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Biodegradable Plastic Alternatives from Terrestrial Sources: Research, Technology Development, and Manufacturing in the Philippines

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ABSTRACT

Plastic pollution in the Philippines is severe, and microplastics have entered its food web, posing serious health threats. One holistic strategy to address plastic pollution is the development of a sustainable and vibrant biodegradable bioplastic industry, supported and promoted by government policies and programs, with products that can be used as alternatives to petro-based, nonbiodegradable plastics that cause massive pollution. This study reports on the status of research and technology development and manufacturing of biodegradable plastic packaging materials derived from terrestrial sources such as plants, microorganisms, and agricultural wastes in the Philippines. Various researches on bioplastics production at different institutions, their resources such as funding, availability of equipment for analysis and for upscaling, and the lack of and limited time of researchers are reported. The country's bioplastic industry remains in its early growing stage, with only two small manufacturers of bioplastics: OIKOS Sustainable Solutions and EcoNest Philippines. Both enterprises use starch pellets and technology imported from Indonesia to produce bioplastic films. Sources of cassava for the starch pellets were identified. Other local companies produce oxo-degradable plastics, which they wrongly brand as biodegradable. Policies to enhance and strengthen bioplastic research, technology development, and manufacturing using terrestrial sources in the country to be able to replace single-use plastics (SUPs) with biodegradable ones, ban oxo-degradable plastics, as well as promote proper solid waste management, involving the national and local governments, are presented.

Keywords: bioplastics, biodegradable plastics, single-use plastics, plastic pollution, biodegradability

Abbreviations: Board of Investment (BOI); Bureau of Agricultural Research (BAR); cellulose nanocrystals (CNC); cellulose acetate (CA); cellulose nanofibril (CNF); chitosan (CH); Commission on Higher Education (CHED); Department of Agriculture (DA); Department of Education (DepEd); Department of Environment and Natural Resources (DENR); Department of Science and Technology (DOST); Department of Trade and Industry (DTI); Extended Producer Responsibility (EPR); halloysite nanotubes (HNT); Forest Products Research and Development Institute (FPRDI); Industrial Technology Development Institute (ITDI); Institute of Plant Breeding (IPB); low density polyethylene (LDPE); mango kernel starch (MKS); Micro, small, medium enterprise (MSME); microcrystalline cellulose (MCC); National Academy of Science and Technology Philippines (NAST PHL); National Research Council of the Philippines (NRCP); Philippine Center for Postharvest Development and Mechanization (PhilMech); Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARRD); Philippine Council for Industry, Energy and Emerging Technology Research and Development (PCIERRD); polybutylene adipate terephthalate (PBAT); polybutylene succinate (PBS); polycaprolactone (PCL); polyethylene (PE); polyethylene terephthalate (PET); polyhydroxyalkanoates (PHA); polylactic acid (PLA); polypropylene (PP); polystyrene (PS); polyurethane (PU); polyvinyl alcohol (PVA); polyvinyl chloride (PVC); Pro-oxidant Additive Containing (PAC); single use plastics (SUP); suspended atmospheric microplastics (SAMPs); 2,2,6,6,-tetramethylpiperidine-1-oxyl (TEMPO); thermoplastic starch (TPS); University of the Philippines Diliman (UPD); University of the Philippines Los Baños (UPLB).

INTRODUCTION

Plastic pollution in the country is so pervasive that microplastics (<2 mm) have been detected even in scarcely populated lakes like Lake Yambo in San Pablo City (Natuel et al. 2023). Microplastic threads or fragments have been found in the guts of commonly eaten fish caught in Samar Sea (Hubayan et al. 2023) and in Pasig River (Espiritu et al. 2023), in bivalves harvested in Bacoor Bay (Insigne et al. 2022), and in 97% of milkfish in aquaculture ponds in Butuan Bay (Simalatan et al. 2023). Microplastic contamination has likewise been reported in selected staple consumer food products such as salt, sugar, uncooked and cooked rice, and fish sauce sold in wet markets in Metro Manila (Espiritu et al. 2024) and as suspended atmospheric microplastics (SAMPs) in ambient air in Metro Manila (Romarate et al. 2023). From these reports, we can conclude that microplastics are almost everywhere in the country's environment and pose serious threats to public health. Many review articles have been published on the effects of micro- and nanoplastic particles on health, and the more recent ones are cited herein (Abbas et al. 2025; Winiarska et al. 2024).

These microplastic particles aid in pathogen dispersal by providing a colonizable raft for organisms to adhere to, especially in aquatic systems. Other pollutants, such as heavy metals and antibiotics, also adhere to plastic surfaces, which leads to other consequences in areas where they are deposited, such as the spread of antibiotic resistance (Siddique et al. 2025).

Jambeck and co-workers (2015) ranked the Philippines third in the amount of plastic marine debris, while Meijer and co-workers (2021) ranked the Philippines first in plastic emission into the ocean due to mismanaged plastic waste. There is, therefore, a need to formulate alternative courses of action that will help address plastic pollution in this country from a holistic perspective. One such approach is the use of biodegradable "bioplastics" for various applications.

Plastics are widely used materials that are long-lasting and fossil-based polymers of chemicals such as polyethylene (PE), polyvinyl chloride (PVC), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), and polyurethane (PU), and are highly resistant to degradation. Bioplastics, on the other hand, refer to polymers created from renewable raw materials and are classified into biodegradable and non-biodegradable, according to the bioplastic industry classification (Precedence Research 2023; Statista 2023).

Biodegradable bioplastics are made using biodegradable polymers such as polylactic acid (PLA), starch blends, polybutylene adipate terephthalate (PBAT), polyhydroxyalkanoates (PHA), polycaprolactone, polybutylene succinate (PBS), and cellulose acetate (CA). Starch-based polymers can be sourced from potatoes, cassava, corn, tapioca, wheat, and rice. On the other hand, non-biodegradable bioplastics are those produced using non-biodegradable polymers from renewable sources, such as PE, PVC, PP, PET, and polyamide, which are similar to those obtained from fossil-based sources.

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The term "bioplastics" is therefore a misnomer and is misleading, as the non-biodegradable "bioplastics" are degraded only under optimal industrial composting conditions, but their degradation in nature may take decades or thousands of years, if at all. The degradation of such materials has resulted in microfragments of plastics (microplastics), which have contaminated bodies of water (Melchor Martinez et al. 2022).

Biodegradable means that the material will eventually degrade into carbon dioxide and water. Papers which review biodegradation of plastics include the following: Arikan and Ozoy 2015; del Rosario 2019; Melchor Martinez et al. 2022.

The global production capacity of bioplastics increased to 2.2 million metric tons (1.1 M MT biodegradable, 1.07 M MT bio-based/non-biodegradable) in 2022 from 1.8 million MT in 2021 (Statista 2023). The bioplastics market was estimated at USD 12.42 billion in 2022 and is expected to rise to USD 63.55 billion by 2032, with a compound annual growth rate of 17.80%. The biodegradable product component is projected to grow at 17% from 2023 to 2032 (Precedence Research 2023). Bioplastics are utilized in packaging (48%), consumer electronics, catering items, agriculture/horticulture, automotive, and toys, as well as textiles and a variety of other applications. Increasing uses are found in automotives, transportation, and building and construction as the functional polymer capabilities of bioplastics are improved and varied.

This paper reports on the status of biodegradable bioplastics in the Philippines: the R&D, technology development, and manufacturing of biodegradable materials that can be substituted for plastics for specific uses and are derived from terrestrial sources such as plants, microorganisms, agricultural wastes, and the like. This study presents comprehensive policy recommendations to the executive and legislative branches of government that address gaps in R&D on bioplastics, strengthen the supply chain of feedstocks for bioplastics manufacture, promote education among different stakeholders, promulgate and implement rules and regulations to enable the bioplastic industry to successfully thrive, and, at the same time, address plastic pollution in the country. Studies on bioplastics from marine sources in the Philippines, which are also part of the NAST PHL Special Concerns Project TWG #11, are reported by del Rosario (2024) and Montaño (2024).

This study's specific objectives are: (a) to determine the status of research and development and manufacturing of biodegradable bioplastics using terrestrial sources in the Philippines and other countries; (b) to analyze the strengths and weaknesses, and challenges of research, technology development, and manufacturing of terrestrial bio-based bioplastic production in the Philippines; and (c) to recommend policies to enhance and strengthen bioplastic research, technology development, and manufacturing using terrestrial sources in the country.

METHODOLOGY

An extensive review of related literature (journal publications, books, government reports, international private and public organization reports and the like) was undertaken.

Site visits were conducted to interview and gather additional information and insights on researches and/or production, facilities and challenges. Institutions visited were the laboratory facilities at the Department of Mining, Metallurgical and Materials Engineering, UP Diliman College of Engineering and the Industrial and Technology Development Institute of the Department of Science and Technology and its various laboratories. Visits to the factories of EcoNest Philippines and OIKOS in Bulacan were also conducted. Online meetings were likewise conducted with the following: EcoNest PHL, OIKOS, First in Colours (FIC) Inc., and the DA-PhilMech.

A roundtable discussion was held on October 22, 2024, in Manila with 27 stakeholders-participants from the academe, industry, and government.

A Brief Background on Bioplastics

Definition

As earlier defined, bioplastics refer to polymers created from renewable raw materials and are classified as biodegradable and non-biodegradable, according to the bioplastic industry classification (Precedence Research 2023; Statista 2023). Examples of biodegradable polymers include polylactic acid, starch blends, polybutylene adipate terephthalate (PBAT), polyhydroxyalkanoates (PHA), polycaprolactone,

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polybutylene succinate (PBS), and cellulose acetate. Starch-based polymers can be sourced from potatoes, cassava, corn, tapioca, wheat and rice. Some non-biodegradable polymers from renewable sources include PE, PVC, PP, PET, polyamide, and others similar to those obtained from fossil-based sources.

Table 1 shows the different chemical polymers which, even if derived from biomass, are not biodegradable—meaning they are largely resistant to hydrolysis—and those that are biodegradable or largely susceptible to hydrolysis.

Oxo-degradable and oxo-biodegradable plastics

Oxo-degradable or oxo-biodegradable plastics (also called Pro-oxidant Additive Containing [PAC] Plastic) are made using conventional plastic polymers, such as High-Density Polyethylene (HDPE), with additives that promote oxidation of the plastic material, causing it to become brittle and fragments. According to a study on the environmental impact of "oxo-degradable" plastics conducted for the European Commission (Hann et al. 2016), evidence suggests that PAC plastic undergoes the stage of abiotic degradation triggered by the pro-oxidant additives, resulting in reduced molecular weight of areas on the plastic surface to a size where microorganisms can consume the plastic into the biodegradation phase. However, if such conditions are absent, biodegradation will not occur, or the PAC plastic will behave like regular or conventional plastic, or its biodegradation will be slowed significantly.

Hann et al. (2016) included a list of countries that have issued policies on degradable plastics. In 2019, the European Union (EU) issued Directive 2019/904 on the reduction of the impact of certain plastic products on the environment, which specified the prohibition of "member states in the placing on the market...of products made from oxo-degradable plastic."

In the Philippines, there are manufacturers of oxo-biodegradable or oxo-degradable plastics that claim their products' biodegradability in the environment.

Research and Development of Bioplastics Technology from Terrestrial Sources in the Philippines

Research on bioplastics in the Philippines possibly started in the 2000s and began to grow in the second

Table 1. Fossil-based and biomass-based chemical polymer components which are utilized in producing plastics.

Fossil-Based	Biomass-based
Non-biodegradable, highly durable, and resistant to hydrolysis Chemically synthesized	
Polystyrene (PS) Polyethylene terephthalate (PET) Polyvinylchloride (PVC) Polyethylene (PE) Polypropylene (PP)	Biopolyethylene (bioPE) Biopolypropylene (bioPP) Biopolycarbonate (bioPC) Polyurethane (bioPU) Biopolyethylene terephthalate (bioPET) Polyethylene furanoate (PEF)
Biodegradable, highly susceptible to hydrolysis	
polybutylene adipate-co-tere-phthalate (PBAT) polyvinyl alcohol (PVA) polybutylene succinate (PBS)	Chemically polymerized Polylactic acid (PLA) Polybutylene succinate (bioPBS) Biologically polymerized PHAs Chemically Extracted Starch Cellulose

Adapted from Rosenbloom (2023)

decade. This section traces the growth of bioplastic researches in the country, identifies the problems and challenges, and provides a glimpse of a promising future in the 2020s.

Utilizing starch and cellulose from plants

At the DOST-ITDI. Researches on thermoplastic starch (TPS) at the Department of Science and Technology-Industrial Technology Development Institute (DOST-ITDI) started in 2000s, centered on improving the properties of thermoplastic starch by blending it with synthetic polylactic acid (PLA) and nanoclay (Paglicawan et al. 2012). Thermoplastic starch is biodegradable, but since starch has low water solubility, it has to be blended with other biodegradable polymers or other materials. Their study of TPS with nanoclay and PLA at 70:30 and 30:70 ratios showed that the mechanical properties of PLA/TPS nanocomposite with maleic anhydride were higher than the physical blends of PLA/TPS without maleic anhydride and nanoclay. X-ray diffraction analysis of the blends showed the intercalation of nanoclay within the blend matrix and that the microstructure of the blends with maleic anhydride had homogeneous and smoother surface. Moreover, the crystallization temperature of these blends was lower compared with only TPS/nanoclay/PLA and had better water resistance than the physical blend of TPS and PLA (Paglicawan et al. 2012). This research resulted in the application and grant of Utility Model Nos. 2-2014 000614 and 2-2014 000615 under RA 8293 by the Philippine Intellectual Property Office (Paglicawan et al. 2014 a,b).

A more recent study showed that the PLA/microcrystalline cellulose (MCC) composites with 3% cellulose increased tensile strength by 32%. The MCC fibers significantly influence the chemical, structural, and mechanical properties of the 3D-printed PLA/MCC composites (Custodio et al. 2021), which can be used to produce injection-molded products such as cutlery. The team also prepared starch nanocrystals with antimicrobial activity, which can be used in the preparation of biodegradable plastics (Emolaga et al. 2022).

At the University of the Philippines Diliman and UP Los Baños. The group of Dr. MDL Balela at UP Diliman and Drs. RD Manalo and MU Herrera at UPLB has worked on citric acid as a crosslinking agent and its effects on selected properties of cassava starch films and the use of nanocellulose from mature coconut husk to reinforce composite films (Figure 1). Their results showed that the films produced had high UV barrier capacity in the UV region and high 80% transmittance values in the visible region. The film made with 10% citric acid had a good combination of tensile strength, elongation, and fracture stress (Ramos et al. 2023). Nanocellulose extracted from mature coconut husk using sulfuric acid hydrolysis had an agglomerated rod-shaped structure and a low aspect ratio, as shown by atomic force microscopy, compared with nanocellulose obtained from young or immature coconut husk (Jumadiao et al. 2023).

Succeeding research aimed at developing films for active food packaging showed that crosslinked modified tapioca (cassava) starch films with cellulose nanocrystals (CNC) and halloysite nanotubes (HNT) had the highest tensile strength and lowest elongation in films containing 5% CNC and 5% HNT. The resulting films had good transmission capacity for visible light, while films with HNT outperformed films with CNC in UV-blocking ability. Figure 1 shows photos of crosslinked tapioca starch films with varying concentrations of CNC from 0 to 7%, and of HNT, from 0 to 15% (Ranada et al. 2024).

At the University of the Philippines Los Baños College of Engineering and Agricultural Technology (CEAT). The research group led by Dr. EK Peralta conducted a study on the development of corn starch-based nanocomposite sheets using nanosilica derived from recycled rice hull ash (Dorado et al. 2017). The nanocomposite sheets of nanosilica and corn starch were produced at three nanosilica concentrations of 1%, 2%, and 3%. With nanosilica, the composite sheets improved in tensile strength and water resistance.

Another study examined the production of nanocellulose and biocomposites from the shoots of the bamboo Kiling (*Bambusa vulgaris* Schrader ex Wendland) (Jara et al. 2020). Nanocellulose was obtained after pretreating the cellulose extracted from the bamboo shoots with water, bleaching, and alkali treatment. The nanocellulose, when added to polyvinyl alcohol (PVA) films, improved the mechanical properties of the reinforced PVA films.

At the Department of Agriculture-Philippine Center for Postharvest Development and Mechanization (PhilMech). Researchers at DA-PhilMech are addressing

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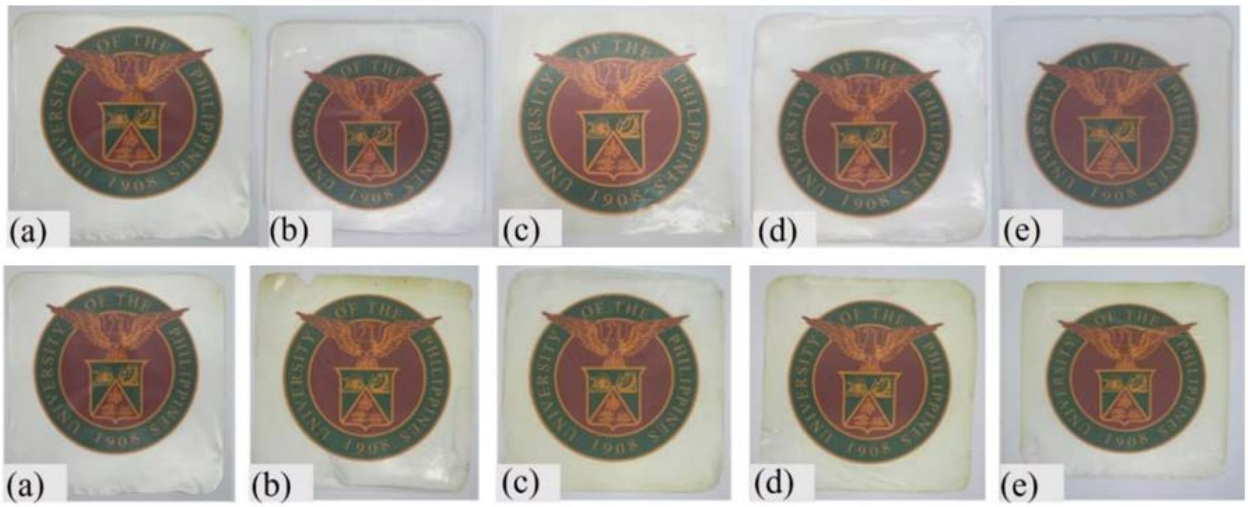

Figure 1. Digital images of crosslinked tapioca starch film with (a) 0%, (b) 1%, (c) 3%, (d) 5%, (e) 7% CNC (upper panel); (a) 0%, (b) 2.5%, (c) 5%, (d) 10% and (e)15% HNT (lower panel). (Ranada et al. 2024). (Permission to use Figure 1 obtained from the authors).

Figure 2. The PhilMech-FiC biodegradable fruit bag.
(With permission to use photo from the authors).

the need to develop biodegradable fruit bags for the mango, cacao, and banana industries. Tuates and Caparino (2016), in collaboration with First in Colours (FiC), developed the fruit bags using cassava starch and polybutylene succinate (PBS) (Figure 2). The PhilMech-FiC fruit bags had tensile strength within the range of low-density polyethylene (LDPE) and elongation within the range of high-density polyethylene (HDPE), and had higher density, thickness swelling, and water absorption. LDPE and HDPE are used in packaging, plastic film sheets, and containers, among others. Field testing showed that the quality of fruits using the PhilMech-FiC bags was comparable with existing bagging materials in terms of percent marketable mangoes, physical properties such as peel color at the ripe stage, flesh color, TSS, Brix number, and percent edible portion.

Biodegradable film was also obtained using starch from taro *Colocasia esculenta* (L.) Schott and glycerol as a plasticizer at 2%, 3%, and 4% (Briones et al. 2020). Results showed that taro and glycerol-based biodegradable film obtained the lowest density, water absorption, and thickness swelling of 0.98 g cm^{-3}, 51.53%, and 9.29%, respectively, and the highest tensile strength and elongation of 9.51 MPa and 21.60%. After one week, the taro starch-glycerol film was found to have degraded by 64.45%.

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At the Center for Advanced New Material, Engineering, and Emerging Technologies (CANMEET), University of San Agustin. A study at CANMEET (Amaba et al. 2023) utilized mango kernel starch (MKS) and chitosan (CH) with glycerol as a plasticizer and successfully produced a bioplastic film at a CH:MKS ratio of 1:0.17 and a glycerol concentration of 15.86% with desirable characteristics, in terms of mechanical properties, water vapor transmittance rate, surface morphology, and biodegradability.

Utilizing polyhydroxyalkanoates (PHAs) with starch and other components

At the University of the Philippines Los Baños CEAT. The group of Dr. JS Ventura has led a series of studies on the potential of polyhydroxyalkanoates (PHA) as substitutes for petroleum-based plastics. The study, which employed the Analytic Hierarchy Process (AHP) and Grey Relational Analysis (GRA), identified the following criterion ranking: conversion efficiency, cellulose content, and processing cost (Requizo et al. 2018). The most preferred lignocellulosic substrates for PHA production were identified to be corn stover, followed by banana pseudostem and sugarcane bagasse. Sensitivity analysis also proved that corn stover is an excellent feedstock candidate, particularly if the conversion efficiency and processing cost criteria are given higher weights. Related studies such as economic and life cycle analyses, as well as process improvement, may also be incorporated with the results of this study to provide comprehensive information on selecting a suitable feedstock for sustainable PHA production.

The study on the production potential of polyhydroxybutyrate (PHB) by *Bacillus megaterium* PNCM 1890 using carbon substrates from sugarcane bagasse, corn stover, and banana pseudostem (Dañez et al. 2020) showed that combining PHB with starch as a biomass filler at 20/80 w/w and lauric acid as a plasticizer improved the thermal properties and tensile strength of the composites. Adorna et al. (2020) showed that thermal properties and the elastic strain of the films improved with the addition of lauric acid, although the tensile strength decreased slightly compared with pure PHB/S films.

Optimization studies of pretreatment methods for banana pseudostem—steam explosion and sequential steam explosion-dilute acid pretreatment—showed that sequential pretreatment was more effective in producing hydrolysates from banana pseudostem for PHB production (Mabazza et al. 2020).

More recent studies focused on the optimization of pretreatment methods for corn stover and sugarcane bagasse to produce sugar-rich hydrolysates for PHB production. Between steam explosion and sequential steam explosion–dilute acid pretreatment, the former was found to be more effective in producing sugar-rich hydrolysates from corn stover for PHB production (Perez et al. 2023). For sugarcane bagasse, sequential pretreatment of steam explosion and sulfuric acid pretreatment was effective in producing hydrolysates with 87% reducing sugar. PHB was successfully produced using the hydrolysate through bacterial fermentation (*Bacillus megaterium* PNCM 1890) (Barrameda et al. 2023).

At the DOST Forest Products Research and Development Institute (FPRDI). The DOST-FPRDI project centered on the use of abaca fibers as a viable and economical source of nanocellulose for bioplastic production (Lapuz et al. 2022). An initial study evaluated the production of nanocellulose in a locally fabricated 500 L reactor using 2,2,6,6-tetramethylpiperidine-1-oxyl (TEMPO) radical oxidation, which produced 46.7% white gel material with 2.23% solid content. Nanocellulose films were produced from the nanocellulose fibers using vacuum drying or oven drying. Cellulose nanofibril (CNF) films showed high tensile strength, indicating the potential use of abaca nanomaterial as a substitute for oil-based packaging materials.

In another study (Balagot et al. 2022), the enzymatic method was utilized to hydrolyze abaca fiber. The commercial-grade abaca pulp was first disintegrated using a blender and hydrolyzed with cellulase for 72 h at 50 °C and 120 rpm. This resulted in aggregated, elongated, needle-like nanocellulose with higher cellulose crystallinity. The nanocellulose from abaca fibers was successfully used as a reinforcement filler in starch films (Lapuz et al. 2024).

From the above, several projects can be deemed to be ready for scaling up from lab to pilot scale: (a) the fruit bag of DA-PhilMech; (b) production of polyalkanoates by fermentation; (c) production of nanocellulose from

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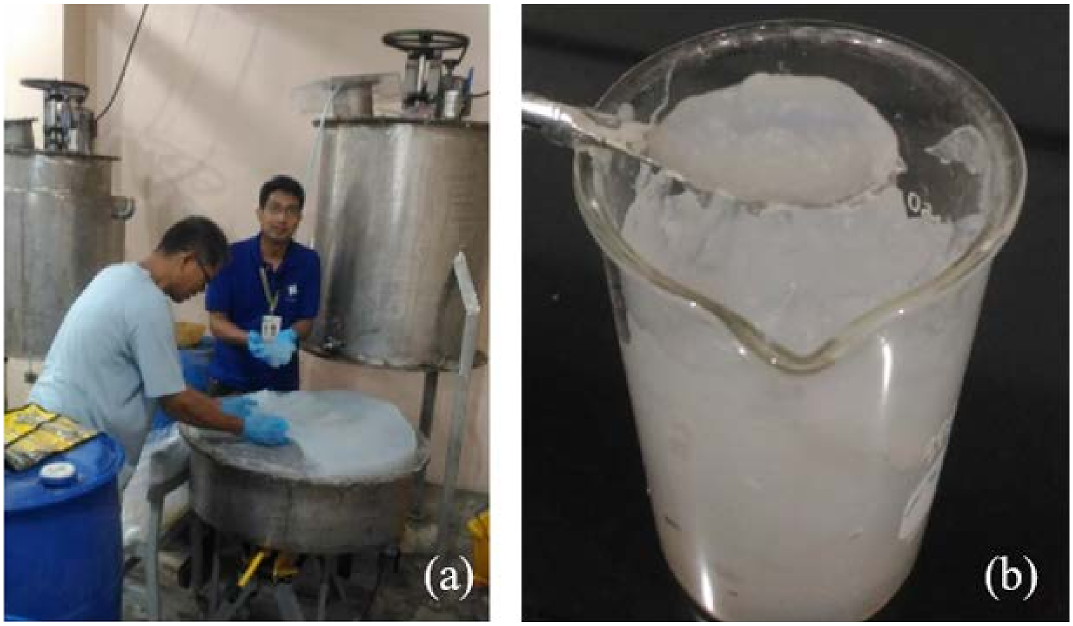

Figure 3. Large scale production of the NC-TEMPO (a) showing the 500-liter fermentor and collecting the CNF-TEMPO; (b) gel-like CNF-TEMPO slurry. (With permission to use photos from the authors.)

abaca and other fiber sources; (d) production of starch blends and plastic films; and, possibly, (e) the production of active films from nanocellulose-starch blends.

The above researches can be considered innovative and address the properties of bioplastics that can compare with those of petro-based plastics, including biodegradability, which makes these products good alternatives. Moreover, the use of agricultural wastes as feedstocks for biodegradable plastics can put these wastes to good use. However, weaknesses include lack of continuity to reach pilot scale level and a lack of collaboration with stakeholders, including the bioplastics manufacturers and the feedstock provider.

R&D Budget and Facilities for Bioplastic Technology Development and Production

Budget and facilities are major considerations in the research and technology development of any product. Table 2 is a partial list of projects, budgets, and funding agencies related to bioplastic technology development and production. The DOST grants can vary from a PhP 1 million grant that accompanies a NAST PHL Outstanding Young Scientist award to the PhP 64 million grant for a development and scale-up project. DOST-PCIEERD also has a Start Up Grant Fund Program and it is noted that private company SACHI Inc. obtained this grant for a project on the “Improvement and Market Validation of Cassava Bioplastic” (https://www.dost.gov.ph/knowledge-resources/news/84-2024-news/3727-dost-bares-three-techs-to-solve-philippines-plastic-concerns.html).

For the lab-scale production of biofilms, the basic equipment, such as reactors, fermenters, blenders, extruders, digital calipers, and the like, are usually available in all the laboratories. Instruments used in characterizing films, such as Scanning Electron Microscope (SEM), Universal Testing Machine, transmission electron microscope, Differential Scanning Calorimetry, and X-ray Diffraction, are available in certain laboratories. Institutions such as the DA PhilMech, the UPLB CEAT, UPLB CFNR, and DOST FPRDI are noted to now have or are waiting for machinery needed for pilot-scale operation.

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Table 2. Partial list of projects on bioplastics R&D in the Philippines.

Project Title	Duration	Funding Agency
CEAT UPLB **Jey-R S. Ventura, PhD (Project Leader)**		
Polyhydroxyalkanoates (PHA) Production from Less Recalcitrant Biomass and Waste Feedstocks: Process Efficiency Enhancements, Strain Improvements and Scale-up Validation	Feb 12, 2024 – Feb 11, 2027 (*ongoing*)	DOST-GIA
Polyhydroxybutyrate (PHB) Property Improvement and Development of Filament for 3D Printing Applications	Sep. 1, 2019 – Feb. 28, 2021 (*completed*)	DOST-NAST (Outstanding Young Scientist OYS Grant)
Polyhydroxyalkanoates (PHA) production from agricultural residues	May 1, 2017 – June. 16, 2021 (completed)	DOST-PCIEERD
FPRDI DOST **Anniver Ryan P. Lapuz, PhD (Project Leader)**		
Application of Cellulose Nanocrystals Extracted from Bandala Fibers as Reinforcement Material in Starch-based Bioplastic Film	2 years	DOST-PCAARRD
Bamboo based CNF aerogel infused with ecofriendly sodium biocarbonate as fire retardant additive in insulation materials	2024-2025	DOST-PCIERRD
UP DILIMAN-UP LOS BAÑOS collaboration **Mary Donnabelle Balela, PhD (Project Leader)**		
Development of Active Food Packaging Based on Calamansi (*Citrofortunella microcarpa*)-Crosslinked Cassava Starch/Nanocellulose/Halloysite Nanocomposite Film Collaborators: Marvin Herrera, PhD, Ronniel Manalo, Hui Lin Ong, PhD	2 years	UP OVPAA-EIDR-C09-10
Department of Forest Products and Paper Science, College of Forestry and Natural Resources (CFNR), UPLB.) **Prof. Ronniel D. Manalo (Project Leader)**		
Production, Characterization, and Potential Applications of Biodegradable Plastic from Bamboo (BambuPlastic)	1-Sep-21 to 31-Aug-23 (*ongoing*)	PCAARRD
University of San Agustin, Iloilo City Noel **Peter Tan, PhD (Project Leader)**		
Nano-enabled bioplastic from regenerated cellulose	July 03, 2023 - July 02, 2024	PCIEERD
SACHI Group, Inc., **Prince Darhyl Anthony Ryan Ang (Project Leader)**		
Improvement and Market Validation of Cassava Bioplastic	March 16, 2023 - April 30, 2024	PCIEERD

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Figure 4. Machineries for pilot scale production of films at the DA PhilMech.
(Photos from DA PhilMech used with permission)

Challenge to RDI

While the budget, equipment, and technical manpower for research, development, and innovation have improved over the past 20 years, much more is needed. Data showed that the Philippines has improved its number of researchers from 180 in 2013 to 356 researchers per million population and investments in R&D, with a GERD to GDP ratio of 0.16% in 2015 to 0.32% in 2018, although this pales in comparison with the data for neighboring countries such as Malaysia with 2018 data of 1.44% GERD to GDP ratio and 2,587 researchers per million population (DOST 2021).

Another major problem is the time available for the projects by researchers. Full-time researchers in universities and researchers in government research institutes usually handle as many as four to five projects while attending to other duties. On the other hand, faculty researchers have teaching duties as their primary responsibility and can handle fewer projects. Additional staff for the project are contract services, and after training the staff, they may not be renewed, as there may be no other projects or regular items available.

While all laboratories should have the basic equipment needed for the researchers' experiments, the more sophisticated and expensive ones might be available only in a few laboratories, such as those in the UP System, the different institutes of departments, such as in the DA and the DOST, and in private sector manufacturing facilities. It is hoped that the different research institutes and the funding agencies could have a commitment to facility sharing to enable researchers to conduct their research smoothly.

It is also important that, even during the early stages of project reviews, the possibility of continuing a project to the pilot scale should be discussed so that plans for its continuation can be requested and arranged. This is important for the technology's step towards semi- and full commercialization. The project leaders should also be knowledgeable in intellectual property (IP) rights and consult their technology development offices on the possibility of protecting their project product(s) with IP protection.

Bioplastics Manufacturing Using Materials from Terrestrial Sources in the Philippines

The bioplastic industry in the Philippines is still in its infancy. This section presents and discusses the following: (a) manufacture of bioplastics in the country; (b) production of feedstock for the bioplastics industry; (c) the status and challenges that face the bioplastic industry.

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Manufacturers of bioplastics in the Philippines

This study identified two small manufacturers of bioplastics based in Bulacan: OIKOS Sustainable Solutions (https://oikosph.com/) and EcoNest Philippines (https://www.econestph.com). Both are small-scale MSMEs and BOI-registered companies that produce biomass-based biodegradable packaging products, such as shopping bags of various sizes and which can be custom-designed. OIKOS uses both corn and cassava starch pellets, while EcoNest uses cassava starch pellets. They import their starch pellets and technology to produce plastic films from Indonesia.

D&L Polymers & Colours, Inc. (DLPC), a subsidiary of D&L Industries, Inc. (DNL), manufactures Bionolle Starcla, an environmentally friendly bag made from 100% plant-based materials and starch-based biopolymer, which is used as garbage and shopping bags and can fully decompose in three months. The product is shipped to Japan under an agreement signed in 2013 by DLPC and Showa Denko K.K., Japan's leading chemical engineering company, to be used in agriculture in Japan and in Italy. DLPC was also given certification by Berlin-based organization DIN CERTCO, which provides conformity assessments based on several international standards. Biodegradable plastic products under the formulation of D&L are registered under the Biorez brand and are used in making films, straws, containers, and cutlery.

The study "Market Readiness for Sustainable Packaging in Bacolod City and Iloilo City" (PCEPSDI 2021) identified other industry players such as Licton, Donewell, and D&L. D&L produces oxo-biodegradable plastic packaging using the additive Biomate, an environmental technology verified (ETV 08-013) by DOST-ITDI and by the SP Technical Research Institute of Sweden, and meets American standards for plastics biodegradability. They claim that "with as little as 2% dosage of Biomate, single-use plastics can achieve over 90% biodegradation within two years."

Philippine Bioresins Corporation was given an ETV certificate by DOST-ITDI in 2019 confirming that the biodegradable PP produced by the company would be 64.6% degraded in 24 months, compared to 4.5% for the same period for conventional plastic packaging. During the same year, this company tied up with San Miguel Corporation to supply the latter with bio-based packaging for food and nonfood products, such as cement and feed sacks, grocery bags, and other single-use plastic packaging.

The same study (PCEPSDI 2021) also reported the unregulated labelling of biodegradable plastic packaging in the market, such as the use of the DOST ETV information and claims of biodegradability. In addition, the labeling of the oxo-degradable plastics as biodegradable or as bioplastics may be misleading, as they are made of plastic components like polyethylene (PE), polypropylene (PP), and polystyrene (PS), mixed with additives like cobalt, iron, or manganese (https://www.european-bioplastics.org/bioplastics/standards/oxo-degradables/). As discussed earlier, oxo-degradable plastics are not biodegradable.

Production and Supply of Feedstocks for Bioplastic Manufacturing

In the Philippines, the commercial manufacturers of biodegradable packaging items are using as feedstock, cassava and corn for the starch, sugarcane bagasse, and other agricultural residues such as mango kernel, banana and abaca fiber, rice and corn, coconut husks, and other crops wastes for the extraction of cellulose for the production of nanocellulose and for production of sugar rich hydrolysates for fermentation.

For the agro-industrial wastes, sugar bagasse is now primarily used as biofuel, but the others are abundant and should be utilized in producing other food and nonfood products, such as bioplastic material.

For starch, cassava might be the better option, as corn is primarily used for animal feed. Varietal improvement R&D on cassava is ongoing at the Visayas State University-Philippine Root Crops Training and Research Center and at the Institute of Plant Breeding, College of Agriculture and Food Science, UPLB. These two institutions have developed and released outstanding varieties in the past 40 years or so.

National cassava production was 2,560,042.89 metric tons in 2022 (PSA). The top three regions that produce cassava are: Northern Mindanao (39%), Bangsamoro Autonomous Region of Muslim Mindanao (BARMM) (31%), and Cagayan Valley (7%). Northern Mindanao has four (4) major cassava starch manufacturers, namely, Philippine Agro Industrial Corp (Cagayan de Oro), Bio-Green Processing Inc. (Bukidnon), Triangle

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Industrial Corp. (Bukidnon), and Matling Industrial and Commercial Corp. (Lanao). The fifth is Fatima Multipurpose Cooperative (Region 8). In June 2022, the BOI approved a PhP756 M cassava starch project of Daesang Philippines Corp, which started production in January 2023 in its plant in Misamis Oriental. In 2022, the Philippines exported USD2.68M cassava but also imported USD290K worth of cassava (OEC 2024).

However, it seems that this concern about cassava feedstocks competing with the need for food security may not be a challenge or a problem. According to FATIMA, a multipurpose cooperative in Leyte, they can supply the cassava feedstock the bioplastic industry needs. Their farmers' average yield per ha is 40 tons per ha, which is four times higher than the national average cassava yield of only about 10 tons per ha. Their farmers are using a high-yielding cassava variety and agricultural practices developed by the Philippine Root Crops Training and Research Center in Visayas State University (NAST PHL 2024).

Challenges: Production Costs and Problems, Government Support and Policies, and R&D-Technical Manpower Support

The National Academy of Science and Technology Philippines (NAST PHL) held a Round Table Discussion (RTD) on the Development of Bioplastics from Terrestrial Sources in the Philippines: R&D and Policy Needs, on October 22, 2024 in Manila, which was participated in by 27 stakeholders from industry, academe, and government.

The objectives of the RTD were: (a) to forge collaboration between manufacturers of compostable packaging materials and researchers to develop and produce affordable and consumer friendly alternatives to petro-based plastic bags; (b) to underscore research gaps and bring these to the attention of funding agencies; (c) to bring together stakeholders in the cassava industry and help cassava farmers increase their production to produce feedstocks for both starch and bioplastic industries; and (d) to identify policies and regulations to support the development of bioplastics from cassava sourced locally, among others; and (e) to identify policy support that can sway manufacturers to produce bioplastics; and for food packagers and wet market sellers to use bioplastics in their businesses (NAST PHL 2024).

Among the problems, constraints, and possible solutions identified and discussed during the forum are the following:

High Production Costs and Technical Problems. Current manufacturers in the Philippines, including OIKOS Sustainable Solutions and EcoNest PHL, face significant challenges in producing competitive bioplastic products. Industry representatives emphasized that bioplastic products currently cost 40–100% more than traditional plastics, making market penetration difficult without policy support.

Among the challenges facing local bioplastic manufacturers are technical and operational problems such as achieving thickness to attain strength comparable to traditional plastic, improving wet durability, low production efficiency, high waste generation, and extended processing times for operations like sealing, and finding ways to reduce costs (Guerrero 2024). Their challenges go beyond basic material costs, since even if their raw material costs were equal to conventional plastics, multiple technical and operational challenges faced by OIKOS increase final product costs.

Government support and policies. Some of the constraints identified by the manufacturer representatives include the following: (1) Biodegradable plastic manufacturers are constrained by regulatory frameworks such as Section 27 of RA 9003 that set the price of alternatives to not more than 10% of the cost of incumbent materials, which significantly hinders their development capabilities (Tan 2024). (2) The Extended Producer Responsibility (EPR) law (RA 11898) has not provided the expected benefits for bioplastics manufacturers. In fact, the law does not explicitly mention the use of bioplastics and lacks specific provisions promoting bioplastics adoption (EMB DENR 2024). Thus, there is a need for clearer policies specifically supporting bioplastics adoption and standards for biodegradability testing. The newly established testing facility at ITDI for biodegradability and compostability certification was noted as a positive development.

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Some policy interventions to support the bioplastics industry were thus recommended, such as (a) government incentives for bioplastics manufacturers, (b) stricter implementation of single-use plastic ban, (c) recognition of bioplastics as a superior alternative to paper bags, and (d) the development of comprehensive support systems for manufacturers. Without these support mechanisms and policy frameworks, the industry continues to struggle with market penetration and cost competitiveness.

Presently, the bioplastic manufacturers survive through premium markets like high-end hotels and restaurants, the cosmetics industry, and premium retail segments. These sectors can absorb the higher costs due to better profit margins and environmentally conscious customers. A survey conducted by the D&L company showed that Filipino consumers generally support eco-friendly products, but cost remains the primary barrier to widespread adoption (Tan 2024).

Government agencies, including the Board of Investments (BOI) of the Department of Trade and Industry (DTI), presented various support mechanisms for the industry. BOI offers fiscal incentives through the Strategic Investment Priority Plan (SIPP), including income tax holidays and duty-free importation of capital equipment.

During the meeting, it was reported that the BOI, led by Director Racquel B. Echague and representatives from the DOST-ITDI, Climate Change Commission, Philippine Plastics Industry Association, Inc. (PPIA), Philippine Alliance for Recycling and Materials Sustainability (PARMS), and BOI-registered local manufacturers of bio-bags, undertook a five-day benchmarking and capacity-building activity in South Korea in July 2024 to gather crucial inputs for the formulation of the Philippine Bioplastics Industry Roadmap. The visit included lectures on bioplastics testing, certification labeling, and R&D strategy. The study report "Building Plastic Circularity through Bio-degradable Plastic Program to Ensure Zero Waste-Philippines" was released in July 2025 (KSP-GGGI 2024), and a workshop on the roadmap was held on August 4-5, 2025, which resulted in the crafting of the roadmap (DTI-BOI 2025).

R&D-Technical Manpower Support. As shown earlier, the country has the technical manpower and expertise in the R&D on bioplastics in the different universities and government research institutes. Their number, budget, and laboratory facilities and equipment support have grown perhaps in the past 15 years, but certainly these have to further improve to address increasing technological needs.

As early as 2012, the ITDI team had already published a study on thermoplastic starch/PLA films (Paglicawan et al. 2012). In 2016, the team secured two Utility Model registrations on the composition and production of thermoplastic nanocomposites and PLA (Paglicawan et al. 2016). However, the developed technology failed to be adopted by plastic manufacturers for various reasons, including the lack of data when the technology is scaled up—thus, the need for selected technologies to scale up from lab to pilot scale. Another technology—the bioplastic fruit bags developed by the DA-PhilMech—was produced and underwent limited field testing (Tuates and Caparino 2016). The biodegradable pellets and fruit bags were produced at the D&L facility in Cabuyao, Laguna. Indeed, these PhilMech-FIC biodegradable fruit bags represent a most welcome product from a collaboration between industry and a research institution to develop, pilot produce, and field test a product which are the steps needed for commercialization.

The production of polyhydroxybutyrate and polyhydroxyalkanoates by biofermentation of agricultural products and wastes has also been studied by Filipino researchers, as discussed earlier.

Although there has been an improvement in the number, budget, facilities in the universities and government research institutes, the country still lags in the number of researchers as well as in the budget for R&D. A 2021 study (DOST 2021) showed that the Philippines has 356 researchers per million population and investments in R&D, with a GERD to GDP ratio of 0.32% in 2018, and this pales in comparison with neighboring countries such as Malaysia with a 2018 R%D data of 1.44% GERD to GDP ratio and 2,585 researchers per million population. While the different universities are able to graduate the technical manpower, many are unable to get regular positions in academe, government, and industry, thus forcing them to look for greener pastures abroad.

The round table discussion provided a venue for researchers and manufacturers to listen to each other, share experiences, and collaborate.

The above section presented and discussed the following: (a) the manufacture of bioplastics in the country by two small companies, indicating that most bioplastics available in the country are imported and SUPs, which are much cheaper and are used incessantly; (b) production of feedstock, primarily cassava, for the bioplastics industry is promising as producers believe that expansion of production can be met by the cooperatives; and (c) the challenges facing the bioplastic industry which include lack of policy supporting it, now hopefully, could be met by the DTI-BOI Bioplastic Industry Roadmap and, in due time, the revision of the RA 9003 to incentivize the use of bioplastics and the industry itself.

Waste Management of Bioplastics

While fully biodegradable bioplastics can degrade in the environment, their mixing with regular plastics will affect the recycling of plastics. Thus, proper disposal of bioplastics must be adopted. Manufacturers of biodegradable plastics should clearly label their products as certified biodegradables to help consumers with the proper disposal of bioplastic waste materials.

Some guidelines on the proper disposal of biodegradable packaging materials are the following:

1. Segregation at point source. It is important that biodegradables are not mixed with non-biodegradables.

2. Biodegradable plastics, if possible, should be reused, e.g., to collect organic household wastes. They can be mixed with other organic or biodegradable materials, such as food wastes, and the like, and composted — allowed to decay under natural conditions in an open pit and be converted to organic fertilizer. They can also be buried in soil to undergo decomposition.

   Biodegradable and compostable plastic packaging contributes to excellent compost from organic waste recycling. Flores et al. (2025) conducted a study on the decomposition of bioplastics (corn and cassava starch bags) in two different soil types. Degradation was assessed using microscopy and the presence of holes or physical manifestations of decomposition. Initial results showed that degradation started in the third week, with the greatest decay taking place in the fifth and sixth week. Decomposition in garden soil was 30% to 50% faster than in mixed soil (sandy, clay, loam). The presence of Trichoderma sp. improved the degradation of the corn and cassava bioplastics in the mixed soil and had the most observable and consistent degradation, which started at week two and had consistent degradation with time.

Creating Market Niches for the Philippine Bioplastic Industry

To increase the market for bioplastics in the different sectors of society, market niches should be strengthened or created, such as:

(a) the high-end market segments and specific applications where price sensitivity is less. These include sectors such as hotels, high-end restaurants and food companies, electronics, garments, packaging, and cosmetics, and other companies, where environmental sustainability is a company goal;

(b) penetrating and increasing the market for shopping bags for dry goods in supermarkets, local markets, and online marketers;

(c) creating markets for high-end personal care products (e.g., diapers), upscale restaurant supplies (e.g., napkins), luxury packaging, and specialized medical supplies. These markets offer higher margins and cater to environmentally conscious consumers who are less price-sensitive.

(d) manufacture of sterilizable biodegradables. Enormous quantities of conventional polypropylene (PP) bags and bottles are utilized by hospitals, clinics, medical research institutions, mushroom growers, SMEs engaged in microbial biofertilizers, and academe engaged in microbiology research. A recent review paper discussed the state of and challenges in using biodegradable plastics for medical uses, such as biocompatibility, mechanical properties, and durability to withstand sterilization and actual use, undergoing regulatory compliance, managing costs and scalability, and selecting suitable materials with optimum or ideal performance (Moshkbid et al. 2024).

RECOMMENDATIONS

The biggest challenge facing the Philippines is convincing the Filipino people that there is a need to replace the conventional plastic packaging materials with biodegradable wrappers. We are facing serious health threats from plastic pollutants in food, air, and water.

Thus, a massive education and information dissemination campaign starting at homes and in workplaces is needed to inform and help change the behavior of all stakeholders to reduce plastic pollution by reducing the use of single-use plastics, and using biodegradable packaging. This will support the industry of biodegradable plastic enterprises in the country.

The following are therefore recommended:

1. Concerned government agencies to issue a policy to support the bioplastic industry and the use of bioplastics in the country. Support the BOI initiative— the Philippine Bioplastics Industry Roadmap.

2. DOST to issue a directive to PCIERRD, NRCP and PCAARRD to organize the biodegradable BOI-registered SMEs, researchers from academe and ITDI tie up and to fund researches that will be conducted in relation to the following: (a) produce sterilizable bags to replace polypropylene bags used in all health and microbiology related activities; (b) solve the technical and operational challenges met by SMEs in manufacture of biodegradable packaging materials.

3. DA to issue a directive to Bureau of Agriculture Research (BAR) and PhilMech to organize the biodegradable BOI-registered SMEs, researchers from academe and ITDI tie up and to fund researches that will be conducted in relation to the following: (a) produce biodegradable bags for specific markets, e.g., sterilizable bags for health and microbiology related activities; (b) assist the MSMEs in addressing and solving the technical and operational challenges in the manufacture of biodegradable packaging materials.

4. The Philippine Congress–House of Representatives and the Senate–to pass a law that addresses the issue of banning Single Use Plastics (SUP) and oxo-degradable plastics. (a) Banning SUPs and the use of sachets in consumer products can be done in a staggered system for five years to prepare all concerned businesses for the eventual phaseout of these plastic products and support the BOI initiative Philippine Bioindustry Roadmap. The first step taken by Asian countries with thriving and successful bioplastic industries to foster the growth of the said industries is the adoption and implementation of a law that eventually led to the ban of SUPs in their countries. (b) Oxo-degradable plastics are wrongly "labelled" as biodegradable by manufacturers and mislead consumers. Thus, the banning of oxo-degradable plastics should be adopted, following the European Union's prohibition on oxo-degradable plastics in 2019.

5. The DA and the DTI issue directives to Regional Directors in Regions where cassava is a major crop to organize the farmers into cooperatives, provide them with training and incentives to achieve maximum yield of cassava to supply the needs of the country's starch and bioplastic industries, to assure assistance to bioplastic and starch industries, and provide inclusive growth.

6. The DepEd and CHED to issue directives to Directors of Public and Private Schools and Universities to incorporate ladderized learning modules at all levels of education the following: the plastic pollution threat to health, importance of using biodegradable packaging materials, concepts and procedures of proper solid waste management, key provisions of RA 9003, EPR Law and Roadmap to Zero wastes and to influence students to properly implement these rules and regulations on proper plastic management.

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Contribution of authors:

EMT Mendoza interviewed, gathered data and wrote the section on the different researches on bioplastics conducted by DOST-ITDI, DOST-FPRDI, UPLB-College of Engineering and Agro-Industrial Technology, UPLB-College of Forestry and Natural Resources, and UP Diliman-College of Engineering, and DA PhilMech. VC Cuevas made the initial contacts and interviewed staff of EcoNest, OIKOS, and D&L, obtained data and prepared the report sections on local manufacturers, waste management of bioplastics, and recommendations. Both authors visited EcoNest and OIKOS manufacturing plants, DOST-DTI, and UP Diliman, and co-organized the round table discussion with participants from the academe, industry, and government.

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The authors declare no conflict of or competing interest.

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