method is the basis of the standard ASTM D792-20 test method which involves weighing the test specimen in air and when submerged in distilled water held by a wire. It is applied for large plastic items such as tubes, rods and molded items. The density gradient technique is applied in the standard ASTM D1505-18 test method (equivalent to ISO 1183-2), wherein the test specimen is placed in a liquid column exhibiting a density gradient. The level where the sample settles down is measured and compared with standards of known density.

The crystallinity of plastics is determined using differential scanning calorimetry (DSC) measurements. The DSC peaks are used to calculate heat of fusion of the specimen at room temperature and at the melting point. The standard ASTM F2625-10 method describes the protocol for the measurement of the percent crystallinity, together with the heat of fusion and melting point, of ultra-high molecular weight polyethylene (ASTM 2023)

Thermal properties. The thermal properties of bioplastics indicate the behavior of the material upon heating. These properties are important in designing the protocol for the processing and utilization of the polymer. At low temperature, the plastic material is in a glassy state, which is characterized by hardness and brittleness. These properties can be associated with the restricted molecular motion at low temperatures.

As the temperature is increased, bulk material becomes soft and pliant, transforming from the glassy state to a rubbery state. This transition happens at a specific temperature known as the **glass transition temperature** (Tg). At this temperature, the molecules acquire sufficient energy to decouple from each other and exhibit a wiggling motion. Further heating beyond the glass transition temperature, the solid polymer melts and is converted into a liquid. Complete liquefaction occurs at a characteristic **melting temperature** (Tm).

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

The glass transition temperature and the melting temperature are measured using differential scanning calorimetry (DSC) and dynamic mechanical analysis (DMA). DSC monitors the heat flow using a thermocouple over a range of temperature, while DMA analyzes the change in the viscoelasticity of the material through a force transducer at different temperature. Figure 3 presents DSC and DMA thermograms, with annotations on the changes occurring at different temperature ranges.

The DSC was the technique adopted in the standard ASTM E-1356-08 method for the assignment of the glass transition temperature until 2023. Presently, the standard ASTM E1640-118 for the determination of the glass transition temperature is based on the dynamic mechanical analysis (ASTM 2023).

Mechanical properties. The mechanical properties of bioplastics describe the reaction of the material to a stress. These characteristics provide prime information on the suitability of the polymer for certain applications. These properties are dependent on the type of plastic, chemical modification, additives and processing conditions (Balani et al. 2015).

The capacity of the bioplastic to endure stress is expressed by the **ultimate tensile strength (UTS)**, or simply **tensile strength**. This parameter indicates the maximum force that can be applied to a plastic material without breaking it. This parameter forecasts how a material will behave under tensile loading. Initially, the plastic material behaves elastically, returning to its original state upon removal of the applied force. However, a limit is reached when the material is no longer elastic and the applied force, known as the **yield strength**, will cause a permanent deformation (Boey et al. 2022). Figure 4 shows a stress-strain curve illustrating the relation of the tensile strength to the yield strength.

The deformation of the sample caused by the application of a force equal to the yield strength and the tensile strength is given by the **percent elongation at yield** and **percent elongation at break**, respectively. These metrics are obtained from the ratio of the change in length to the original length. The resistance of the polymer to elastic deformation is described by the **Young's modulus** (or **modulus of elasticity**) which is the ratio of the applied stretching force per unit area to the resulting axial strain (or deformation). The **toughness** of the material provides a measure of the energy of the material upon its breakage. These properties are estimated from parameters presented in a strain-vs-stress plot, as shown in Figure 4.

Tensile testing (or tension testing) is among the basic methods for the characterization of plastic materials. It involves subjecting the test material to a tensile force and quantifying the response of the specimen. The standard test methods for measuring these mechanical properties are ASTM D638 test method and the ISO 527-1:2019 test method (ASTM 2023; ISO 2019).

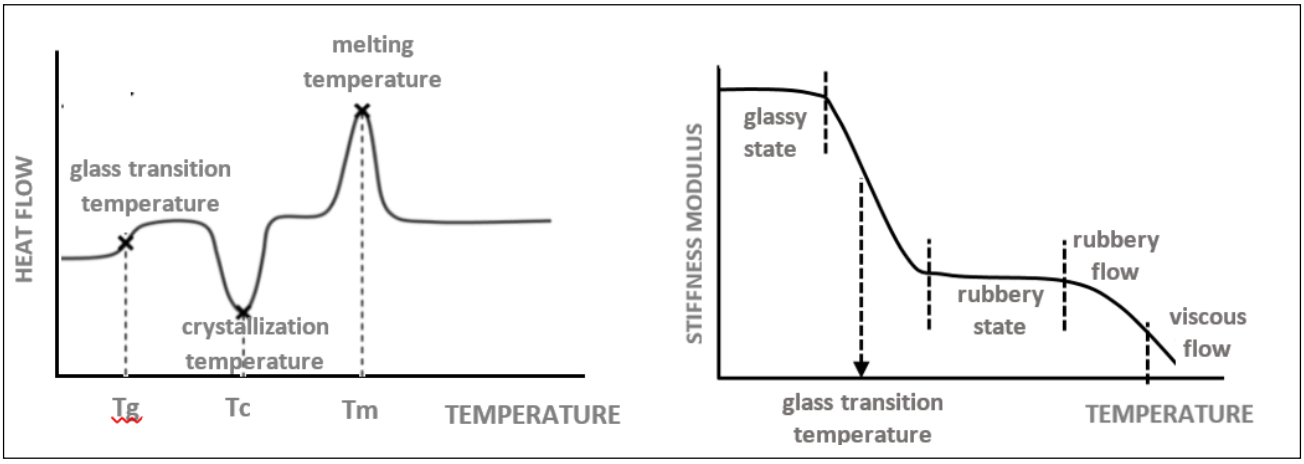

Figure 3. (A) DSC plot and (B) DMA plot showing the glass transition temperature.

Transactions NAST PHL Vol. 48 (2026)
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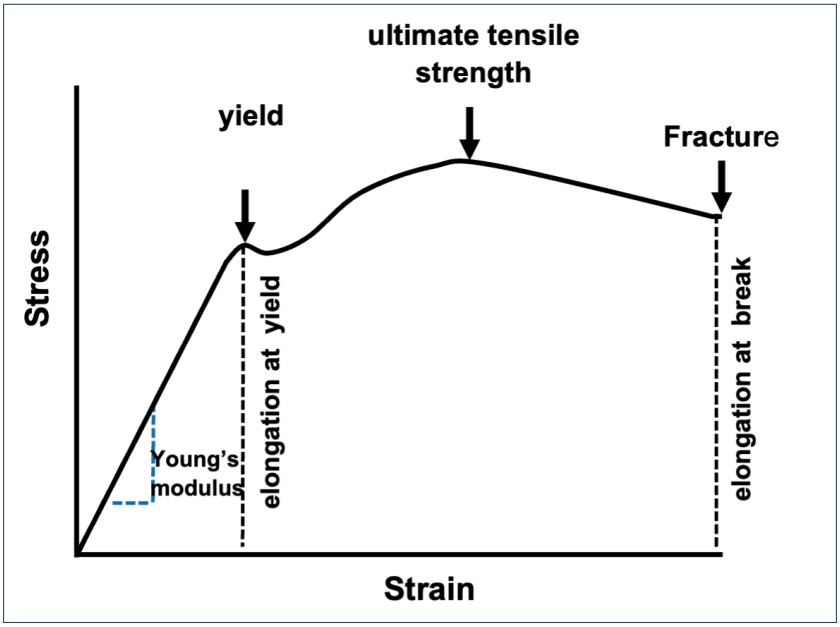

Figure 4. Strain-vs-stress plot showing the mechanical properties of a polymer.

Barrier properties. The barrier properties refer to the ability of a material to allow the passage of small molecules, such as oxygen, carbon dioxide, and water vapor through a polymer film and enter the environment on the other side of the film (Marano et al. 2022; Galic et al. 2017). These parameters indicate the resistance of the plastic material to the permeation of gases. The polymer provides a protective barrier that prevents the exposure of the enclosed material from the external environment.

A number of standard methods have been developed for the measurement of the transmission of oxygen, carbon dioxide, and water vapor through different forms of plastic (Galic et al. 2017). The standard ASTM D1434-23 test method determines the gas permeability characteristics of plastic film and sheeting through a manometric method (ASTM 2023). It describes the measurement of the steady-state transmission rate of a gas through the plastic material. The oxygen transmission rate (OTR) is covered by the standard ASTM D3985-17 test method which employ a coulometric sensor to monitor the amount of oxygen transmitted (ASTM 2023). The determination of the steady-state transmission of carbon dioxide gas (CO2TR) through an infrared detector is presented in the standard ASTM F2476-20 test method (ASTM 2023). The measurement of the transmission rate of water vapor (WVTR) is detailed in the standard ASTM E398-13 test method that is based on a dynamic relative humidity measurement technique (ASTM 2023).

FACTORS AFFECTING THE PHYSICOCHEMICAL PROPERTIES OF BIOPLASTICS

Several factors determine the physicochemical properties exhibited by bioplastics. These factors influence the arrangement of the biomolecules in the material bulk, causing modifications in the interaction among these macromolecules and affecting the properties of the bioplastic. These factors could be exploited in order to improve the performance characteristics of the bioplastics in its field of applications.

Nature of the biopolymer. The chemical nature of the biomolecule comprising the bioplastic determines the physicochemical behavior of the material. This effect is manifested in the properties of the natural sources from where the biomolecules was derived. Carbohydrates, such as cellulose and chitin, and proteins, such as keratin and gluten, provide structural framework in the biological systems where they occur.

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

These biomolecules have been utilized to contribute to the mechanical properties of some bioplastic materials (Agustin et al. 2013; El-Wakil et al. 2015).

The presence of hydrophilic functional groups in the biopolymer molecules influence the water absorption and barrier properties bioplastics, particularly those based in carbohydrates and proteins. The hydroxyl groups in the starch macromolecules have strong affinity to water, making the starch-based bioplastic highly permeable to water vapor (Garcia et al. 2009; Sanyang et al. 2015).

Plasticizers. The presence of plasticizers in plastic materials modifies significantly the mechanical properties of the polymer. These additives usually reduce the intermolecular forces between the macromolecules by disrupting the hydrogen bonding between polymer molecules, leading to a greater freedom of molecular motion and increased flexibility of the material bulk. It causes the material to be less ductile and more viscoelastic. Glycerol, sorbitol, and citrates are the common plasticizers employed in bioplastics. Maximum tensile strength is obtained at low plasticizer concentrations, beyond which a reduction in mechanical strength occurs (Sanyang et al. 2015; Sabathini et al. 2018). This behavior has been attributed to the formation of hydrogen bonds between the plasticizer and biopolymer molecules, which becomes extensive at high plasticizer concentration and causes disruption of the hydrogen bonds between the polymer macromolecules. The reduced cohesion between polymer molecules is manifested by a reduction in the tensile strength of the material.

Plasticizers also affect the barrier property of bioplastics. Plasticizers, such as glycerol and sorbitol, facilitate the passage of water vapor and oxygen molecules through the bioplastic material, due to the looser packing of the polymer molecules (Benitez et al. 2024). However, at high concentrations, glycerol was observed to behave as an anti-plasticizer in zein-based plastics, causing a decrease in oxygen permeability of the film material. This unusual behavior was attributed to a decrease in the solubility of oxygen at high glycerol concentrations (Liang et al. 2015)

Fillers. In order to produce bioplastics with improved properties, filler materials are incorporated. These additives add bulk to the product and reduces the cost of production. Clay, chitosan, carboxymethylcellulose, silica, and sodium silicate improved the tensile strength and viscosity of starch-based bioplastics (Olasinawa et al. 2022; Safitri et al. 2022). This enhancement was attributed to the formation of hydrogen bonds between the filler and the polymer. However, at high concentrations, some fillers cause a reduction in the mechanical strength due to the formation of lumps.

Natural fibers have also been incorporated as fillers in starch bioplastics. These fibers increase the mechanical properties of bioplastics by providing a reinforcement for the polymer matrix. The addition of coconut husk fiber, cotton fiber, wool fiber, jute fiber and hair fibers caused a significant effect in the tensile strength of corn starch-based bioplastics (Babalola 2019; Jethoo 2019).

Moisture content. The moisture content of the bioplastic affects the mechanical properties of the material. A high-water content relative to the biopolymer causes a decrease in the tensile strength of the material. The presence of water molecules decreases the hydrogen bonds formed between the polymer macromolecule. This effect was observed in agar-based bioplastics (Agusman et al. 2021).

The water content of the bioplastic is influenced by the presence of a plasticizer, such as glycerol. As the plasticizer content was increased, the water absorption of starch-based films also increased, causing a lowering in the tensile strength of the bioplastic. In order to obtain a mechanically durable bioplastic, the plasticizer concentration has to be optimized in order to control water absorption (Nasir et al. 2021).

COMPARISON OF PHYSICOCHEMICAL PROPERTIES OF BIOPLASTICS

The values of some physicochemical properties of the different types of bioplastics are presented in Annex 1 to 6. The materials cited in the tables include (1) carbohydrate-based bioplastics, (2) protein-based bioplastics, (3) microbial-based bioplastics, (4) algae-

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

based bioplastics, (5) polymer-based bioplastics and (6) commercial bioplastics. The tables contain information on the bioplastics, including their composites and blends.

Tensile strength. A comparison of the tensile strength of the different types of bioplastics is shown in the min-max bar graph presented in Figure 5. The protein-based bioplastics, which are derived chicken feathers, porcine plasma, and wheat, exhibited the lowest tensile strength. The carbohydrate-based bioplastics displayed tensile strengths ranging from 0.36 to 74 MPa, with the higher values (22 to 74 MPa) shown by those prepared from chitin and alginate, and the lower values and the lower values (0.36 to 36 MPa) exhibited by those prepared from starch and cellulose. The starch-based bioplastics were derived from corn, potato, cassava, sago, and kaong (*Arenga pinnata*), with the last two sources yielding high-strength materials. The tensile strength of the algae-based materials ranged from 4.7 to 95 MPa, with the higher values obtained from carrageenan and agar when combined with polymers and nanoparticles. The commercial bioplastics yielded higher values tensile strength values, their plasticizer content having been optimized. In general, the tensile strength of bioplastics is lower than the conventional fossil-based plastics. However, some bioplastics showed comparable mechanical properties to those of conventional plastics, such as high-density polyethylene (10–60 MPa), polystyrene (30–60 MPa) and polyurethane (13.79–27.58 MPa) (Bhasney et al. 2017).

Percent elongation. Figure 6 shows a min-max bar graph of the percent elongation at break exhibited by the different types of bioplastics. The polymer-based bioplastics and the commercial bioplastics, which are mostly polymer-based, exhibited a percent elongation of over 100%. The polymers employed in these materials are polylactic acid (PLA) and polybutylene adipate terephthalate (PBAT). The high elongation percentage indicates that the material could be stretched to several times its original length before it breaks. Some of the algae-based bioplastics also showed an elongation of over 100%. The values of the percent elongation of the carbohydrate-based and the protein-based bioplastic were low, as low as 1% for some of the materials. Several conventional plastics, such as polyvinyl chloride (25%) polyethylene terephthalate (30%) and polystyrene (1%), have values in the same range as those exhibited by bioplastics.

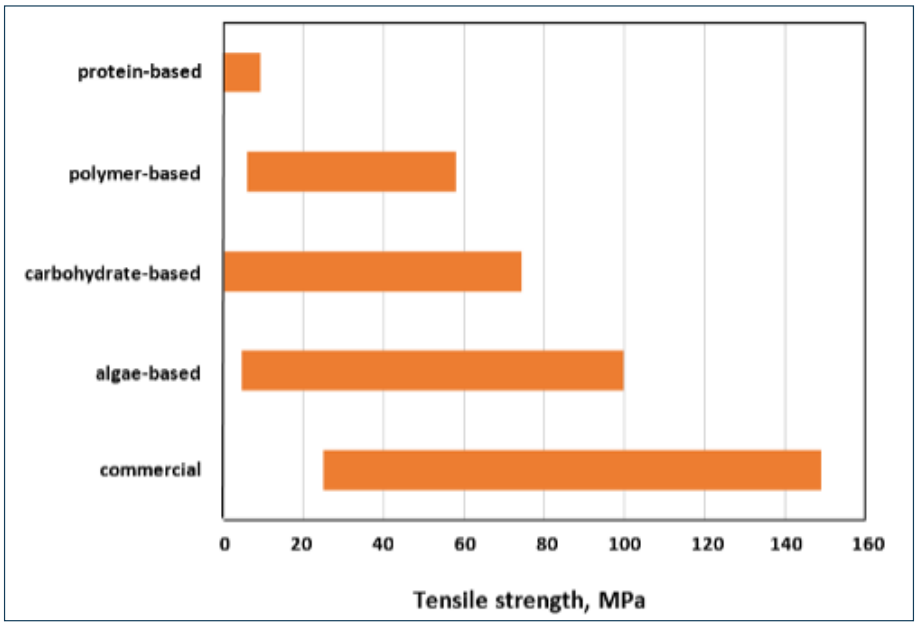

Figure 5. Comparison of the tensile strength of the different types of bioplastics.

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

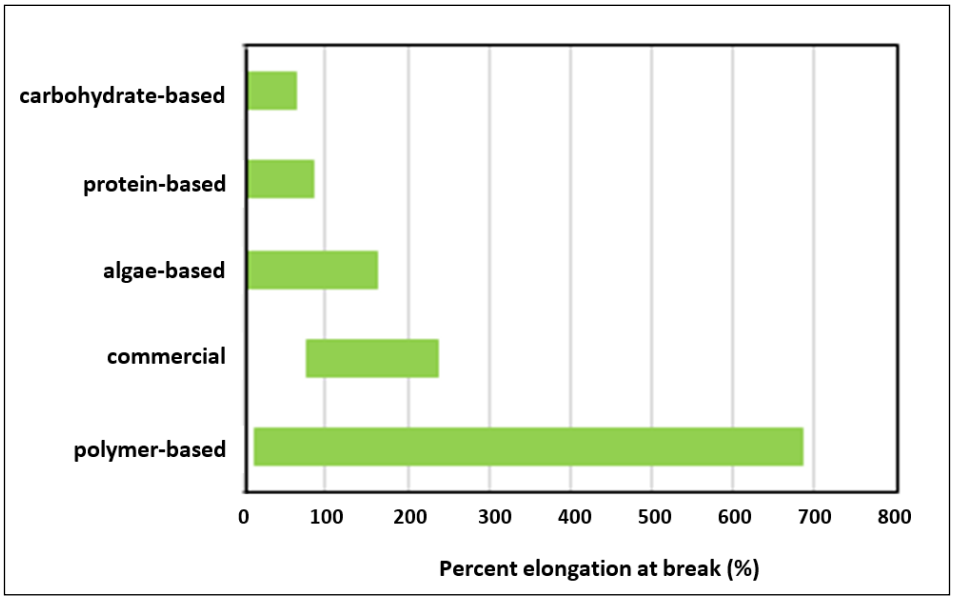

Figure 6. Comparison of the percent elongation at break of the different types of bioplastics.

Barrier properties. Table 1 presents the very limited information obtained for barrier properties the different types of bioplastics. Most of the work on bioplastics seem to focus on the characterization of the mechanical properties, and few measured the barrier properties. The starch-based bioplastics had poor barrier properties to water vapor and oxygen, indicating the permeability of the materials to these gases. The cellulose-based and algae-based bioplastics had high barrier properties to water vapor, preventing the passage of water through layer of these materials. The common plastics exhibit varied values of barrier properties to water vapor, such as polyethylene (86 g µm m^{-2} day^{-1} kPa^{-1}) which has a low permeability to water vapor, and polyvinyl alcohol (42,000 g µm m^{-2} day^{-1} kPa^{-1}) which is highly permeable to water vapor.

STANDARDS FOR PHYSICOCHEMICAL PROPERTIES OF BIOPLASTICS

Standards are established by industrial stakeholders to ensure the authenticity and quality of products, services and processes. These are guidelines that define the technical specifications for the acceptability of a product or material. The standards also describe the test methods for the measurement of the specified parameters (European Bioplastics 2023).

Standards for bioplastics have been created by the International Organization for Standardization (ISO), the European Committee for Standardization (CEN) and the American Society for Testing and Measurement (ASTM) (Melchor-Martinez 2022). National standards for bioplastics have been established in some countries, such as the United Kingdom, Austria, Germany, and Mexico, mirroring the ISO standards. These standards focused on the composition, biodegradability and composability of bioplastics using specific techniques and conditions.

Several standards exist for the measurement of the bio-based carbon content of bioplastics (Kunioka 2013). The ASTM standard D6866-12 specifies two methods for the determination of bio-based or biogenic carbon through the measurement of radiocarbon using accelerator mass spectroscopy (AMS) with isotope ratio mass spectrometry (IRMS) and liquid scintillation counter (LSC). This standard is harmonized with the ISO standard 16620-2. The CEN standard TS16137 describes the evaluation of the bio-based carbon content of plastics through the measurement of radiocarbon using the proportional scintillation counter (PSM) method, beta-ionization (BI) technique and accelerator mass spectrometry.

For the other physicochemical properties of

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Table 1. Barrier classification of bioplastics to water vapor and oxygen. Adapted from Wang et al. (2018).

Grade	Water vapor permeability (g µm m-2 day-1kPa-1)	Bioplastic	Oxygen permeability (cm3µm m-2 day-1 atm-1)	Bioplastic
Poor	>3000	Starch-based	>40000	Starch-based Cellulose-based
Low	1000-3000	-	4000-40000	-
Medium	400-1000	-	400-4000	-
High	40-400	Protein-based Algae-based	40-400	-
Very high	<40	Cellulose-based	40	-

bioplastics, ISO, and ASTM standards for the conventional plastic are commonly adopted. These standards encompass product quality and the materials' performance according to their tensile strength, elongation, Young's modulus, water vapor permeability, and oxygen permeability (Pilla 2011).

Some countries have specified values for standards for mechanical properties. The Japanese Industrial Standard JIS-1707 specifies a tensile strength value of 0.3923 MPa and an elongation value of at least 70% (Sani et al. 2023). The Indonesia National Standard SNI 7818:2014 has set for biodegradable plastics a minimum of 1.37 MPa as the quality standard for tensile strength and 400–-1,220% as the quality standard for elongation at break (Badan Standarisasi Nasional 2014).

CONCLUSION

Biodegradable bioplastics present a green alternative to fossil-based plastics in many fields of applications. However, their usefulness as a replacement to the conventional plastics is dependent on their physicochemical properties, such as mechanical strength, water resistance and transparency. Terrestrial, marine and microbial sources of bioplastics have been explored, but their characteristics have limited their applications. The evaluation of their properties, particularly the mechanical, thermal and barrier properties, is critical in deciding the suitability of the bioplastic for its intended use. This information could also be useful in determining the authenticity of a bioplastic product and establishing the application of these materials, such as in packaging, agriculture and consumer products.

Acknowledgements:

This paper was completed through a Commissioned Paper Grant from the National Academy of Science and Technology Philippines, under its Special Concern Program – Technical Working Group on Bioplastics

Contributions of authors:

The conceptualization of the paper was done by FSIII, and the succeeding phases in the finalization of the paper (including collation and representation of the information, analysis and discussion of the information, writing and finalizing the draft) were carried out jointly by the two authors. The authors read and approved the final manuscript.

Declaration of conflict of author:

The authors declare no conflict of interest in the conduct of the study.

Declaration of the use of AI:

The author did not employ generative artificial intelligence in the preparation of this paper.

The authors approve the publication of this paper.

Transactions NAST PHL Vol. 48 (2026)
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doi.org/10.57043/transnastphl.2026.0000

Annex 1. Physicochemical properties of carbohydrate-based bioplastics.

Source	Tensile Strength (MPa)	Elongation		Young's Modulus (MPa)	WVP g µm/ (m^2 day kPa)	OP cm^3.µm/ m^2.day.kPa	Reference
		At Break (%)	At Maximum Load (%)				
Cassava Starch/ Glycerol	1.70	5.13	3.50	47.86	-	-	Mojibayo et al. 2020
Potato Starch	2.60	47.0	-	-	-	-	Park et al. 2003
Potato Starch/ 5% Sodium MMT/ Glycerol	3.30	57.2	-	-	-	-	
Potato Starch/ 10% Cloisite 30B/ Glycerol	3.00	45.7	-	-	-	-	
Corn Starch/ Glycerin	5.00 (1.0)	31 (11)		125 (4)	-	-	de Carvalho et al. 2001
Corn Starch/ 50 % Kaolin/Glycerin	7.4 (0.3)	14 (1)		293 (16)	-	-	
Unfilled Cassava Starch/ Glycerol	-	-	-	38.0	39,000	-	Garcia et al. 2009
Cassava Starch/ Maize Starch Nanocrystals/ Glycerol	-	-	-	147	23,000	-	
Arenga pinnata Starch/ 15% Glycerol	9.59	26.52	-	-	50,000	-	Sanyang et al. 2015
Arenga pinnata Starch/ 30% Glycerol	2.64	61.63	-	-	57,000	-	
Arenga pinnata Starch /45% Glycerol	1.67	28.39	-	-	75,000	-	
Arenga pinnata Starch/ 15% Sorbitol	28.35	5.38	-	-	41,000	-	
Arenga pinnata Starch/ 30% Sorbitol	11.79	34.5	-	-	50,000	-	

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Source	Tensile Strength (MPa)	Elongation		Young's Modulus (MPa)	WVP g µm/ (m^2 day kPa)	OP cm^3.µm/ m^2.day.kPa	Reference
		At Break (%)	At Maximum Load (%)				
Arenga pinnata Starch/ 45% Sorbitol	5.84	~50.0	-	-	53,000	-	
Arenga pinnata Starch/ 15% Gly-Sorbitol	15.82	15.1	-	-	48,000	-	
Arenga pinnata Starch/ 30% Gly-Sorbitol	7.79	46.65	-	-	54,000	-	
Arenga pinnata Starch/ 45% Gly-Sorbitol	3.99	34.27	-	-	73,000	-	
Sago Starch/ 30 w/w% Glycerol	23.06	-	-	-	-	-	Zuraida et al. 2012
Sago Starch/ 30 w/w% Glycerol/ 0 wt% Water	3.29	-	-	-	-	-	
Sago Starch/ 30 w/w% Glycerol/ 30 w/w% Citric Acid	24.76	-	-	-	-	-	
Sugar Cane Bagasse/ Tapioca Starch/ Glycerol	2.5 (0.3)	7.12	-	82.03	-	-	Asrofi et al. 2020
0% Methylated cornstarch/PVA	~32	~350	-	-	-	-	Guohua et al. 2006
35% Methylated cornstarch/PVA	~18	~190	-	-	-	-	
Corn starch/ Glycerol	35.7	0.33	-	2233	17,000	1.6×10^6	Fabra et al. 2017
Corn starch/ *Nanno-cloropsis gaditana*/ Glycerol	24.0	1.5	-	2056	11,000	7.9×10^5	
Cassava starch w/ 0% coconut fiber content/ Glycerin	0.36	-	-	2.67	-	-	Babalola & Olorunnisola. 2019

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Source	Tensile Strength (MPa)	Elongation		Young's Modulus (MPa)	WVP g µm/ (m^2 day kPa)	OP cm^3.µm/ m^2.day.kPa	Reference
		At Break (%)	At Maximum Load (%)				
Cassava starch w/ 10% coconut fiber content/ Glycerin	0.68	-	-	4.91	-	-	
Cassava starch w/ 20% coconut fiber content/ Glycerin	0.37	-	-	3.32	-	-	Babalola & Olorunnisola. 2019
100 w/w Chitin film	63.1 (4.4)	7.2 (1.4)	-	-	-	-	Suyatma et al. 2005
95 w/w Chitin/ 5 w/w Glycerol	59.5 (4.4)	19.1 (2.8)	-	-	-	-	
60 w/w Chitin/							
40 w/w Glycerol	22.0 (2.2)	84.2 (6.2)	-	-	-	-	
95 w/w Chitin/ 5 w/w Ethylene glycol	53.7 (3.7)	16.8 (1.2)	-	-	-	-	
60 w/w Chitin/							
40 w/w Ethylene glycol	33.2 (3.6)	67.0 (5.3)	-	-	-	-	
95 w/w Chitin/ 5 w/w Polyethylene glycol	65.1 (1.4)	12.1 (1.8)	-	-	-	-	
60 w/w Chitin/ 40 w/w Polyethylene glycol	36.6 (2.5)	79.7 (6.7)	-	-	-	-	
95 w/w Chitin/ 5 w/w Propylene glycol	74.2 (1.7)	6.4 (0.6)	-	-	-	-	
100 w/w Chitin film	65.4 (5.7)	4.7 (0.5)	-	-	-	-	
95 w/w Chitin/ 5 w/w Glycerol	64.2 (2.7)	8.8 (1.8)	-	-	-	-	
60 w/w Chitin/							
40 w/w Glycerol	12.6 (2.4)	33.9 (5.9)	-	-	-	-	
95 w/w Chitin/ 5 w/w Ethylene glycol	60.8 (4.3)	9.4 (3.8)	-	-	-	-	
60 w/w Chitin/40 w/w Ethylene glycol	49.1 (4.1)	24.6 (4.9)	-	-	-	-	

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Source	Tensile Strength (MPa)	Elongation		Young's Modulus (MPa)	WVP g µm/ (m^2 day kPa)	OP cm^3.µm/ m^2.day.kPa	Reference
		At Break (%)	At Maximum Load (%)				
95 w/w Chitin/ 5 w/w Polyethylene glycol	61.0 (6.0)	12.4 (1.3)	-	-	-	-	
60 w/w Chitn/ 40 w/w Polyethylene glycol	22.9 (2.1)	53.6 (2.9)	-	-	-	-	
95 w/w Chitin/ 5 w/w PPG (20-week storage)	69.8 (2.9)	4.3 (0.6)	-	-	-	-	
60 w/w Chitin/ 40 w/w Propylene glycol	69.8 (2.9)	4.3 (0.6)	-	-	-	-	
60 w/w Chitin/ 40 w/w Propylene glycol	49.6 (6.8)	7.0 (0.4)	-	-	-	-	
PVA	42	152	-	500	-	-	Eghbalifam et al. 2015
PVA/Sodium alginate, SA	45	56	-	710	-	-	
PVA/SA/1.33% Ag+ (5 dose)	36	42	-	570	-	-	
PVA/SA/1.33% Ag+ (12 dose)	38	25	-	610	-	-	
PVA/SA/1.33% Ag+ (15 dose)	47	22	-	650	-	-	
Carrot Waste/ Pectin & Sugar	38 (5)	~6	-	1300 (0.2)	-	$9.1x10^4$ (Pure carrot); 46.8 (Pure PVA); 31.2 (carrot: PVA blend)	Perotto et al. 2018
Radicchio Waste/ Pectin & Sugar	~4	~5	-	~220	-	-	
Parsley Waste/ Pectin & Sugar	~7	~10	-	~190	-	-	

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Source	Tensile Strength (MPa)	Elongation		Young's Modulus (MPa)	WVP g µm/ (m^2 day kPa)	OP cm^3.µm/ m^2.day.kPa	Reference
		At Break (%)	At Maximum Load (%)				
Cauliflower Waste/Pectin & Sugar	~11	~4	-	~460	-	-	
Garlic stalk: CNC (100:5)	15.60	-	-	439.6	-	-	Agustin et al. 2013
Rice straw: CNC (100:10)	26.80	-	-	898.0	-	-	
100% Cocoa pod husk)/Glycerol/ Sorbitol	-	-	-	-	2.4	-	Azmin et al. 2020
25% Cocoa pod husk 75% Sugarcane bagasse fiber/ Glycerol/Sorbitol	-	-	-	-	3.2	-	
100% Sugarcane bagasse fiber/ Glycerol/Sorbitol	-	-	-	-	3.7	-	
100% Rice straws/ Glycerol	10.0 (0.5)	33.1 (2.6)	-	327 (52)	-	-	Agustin et al. 2013; Agustin et al. 2014
100% Rice straws/ 5% CMC/Glycerol	14.0 (1.5)	23.1 (2.4)	-	504 (26)	-	-	
100% Rice straws/ 15% CMC/Glycerol	26.0 (1.2)	3.6 (0.4)	-	896 (51)	-	-	
Wheat Gluten/0% CMC/Glycerol	-	~27.5	-	-	138	-	El-Wakil et al. 2015
Wheat Gluten/2.5% CMC/Glycerol	-	~40.0	-	-	~112	-	
Wheat Gluten/7.5% CMC/Glycerol	-	~50.0	-	-	~121	-	
Wheat Gluten/12.5% CMC/Glycerol	-	~80.0	-	-	~86.4	-	

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Source	Tensile Strength (MPa)	Elongation		Young's Modulus (MPa)	WVP g µm/ (m^2 day kPa)	OP cm^3.µm/ m^2.day.kPa	Reference
		At Break (%)	At Maximum Load (%)				
Wheat Gluten/0% TiO2 NP/Glycerol	-	~10.0	-	-	~121	-	
Wheat Gluten/0.2% TiO2 NP/Glycerol	-	~16.0	-	-	~112	-	
Wheat Gluten/0.6% TiO2 NP/Glycerol	-	~34.0	-	-	~104	-	
Wheat Gluten/1.0% TiO2 NP/Glycerol	-	~31.0	-	-	~104	-	

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Annex 2. Physicochemical properties of protein-based bioplastics.

Source	Tensile Strength (MPa)	Elongation		Young's Modulus (MPa)	WVP $cm^3.\mu m/m^2.day.kPa$	OP $cm^3.\mu m/m^2.day.kPa$	Reference
		At Break (%)	At Maximum Load (%)				
Wheat Gluten/ Glycerol	~0.75 (Extrusion)	-	~2.50	~19.9	-	-	Jiménez-Rosado et al. 2019
Wheat Gluten/ Glycerol	~1.60 (Compression Molding)	-	~1.50	~5.90	-	-	
Wheat Gluten/ Glycerol	~1.25 (Extrusion)	-	~2.50	~14.9	-	-	
Wheat Gluten/ Glyoxal/Glycerol	~0.50 (Extrusion)	-	~0.750	~20.0	-	-	
Wheat Gluten/ Xanthan Gum/ Glycerol	~0.75 (Extrusion)	-	~0.800	~17.5	-	-	
Keratin Protein (Chicken Feathers)/ Glycerol	~0.300 At 0 wt% Glycerol	-	-	~24.00	-	-	Ramakrishnan et al. 2018
	~0.100 At 5 wt% Glycerol	-	-	~18.75	-	-	
Alkali treated chicken feathers/ Glycerol	7.8 (1.2)	17.6 (7.3) At 3-min comp. time	-	242 (80)	-	-	Reddy et al. 2013
	7.1 (0.8)	36.7 (8.5) At 7-min comp. time	-	158 (42)	-	-	
Alkali treated chicken feathers/ Glycerol	9.0 (0.8)	3.8 (0.8) At 130°C comp. time	-	434 (32)	-	-	
	5.9 (0.8)	31.7 (6.4) At 175°C comp. time	-	136 (23)	-	-	
0.05% alkali treated chicken feathers	5.9 (0.8)	10.1 (2.5)	-	214 (23)	-	-	

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Source	Tensile Strength (MPa)	Elongation		Young's Modulus (MPa)	WVP $cm^3.\mu m/m^2.day.kPa$	OP $cm^3.\mu m/m^2.day.kPa$	Reference
		At Break (%)	At Maximum Load (%)				
0.05% alkali treated chicken feathers	5.9 (0.8)	10.1 (2.5)	-	214 (23)	-	-	
0.25% alkali treated chicken feathers	4.4 (0.6)	20.4 (4.5)	-	107 (16)	-	-	
Alkali treated chicken feathers w/ 0% citric acid	5.9 (0.8) At 65% R.H	31.7 (6.4)	-	136 (23)	-	-	
Alkali treated chicken feathers w/ 5% citric acid	5.5 (0.7) At 65% R.H	11.3 (6.8)	-	230 (73)	-	-	
Alkali treated chicken feathers w/ 0% citric acid	0.7 (0.2) At 90% R.H	26.8 (6.1)	-	3.6 (0.5)	-	-	
Alkali treated chicken feathers w/ 2% citric acid	1.8 (0.2) At 90% R.H	24.6 (6.2)	-	18.1 (3.7)	-	-	
1.80 wt% cyano-ethylated chicken feathers/Glycerol	4.2 (1.5)	5.8 (2.1)	-	197 (103)	-	-	Reddy et al. 2011
3.63 wt% cyano-ethylated chicken feathers/Glycerol	1.6 (0.5)	14.2 (4.1)	-	23 (7)	-	-	
50:50 Porcine plasma protein (PPP)/Glycerol	~0.20	-	-	~2.90	-	-	Alvarez-Castillo et al. 2019
55:45 PPP/ Glycerol	~0.43	-	-	~8.13	-	-	
60:40 PPP/ Glycerol	~0.52	-	-	~12.2	-	-	

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Annex 3. Physicochemical properties of microbial-based bioplastics.

Source	Tensile Strength (MPa)	Elongation		Young's Modulus (MPa)	WVP $cm^3.\mu m/m^2.day.kPa$	OP $cm^3.\mu m/m^2.day.kPa$	Reference
		At Break (%)	At Maximum Load (%)				
Crude Palm Kernel Oil/ *Cupriavidus necator* P(3HB-co-32% 3HHx)	8 (1)	856 (21)	-	101 (6)	-	-	Wong et al. 2012
Crude Palm Kernel Oil/ *Cupriavidus necator* P(3HB-co-43% 3HHx)	5 (1)	481 (47)	-	75 (9)	-	-	
Crude Palm Kernel Oil/ *Cupriavidus necator* P(3HB-co-60% 3HHx)	<1 (1)	1075 (158)	-	<1 (0)	-	-	
Poly(3-Hydroxy-butyrate), P(3HB)	40	5	-	3500	-	-	Khanna & Srivastava et al. 2005
P93HB-co-3HV), 3% mol Hydroxy-valerate (3HV)	38	-	-	2900	-	-	
P(3HB-co-3HV) 25% mol 3HV	30	-	-	700	-	-	
P(3HB-co-4HB), 3% mol 4HB	28	45	-	-	-	-	
P(3HB-co-4HB), 90% mol 4HB	65	1080	-	100	-	-	
P(4HB)	104	1000	-	149	-	-	
P(3-HHx-co-3HO), 3-Hydroxy-octanoate	10	300	-	-	-	-	
P(3HB-co-3HHx)	20	850	-	-	-	-	

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Annex 4. Physicochemical properties of algae-based bioplastics.

Source	Tensile Strength (MPa)	Elongation		Young's Modulus (MPa)	WVP $cm^3.\mu m/m^2.day.kPa$	OP $cm^3.\mu m/m^2.day.kPa$	Reference
		At Break (%)	At Maximum Load (%)				
Wheat Gluten/ 35% Glycerol	2.6 (0.3)	120.6 (13.7)	-	44.1 (8.9)	-	-	Ciapponi et al. 2019
Wheat Gluten/ *Spirulina platensis*/ 35% Glycerol	5.1 (0.7) At 20 php	57.3 (13.0)	-	217.6 (41.3)	-	-	
	6.5 (1.2) At 30 php	29.8 (5.4)	-	307.0 (45.8)	-	-	
Wheat Gluten/ 35% 1,4-butanediol	3.3 (0.4)	105.2 (13.8)	-	36.5 (9.0)	-	-	
Wheat Gluten/ *Spirulina platensis*/ 35% 1,4-butanediol	4.2 (0.6) At 10 php	82.1 (10.5)	-	51.5 (11.3)	-	-	
	4.7 (0.5) At 20 php	60.7 (14.6)	-	94.0 (28.3)	-	-	
	4.9 (0.9) At 30 php	22.2 (7.8)	-	273.1 (59.0)	-	-	
Chlorella vulgaris	5.7	-	-	270	-	-	Zeller et al. 2013
Chlorella vulgaris/ *Glycerol*	1.6	-	-	53	-	-	
Spirulina platensis	3.0	-	-	249	-	-	
Spirulina platensis/Glycerol	1.9	-	-	98	-	-	
Spirulina platensis/ PVAl & Maleic anhydride/ Glycerol	2.77 At 25 wt%	59.2	-	-	-	-	Gozan & Noviasari. 2018
	2.72 At 30 wt%	66.0	-	-	-	-	
Chlorella vulgaris/ PVA/ Glycerol/ Water	2.040 (0.1471)	159.60 (35.75)	-	-	-	-	Sabathini et al. 2018
			-	-	-	-	
Polypropylene/ Starch/ *Spirulina*/ Glycerin	19.45	34.8	-	1178.95	-	-	Shi et al. 2012
Pro-fax SV954 w/ *Spirulina*/ Glycerin	24.22	9.63	-	1652.65	-	-	
Polypropylene/ *Nanno-Chloropsis*/ Starch/Glycerin	17.11	9.36	-	1028.62	-	-	

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Source	Tensile Strength (MPa)	Elongation		Young's Modulus (MPa)	WVP $cm^3.\mu m/m^2.day.kPa$	OP $cm^3.\mu m/m^2.day.kPa$	Reference
		At Break (%)	At Maximum Load (%)				
Chlorella w/o poly-ethylene modification	24.40 (0.08) At 0 wt%	-	-	-	-	-	Zhang and Kabeya 1999
	19.96 (0.27) At 10 wt%	26.3 (0.2)	-	360 (20)	-	-	
20% *Chlorella* w/ 80% PVC	34.6	1.86	-	-	-	-	Zhang et al. 2000
PVC w/ KM-55 stabilizer	50.2	180	-	-	-	-	
Spirulina w/ PLA	95.52 (1.93)	4.47 (0.05)	-	3310 (50)	-	-	Simonic and Zemljic. 2021
95% PLA/5% Algal	81.16 (0.48)	3.88 (0.15)	-	3280 (63)	-	-	
90% PLA/ 10% Algal	69.46 (0.98)	2.91 (0.51)	-	3310 (75)	-	-	
95% PLA/ 5% *Spirulina*	62.47 (7.26)	2.32 (0.56)	-	3320 (65)	-	-	
90% PLA/ 10% *Spirulina*	77.23 (2.78)	3.55 (0.56)	-	3370 (44)	-	-	
PBS	33.3 (0.4)	14.2 (2.14)	-	583 (5)	-	-	Toro et al. 2013
PBS (20)/ *Botryococcus braunii* (80)	21.6 (0.7)	8.6 (0.80)	-	689 (14)	-	-	
PBS (30)/ *Coccus braunii* (70)	18.7 (1.0)	7.6 (0.58)	-	780 (16)	-	-	
PBAT	~20.5	~625	-	~49.0	-	-	Torres et al. 2015
PBAT (80)/ *Nanno-Chloropsis gaditana* (20)	~10.0	~380	-	~90.0	-	-	
PBAT (70)/ *Nanno-Chloropsis gaditana* (30)	~8.0	~280	-	~118.0	-	-	
PBAT (76)/ *Nanno-Chloropsis gaditana* (24)/ Glycerol	~8.9	~460	-	~55.0	-	-	

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Source	Tensile Strength (MPa)	Elongation		Young's Modulus (MPa)	WVP $cm^3.\mu m/m^2.day.kPa$	OP $cm^3.\mu m/m^2.day.kPa$	Reference
		At Break (%)	At Maximum Load (%)				
PBAT (73)/ *Nanno-Chloropsis gaditana* (24)/ Glycerol	~9.0 At 10 phr water	~460	-	~65.0	-	-	
PBAT (71)/ *Nanno-Chloropsis gaditana* (29)/ Glycerol	~7.5 At 10 phr water & 15 phr urea	~325	-	~60.0	-	-	
PBAT (68)/ *Nanno-Chloropsis gaditana* (32)/ Glycerol	~7.0 At 10 phr water & 30 phr urea	~275	-	~92.0	-	-	
Carra-geenan based bio-nano-composite films (C1)	7.30	1.00	-	-	-	-	Sudhakar et al. 2022
Carra-geenan w/ ZnO nanoparticle (S1)	9.10	4.60	-	-	-	-	
Carra-geenan w/ CuO nanoparticle (S2)	10.40	4.60	-	-	-	-	
Carra-geenan w/ SiO_2 Nanoparticle (S3)	7.80	2.00	-	-	-	-	
Kappa-phycus nano-composite films (C2)	4.80	1.11	-	-	-	-	
Kappa-phycus w/ ZnO nanoparticle	8.10	6.00	-	-	-	-	
Kappa-phycus w/ CuO nanoparticle	7.00	5.30	-	-	-	-	
Kappa-phycus w/ SiO_2 nanoparticle	5.40	3.50	-	-	-	-	
30% *Ulva sp.* w/ 70% Polypropylene	22	-	7	-	-	-	Hassan et al. 2008

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Source	Tensile Strength (MPa)	Elongation		Young's Modulus (MPa)	WVP $cm^3.\mu m/m^2.day.kPa$	OP $cm^3.\mu m/m^2.day.kPa$	Reference
		At Break (%)	At Maximum Load (%)				
20% *Entero-morpha* crinite w/ 80% Poly-Propylene	42.9	-	-	-	-	-	Jang et al. 2013
Spirulina sp. / PVA	26	-	45	610	-	-	Shi et al. 2017
Ulva sp./ *Plantago ovata*/ Polyethylene glycol	-	27.16	-	46.62 (2.4) at 32°C	-	-	El Semary et al. 2022
	-	46.04	-	42.83 (1.9) at 35°C	-	-	
	-	45.50	-	44.85 (21) at 40°C	-	-	
Carrageenan	57.0 (4.6)	4.4 (0.3)	-	3300 (10)	149,000	-	Roy et al. 2019
Carrageenan/ 0.075 wt% AgNP	74.4 (1.1)	6.8 (0.5)	-	2700 (20)	188,000	-	
Carrageenan/ 0.3 wt% AgNP	49.8 (3.4)	16.1 (0.2)	-	1330 (20)	255,000	-	
Carrageenan	40.9 (4.4)	8.0 (2.9)	-	1394 (211)	143,000	-	Saedi et al. 2020
Carrageenan/ Sulfur NP (elemental sulfur)	40.8 (4.6)	8.8 (1.7)	-	1285 (153)	111,000	-	
Carrageenan/ Sulfur NP (sodium thiosulfate)	42.9 (4.7)	8.1 (2.8)	-	1365 (199)	118,000	-	
Agar	40.3 (4.0)	19.4 (4.2)	-	1390 (230)	172,000	-	Shankar and Rhim, 2017
Agar/lignin	44.1 (3.6)	16.1 (4.3)	-	1480 (130)	165,000	-	
Agar/lignin/0.5 wt% AgNP	45.5 (4.6)	16.2 (5.1)	-	1490 (150)	148,000	-	
Agar/lignin/1.0 wt% AgNP	49.7 (3.3)	16.7 (4.7)	-	1600 (80)	135,000	-	
Agar/lignin/1.5 wt% AgNP	47.0 (3.5)	16.2 (3.4)	-	1520 (230)	144,000	-	

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Annex 5. Physicochemical properties of polymer-based bioplastics.

Source	Tensile Strength (MPa)	Elongation		Young's Modulus (MPa)	WVP $cm^3.\mu m/m^2.day.kPa$	OP $cm^3.\mu m/m^2.day.kPa$	Reference
		At Break (%)	At Maximum Load (%)				
Polypro-pylene	34.5	400	-	1700	-	-	Khanna & Srivastava. 2005
Polyethylene-terepthalate	56	7300	-	2200	-	-	
Polystyrene	50	-		3100	-	-	
LDPE	10	620	-	200			
PLA-A	52.4	15.1	-	-	-	-	Ji et al. 2013
PLA-A1	12.8	76.4	-	-	-	-	
PLA-A2	17.0	52.0	-	-	-	-	
PLA-A3	11.9	44.3	-	-	-	-	
PLA-A4	13.6	88.6	-	-	-	-	
PLA-B	45.4	3.6	-	-	-	-	
PLA-B1	9.1	58.1	-	-	-	-	
PLA-B2	13.3	48.0	-	-	-	-	
PLA-B3	11.3	34.7	-	-	-	-	
PLA-B4	10.5	60.1	-	-	-	-	
PLA-C	46.5	12.1	-	-	-	-	
PLA-C1	6.4	54.4	-	-	-	-	
PLA-C2	9.7	33.0	-	-	-	-	
PLA-C3	11.4	55.8	-	-	-	-	
PLA-C4	6.4	55.4	-	-	-	-	
PLA-C5	11.3	55.3	-	-	-	-	
PLA-C6	5.6	31.3	-	-	-	-	
PLA-C7	3.4	25.7	-	-	-	-	
PLA-D	49.0	9.8	-	-	-	-	
PLA-D2	8.3	48.1	-	-	-	-	
PLA-D3	5.8	34.1	-	-	-	-	
Starch-PBAT based blends MD	20	287	-	-	-	-	Jian et al. 2020
Starch-PBAT based blends TD	18	532	-	-	-	-	
PLA-PBAT based blends MD	22	258	-	-	-	-	

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Source	Tensile Strength (MPa)	Elongation		Young's Modulus (MPa)	WVP $cm^3.\mu m/m^2.day.kPa$	OP $cm^3.\mu m/m^2.day.kPa$	Reference
		At Break (%)	At Maximum Load (%)				
PLA-PBAT based blends TD	29	241	-	-	-	-	
PBAT	21	670	-	-	-	-	

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Annex 6. Physicochemical properties of commercial bioplastics.

Source	Tensile Strength (MPa)	Elongation		Young's Modulus (MPa)	WVP $cm^3.\mu m/m^2.day.kPa$	OP $cm^3.\mu m/m^2.day.kPa$	Reference
		At Break (%)	At Maximum Load (%)				
PLA by NatureWorks (50 µm green algae)	~66 At 0 wt%	-		~2600	-		Bulota and Budtova. 2015
	~60 At 2 wt%	-		~1800	-		
	~30 At 40 wt%	-		~3400	-		
PLA (50 µm brown algae	~66 At 0 wt%	-		~2600	-		
	~60 At 2 wt%	-		~1400	-		
	~29 At 40 wt%	-		~2800	-		
PLA (50 µm red algae)	~66 At 0 wt%	-		~2600	-		
	~59 At 2 wt%	-		~1500	-		
	~28 At 40 wt%	-		~2400	-		
PLA (200-400 µm green algae)	~65 At 0 wt%	-		~2600	-		
	~59 At 2 wt%	-		~2400	-		
	~32 At 40 wt%	-		~3700	-		
PLA (200-400 µm brown algae)	~65 At 0 wt%	-		~2600	-		
	~59 At 2 wt%	-		~1600	-		
	~29 At 40 wt%	-		~2700	-		
PLA (200-400 µm red algae)	~65 At 0 wt%	-		~2600	-		
	~60 At 2 wt%	-		~2400	-		
	~28 At 40 wt%	-		~2900	-		

Transactions NAST PHL Vol. 48 (2026)
doi.org/10.57043/transnastphl.2026.0000

Source	Tensile Strength (MPa)	Elongation		Young's Modulus (MPa)	WVP $cm^3.\mu m/m^2.day.kPa$	OP $cm^3.\mu m/m^2.day.kPa$	Reference
		At Break (%)	At Maximum Load (%)				
PLA 3010D by Nature Works	53	-	-	3500	-	-	Drumright et al. 2000
PLA 2000D by Nature Works	48	-	-	-	-	-	
D7340-R (Durabio) by Mitsubishi Chemical Group	78	77	-	2700	-	-	Mitsubishi Chemical. (n.d.)
D6350-R (Durabio)	70	110	-	2500	-	-	
D5380-R (Durabio)	64	130	-	2300	-	-	
D5360-R (Durabio)	63	115	-	2050	-	-	
Luminy L105 by Total Energies Corbion	50	≤ 5	-	-	-	-	Totalenergi-escorbion 2022
Eastman TREVA	51	21	-	-	-	-	Eastman Treva 2018