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Bioplastic from Peel and Rind of Tropical Fruits in Southeast Asia: A Mini-Review

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ABSTRACT

Southeast Asian (SEA) countries have faced numerous challenges in managing their increasing amount of agricultural waste, particularly fruit waste. Fruit waste, like peel and rind, constitutes a substantial portion of total waste generated in SEA countries due to the high consumption of fruits in the region. In addition, inadequate waste management infrastructure, lack of proper disposal methods, and low awareness among the public have exacerbated the problem. The overproduction of plastic waste has become a global environmental issue, and SEA countries are not exempt from this problem. However, using bioplastics made from fruit peel and rind can reduce the dependence on traditional plastics. This paper aims to provide a mini-review regarding bioplastic production from fruit waste (peels and rinds) generated from tropical fruit of SEA countries. Moreover, this mini-review aims to evaluate their potential to replace traditional plastics in various industries. One potential method to solve this issue is converting fruit waste into bioplastics, which can provide a sustainable and eco-friendly alternative to conventional plastics. Bioplastics, derived from renewable sources such as fruit waste, are biodegradable, compostable, and can reduce carbon footprint. The findings of this paper indicate that fruit waste from peel and rind is a promising source of raw materials for bioplastic production in SEA countries. Bioplastics' fruit waste properties are comparable to conventional plastics and their applications. Furthermore, using fruit waste for bioplastic production can address the region's waste management issue. In conclusion, bioplastics from fruit waste have great potential to replace *traditional plastics in SEA countries. Fruit waste provides a sustainable and cost-effective alternative raw materials for bioplastic production. Implementing fruit waste utilization for bioplastic production can contribute to developing a circular economy and aid in managing regional waste.*

Keywords: Bioplastics; Fruit Peel; Fruit Rind; Southeast Asian; Fruit Waste

INTRODUCTION

In recent year, the increased global concern for environmental sustainability has led to the development of eco-friendly alternatives to traditional plastics that is not degradable and cause environmental pollution. Bioplastics are biodegradable polymers made from polymers that come from living things; for example, renewable sources from plant matter have emerged as a viable solution due to their potential to mitigate the environmental impact associated with plastics [1] Southeast Asian (SEA) countries are well-known for their rich biodiversity and abundance of tropical fruits that produce fruit waste (peel and rind), for example, banana peel [2,3], pineapple peel [2,4], rambutan peel [5–9], mangosteen peel, mango peel, durian rind, and jackfruit rind. These peels and rinds offer a promising feedstock for the production of bioplastics that act as bio-fillers in bioplastic production [2].

This paper aims to provide a mini-review of the bioplastic derived from fruit waste in SEA countries. The focus will be exploring the potential of using fruit waste, specifically fruit peel and rind, as a feedstock for bioplastic production. By examining the bioplastics that can be obtained from peel and rind, this review aims to contribute to the development of sustainable and environmentally friendly alternatives to conventional plastics in the SEA region, as there are fewer papers focusing on the elaboration of bioplastic from peel and rind in the context of SEA countries.

Furthermore, this paper will also examine the challenges and opportunities associated with the production and adoption of bioplastics in SEA countries. By analyzing the current state of bioplastic production, assessing the technological and economic constraints, and identifying potential strategies for overcoming these challenges, this review could be helpful for researchers, policymakers, and businesses interested in developing sustainable and environmentally friendly alternatives to traditional plastics in the SEA region.

Biodegradable Polymer

The biodegradable polymer is a material degraded in the environment to produce carbon dioxide and water [10,11]. The phrase "biodegradable" refers to materials that, when exposed to a microbiological climate and humidity, disintegrate or break down naturally into biogases and biomass, mainly carbon dioxide and water [12]. Biodegradable polymers can degrade after encounters with biological factors, and it is called biodegradability [2,10]. Specifically, there are three primary phases in the biodegradation of polymers. First is biodeterioration, which is the alteration of the polymer's mechanical, chemical, and physical properties due to the growth of microorganisms on or inside the polymer's surface. Next is biofragmentation, in which microorganisms convert polymers to oligomers and monomers. Lastly is assimilation, in which microorganisms are supplied with essential carbon, energy, and nutrient sources from polymer fragmentation and convert plastic carbon dioxide, water, and biomass [13]. Figure 1 below illustrates the overall process of biodegradation process of polymer waste.

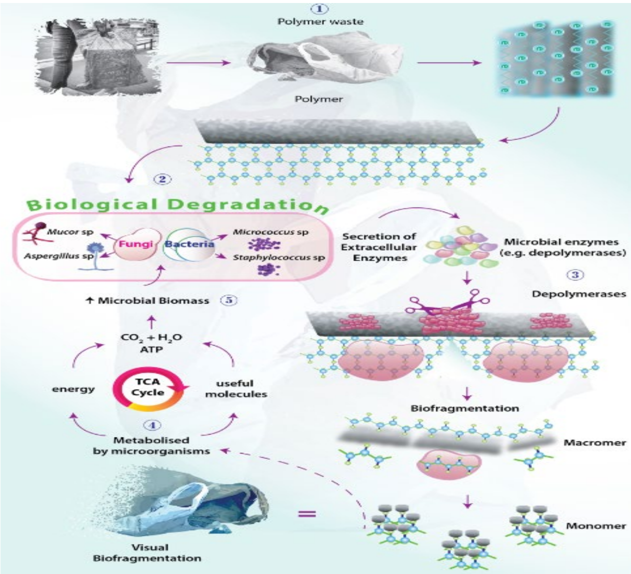

Figure 1: Overall Biodegradation Process of Polymer Waste [7]

What is Bioplastic?

Bioplastics are biodegradable polymers that are derived from living organisms. Microorganisms and water in compost piles can break down these polymers in a good way for the environment [1]. Bioplastics can be put into three groups. First, are biodegradable polymers made from petroleum (fossil-based). The second is bioplastics made from petroleum and other materials (bio-petroleum). The third is bioplastics made from renewable resources (naturally from plants and animals). There are numerous environmental advantages of bioplastics, such as reducing carbon footprint and greenhouse gas (GHG) emissions, requiring less energy to create it, minimizing permanent trash, and making the environment considerably more secure and have the potential to replace petroleum-based plastics in a sustainable way [13]. Bioplastics also offer advantages in their creation, such as allowing far more water vapour through than ordinary plastic, feeling less oily, being easy to print on, being softer, and more tactile. The way bioplastic is made can be different depending on the material used, the properties of the bioplastic made, and how the product is put together [1].

Production of Tropical Fruit in Southeast Asia Countries

Southeast Asian (SEA) countries consist of ten ASEAN member states (Figure 2): Malaysian, Thailand, Singapore, Indonesia, Brunei, Philippines, Cambodia, Laos, Vietnam and Myanmar) [14–18]. Figure 2 below illustrates the ASEAN country map and common tropical fruits produced and fruit waste generated (peels and rinds).

Fruit wastes, including pomace, skin, peel, seed, and rind, are categorized as unavoidable waste that cannot be eaten or sold [2,19–22]. Therefore, these fruit waste will be disposed of in landfills because they are more biodegradable than other trash. Unfortunately, several fruits, such as banana peel, pumpkin peel, jackfruit rind, and durian rind, have the majority of their nutritious content in the form of inedible parts, resulting in the waste of the majority of the nutritional content [21]. For example, the peel or rinds of lemons, mangoes, avocados and jackfruit contain almost 15 % more phenolic compounds than fruit pulp [23]. Thus, instead of being solely dumped, these fruit wastes are used to make more beneficial goods with the addition of other chemicals that can be used endlessly, such as bioplastics

[24]. In this review, the discussion of fruit waste in the context of peel and rind is elaborated in detail due to the limited discussion focused on this part of fruit waste. Fruit peel is part of fruit skin peeled or cut out using a sharp tool. This part acts as an outer protective layer that covers its flesh to ensure stabilization of fruit integrity [25,26]. Fruit rind is defined as a by-product from the industries and has been discarded due to unconsumability. Fruit rind is majorly found in fruits that have hard skin, for example, durian [27–31], jackfruit [32]and pomegranate [3,33,34].

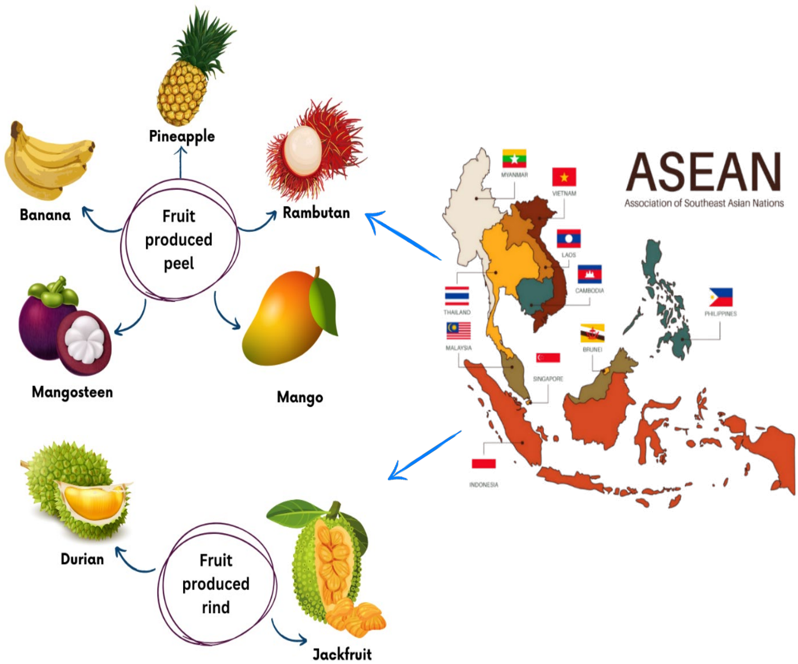

Figure 2: Diagram that illustrates the map of ASEAN country and common tropical fruits produced and fruit waste generated (peels and rinds)

Table 1: Summary of Tropical Fruit of Southeast Asia Countries and findings related to biodegradable/bioplastic production.

Tropical Fruit and Their Waste	Produced Country	Key Findings
Banana Peel	Malaysia, Thailand, Indonesia, Myanmar, Philippines	Pectin from banana peel has been successfully extracted using acid hydrolysis (HCl). Then, this banana peel pectin is used to fabricate banana peel bioplastic. This process involved mixing pectin with CaSO4 and water and adding a starch solution. Then, 5 % glacial acetic acid and glycerin were added. Finally, bioplastic of banana peel is produced. Banana peel bioplastic exhibited biodegradable properties based on the bioplastic's colour changes after 2 weeks of soil buried test [35]. Natural-based bioplastic consisting of banana peels reinforced corn starch, potato starch, and sage exhibited high elongation at break. However, its tensile strength and Young Modulus are low. Whereas chemical-based bioplastic, prepared via alkaline treatment of NaOH and acid hydrolysis using HCl, exhibits improved tensile strength and Young Modulus, its elongation at break value is reduced [36]. Bioplastic from banana waste has been developed, and it exhibited good interaction between the banana fibre waste and starch matrix based on SEM image [37]. A bioplastic derived from the banana peel of Musa Paradisica. Fomatypica reinforced chitosan matrix with acetic acid and various compositions of glycerol and sorbitol has been successfully extracted via solution casting. Bioplastic with 3 % glycerol (% v / v) exhibited a tensile strength of 46.4201 MPa and percent elongation at break (15.15152 %). A sample of 5 % sorbitol (% v / v) has a tensile strength with a value of 31.4228 MPa and elongation at break with a percentage of 15.15152 % [38].

		Bioplastic derived from banana peel-reinforced cassava starch has been successfully prepared. This bioplastic exhibited good mechanical and thermal properties. Moreover, this bioplastic-based banana peel degraded after 12 days buried in the soil [39]. Starch-based bioplastic banana peel has been prepared with commercialized chitin and extracted chitin. Adding chitin to the starch-based banana peel bioplastic improved the physical and mechanical properties of the film [40].
Pineapple Peel	Indonesia, Malaysia, Thailand	Cellulose from pineapple peel can be synthesized by using two methods: chemical or fermentation method. Cellulose derivatives such as hydroxycellulose, methylcellulose, cellulose acetate, and carboxymethylcellulose (CMC) can be produced based on our methods. Cellulose synthesized from pineapple peel can be applied material in drug delivery and biodegradable material production [41]. Bacterial cellulose (BC) film has been prepared from BC pellicle from the pineapple waste extract, including pineapple peel. The size of the BC pellicle decreased after the treatment chemical pre-treatment with NaOH, hydrogen peroxide, and ionic liquid of BmimCl [42]. Biocomposite of bacterial cellulose with polyethylene glycol has been successfully prepared using BC pellicle. This biocomposite membrane film exhibits high mechanical properties, crystallinity, and high purity of cellulose [43].

Pineapple Peel	Indonesia, Malaysia, Thailand	Pectin from pineapple peel waste has been successfully extracted via microwave-assisted extraction (MAE). This method is faster than conventional heating because less solvent and time are used. The percentage yield of pectin is increased by 21.5 % compared to the conventional heating technique. Therefore, pectin extracted can be used as a bio-filler to reinforce polymer for packaging applications [44]. Cellulose and cellulose nanospheres have been successfully extracted from pineapple peel (agricultural by-products in Chiang Rai, Thailand). Cellulose and cellulose nanospheres extraction involved bleaching treatment (sodium hypochlorite, NaOCl) and alkaline treatment using KOH. Then, proceed with acid hydrolysis treatment (60 % sulfuric acid). Cellulose and cellulose nanospheres can be used as fillers in biodegradable composite and nanocomposite for packaging applications [45]. Rambutan peel produces rambutan flour blended with linear low-density polyethylene (LLDPE). The blending process has been performed in the Brabender internal mixer at 160 oC. This blend exhibited low tensile strength and strain as the composition of rambutan peel flour (RPF) increased in the LLDPE matrix. This phenomenon might be due to the poor interfacial adhesion between RPF and LLDPE. However, the Young Modulus increased as the composition of the RPF increased [7].

Rambutan Peel	Malaysia, Thailand	Rambutan peel flour (RPF)/LLDPE blend exhibited improved mechanical properties when Adipic Acid (AA) was added to the blend. AA improved the interfacial adhesion between the RPF and LLDPE matrix. Therefore, the Young Modulus of the blend increased compared to the previous study of the blend without AA [46,47]. Active packaging film was produced from a starch blend with whey protein, rambutan peel extract, and cinnamon oil. Rambutan peel extract contains a high percentage of geraniin mixed with polyphenolic compounds that increase the antibacterial and antioxidant properties of the film. Therefore, salami wrapped with active packaging (rambutan peel extract + cinnamon essential oil) has a stable redness compared to non-active packaging film [9]. Bio-based food packaging of whey protein isolate (WPI) film has been prepared by incorporating rambutan peel extract (RPE) with Cinnamon Oil Extract (COE) with different weight ratios ((10:0, 9:1, 8:2, 7:3, 6:4, 5:5, 4:6, 3:7, 2:8, 1:9, and 0:10). Nine strains of bacteria including gram-positive and gram-negative bacteria were selected as the representative of pathogenic and food spoilage bacteria. WPI, with a 5:5 ratio of RPE to COE, exhibits excellent synergistic effects against these 9 strains of bacteria due to the improving antimicrobial activity. Moreover, the mechanical and physical properties of the film also improved [48].

		Rambutan peel extract exhibiting high antioxidant properties has been incorporated with biodegradable polymer to produce active packaging. A high content of geraniin will retarded the lipid peroxidation during food processing and storage. Therefore, food spoilage can be prevented by using active packaging incorporated with rambutan peel extract [25].
Mangosteen Peel	Malaysia	Extracted mangosteen-CNC acts as a bio-filler to reinforce the cassava starch matrix. The addition of CNC to the starch matrix exhibits high tensile strength, high tensile modulus, low elongation at break, and low density. However, the film's mechanical properties decreased as CNC's composition increased [49].
Mango Peel	Thailand, Vietnam	Pectin has been successfully extracted from the mango peel of 'Nam Dok Mai' and used to produce thin film, which has the potential for biodegradable packaging and drug delivery application [50,51]. Mango peel pectin has been extracted from various Vietnamese Mango cultivars. Overall, the mean esterification value of extracted pectin suggests that it should be considered high methoxy pectin (HMP) that can potentially act as a bio-filler in biodegradable packaging and application in the food processing industry [52]. Extraction of cellulose that is used as bio-fillers in PLA matrix for biodegradable plastic [53].

Durian rind	Malaysia, Thailand, Indonesia, Singapore	Carboxymethyl cellulose (CMC) is extracted and followed by CMC biodegradable film fabrication or packaging application [29]. Sodium monochloroacetate converts cellulose in durian peel waste into carboxymethyl cellulose. The best ratio of sodium monochloroacetate towards cellulose is 7:5. The reaction time is 4 hours, producing a high percentage yield of CMC and a high degree of substitution [54]. Durian cellulose (DC) regenerated film is prepared using a 'green' solvent of LiCl/DMAc. The DC film exhibits high transparency and improved mechanical and thermal properties. DC regenerated film has the potential to be applied as flower packaging to maintain the freshness of fresh flowers [27]. Biocomposite corn starch-based film has been prepared from jack fruit rind microcrystalline cellulose (JR-MCC). The tensile strength and Young Modulus decreased as the composition of JR-MCC increased, while the value of elongation at break increased [32].
Jackfruit rind	Malaysia, Vietnam	Pure nanocellulose was extracted from jack fruit rind using the acid hydrolysis method and mixed with a different type of plasticizer (glycerol, polyethylene glycol, PVA, triethyl citrate) and filler of frankincense. The surface morphology of nanocellulose film was improved. Moreover, the thermal properties also increased based on the increasing glass transition temperature value. Nanocellulose film derived from this jackfruit rind can potentially substitute petroleum-sed plastic for packaging applications [55].

CONCLUSION

Using fruit peel as a feedstock for bioplastic production gives a promising solution to replace traditional plastics in Southeast Asian (SEA) countries. This mini-review has highlighted the vast potential of bioplastics derived from fruit waste in driving sustainable development and addressing the environmental challenges faced by the region. Various types of fruit peel-based bioplastics offer a range of desirable properties, including biodegradability, renewability, and cost-effectiveness. These characteristics make bioplastics a great alternative to traditional plastics. Their biodegradability ensures reduced environmental impact, while their renewable nature addresses resource depletion concerns. Additionally, the cost-effectiveness of bioplastics presents economic advantages.

Adopting fruit peel-based bioplastics aligns with the principles of a circular economy, promoting the efficient use of resources and minimizing waste generation. It allows the establishment of a closed-loop system where fruit waste is collected, processed, and transformed into bioplastics. It can be used in various applications, including packaging, consumer goods, medical instruments, and agricultural materials.

Furthermore, the production offers socio-economic opportunities to SEA countries. It creates opportunities for local industries, stimulates job growth, and fosters innovation and technological advancements in the bioplastics sector. Additionally, the shift towards bioplastics can enhance the sustainability image of the region, attracting investment and market opportunities from environmentally-conscious consumers and businesses. However, there are still many challenges faced by the SEA countries, especially limitation of research funding, unstable economy, and politics of a few SEA countries that might affect the research and development regarding utilization of fruit peel waste.

In conclusion, by implementing fruit waste utilization for bioplastic production, SEA countries can move towards a more environmentally friendly and sustainable future while simultaneously addressing the issue of waste management. Continued research, stakeholder collaboration, and supportive policy frameworks are essential to advance the region's development and adoption of fruit waste-based bioplastics.

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