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Polyhydroxyalkanoates from Fruit Wastes; A Sustainable Panacea for the Plastic Crisis!

"White pollution" which is defined as the solid waste generated through the consumption of different types of plastic products, has been identified as a significant global environmental issue threatening the natural environment, human health, and economies with regard to pollution. Plastics are chemically inert, preventing unnecessary gas and moisture exchange with the surroundings.

Food packaging is an application where plastics are extensively used, as it significantly reduces the possibility of microbial contamination while retaining food quality. Moreover, it is lighter, possesses high specific strength, and is tear resistant. Plastics can be produced colorless or transparent if necessary, allowing the consumer to view food products through the packaging. It can also be easily moulded to fit the shape of the food item it is holding without affecting its performance requirements. Its stiffness and increased strength ratio make it desirable to be used as food containers and cutlery in rigid food ware applications.

Thermoplastics are primarily used in the food service industry and include polypropylene (PP), polyethylene (PE), low-density polyethylene (LDPE), high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE), polyvinyl chloride (PVC), polyurethane (PU), polyethylene terephthalate (PET), and polystyrene (PS). PET, PP, PVC, PS, and PE are the five most abundantly used polymers in packaging industry as they possess different desirable attributes relevant to their applications in terms of food packaging and service (Figure 1).

Excluding the economical and user-convenient properties of conventional plastics, it is one of the most significant obstacles to our planet and therefore needs to be solved with a sustainable solution. "Green plastics" (biodegradable plastics) have recently gained popularity as a material with a wide range of applications in everyday life. Bioplastics are known to be biodegradable and/or bio-derived. However, bioplastics such as polybutylene-succinate (PBS), and thermoplastic-starch (TPS) lack the desired properties for packaging materials as they consist of deficient properties such as excessive softness, poor gas and water barrier properties, hydrophilicity etc. Even though polylactic-acid (PLA) is a bio-based and biodegradable plastic, it requires synthetic polymerization and in terms of biodegradation, engineered industrial environments are required (Figure 2) Hence, recent bioplastic studies have determined PHA as the "greenest" plastic.1

PHAs are a group of linear polyesters that are naturally produced by bacterial fermentation2 of sugar or lipids in more than 300 different species of bacteria, synthesized as intracellular granules when abundant carbon source is provided whilst other nutrients (nitrogen, phosphorus, sulphur etc.) are limited. It comprises of typical packaging material preferred properties3 being a nontoxic, water-insoluble, UV stable and biocompatible thermoplastic. Properties can be further improved by blending with other polymers, enzymes and inorganic materials, allowing PHA for a wider range of applications. Above all, the most intriguing property and the another advantage of PHA is being readily biodegradable in the ambient environment. PHAs are able for complete biodegradation in anaerobic wastewater after 6 weeks, in the soil after 75 weeks and in sea water after 350 weeks. Food containers, fabric and films, disposable items such as razors, toys, rubbish bags, paper coatings, cosmetics and cosmetic packaging, and tissue engineering scaffolds are already being industrially produced by a number of global companies worldwide, i.e. Hydal: Czech Republic, Bluepha: China, Bio on: Italy, Bio-Matera: Canada etc.

According to a recent study carried out in University of Moratuwa, inexpensive plant-based feedstocks can be used for PHA production. The study revealed that the industrial wastes from food industries available in Sri Lanka are proved to be favored by PHA-producing microorganisms that produce the polymer in significant quantities. Fruit wastes generated in the food industry were used as the carbon substrate, and PHA polymer was synthesized using Bacillus subtilis bacteria species in a fermentation media with ambient environmental conditions. Fruit wastes (peel, core and seeds) from Sri Lankan tropical fruits (i.e. papaya, pineapple, mango and watermelon) that are abundantly used in the food industry were utilized to investigate the PHA synthesis, which will be developed in further research work. The highest yield was delivered by papaya, pineapple, mango and watermelon respectively. However, the major impediment in PHA synthesis is the cost of production which is approximately three times more expensive than petroleum-based polymers. 50% of the production cost is due to the substrate cost and downstream processing. Researchers are investigating PHA synthesis using different types of low-cost carbon substrates (i.e. Cane molasses, fruit wastes, waste oil, waste products from the dairy industry etc.).

Beneficial products can be developed from the biopolymer and can be utilized in the packaging industry, which will provide one of the most appropriate, and sustainable panaceas, which will pave the way to replace "White plastics" from "Green plastics". PHA has the potential to play a significant role in being the "Greenest Bioplastic" ensuring a sustainable future in terms of plastic packaging industry.

"The highest yield was delivered by papaya, pineapple, mango and watermelon respectively."

<table>
<tr><th>Application in Food packaging</th><th>Polymer (non-biodegradable)</th><th>Required property</th><th>Manufacturing Process</th></tr>
<tr><td>Bottles and caps (for soft drinks, cider, water, oils)</td><td>PP</td><td rowspan="4">Good barrier to moisture,
Strength, and chemical resistance
Inferior gas barrier
Light in weight
Translucent appearance
Recyclable</td><td>Blow-molding
Extrusion stretch</td></tr>
<tr><td>Food containers, pots, tubs (for condiments, cold food items, etc.)</td><td>PP</td><td>Injection moulding/thermoforming</td></tr>
<tr><td>Films (film bags, heat-sealed overwrapping films), carrier bags, pouches, food ware laminate coating.</td><td>PE (LDPE and LLDPE)</td><td>Cast and oriented processes</td></tr>
<tr><td>Containers (milk, juices, soups), single-use disposable containers</td><td>PE (HDPE)</td><td>Thermoforming and blow moulding</td></tr>
<tr><td>Bottle (for beverages, juices, water, etc.), wide-mouth jars, and tubs
Boil-in-bag food items, snacks, and confectionery packaging</td><td>PET</td><td>Good strength, barrier, and temperature properties.
Clear appearance.
Resistant to shattering.
Recyclable</td><td>Injection stretch blow moulding
Thermoforming</td></tr>
<tr><td>Disposable “plastic glasses” for beverages, coating layer for other food ware materials</td><td>Crystal PS (Polystyrene)</td><td rowspan="3">Clear appearance.
Inferior barrier properties</td><td rowspan="3">Thermoforming and injection moulding</td></tr>
<tr><td>Food trays (for packaged food products), disposable beverage cups.</td><td>Foamed PS</td></tr>
<tr><td>Packaging carton windows, wrapping for fresh produce, vending cups, and tubs.</td><td>Film PS</td></tr>
<tr><td>General-purpose food tray, tamper-evident packaging, blister packaging), bottles (fruit squash, water, cooking oils)</td><td>PVC-U</td><td rowspan="2">Moldable
Good chemical resistance.
Clear appearance
Recyclable
Contains Chlorine</td><td>Thermoformed sheets and foils</td></tr>
<tr><td>Cap seals (canned and bottled food), closures, and can linings</td><td>PVC-P</td><td>Cling and stretch films</td></tr>
</table>

Table 1: Different desirable attributes of abundantly used plastics relevant to their applications in terms of food packaging and service

	Mechanical Properties	Moulded Products	Water Resistance	Barrier Properties
TPS	Limited	✓	✗	Excellent O_2 Poor water
PLA	Brittle but can be modified	✓	Limited	Poor O_2 Fair Water
PBS	Poor mechanical properties	✓	✗	Good O_2 - Poor Water
PHA	Relatively flexible	✓	✓	Good O_2 Good Water

Table 2: Comparison of properties in bio-based biodegradable plastics
(TPS- thermoplastic starch, PLA- polylactic acid, PBS- polybutylene succinate, PHA- polyhydroxyalkanoates)

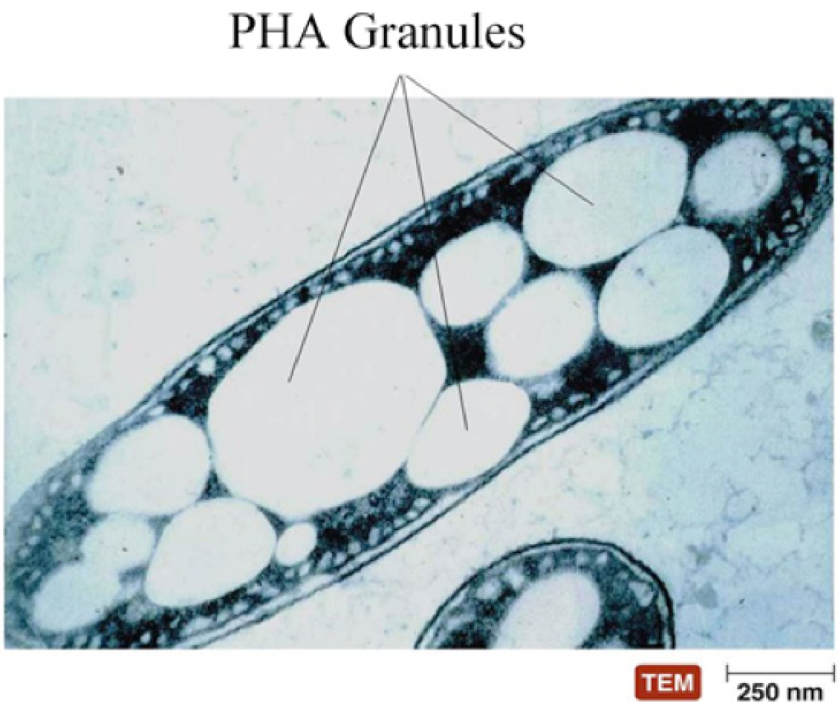

Figure 1: PHA granules accumulated in a bacterial cell (Azotobacter chroococcum)

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