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Sustainable Packaging From Plant Waste For Environmental Benefits

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Abstract

Environmentally friendly plastics made from renewable sources which are biodegradable and compostable have the potential to solve a variety of waste management issues related to disposable packaging. Environment covers a broad topic including waste reduction, material selection, and energy use to reduce environmental impacts.

Biopolymer-based for food packaging materials is a potential solution to address environmental pollution from non-biodegradable food packaging materials. Tropical plants like potato, rice, maize and tapioca are abundant and could provide huge benefits to produce **biopolymer-based packaging materials** with short functional life. This paper is focusing on one of the most growing interest among researches - the **sugar palm tree**. It grows wild in many places in many Asia countries for its sap to convert into sugars. It is reported as one of the most diverse multipurpose tree species where the root, stem, fibers, leaves, sap from flowers, and fruits can be utilized in making beneficial products. However, when the tree is no longer productive in producing sugar and fruits, the **tree starch can be extracted** and utilized for other purposes. Fascinating discovery of sugar palms starch is its ability to produce biopolymer which has biodegradable and compostable advantageous and address the criticism about use of food sources (potato, tapioca and rice) as **polymeric matrix**. Whilst, the **long and black fiber covering the tree's trunk** is popular among locals to have high strength and stiffness and traditionally used to make broom, brushes, and hand crafts. Studies also proved its capabilities as reinforcement material in biopolymer composites. Therefore, **natural fibre reinforced biopolymer composites or green biocomposites from a single tree** (sugar palm) is an excellent potential to achieve environmentally friendly packaging. This gives potential **to boost local jobs and wealth distribution where the culture of family farms is empowered**, and reverse logistics systems are strengthened. Additionally, it would certainly enhance **community awareness regarding environmental issues**.

The Problem of Conventional Plastics

Sources: Soroudi and Jakubowicz, 2013; Sapuan, 2017; *Geyer et al., 2017 ;* Su et al., 2018

Non-biodegradablity

The ability of a substance to break down into small enough parts so that microorganisms can consume it. All products eventually biodegrade, but plastics take much longer.

Recycling constraints

Waste segregation is not yet a culture in most homes and even when they do, garbage collectors may mix it because of technical and economical constraints for recycling. The amount of plastics waste accumulated in landfills and natural environment will be roughly 12,000 million metric tonne (Mt.)

Fossil fuel dependency

Petroleum byproducts – polypropylene (PE, PET, HDPE, PP, PS), a plastic commonly found in food packaging manufacturing. Reliance on greenhouse gas emissions need to be reduced.

Environmental Pollution

Small components of plastics found on the surface and throughout the water column, are likely to be ingested by marine organisms and is a threat to marine life.

Social and Economy Issues

Chemical contamination risks to human health, can cause a drop in the demand for and/or in the value of fish, leading to losses to the fisheries and aquaculture sector. The marine litter on beaches reduces tourism and recreation activities.

The Solution

- Bio-based plastics can imitate the life cycle of biomass – includes **conservation of fossil resources, water and CO2 production** (Siracusa et al., 2018)

Biodegradable and compostable

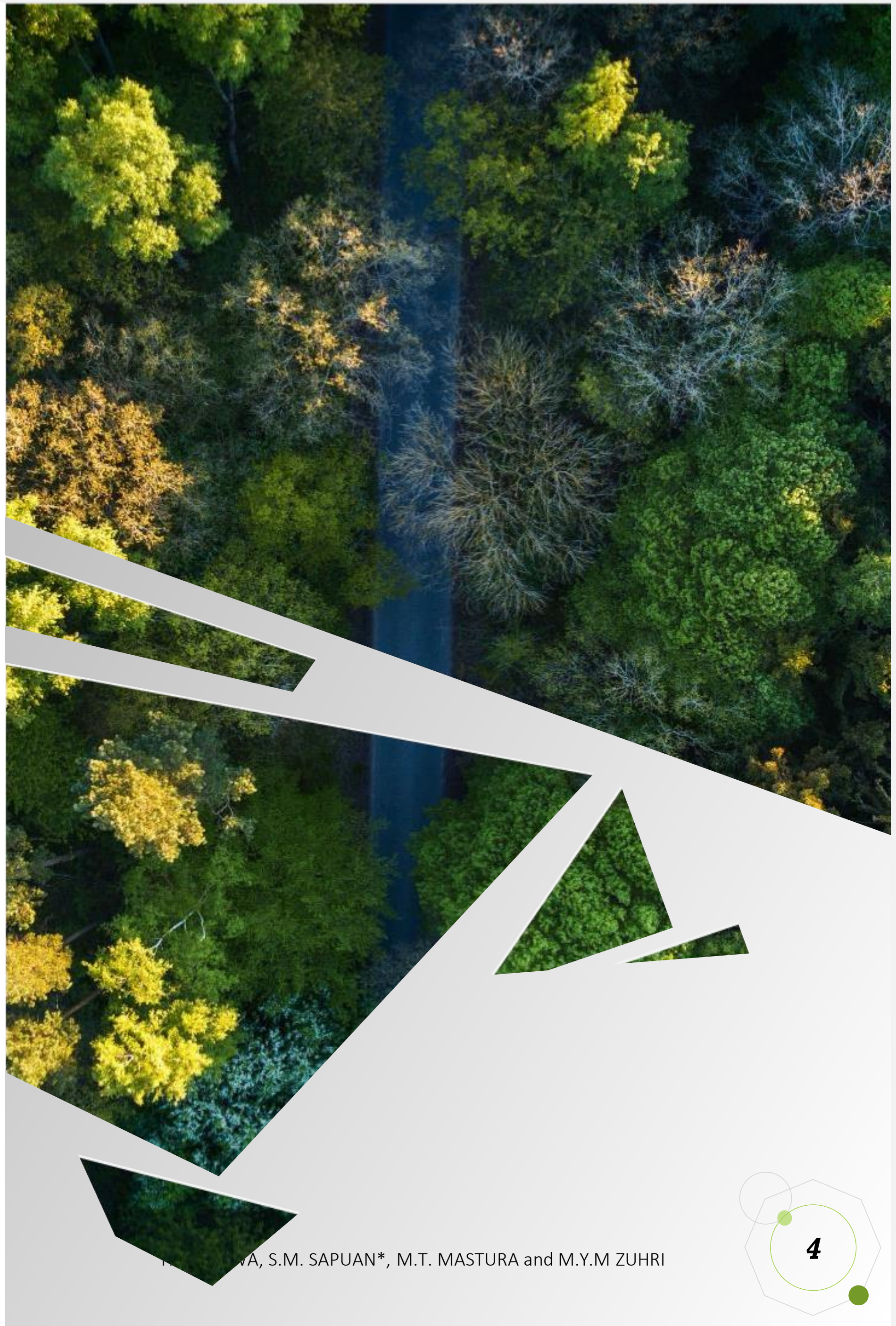
A biodegradable material is **not necessarily** compostable. A compostable material is always biodegradable.

Renewable resources

Utilizing **abundant resources** from plant waste to produce bio-plastics which is biodegradable and compostable

Design for Sustainability (D4S)

Minimizing the **unnecessary environmental, social, and economic impacts** in the product's supply chain and **throughout its life cycle**



Design for Sustainability

Environmental

Ensure of **low ecological damages** (i.e global warming, eco-toxicity), **human health damages** (i.e air pollution, carcinogens) and **resource depletion** (fuel and its derivatives)

Economic

Increase **energy efficiency**, reduce **power consumption**, efficient **material utilization**, less **operational cost**, lower **installation and training cost** ; and **purchase market value**

Social

Ethical labor practice where employees are fairly and ethically treated, termination of the **economic exploitation of children**, community development on **basic necessities** such as health, education and water facilities; and **sharing of wealth**

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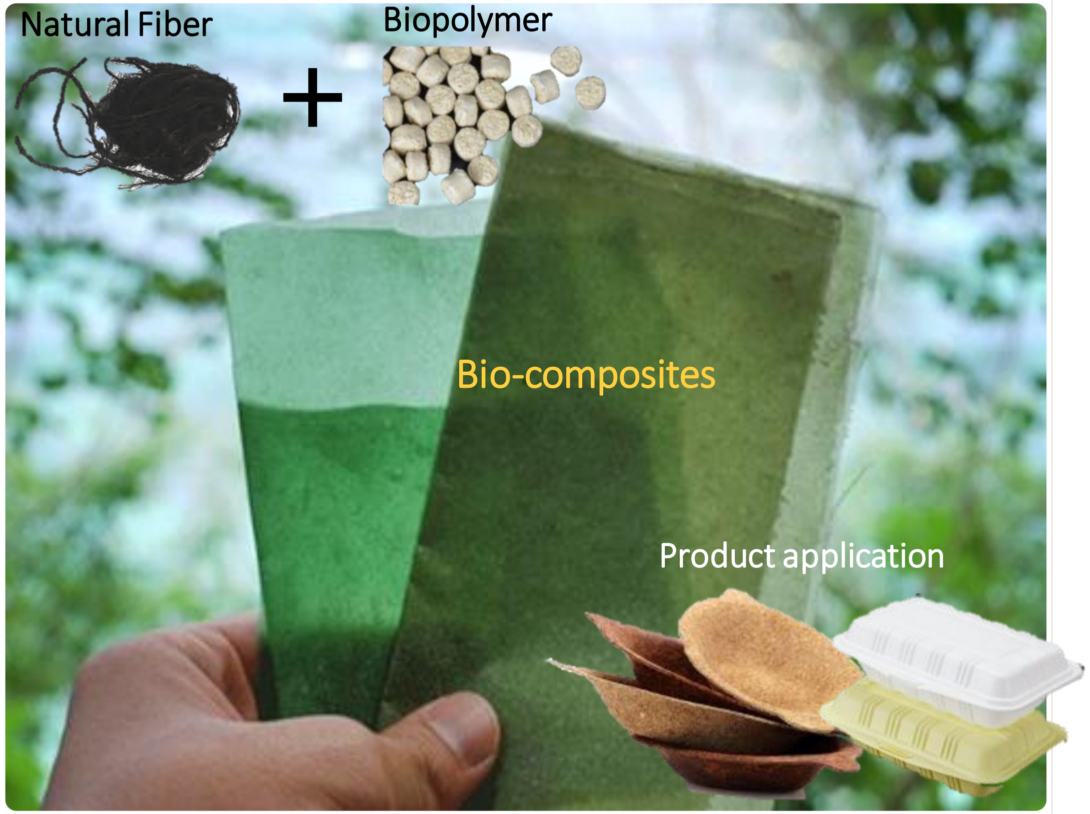
Green Bio-Composites

- Composites which **either one of the matrices or fibres, or both** matrix and fibre, are **derived from biological resources**. Both constituents (matrix and reinforcement fibre) derived from renewable resources are termed as **"green bio-composites"** (Al-oqla & Omari, 2017; Mitra, 2014)
- Can retain the whole carbon content and save primary resources; furthermore, they offer **reductions in weight and cost**, and give less reliance on foreign oil resources (Soroudi and Jakubowicz, 2013)

Advantages:

- Biodegradable and compostable
- Abundant availability from renewal resources
- Lower production cost
- Lower green house gas emissions
- Less health effects
- Minimized waste volume on landfills
- Better growth in agricultural and chemical industries
- Lower consumption of energy to process natural fibres (20-25% lower than synthetic fibres)
- Can save at least 20 MJ of renewable energy per kilogram of polymer
- Eliminate at least 1kg of CO2 per kilogram of polymer
- Minimize most other environmental impacts, at least by 20%



Design for Single-Use Food Packaging

Food packaging roles/ function

- To **protect** food products; to **preserve** products; to deliver products **in quantities and formats tailored** to suit how and when they will be consumed; to **dispense products conveniently and safely** (easy-open features, re-closability and child-resistant closures); to add **convenience** to the products; and to **improve sales** (Rundh, 2005; M L Sanyang et al., 2016)
- To **hinder gain or loss of moisture**, prevent **microbial contamination** and act as a **barrier against permeation** of water vapor, oxygen, carbon dioxide and other volatile compounds (Rhim, Park, & Ha, 2013)

- Related to the physical properties of the food, to protect at the same time **encouraging hygien**e, **safety** and **enabling distribution** (Fernqvist et al., 2015)
- Requirements of packaging material are **specific to the type of food to be packed** i.e materials need to fulfil different needs in terms of light, moisture, water vapour, and gas barriers (Bugnicourt et al., 2013)
- General properties required for food packaging materials – **Mechanical properties, Barrier properties, Chemical resistance, Grease resistance, Anti-microbacterial function, Thermal properties, Optical properties and environmentally friendly** (Rhim, Park, & Ha, 2013; Siracusa et al., 2008)
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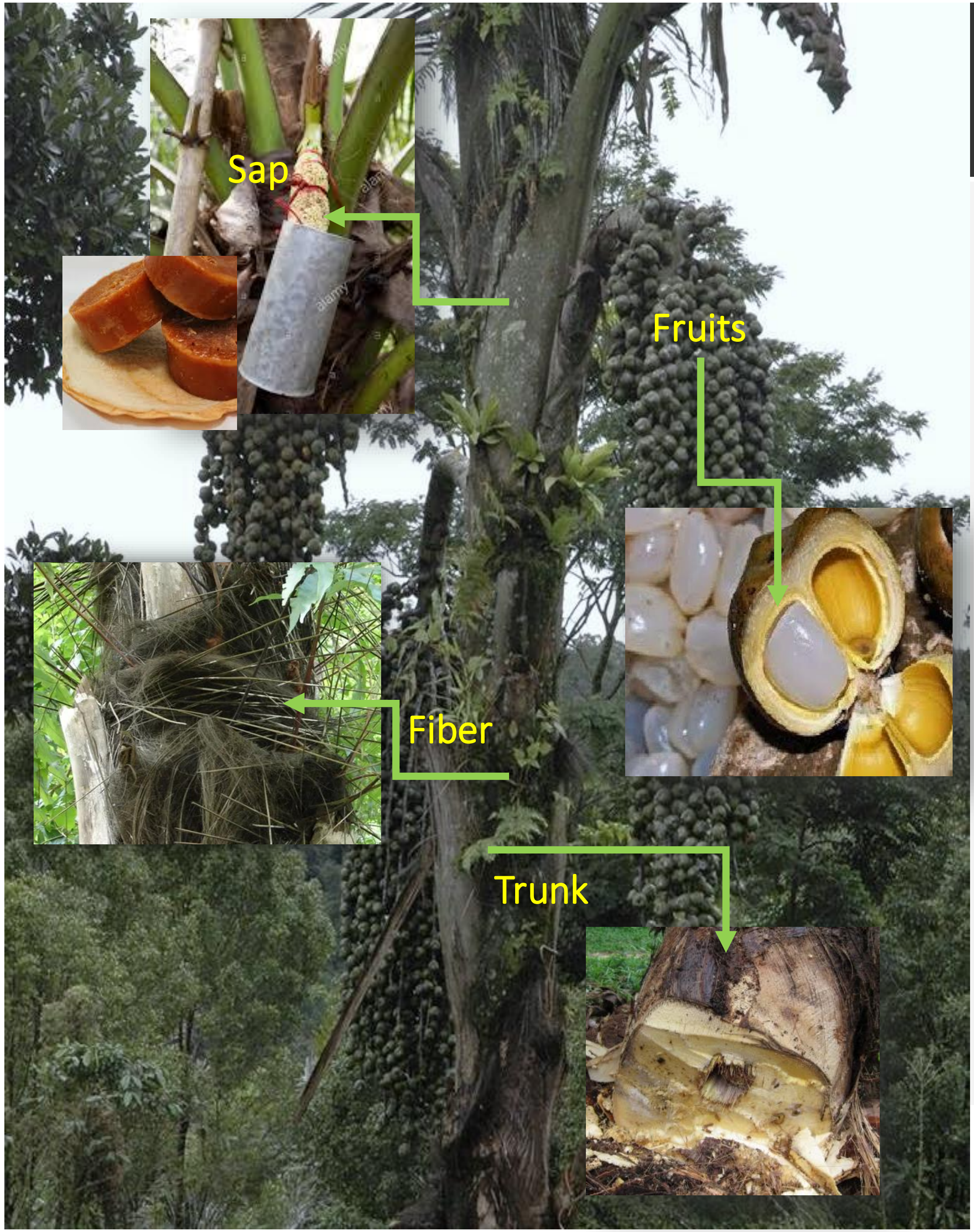


Sugar Palm Trees

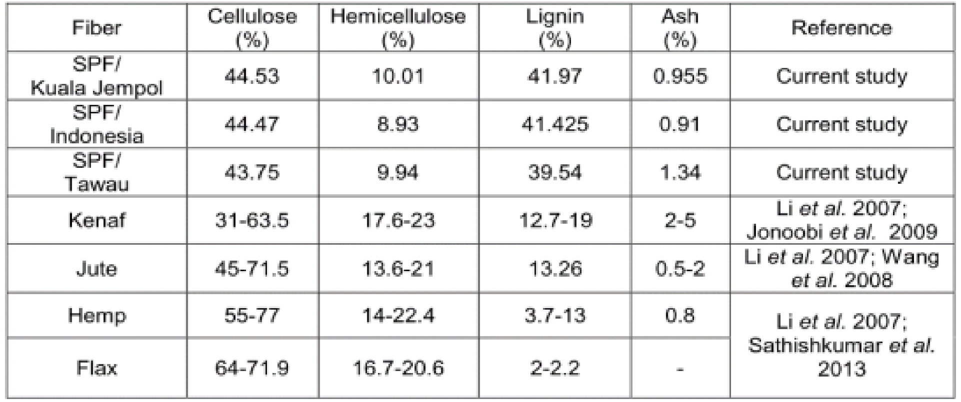
- Medium-sized palm, growing to 20 – 30 m tall, with the trunk remaining covered by the rough old leaf bases. The trunk is around 65 cm in diameter, and **covered with black fibers** and spines. The fruit from sugar palm trees can be consumed raw or as an ingredient for desserts.
- The sap is processed to produce sugar palm syrup commercially and is widely used as main ingredient for traditional cakes, and can be used to produce bioethanol through fermentation.
- Sugar palm fiber (SPF) is popular among locals to have **high strength and stiffness** to produce rope, and found to be great potential as reinforcement in polymer matrix composites. It **does not need any secondary process** like other natural fiber and is ready to use.
- Starch has been considered as one of the most promising biopolymer due to its **easy availability, biodegradability, lower cost and renewability**. Sugar palm tree is able to produce 50–100 kg of starch extracted from its trunk after it is unable to produce fruits or yield sap. Native sugar palm starch (SPS) with the **addition of plasticizers would improve the flexibility, extensibility and ductility of plasticized films.**
- **Green biocomposites can be produced from a single tree**

Source: Sanyang et al., 2015; Sanyang et al., 2016; Jumaidin et al., 2016; Huzaifah et al., 2017

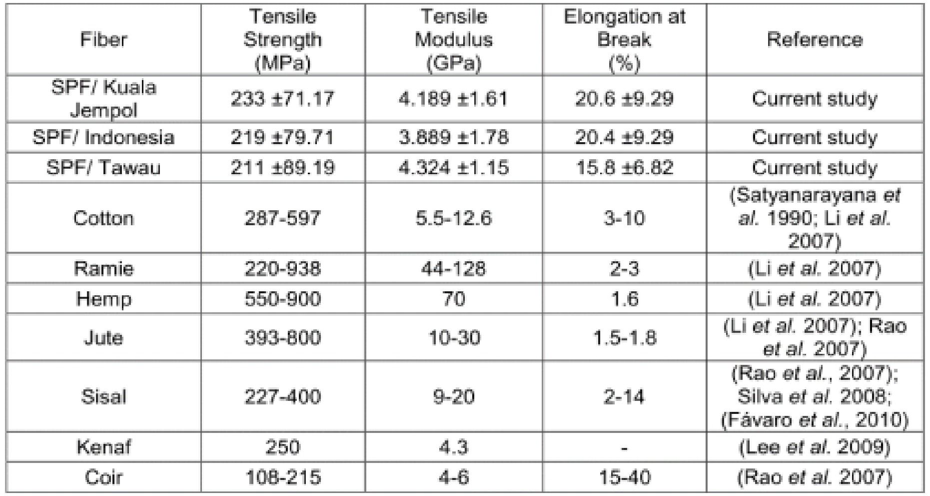
SPF and SPS Characterization

SPF - Physical, Chemical and Mechanical Properties of SPF (Huzaifah et al.(2017)

Fiber	Tawau	Kuala Jempol	Indonesia
Diameter (mm)	0.349 ±0.037	0.4 ±0.079	0.457 ±0.095
Density (g/cm³)	1.4460 ±0.009	1.4623 ±0.0121	1.4426 ±0.0035
Water absorption (%)	156.56 ±19.64	161.96 ±34.04	80.32 ±13.3
Moisture content (%)	7.05 ±1.62	6.45 ±1.07	5.63 ±0.4

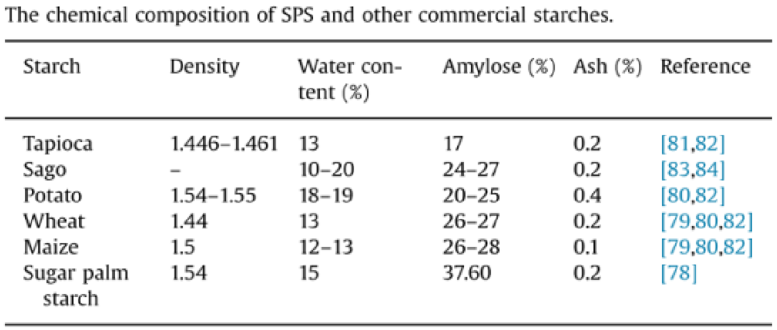


Fiber	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Ash (%)	Reference
SPF/ Kuala Jempol	44.53	10.01	41.97	0.955	Current study
SPF/ Indonesia	44.47	8.93	41.425	0.91	Current study
SPF/ Tawau	43.75	9.94	39.54	1.34	Current study
Kenaf	31-63.5	17.6-23	12.7-19	2-5	Li *et al.* 2007; Jonoobi *et al.* 2009
Jute	45-71.5	13.6-21	13.26	0.5-2	Li *et al.* 2007; Wang *et al.* 2008
Hemp	55-77	14-22.4	3.7-13	0.8	Li *et al.* 2007; Sathishkumar *et al.* 2013
Flax	64-71.9	16.7-20.6	2-2.2	-	



Fiber	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation at Break (%)	Reference
SPF/ Kuala Jempol	233 ±71.17	4.189 ±1.61	20.6 ±9.29	Current study
SPF/ Indonesia	219 ±79.71	3.889 ±1.78	20.4 ±9.29	Current study
SPF/ Tawau	211 ±89.19	4.324 ±1.15	15.8 ±6.82	Current study
Cotton	287-597	5.5-12.6	3-10	(Satyanarayana *et al.* 1990; Li *et al.* 2007)
Ramie	220-938	44-128	2-3	(Li *et al.* 2007)
Hemp	550-900	70	1.6	(Li *et al.* 2007)
Jute	393-800	10-30	1.5-1.8	(Li *et al.* 2007); Rao *et al.* 2007)
Sisal	227-400	9-20	2-14	(Rao *et al.*, 2007); Silva *et al.* 2008; (Fávaro *et al.*, 2010)
Kenaf	250	4.3	-	(Lee *et al.* 2009)
Coir	108-215	4-6	15-40	(Rao *et al.* 2007)

SPS- Chemical composition and T_g and Water Vapor Permeabillity (WVP) characteristics according to plasticizers type (Sanyang et al, 2015, Sanyang et al, 2016)



The chemical composition of SPS and other commercial starches.

Starch	Density	Water content (%)	Amylose (%)	Ash (%)	Reference
Tapioca	1.446–1.461	13	17	0.2	[81,82]
Sago	–	10–20	24–27	0.2	[83,84]
Potato	1.54–1.55	18–19	20–25	0.4	[80,82]
Wheat	1.44	13	26–27	0.2	[79,80,82]
Maize	1.5	12–13	26–28	0.1	[79,80,82]
Sugar palm starch	1.54	15	37.60	0.2	[78]

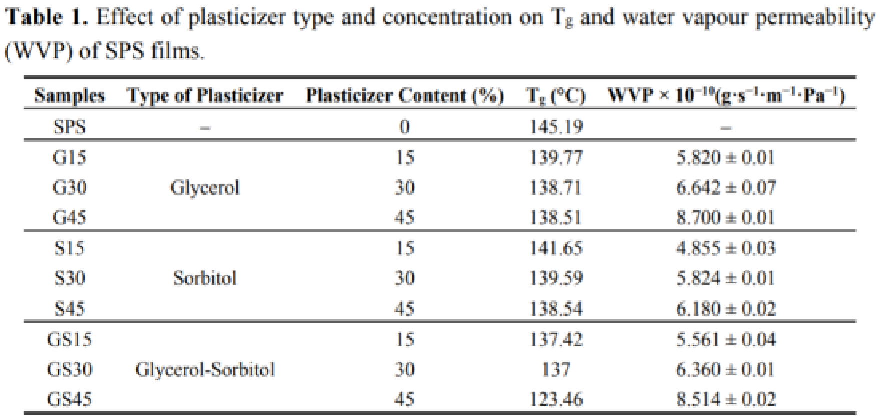


Table 1. Effect of plasticizer type and concentration on T_g and water vapour permeability (WVP) of SPS films.

Samples	Type of Plasticizer	Plasticizer Content (%)	T_g (°C)	WVP × 10^{-10}($g \cdot s^{-1} \cdot m^{-1} \cdot Pa^{-1}$)
SPS	–	0	145.19	–
G15	Glycerol	15	139.77	5.820 ± 0.01
G30		30	138.71	6.642 ± 0.07
G45		45	138.51	8.700 ± 0.01
S15	Sorbitol	15	141.65	4.855 ± 0.03
S30		30	139.59	5.824 ± 0.01
S45		45	138.54	6.180 ± 0.02
GS15	Glycerol-Sorbitol	15	137.42	5.561 ± 0.04
GS30		30	137	6.360 ± 0.01
GS45		45	123.46	8.514 ± 0.02

Market Opportunity

- Plastic packaging that escapes collection systems caused polluted ocean and clogging urban infrastructure, **generating significant economic costs by reducing the productivity of vital natural systems**. The **cost of such after-use externalities** for plastic packaging, plus the **cost associated with greenhouse gas emissions from its production**, is conservatively estimated at **USD 40 billion annually — exceeding the plastic packaging industry's profit pool"** - *Ellen MacArthur Foundation, The New Plastics Economy: Rethinking the future of plastics, 2016*
- Application of bioplastics and biopolymer in food packaging manufacturing are estimated to have the **highest growth rate** in the period of 2016-2021 and representing a **market value of USD 5.08 Billion by 2021** *(www.marketsandmarkets.com)*
- **Higher demand** of biopolymer and natural fiber **creates industrial crop source** for the **economic improvement of rural and agriculture-based communities**. Starch production requires **low infrastructure**, allows small scale producers to operate in the market, potentially **increasing local jobs and wealth distribution**, **empowering the culture of family farms**, and **enhancing reverse logistics systems** (by-product/ waste goes back in the supply chain)
- Opportunities for local villagers **to learn advanced techniques and skills** of proper natural fiber process method -> this lead to **development of locally manufactured natural composites**
- **Intermediates** of natural fiber and starch biopolymer could be also **supplied to high-technology engineering companies for commercial composites or products**.
- This will boost **awareness** among local community regarding **environmental issues and public health safety**, and could engaged individuals and communities to take **urgent action** and to **make informed and responsible decisions**.

Summary

> “SUSTAINABLE DESIGN IS MORE THAN GOOD BUSINESS, IT’S THE RIGHT THING TO DO.”

Thank You

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