

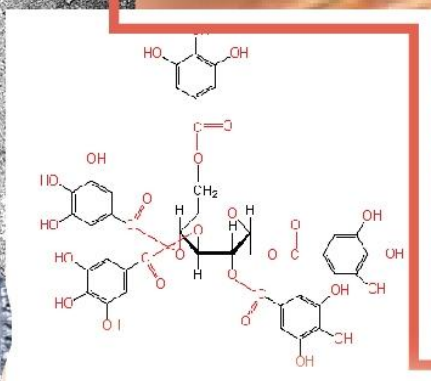
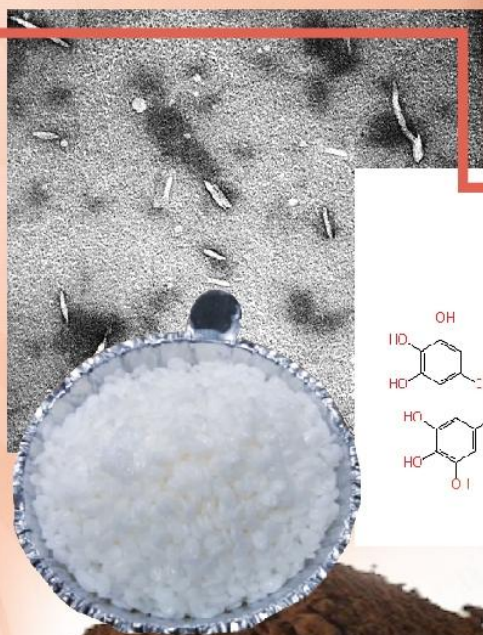
# INTROPica

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INSTITUTE OF TROPICAL FORESTRY AND FOREST PRODUCTS

Centre of R&D in Tropical Biocomposite and Bioresource Management

## BIORESIN & SUSTAINABLE BIOPOLYMER





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## FROM THE EDITOR

السلام عليكم ورحمة الله وبركاته

Welcome to the 14th issue of INTROPica!

We are very proud to announce that INTROP has been recognized as a Higher Institution Centre of Excellence (HICoE) in the field of Tropical Wood and Fibre. A page dedicated to the success of INTROP in getting HICoE status can be found in this issue. Well done INTROPians!

"Bioresin and Sustainable Biopolymer" has been chosen as the theme for this INTROPica issue since we realize its relevance to INTROP's focused area – Tropical Wood and Fibre. The increasing awareness for a clean environment and the escalating price of crude oil has urged an increasing demand for bioresource-based polymers. Biopolymers derived from renewable resources such as lignocellulosic materials are the primary drive for sustainable development without jeopardizing our nature. The utilization of bioresin and biopolymers possesses great impact by reducing the reliance on petroleum, reducing carbon foot print and promoting green economy in the nation.

In this issue, we are highlighting research and innovations related to sustainable biopolymer synthesis and technology. Written by respected experts, this issue covers the current research development of bioresin and biopolymer for various applications. We believe that this INTROPica has a key role to promote and share our research on sustainable biopolymer technology to the community.

Apart from research articles, as usual we are sharing some of the INTROP recent achievements and news. We hope you will enjoy reading this INTROPica issue as much as we enjoy publishing it!

-The Editors.

## TABLE OF CONTENT

From the Editor	Page 2
HICoE	Page 3
Research Articles	Page 33
Achievements 2016	Page 34
Awards	Page 35
Students Graduated in 2016	Page 36
Events	Page 38
New Member	Page 43
WOBIC 2017	Page 44
Equipment	Page 46

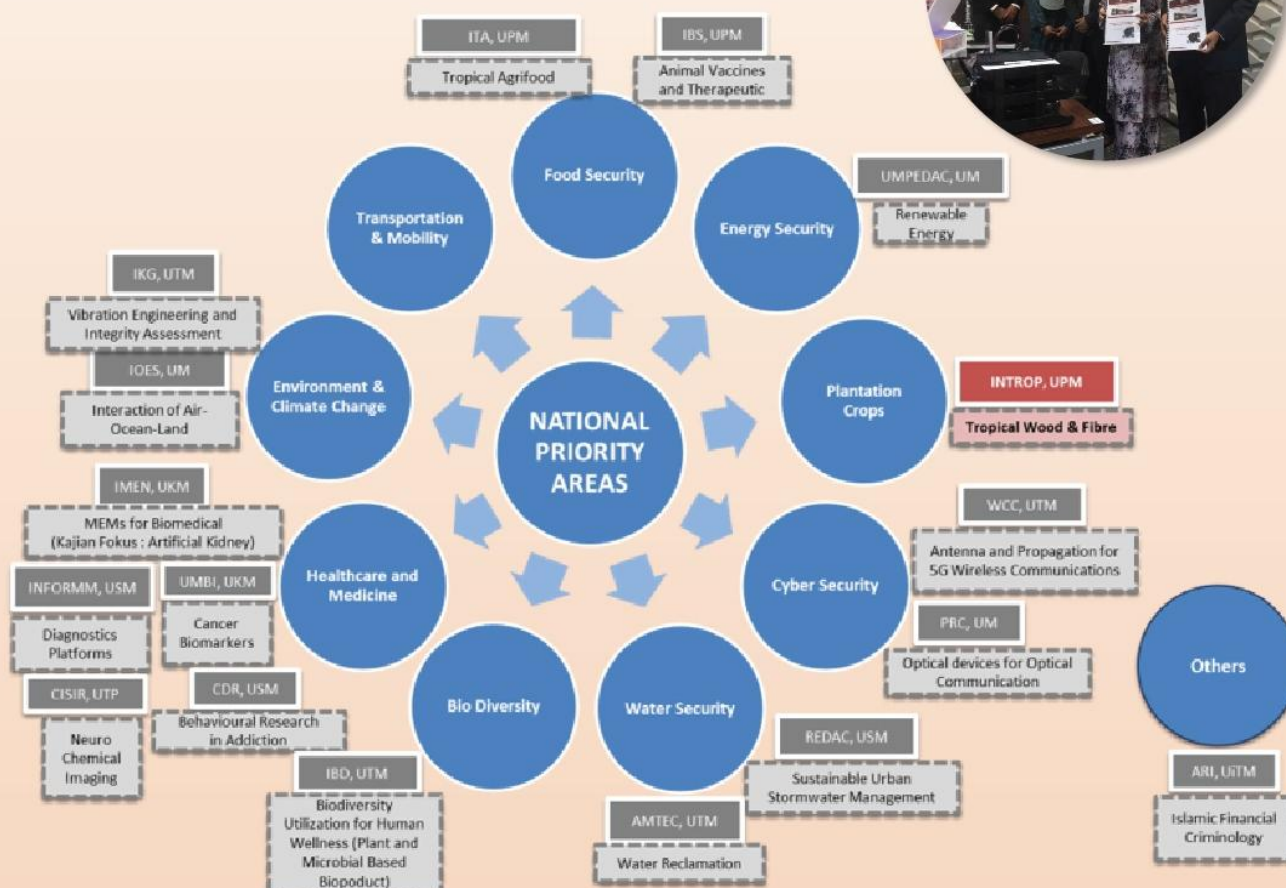


## INTROP IS NOW A HICoE!

INTROP has been recognized as a Higher Institution Centre of Excellence (HICoE) in the field of Tropical Wood and Fibre. The status is given by the Ministry of Higher Education (MOHE), Malaysia for 3 years, starting from 1 January 2017 until 31 December 2019. About RM 6.75 million has been allocated for INTROP throughout these 3 years; mainly for strategizing INTROP to be the leader in the focused area, i.e. Tropical Wood and Fibre. Among the actions planned are to strengthen the research programs in INTROP by conducting emerging and innovative research; to improve visibility of INTROP researchers by targeting for high impact publications, networking activities and giving lectures / seminars locally and abroad; to generate proactive and effective human capital by providing trainings; and to upgrade the facilities in INTROP. The fund will also assist INTROP to increase the capacity of the research laboratory towards achieving ISO17025 accreditation.

This recognition has placed INTROP amongst the 19 HICoEs in Malaysia, which will drive the 9 National Priority Areas (NPA) towards a higher level.

INTROPians are very proud with this achievement. With knowledge we serve!





# Jatropha Oil in Spotlight for The Production of Bioresin & Sustainable Polymer

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## Introduction

Most polymeric products are produced from non-renewable petroleum oil, which is unpredictable in terms of price and availability. Enforcement of a sustainable development pressures the chemical industry to move towards a bio-based product, which is synthesised from renewable resources such as vegetable oil. This could lead in reducing environmental impacts associated with the waste of petroleum based products such as a greenhouse gas emission (Desroches et al., 2012). Figure 1 shows the life cycle of polymers based on vegetable oils. For instance, the biomass from plant-derived resources is extracted in order to yield the vegetable oil, which is subject to chemical modification to improve the reactivity towards a given type of polymerisation approach. The polymers are then made available to the consumers, and once used, they become waste. After degradation and assimilation, they are reused as biomass and the cycle starts again (Samarth & Mahanwar, 2015).

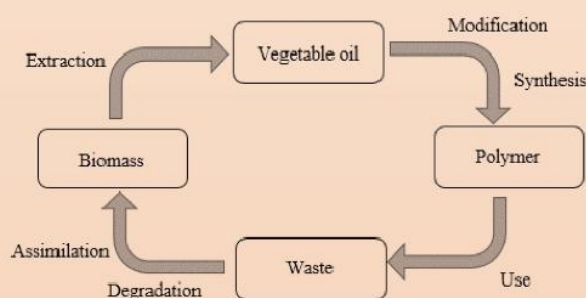


Fig. 1. Life cycle of materials based on vegetable oil (Samarth & Mahanwar, 2015).

Vegetable oil is predominantly made up of triglyceride molecules with varying fatty acid composition depending on the plant, the crop, the season, and the growing conditions. The word "oil" is used for triglycerides that are liquid at ordinary temperatures (Seniha et al., 2006).

Table 1 shows detailed fatty acid compositions of some types of vegetable oil. It showed that jatropha oil consists of 78.9 wt.% of unsaturated fatty acids, mainly oleic acid (43.1 %) and linoleic acid (34.4 %), which is relatively higher than palm oil. The triglyceride structures in vegetable oil vary from molecule to molecule. Fig. 2 shows a general jatropha oil structure consisting of a glycerol backbone attached to oleic, linolenic and stearic acids.

From the polymer point of view, the difference of the degree of unsaturation percentage presented in a variety of vegetable oil leads to the classification of the oil in drying ( $IV > 130$ ), semi-drying ( $100 < IV < 125$ ) and nondrying ( $IV < 100$ ) oils according to their iodine value (IV). Iodine value (IV) is a measure of unsaturation content, which represents the amount of iodine (in mg) that can react with the carbon-carbon double bond presence in vegetable oil. The iodine value of some vegetable oil is listed in Table 1. In this work, some of advancement in polymer synthesis from vegetable oil preferably for coating applications will be highlighted. The spotlight will be on jatropha oil as it is a non-edible oil with 78.9% of unsaturation, suitable for chemical



modification to afford polymeric materials. In Malaysia, *Jatropha* has become one of the most important crops after palm oil and rubber.

### Vegetable Oil-based Polymer and Coatings

Vegetable oil has been used and studied as a raw material for the synthesis of various polymer products. This is a merit of the various functional groups available in the fatty acid chain. Figure 2 shows common functionalities of vegetable oil such as allylic carbon, double bond, alpha carbon and ester groups (Wool, 2005). These characteristics are special in differentiating

the properties of one vegetable oil to another, as well as providing a platform for further chemical modification in polymer synthesis.

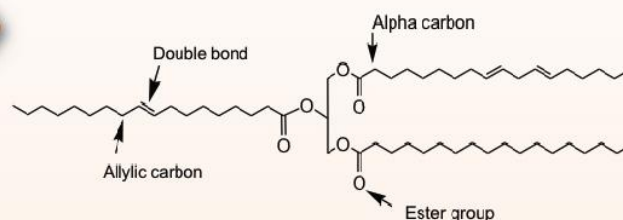


Fig. 2. Functional groups in triglyceride structure of jatropha oil

Table 1. List of fatty acids compositions in some vegetable oils (Sarin et al., 2007 and Lee et al., 1998).

Fatty acid	Palm oil	Jatropha oil	Soybean oil	Canola Oil	Linseed oil	Rapeseed oil	High oleica
Myristic (C <sub>14/0</sub> )			0.1				
Palmitic (C <sub>16/0</sub> )	40.3	14.2	11	8.08	5.5	3	6.4
Palmitoleic (C <sub>16/1</sub> )		1.4	0.1			0.2	0.1
Stearic (C <sub>18/0</sub> )	3.1	6.9	4	1.69	3.5	1	3.1
Oleic (C <sub>18/1</sub> )	43.4	43.1	23.4	57.09	19.1	13.2	82.6
Linoleic (C <sub>18/2</sub> )	13.2	34.4	53.2	23.12	15.3	13.2	2.3
Linolenic (C <sub>18/3</sub> )			7.8	10.02	56.6	9	3.7
Arachidic (C <sub>20/0</sub> )			0.3			0.5	0.2
Gadoleic (C <sub>20/1</sub> )						9	0.4
Behenic (C <sub>22/0</sub> )			0.1			0.5	0.3
Erucic (C <sub>22/1</sub> )						49.2	0.1
Ligoceric (C <sub>24/0</sub> )						1.2	
Saturates	43.4	21.1	15.5	9.77	9	6.2	10
Unsaturates	56.6	78.9	84.5	90.23	91	93.8	89.2
IV (mg)	44-58	102	117-143		94-120	117	

<sup>a</sup> Genetically engineered high oleic acid content soybean oil

Various approaches have been identified for chemical modification of vegetable oil as well as the polymerisation of unmodified and modified vegetable oil such as by free radical, cationic or olefin metathesis as the synthesised polymers could be thermoset and composites. On the other hand, condensation polymerisation could produce polyesters, thermoplastic, polyamides and polyurethane (Xia & Larock, 2010). Epoxidised vegetable oil has the potential to be used as plasticizer to toughen a brittle polymer (Tan & Chow, 2010).

In coating industries, the use of drying oil for surface coatings applications has dated back since a hundred years ago. The film formation of drying oil assisted by free radical polymerisation in which auto oxidation of the fatty acid double bond takes place with the help of oxygen in the atmosphere, produces a crosslinked polymer. However, these processes are very slow.

Besides, the unsaturation on the fatty acid is not sufficiently reactive to allow homo- or copolymerisations directly to produce resins with good mechanical performance as well as chemical resistance (Wool, 2005).

Due to the advancement in chemistry knowledge on modifications of vegetable oil, it is possible to produce vegetable oil based coatings materials from semidrying and nondrying oil with higher drying rates. Besides being renewable, vegetable oil provides the flexibility to the coating due to their aliphatic fatty acid composition. In addition, the polar groups such as epoxide, hydroxyl, carboxyl and urethane were introduced to the fatty acid to act as adhesion promoters (Alam et al., 2014). Some possible polymerisation of modified vegetable oil and its derivatives to afford polymeric materials for coating application is illustrated in Figure 3.



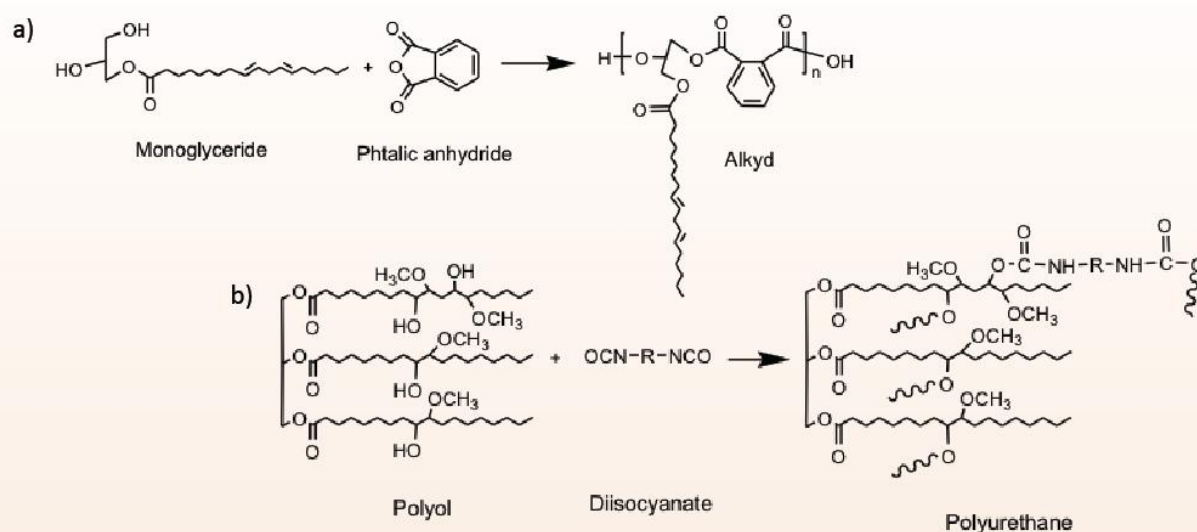


Fig. 3. Possible transformation of modified vegetable oil to polymeric coating materials (a) alkyd and (b) polyurethane.

### Previous Research on Jatropha Oil-based Polymers

Previous research concerning the modification of jatropha oil to afford various types of polymers is summarised in Table 2. Recently, the physicochemical properties of jatropha oil-based polyol with potential to be used as raw material for polyurethane has been reported (Abdullah et al., 2017). A polyurethane (PU) and alkyd resin were successfully produced for adhesives, coatings, and flexible polymer applications. Previous work conducted by Aung et al. (2014) indicated a high performance of PU wood adhesives derived from jatropha oil. They showed excellent shear strength with no adhesive failure of the resin that was used to bind wood substrates. These useful findings suggest the potential of producing PU coatings from jatropha oil

since adhesion is one of the most important characteristics of a good coating material.

Overall, the PU adhesive and coating as well as the alkyd resin were reported to have good thermal stability and excellent adhesion to the substrate (Aung et al., 2014; Boruah et al., 2012; Harjon et al., 2012; Saravari & Praditvatanakit, 2013). The coating products demonstrated a high gloss. Previous work by Harjono et al. (2012) on a PU acrylate coating indicated high optical properties of the product. Interestingly, waterborne polyurethane dispersion was successfully synthesised from jatropha oil. This would be more environmentally friendly coatings as it considered as VOC free coatings.

Table 2. Previous research on jatropha oil-based polymer.

Product	Remarks	Reference
Polyol for polyurethane	•Low viscosity, high molecular weight	Saalah et al. (2017)
Waterborne PU dispersion	•Good thermal stability, Hydrophobic	Saalah et al. (2015)
Wood adhesives	•Good chemical resistance	Aung et al., (2014)
Polyol for flexible PU	•Low viscosity polyol allows more time for molding and additives addition during polyurethane production	Hazmi et al. (2013)
Urethane alkyd	•Good adhesion, excellent resistance to water and acid •Low hardness, long drying time (>1h at 120°C)	Saravari & Praditvatanakit (2013)
PU acrylate coating (paint)	•High Gloss, hardness, adhesion on ABS substrate	Harjono et al. (2012)
Alkyd resin for surface coating	•High gloss, hardness, adhesion and chemical resistance properties •Thermally stable up to 330°C	Boruah et al. (2012)
Alkyd resin for electrical insulation	•The physical and electrical properties meet the standard requirements	Patel et al. (2008)



## Conclusion

Some of advancement in polymer synthesis from vegetable oil preferably for coating applications has been highlighted. The spotlight is on utilization of a non-edible jatropha oil as starting materials for production of bio-based polymers such as polyurethane (PU), alkyd resin, waterborne PU for adhesive and coating applications.

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# Biobased Resins – Towards a Sustainable and Healthier Future

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## Introduction

Biobased resins are a term devised to describe a resin or resin formulation derived from biorenewable resources. Thus, many traditional resins such as protein-based soybean, blood, collagen or casein, or carbohydrate-derivatives from cellulose or starch, natural rubber based adhesives and natural phenolic adhesives such as tannin or lignin may all be classed as biobased resins. The existence of biobased resins is, therefore, not a recent phenomenon and man has been using these adhesives for millennia, long before the advent of MDI [4,4'-methylenebis (phenyl isocyanate)], phenol-formaldehyde (PF), melamine-urea formaldehyde (MUF) or other synthetic systems. Though, with the exponential development of petroleum industry and low in price, synthetic petroleum-based resins rapidly occupied the entire composite wood panels industry.

Nevertheless, there is a dramatic shift in the development of novel materials derived from biorenewable resources in the past few years due to rising environmental awareness, depletion of petroleum resources, and health concerns (Fernandes et al., 2013). Apart from this, biobased materials produced from feedstock that derived from different natural and biorenewable resources have been applied in several end applications such as in the automotive and biomedical fields (Ojijo et al., 2013). Some desire properties of natural and biorenewable materials such as biodegradability, acceptable specific strength, low density, recyclability, ease of separation, high toughness, good thermal properties, no health risk, reduced tool wear, non-irritation to the skin, and enhanced energy recovery have made them a material of choice (Dobos et al., 2012). The availability of biobased materials is abundant and readily available at very low cost as they are derived from natural and renewable feedstock that emerged naturally (Dhakal et al., 2012).

## Synthetic Adhesives

Synthetic adhesives that depend on feedstock derived from petrochemicals are threatened from the instability of the price of the raw materials and the chemical persistence. In addition, adhesives as an important component in engineered wooden products should be separated for life cycle costs and must not impart undesirable effects on building occupants or the environment. Due to these reasons, it can be foreseen that the importance of biobased adhesives especially in the wood manufacturing and construction industries will be increasing soon.

## Market Drivers

Nowadays, synthetic adhesives industry is facing several issues such as increment in raw material costs as well as health and environmental concerns attributed to the utilization of synthetic adhesives. Increasing costs of raw materials, oil price fluctuation and higher costs incurred in the modifications of synthetic resins to comply with environmental and safety regulation had threaten the utilization of synthetic adhesives. The increment in costs will be absorbed by purchasers as sellers would like to maintain their profits and public awareness on the health, safety and environment concerns are the primary market constraints to synthetic adhesives

### i. Health, Safety and Environment Concerns with the Resins:

There is health risk could be generated from particular raw material (chemicals) of such synthetic resins. For example, the most well-known chemical used is formaldehyde in the production of formaldehyde-based adhesives such as urea formaldehyde (UF) and phenol formaldehyde (PF). Excessive exposure of human and environmental to carcinogenic formaldehyde is concerns and risky.



## ii. Health, Safety and Environment Concerns with Other Adhesive Components:

Additionally, other components in the adhesives may also generate some issues. Resins in synthetic adhesives are dissolved in organic solvents which served as carrier so that the resins can be applied easily. Such organic solvents can comprise up to 80% of the final weight of the product and this is the main issue. Volatile organic solvents that emit harmful gases are bad to air quality and legislation in this area is becoming increasingly stringent.

## iii. End of Life Concerns and Recycling

Adhesives are one of the considered contaminants besides paint and wood preservatives which would disturb on the ability to reuse, recycle or in some cases energy recovery from the reclaimed wood resource. If engineered wooden products are bonded with bioresins, it is an attractive way where the used wooden products could be sent for composting, reuse or recovery of energy without any compromising to the environmental or health and safety issues.

## iv. Standards and Best Practice

Many standards and regulations have been devised for assessment of performance for adhesives and adhesives bonded products. New products must pass through the rigor of this process.

Adhesives are an important raw material used in the manufacturing of many kinds of consumer product. Due to the reasons mentioned above, the development of environmentally friendly biobased adhesives is noteworthy and numerous researches in this area indeed have been conducted in the past few decades.

## Types of Biobased Adhesives

As mentioned in the previous section, there are several examples of natural and biorenewable compounds that may offer commercialization prospects for new adhesive systems, these include: tannins, lignin, cashew nut shell liquid (CNSL), carbohydrates, triglycerides and proteins.

### Tannin-Based Adhesives

The primary precursor to form tannins is gallic acid residues that are linked to glucose via glycosidic bonds, as shown in Figure. 1.

Tannins are natural and renewable phenolic chemical compounds. They are classified into two different classes namely hydrolysable tannins and condensed

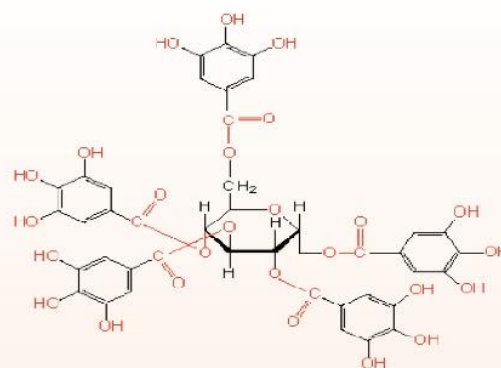


Fig. 1. Basic chemical structure of tannin compounds

Hydrolysable tannins are not commercial feasible to use as feedstock for production of biobased resins and adhesives as their structure is naturally less reactive and limited availability worldwide. Contrary, condensed tannins which are presently constituting majority of the total world production of commercial tannins are more feasible to use as feedstock for the preparation of adhesives and resins when both chemical reactivity and economic factors are come into consideration. Tannin oligomers and polymers occurred in nature through the polymerization of the simplest units known as galloyl. Duplicating similar chemical linkages in adhesive systems could be achieved, for example through Ullmann reactions for the preparation of biphenyls or biaryl ethers.

Condensed tannins are the formation cursors for flavonoids, and are abundantly be found in nature. Beside the presence of tannin in red wine and tea, tannins are able found naturally and abundantly in bark of various trees that could be fulfilled the needs for commercial extraction purpose. This expands the opportunities for timber bark which generated as waste for primary processing procedures for value added end-uses.

### Lignin

Originating from plants, lignin exists in large quantity in plants after cellulose and mainly served as mechanical support and binder to the plant fibers. The polyphenolic in nature of lignin is attributed to its constituents which are comprise of three types of monolignols (p-coumaryl alcohol, coniferyl alcohol and sinapyl alcohol) and those monolignols have an unsubstituted C<sub>3</sub> or C<sub>5</sub> position on the aromatic ring. Moreover, owing to its possession of phenolic and aliphatic hydroxyl groups that can create quinone methide intermediates which are able to react with an aldehyde, tannin, phenol and isocyanate by heating under alkaline condition, lignin is suitable to be utilized as chemical for polymerization reactions in wood adhesives (Abdelwahab and Nassar, 2011; El



Mansouri et al., 2011). As a polyphenol, lignin should behave like phenol in phenol formaldehyde (PF) resins which reacts and crosslinks with formaldehyde to yield hydrophobic and water insoluble adduct. Lignins (lignosulfonate and kraft) which its structure have been modified during the acid and alkaline pulping processes require further crosslinking so that they could be transferred into insoluble resins.

### Cashew Nut Shell Liquid (CNSL)

The cashew tree is originally native to Brazil but it is widely planted in more than 30 countries worldwide due to the popularity of cashew nuts. The nut crop is estimated of around 2.3 million tons per annum. The function of CNSL is to act as a deterrent to prevent

animals eating the exposed kernel and the nut inside. As shown in Figure. 2, the chemical structure of CNSL may differ due to the substitution of 4 different main groups of compounds in the aromatic phenolic ring.

The taste of CNSL is extremely bitter and this is attributed to the phenolic compounds present in CNSL. The phenolic in nature of CNSL makes it a possible feedstock for biobased resins production. However, some factors such as region of production as well as different in seasons would affect the composition of CNSL. This variability may limit the commercial application since the chemical properties may vary from batch to batch.

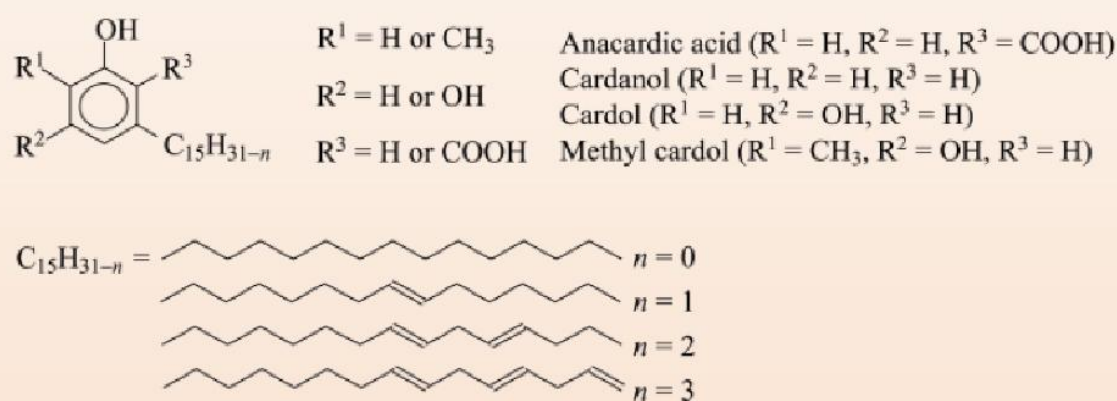


Fig. 2. Components of CNSL.

### Carbohydrates

Gums, polysaccharides (cellulose, starch and hemicellulose) and sugars are example of carbohydrates that can be used to produce adhesives. Carbohydrates-based adhesives are readily available and very cost effective but they unable to serve as binder in engineered wooden products. Narayan et al. (1989) revealed that cellulose-polystyrene graft polymer had been successfully used as binder to produce wood-plastic composite (WPC).

Partly carbohydrates substituted PF resins have been tested to bond wood veneers (Conner and Lorenz, 1986). The authors found that the modified PF resins did not negatively affect the dry or wet shear strength of 2-ply softwood panels.

### Triglyceride

Plant based triglyceride oils can be used to synthesize several different monomers for use in structural applications. These monomers have been used to produce polymers with a wide range of properties. These resins are capable to serve as binder to bond glass

fibers and natural fibers such as flax and hemp to produce composite materials. These resins are also capable to use as binder to produce hybrid composites from the low cost natural fibers and high performance synthetic fibers. Their properties lie between those displayed by the all-glass and all-natural composites.

### Plant-Based Protein

Soya, either the soybean meal or a protein isolated from the soybean is the most studied plant protein adhesive. The water resistance of this resin is low and the bonding strength is also inferior. It can be hot pressed and has been used as binder to fabricate interior softwood plywood in the past.

The utilization history of soy-protein-based wood adhesives can be traced back to centuries ago. However, these adhesives have been extensively replaced by high performance and cheaper petroleum-based adhesives. Adekunle et al. (2011) reported that soybean oil thermosetting polymer had been successfully used as binder to fabricate composites and hybrid composites using jute fabrics and carded lyocell fiber.



### Animal-Based Adhesives

Casein from milk curds has been used as wood adhesive for bonding and lamination of timbers for interior applications. However, its disadvantage is such wood adhesives are very expensive as the raw material is costly. Such animal protein-based wood adhesive is chosen as they possess superior moisture resistance compared to other animal and plant protein glues.

Glues made from blood albumin are water resistance and they were important class of moisture resistant glue for softwood plywood manufacturer before the existence of the synthetic resins. Such wood adhesives exhibited some temperature resistance and are more resistance to the deterioration by mold and fungi than the traditional animal glues and casein glues.

### Conclusions

Biobased resins have been used for centuries in wood industries. Resins or resin formulations derived from natural and biorenewable resources are virtuous for environmental and health aspects. However, due to some technical limitations such as low water resistance, low bonding strength and higher cost, biobased resins have been rapidly replaced by high performance and lower price petroleum based synthetic resins in manufacturing of wooden products. Though, petroleum based synthetic resins are now coming under increasing restrictions due to tightening environmental exposure regulations. Hence, biobased resins should be revived to substitute synthetic resins as a sustainable manner, provided the performance of biobased resins can be improved through robust researches.

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# Use of Oil Palm Biomass for Polyhydroxyalkanoates Biopolymer Production

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## Summary

The palm oil sector generates 80 million dry tonnes of biomass in Malaysia alone. There is increasing potential to utilise oil palm biomass, which are available at the palm oil mills as business-as-usual without any additional collection costs, for higher-value uses such as biopolymers. The National Biomass Strategy 2020 estimated that 12 million dry tonnes of oil palm biomass will likely be utilised for wood products and bioenergy. An additional 20 million tonnes could be mobilised for use as biofuel pellets and bio-based chemical industries. Since many of the biomass technologies are fast maturing and becoming more economically feasible, the trend for oil palm biomass utilisation to value-added and sustainable products such as biopolymers will continue to rise.

**Keywords:** Oil palm biomass, value-added products, biopolymers

## Introduction

It is estimated that 11% of Malaysia's gross national income (GNI) is contributed by the agriculture sector, and from that figure, more than half (8%) is contributed by palm oil sector. Malaysia has been well recognized as the leader of palm oil export globally due to its favourable agro-ecological conditions for crop growth and development. In December 2012, a total area of 5.1 million hectares was planted with oil palm trees which yielded nearly 100 million tonnes of fresh fruit bunch (FFB) and were further processed to produce 20 million tonnes of crude palm oil (CPO) (MPOB, 2013). This large production of palm oil resulted in huge generation of waste and wastewater from the palm oil industry. It was reported that four kg of solid biomass is generated for every kg of palm oil produced. On the other hand, palm oil mill effluent (POME) is generated at 50 % of the total amount of FFB processed (Yacob et al., 2006).

There have been many studies on the utilization of solid and liquid biomass from palm oil industry for biopolymers production. By adopting the research outcome in the industry, sustainable palm oil production could be created as the biomass will not only be discarded efficiently, but it may also contribute to extra income to the industry and give positive impact socially by creating new job opportunities. Furthermore, efficient utilization of oil palm biomass for such bioproducts will also contribute to sustainable production of energy and materials since renewable feedstock are being used.

## Oil Palm Biomass

Oil palm biomass are by-products from palm oil industry, which cover both by-products from the oil palm plantation and palm oil mills. Six types of oil palm biomass have been recognized from the industry, with palm oil mill effluent (POME) as the only liquid biomass. Table 1 shows the types of oil palm biomass, production site, annual generation of biomass and current uses.

It is estimated that the above figure will increase annually and by 2020, the total amount of solid and liquid biomass will reach 85-110 and 70-110 million tonnes, respectively (Agensi Inovasi Malaysia, 2012). Due to the abundance of the biomass, improper treatment of the biomass may create other issues. For example, most of the OPF, OPT and OPEFB are currently discarded at the plantation for nutrient recycling and mulching. However, too large amount of biomass discarded at the plantation will invite snakes and rodents. On the other hand, anaerobic treatment of POME using open pond system will generate methane which adds to the generation of greenhouse gas from the industry. Therefore, efficient treatment and utilization of the biomass are needed in order to ensure sustainable production of palm oil.



Table 1. Oil palm biomass (data adopted from National Biomass Strategy 2020)

Type of biomass	Production site	Amount generated* (million tonnes)	Availability	Current uses
Oil palm fronds (OPF)	Plantation	46	Daily	Discarded at the plantation for soil mulching
Oil palm trunks (OPT)	Plantation	14	At the end of plantation lifecycle (every 25 years)	Discarded at the plantation
Oil palm empty fruit bunch (OPEFB)	Mill	7	Daily	Discarded at the plantation
Oil palm mesocarp fiber (OPMF)	Mill	7	Daily	Fuel for boiler
Oil palm shell (OPS)	Mill	4	Daily	Fuel for boiler
POME	Mill	60	Daily	Anaerobic treatment and discharged to the river

\* 2010 data. Dry weight basis, except for POME.

Oil palm biomass consists of mainly carbohydrate in the form of cellulose and hemicellulose. On the other hand, liquid biomass from palm oil mill, *i.e.* POME contains substantial amount of oil and grease, COD, total solids and nitrogen (Mumtaz et al., 2010). Even though carbon compound in both solid and liquid biomass is in different form, but in overall the high carbon content of both solid and liquid biomass of oil palm indicate that the biomass are suitable to be used as feedstock for the production of value added products such as bioenergy, bio-based chemicals and biopolymers.

### Polyhydroxyalkanoates Biopolymer from Oil Palm Biomass

Biopolymers refer to polymer materials derived from bio-based and renewable resources; such as bioplastics, biocomposites and lignocellulosic materials. Polyhydroxyalkanoates (PHA) is an interesting biopolymer as it is being produced by microorganisms intracellularly as carbon and energy reserve materials when they are under stress conditions (Anderson and Dawes, 1990). PHA can be generally classified into short-chain-length (*scl*) and medium-chain-length (*mcl*), depending on the number of carbons of the alkyl side chains. *scl*-PHA possessing alkyl side chains having up to two carbons, while *mcl*-PHA has at least three carbons on the side chains. Due to the difference in the total number of carbons, these PHAs have different

requirement of substrate in fermentation. The *scl*-PHA requires simpler substrate such as sugars and volatile fatty acids (VFA).

There have been many reports on the production of PHA from oil palm biomass, both solid and liquid. Palm oil mill effluent (POME) for instance, is a good substrate for the production of PHA as it contains substantial amount of VFA. POME is generated as wastewater during sterilization of oil palm fresh fruit bunches (FFB), clarification of palm oil and effluent from hydrocyclone operations. With high biochemical oxygen demand (BOD) and chemical oxygen demand (COD), POME requires pre-treatment before being discharged into the environment. An anaerobic treatment method for POME which is coupled with the production of organic acids for subsequent use in PHA fermentation has been successfully developed (Hassan et al., 1996; 1997; 2002; 2006). It has been reported that the integration of POME treatment and PHA production will sufficiently provide a zero discharge system for palm oil mills. Depending on the scale of operation, concentration of clarified organic acids obtained from treated POME varied from 50-100 g/L. The acids consisted a mixture of acetic, propionic and butyric acids (Hassan et al., 1996). The combination of these acids make POME suitable for the production of *scl*-PHA, especially poly (3-hydroxybutyrate-co-3-hydroxyvalerate), PHBV copolymer. PHBV is generally better in terms of



mechanical and thermal properties compared to its homopolymer, poly(3-hydroxybutyrate), PHB.

Apart from the above studies, there have also been reports by other researchers on the production of PHA from POME. Salmiati and co-workers (2007) reported on the production of PHA from mixed microbial culture in POME. It was found that PHA accumulation in the bacteria reached 40% during the fermentation. Indeed, the use of POME as substrate for PHA production does not only contribute to the use of renewable carbon source for PHA production, but it also helps in the treatment of wastewater from palm oil mill. The 2-in-1 process helps to create sustainable production of PHA from oil palm biomass.

Recently, oil palm frond (OPF) juice has been introduced as another feedstock candidate for fermentation (Zahari

et al., 2012a). OPF juice contains nearly 80 g/L of sugars, of which 70% is glucose. OPF juice is advantageous as fermentation feedstock due to its daily availability; on top of its easy processing, whereby only simple pressing is needed for obtaining the sugars. OPF juice has been utilized for the production of PHA (Zahari et al., 2012a and 2012b) and it was found that the use of OPF juice as substrate yielded higher PHA production compared to the commercial sugars having similar sugars concentration. The higher PHA production was contributed by other minerals and vitamins presence in the OPF juice, which enhanced the bacterial growth and PHA production.

Types and properties of PHAs produced from oil palm biomass are comparable to those produced from other feedstock. The summary of the PHA properties from various carbon sources is shown in Table 2.

**Table 2.** Properties of PHA produced from various carbon sources.

Type of PHA	Carbon source	Mw (kDa)	Tm	Tensile strength (MPa)	Elongation to break (%)	Reference
PHB	Fructose	NA	177	43	5	Doi, 1990
	Maple sap	507	177	NA	NA	Yezza et al., 2007
	Mixture of commercial sugars (glucose, sucrose and fructose)	713	NA	NA	NA	Zahari et al., 2012a
	Sodium acetate	523	153	31	NA	Reddy et al., 2009
	OPF juice	812	162.2	40	8	Zahari et al., 2012a,b
PHBV	Glucose	540	166	35	45	Reddy et al., 2009
	Glycerol	610	171	37	69	Reddy et al., 2009
	Glucose + propionic acid	990 - 1300	NA	NA	NA	Liu et al., 2009
	NA	NA	145	20	50	Tsuge, 2002
	POME organic acids	400 - 1000	139 - 156	NA	NA	Zakaria et al., 2010



PHB produced from OPF juice had higher molecular weight (MW) compared to other PHB produced from other substrates, and had similar mechanical properties compared to that produced from pure fructose. The properties of PHBV produced from POME organic acids on the other hand were varied according to the composition of 3HV fractions (Zakaria et al., 2010), however in overall high molecular weight of PHBV is achievable by using organic acids derived from POME. This shows that oil palm biomass can be a good fermentation substrate for the production of PHA. A detailed economic analysis to study the feasibility of PHA production from POME organic acids was reported by Hassan and co-workers (1997). It was concluded that coupling anaerobic treatment of POME with PHA production would reduce the price of PHA to less than 1

USD / kg, compared to the normal price at 6 USD / kg. The results from the study showed that the use of POME for PHA production is economically feasible, with additional advantage to the environment.

### Conclusions and Future Perspectives

The present trend towards green and sustainable products with low carbon footprints will undoubtedly provide the push for the development of technologies related to the utilisation of biomass resources for value-added products. In conclusion, we can expect increased research and development efforts in the near future which will soon lead to more utilisation of oil palm biomass for sustainable and cost-effective biopolymers production.

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# Lignocellulosic Biomass: The Future of Lignin-based Composites

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## Introduction

Modern society requires feedstocks to ensure the effective function of the modern industrial society. The most promising, natural and renewable resource of feedstock is lignocellulosic materials. A considerable amount of such materials are being generated as by-product by various agro based industries. (Pérez et al., 2002). One of the common practice to disposed much of this lignocellulosic biomass is by burning process; this practice is so common and it not restricted to developing countries alone. However, due to its renewable nature, lignocellulose material has gained interest and special importance from research and economic point of view (Asgher et al., 2013; Ofori-Boateng and Lee, 2013). Therefore, instead of burned in the fields, huge amounts of lignocellulosic biomass can potentially be converted into different high value products including biofuels, value added fine chemicals, and cheap energy sources for microbial fermentation and enzyme production. (Iqbal et al., 201a; Irshad et al., 2013; Isroi et al., 2011).

## Structure and Chemistry of Lignin

Lignocellulosic materials including agricultural wastes, forestry residues, grasses and woody materials are mostly composed of three major units i.e., cellulose, hemicellulose and lignin. For most of the agricultural lignocellulosic biomass, the composition of lignin is about 10-25%, hemicellulose is 20-30%, and cellulose is 40-50% (Iqbal et al., 2011; Kumar et al., 2009; Malherbe and Cloete, 2002).

Figure 1 shows the illustration of lignin, cellulose and hemicellulose in lignocellulosic biomass. Lignin contains three aromatic alcohols (coniferyl alcohol, sinapyl alcohol and p-coumaryl alcohol) produced through a biosynthetic process and forms a protective seal around cellulose and hemicelluloses. As a major structural component of plant cell walls, cellulose responsible for mechanical strength of the biomass. Hemicellulose macromolecules are often repeated polymers of

pentoses and hexoses within the plant cell wall (Calvo-Flores and Dobado, 2010; Jiang et al., 2010 ; Menon and Rao, 2012).

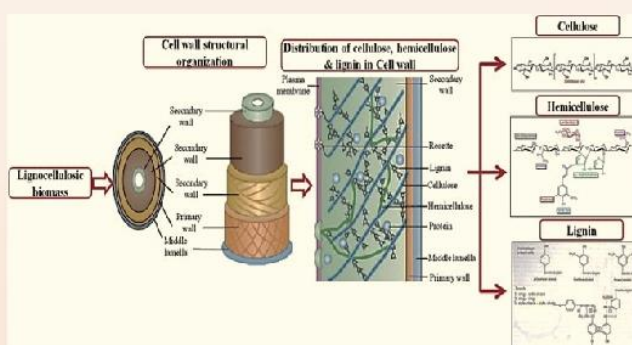


Fig. 1. Diagrammatic illustration of the framework of lignocellulose; cellulose; hemicellulose and lignin. Source: Menon and Rao, 2012.



Fig. 2. Lignin

Although lignin only representing about 10-25% of the biomass by weight Figure 2. It is the most complex material with its long-chain and heterogeneous polymer that composed of phenyl-propane, methoxy groups and non-carbohydrate poly phenolic substance units most commonly linked by ether bonds. Lignin chains fills the gap between and around the cellulose and hemicellulose complexion and acts as a glue for all cell walls components (Hamelinck et al., 2005).

## Processing of Lignin

Lignin is processed using different chemical processes, and each process has its own advantages and disadvantages (Pinkert et al., 2011). Three major processes for extraction of lignin are sulfite, kraft, and



soda. These processes follow either an acid- or base-catalyzed mechanism to break complex lignin structure into low molecular weight fractions and lignin physicochemical properties are affected by these processes (Lora and Glasser, 2002; Doherty et al., 2011).

Sulfite process is an acid catalyzed process that involves the cleavage of the  $\alpha$ -ether linkages and  $\beta$ -ether linkages of lignin. Traditionally, sulfite process has been used in pulping industries and lignin is a byproduct pulping process (Doherty et al., 2011). Three main reactions have been found to take place in the pulping process; (1) reaction between free sulphurous acid and lignin leading to the formation of lignosulfonic acid, (2) soluble lignosulfonates formation with cations (e.g., Mg, Na, or  $\text{NH}_4^+$ ), and (3) lignosulfonates fragmentation. In addition to the formation of lignosulfonates in the sulfite process, degraded carbohydrates are also produced in this reaction (Doherty et al., 2011; Botros et al., 2006).

Kraft process which is frequently used for the preparation of lignin. Unlike lignosulfonates from sulfite process, kraft lignin produced using kraft pulping has been found to exhibit a dark color as most of the time lignin degraded and dissolved into black liquor (Huang et al., 2004). It is insoluble in water and solvent but dissolved in alkali solutions owing to the high concentration of phenolic hydroxyl groups present in kraft lignin. Compared to other types of lignins, kraft lignin contains the highest quantity of the phenolic hydroxyl groups.

Lignin possesses significant potential for being a component of value-added products; however, there has been little success in creating lignin-derived high performance materials. Various researchers have synthesized and characterized lignin containing polymers. Rigid lignin molecules were blended with flexible polymers (Feldman and Lacasse, 1994) and subsequently crosslinked (Kelley et al., 1990; Rials and Glasser, 1984; Hofmann and Glasser, 1994) or copolymerized to form polyurethane, (Reimann et al., 1990; Bonini et al., 2005) polyesters (Bonini et al., 2005) and other copolymers (de Oliveira and Glasser, 1994; Thielemans and Wool, 2005) of different morphologies including interpenetrating polymer networks. However, most of these reported lignin-derived polymers were thermosets and brittle materials, i.e. barely recyclable.

The brittleness of these materials is related to the high crosslink density due to the low molecular weight of the

lignin segments. The highly polydisperse molecular weight of lignin molecules was likely the primary hindrance to synthesizing recyclable high-performance lignin copolymers. Lignin-containing recyclable thermoplastics have not been developed, while such products will have a significant impact on lignin usage as new advanced bio-derived polymers.

The other challenge in using lignin in composites is the poor dispersion of lignin attributed to its propensity to self-aggregate. Lignin is an irregular polymer made up of substituted phenyl rings and phenolic and aliphatic hydroxyl groups, and aggregation is likely due to intermolecular association from hydrogen bonding between the carboxylic acid groups and various ether oxygens and hydroxyl groups, van der Waals attraction of polymer chains, and  $\pi$ - $\pi$  stacking of aromatic groups (Lindstrom, 1979; Deng et al., 2012). Modification of lignin by esterification (Thielemans and Wool, 2005) etherification (Lora and Glasser, 2002) has been used to improve its dispersion in thermoplastics and thermosetting materials and leads to improved performance in composite materials. Graft polymerization is an attractive approach to covalently modify the surface of lignin, resulting in a lignin based copolymer that can be used in a broader range of applications, and allows for the design of novel materials with tailored properties (Kim and Kadla, 2010; Nemoto et al., 2012).

### Applications of Lignin-Based Polymer Composites

Depending upon the applications, the nature of the matrix varies from a synthetic to a natural polymer (Kadla et al., 2002). For most of the applications, the matrix is obtained from synthetic polymers, and very recently, biopolymers are being used as the matrix material (Yue et al., 2012). In general, the reinforcing materials are fibers, either synthetic or natural. Both the polymer matrix and the reinforcement have been found to play an important role in determining the overall physicochemical properties of the composites (Chaochanchaikul et al., 2012; Marklund et al., 2008).

Lignin-based polymer composites have received the interest of the research community all over the world (Megiatto et al., 2008; Park et al., 2008; Nenkova, 2007). Intense efforts are being made to use lignin as a low cost eco-friendly reinforcement to prepare high performance composites (Morandim et al., 2012; Pupure et al., 2013; Stiubianu et al., 2009). However, for some applications, it



is often difficult to blend lignin with other systems such as biopolymers. Some researchers have made efforts to modify lignin with different techniques in order to make it compatible with the polymer matrices (Adcock et al., 2003; Batog et al., 2008).

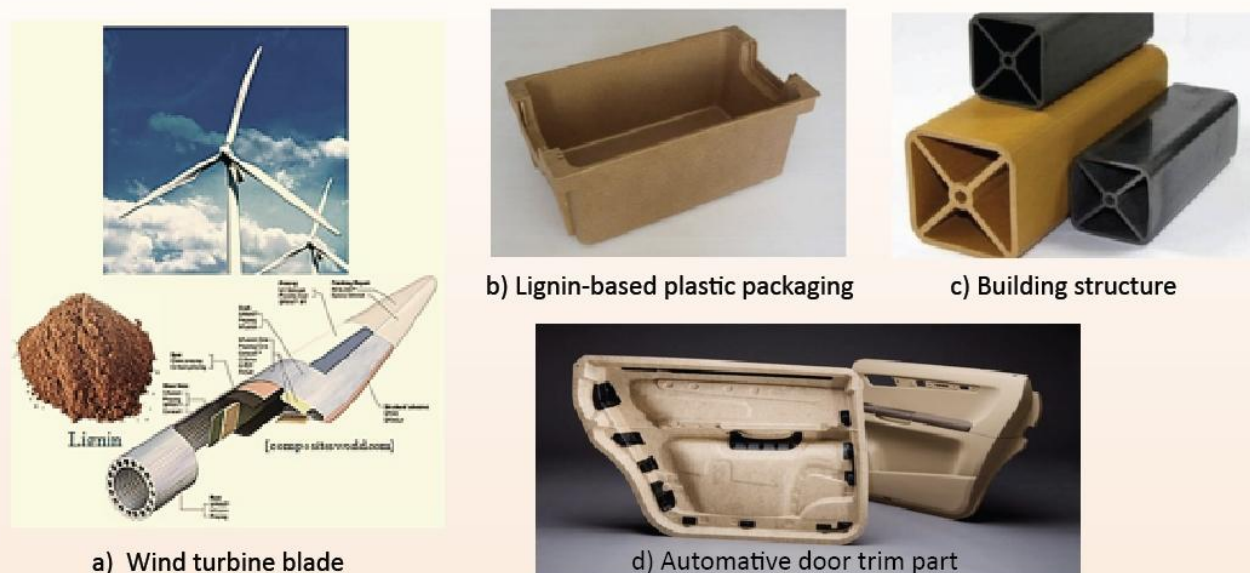


Fig.3. Applications of Lignin-Based Polymer Composites

## Conclusion

Biorenewable materials have been frequently used as low cost reinforcement for polymer composite applications. Most of the environmental friendly polymer composites designed for different applications are based on natural cellulosic fibers. Along with these cellulosic fibers, lignin is a promising alternative for traditional petrochemical-based reinforcement material.

Lignin, cellulose and hemicellulose are the major components of natural polymers that provide strength and rigidity to plant stems. Lignin is the most abundant byproduct of the paper industry because it was produced during the processes aimed at retrieving the polysaccharide component of plants.

Recently, researchers have started exploring the use of lignin as potential reinforcement in polymer composites. The inherent properties of lignin being biodegradable, CO<sub>2</sub> neutral, available abundantly in industrial waste, low in cost, and environmentally friendly, and having antioxidant, antimicrobial, and stabilizer properties make lignin a promising low cost reinforcement. Due to the above-stated advantages, lignin-based polymer composites are promising as a new class of environmentally friendly, low cost, composite materials.

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# Mechanical and Barrier Properties of Cellulose Nanocrystals Reinforced Chitosan Nanocomposites

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## Abstract

Strong study efforts have been concentrated on the application of natural fillers as reinforcing materials for polymer composites, because these fillers are renewable, sustainable and possess low rough nature than mechanically robust nano-sized fillers (Pandey et al., 2001). Cellulose nanocrystals (CNCs) with one dimension in the nano-scale range have great potential as reinforcements in polymer hosts because of their promising mechanical properties with very good strength and stiffness (Cao et al., 2007; Azizi et al., 2013). In the recent years, cellulose nanocrystals have merited considerable attention as potential nano-sized filler in blending with diverse polymers. Cellulose nanocrystals are characteristically rod shaped monocrytals, 2 to 20 nm in diameter and from tens to hundreds of nanometers in length, and extracted after acid hydrolysis of different natural cellulose fibers for example cotton, cellulose fibers from lignocellulosic materials, and marine animal tunicate (Habibi et al., 2010). Cellulose nanocrystals as a reinforcing phase have some advantages over other types of nano-sized fillers, for instance high aspect ratio, large surface area, low density, outstanding mechanical properties, renewability, and bio-compatibility (Xu et al., 2013).

Chitosan (CS) is a heteropolysaccharide achieved from the alkaline deacetylation of chitin which is the most plentiful polysaccharide after cellulose on earth (Ravi Kumar et al., 2000). Chitosan is biocompatible, biodegradable, non-toxic, hydrophilic, and anti-bacterial, thus, it is broadly used in water treatment, agriculture, fabric and textiles, cosmetics, nutritional enhancement and food processing (Sashiwa et al., 2004). The enhanced physical and chemical properties of chitosan are valuable. In this article, CNCs extracted from the acid hydrolysis of cotton were incorporated into CS host to develop the mechanical and oxygen barrier properties of CS/CNCs bio-nanocomposite films.

## Preparation of Bionanocomposite

Chitosan solution was prepared by dissolving 2 g of CS powder in 100 ml of acetic acid solution (1%, v/v), under magnetic stirring at 80°C for 15 min and subsequently cooled. The glycerol plasticizer (25% wt on CS solid base) was then added to the CS solution while stirring for 20 min at 60°C. Nanocomposite samples were fabricated by dispersing different amounts of CNCs (0 wt%, 1 wt%, 3 wt% or 5 wt%) in 100 ml of distilled water for 1 h at room temperature. The obtained suspension was added to the CS solution, stirred for 1 h at room temperature and then sonicated for 30 min at 25°C in a bath type ultrasound sonicator. The suspensions were then poured into glass plates and dried at 25°C for three days, until the solvent was completely evaporated and a self-standing film was achieved.

## Morphology of the CS/CNCs Nanocomposite

The polymer nanocomposites were prepared with different CNCs filler loading level (0 wt%, 1 wt%, 3 wt%, 5 wt%) in CS matrices. Figure 1 shows the rod-like cellulose nanocrystals were well dispersed into the polymer matrix when the low concentrations of CNCs were used. On the other hand, with the increase of CNCs contents into CS hosts, their distribution became poor and most of the cellulose nanocrystals were agglomerated by hydrogen-bonded free hydroxyl groups.

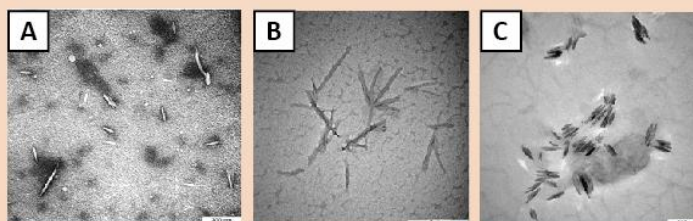


Fig. 1. TEM images of CS/CNCs nanocomposites with 0.1 wt% (A), 3.0 wt% (B), and 5.0 wt% (C) CNCs contents.



## Tensile Properties

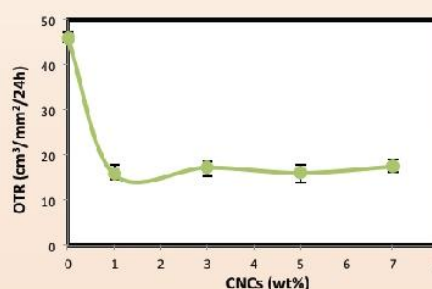
Table 1 shows the effects of CNCs contents on the tensile properties of the CS/CNCs nanocomposite. Tensile values display that the addition of CNCs enabled to promote the tensile strength (Ts) and modulus (Tm) of the films. The maximum values were achieved when 1.0 wt% of CNCs were dispersed in the CS matrix. The nanocomposite showed ~ 87% and 63% tensile strength and modulus enhancements, respectively than that of the original polymer. This improvement is owing to the creation of a network structure originated from the filler-matrix interactions in nanocomposites, which promotes hard portion crystallinity, declines molecular mobility and increases rigidity (Rueda et al., 2013). Furthermore, the incorporation of cellulose nanocrystals from 0 wt% to 5.0 wt% decreased the elongation at break (Eb) of CS nanocomposites films with the highest reduction at 1.0 wt% loading level. This phenomenon can be explained by the fact that the stiff filler network structure, responsible for the enforcing effect, was formed perfectly as the CNCs level was 1.0 wt% which powerfully restricted the chain mobility of the matrix and therefore considerably declined elongation at break (Azeredo et al., 2010).

**Table 1.** Tensile data of CS and its CNCs nanocomposites.

Sample	Ts(MPa)	Tm(MPa)	Eb(mm)
CS/CNCs (0 wt%)	35.1 ± 1.6	295 ± 21	12.2 ± 0.4
CS/CNCs (1 wt%)	66.2 ± 1.4	480 ± 25	6.4 ± 0.5
CS/CNCs (3 wt%)	57.4 ± 1.0	432 ± 39	9.5 ± 0.4
CS/CNCs (5 wt%)	51.2 ± 1.3	401 ± 26	8.9 ± 0.8

## Oxygen Transmission Rate

Figure 2 shows the oxygen transmission rate (OTR) of the pure chitosan film is reduced in the CS nanocomposites, and most considerably declined i.e by ~66%, in the 1.0 wt% CS/CNCs sample. These results propose that the addition of CNCs make a tortuous path for the diffusion of oxygen molecules. When the low contents of CNCs were used, the CNCs were well dispersed as shown in the TEM results, thus yielding a more efficient barrier outcome (Fortunatia et al., 2012). Consequently, a proper affinity between the polymer and the surface of the CNCs can be recommended. A weak affinity would lead to the presence of holes that allow the oxygen molecules to penetrate faster through the film. The OTR is not decreased further with a higher content of CNCs. This can be because of accumulation of the CNCs. The agglomeration seen beyond 1.0 wt% level may provide channels, or holes, in the film that allow more rapid permeation (Paralikar et al., 2008).



**Fig. 2.** Effect of CNCs addition on OTR property of CS films.

## Conclusions

Chitosan nanocomposites were prepared by casting a mixture of chitosan and cellulose nanocrystals. Incorporation of cellulose nanocrystals into chitosan resulted in obtaining composites with enhanced tensile and modulus strength and decreased elongation at break. Use of cellulose nanocrystals with hydrophilic polymer matrix such as chitosan declines its resistance to oxygen permeation.

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# Natural Nanomaterials: Synthesis and Cytotoxicity Analysis

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## Abstract

In this research, natural nanomaterials including cellulose nanocrystal (CNC) and cellulose nanofiber (CNF) with different structures, sizes and surface areas were produced and analyzed. The aim of this study was to compare these nanomaterials based on the effects of their structures and compositions on the cytotoxicity properties.

## Introduction

Kenaf is a natural tropical plant that has been grown commercially to generate secondary source of income for developing countries including Malaysia. Its high cellulose content, ranging between 44 and 63.5% (Jonoobi et al., 2009; Sanadi et al., 2001; Zampaloni et al., 2007) has generated interest in exploiting the material as nanofillers in composites. The nanocrystals and nanofibers can be obtained via acid hydrolysis, mechanical treatment, or enzymatic reaction. The chemical composition of kenaf bast is around 63.5 % cellulose, 17.6 % hemicellulose and 12.7 % lignin (Janoobi et al. 2009).

Cellulose is the most abundant polymer in nature and has long been a major renewable source of materials [1]. Cellulose is a linear natural polymer of anhydroglucose units linked at the one and four carbon atoms by  $\beta$ -glycosidic bonds (Mandal and Chakrabarty, 2011). The cellulosic microfibrils have disordered (amorphous) regions and highly ordered (crystalline) regions as illustrated in Figure 1. The nanofibrillar domains, generally referred to as nanocellulose are a promising raw material for new bio based composites due to their high mechanical strength, stiffness, large surface area, low thermal expansion, optical transparency, renewability, biodegradability, low cost and low toxicity (Brinchi et al., 2013).

Apart from their use as a reinforcing filler for polymers, cellulose nanocrystals (CNC) and cellulose nanofiber (CNF) have been used to fabricate a wide range of other functional materials, including transparent barrier films (Fukuzumi et al., 2008), photonic crystals (Kelly et al.,

carriers, composite materials (Walther et al., 2011) [10], optical and electronic devices (Mendez and Weder, 2010) and super capacitor electrodes (Nyström et al., 2009).

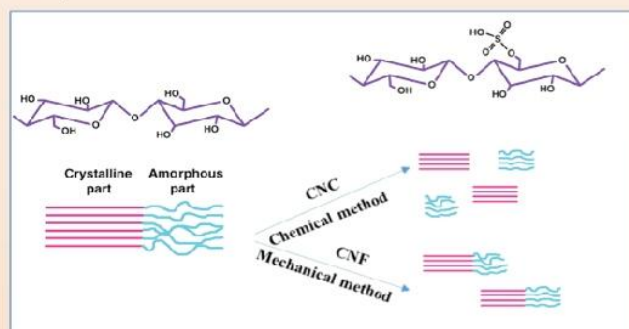


Fig. 1. Crystalline and amorphous region of cellulose and the mechanism of chemical and mechanical treatment for producing CNC and CNF from cellulose

## Synthesis of Nanofibers

Here, CNC and CNF were produced by using acid hydrolysis and mechanical methods, respectively. For preparation of CNC, firstly, acid hydrolysis will be conducted under mechanical stirring by use of  $\text{H}_2\text{SO}_4$  for 45 min. Then the suspension was diluted with cold distilled water and centrifuge for 10 min. This centrifugation step repeats three times. The aqueous suspension was subsequently dialyzed against distilled water until a constant pH was attained. Ultrasonic treatment was then being carried out to disperse the nanocrystals.

For fabricating CNF, water retted Kenaf bast fibers coded as RF was cut to short pieces and then cooked in a



JSR-212 rotatory digester with NaOH and anthraquinone (AQ) solution at 160°C for 2 h. AQ was be added to the cooking liquor to enhance the delignification rate and also protect the fibers from alkali degradation and so called end-wise degradation of cellulosic chains. The obtained pulp was washed and screened thoroughly. Extraction of nanofibers was then done by further mechanical destruction using a super-masscolloider. Aqueous suspensions with the concentration of 3wt% was prepared and blended until gel was formed.

The FESEM and TEM images of the produced nanocellulose were shown in Fig 2. CNCs present a simple needle-like structure with an average length of 200nm, and diameter of 20nm. CNFs exhibited a complex, highly entangled, web-like structure. Twisted/untwisted, curled/straight, and entangled/separate nano-fibrils and their bundles with diameters ranging from 50 to 200 nm in diameter can be identified from the micrograph.

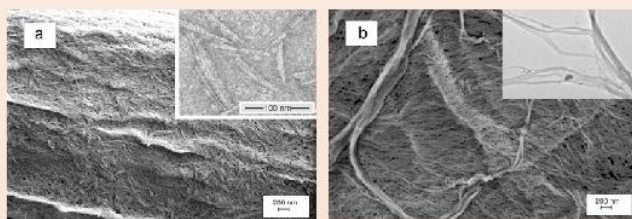


Fig. 2. (a) SEM and TEM images of cellulose nanocrystal (CNC) and (b) cellulose nanofiber (NFC)

### Cytotoxicity Effect on Human Cells

Cell viability of produced nanocellulose was tested by MTT assay. The relative cell viability (%) related to control wells containing cell culture medium without nanoparticles was calculated by the following equation:

$$[A]_{\text{test}} / [A]_{\text{control}} * 100$$

Based on the results shown in Figure 3, The CNF and CNC compound inhibited about 1.1% and 7% of cells at concentration of 100 µg/ml, respectively. At concentration of 12.5 µg/ml, CNF did not exhibit any toxicity towards the cell, as the cells were 100% viable. However this was in contrary to CNC where it was found that the CNC managed to inhibit 1.1% of cells at the same concentration.

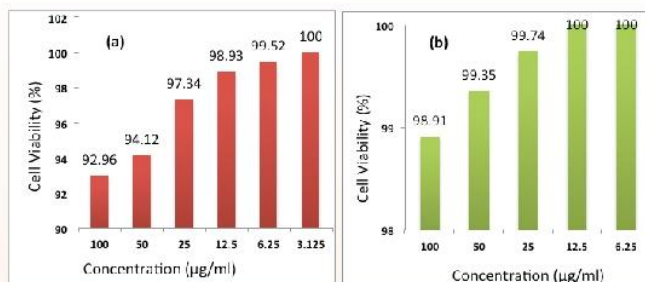


Fig 3. The cytotoxicity effects of (a) CNC, (b) NFC

### Conclusions

In this research, we produced natural nanofibers (CNC and CNF) by using acid hydrolysis and mechanical techniques. SEM and TEM exhibited that CNC had smaller diameter size compared to CNF. The influences of morphology, size and structure of nanomaterials on their cytotoxicity properties were investigated. Overall, CNF had lower cytotoxicity effects rather than CNC which could be related to its preparation methods.

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# Pulp and Paper Industries Residues as Valuable Biopolymer by-products

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## Production Phases in Pulp and Paper Industries

The industry of pulp and paper is a well-established bio-refinery model focally due to the high availability of cellulose and lignin (Silvio, 2015). It has a long chain production process comprises of a few phases as stated in Figure 1. Certain residues for each phase will be wisely employed by the pulp and paper mills that are not for landfills dump but as secondary raw materials or also called as by-products mainly for composting, energy production, bio-fertilisers and more renewable chemicals (Vaz, 2014).

## Wood Logging, Chipping and Virgin Pulp Production

Wood logging are carried out in the forest by leaving the residues. However, recently the wood logs residues are being collected and converted into biofuels. Wood chipping involves the debarking of the wood followed by chipping process. These processes produce barks and small segments of wood that are useful as biofuel and gardening or composting purpose accordingly. The residues are incalculable which proved by Hu et al. (2008) whom applied feedstock pre-treatment strategies to produce ethanol from wood, bark, and forest residues. Virgin pulp production is a process to transform the wood chip shape into individual fibres that is suitable for papermaking production. Subject to the manufacturing of paper, kraft pulping is the foremost chemical pulping method practised by majority pulp and paper producers. During kraft pulping, wood chips are cooked with chemicals in order to break and dilute the lignin that holds the fibres together. Hence, fibres in terms of unbleached pulp derived from woods are finally obtained and at one fell swoop, black liquor is also been collected during the washing of pulps. The black liquor as shown in Figure 2 is a black solution that contains organic and inorganic compounds refers as lignin and spent cooking liquor respectively (Anonymous, 2004). The inorganic compounds namely spent cooking liquor

can be regenerated and reused. The residues from chemical pulping are recognised as green liquor dregs, lime mud and lime sludge (Anonymous, 2004). Whereas in mechanical pulping, separation of fibres is obtained via grinding logs against rotating stone or via refining the chips between a rotating disc and a fixed plate. The residues in such pulping are mixture of fibres and wood components. Most research has proved that black liquor which was understood as hazardous substance due to the presence of lignin has shifted to excellent and potential raw material. In instance, Wang et al. (2017) reused black liquor for enzymatic hydrolysis and ethanol fermentation which indicated water consumption saving of alkaline pre-treatment.

## Recovery Paper Processing and Paper Production

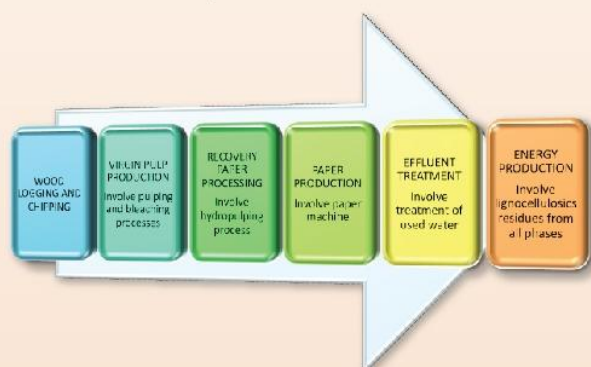
Recovery paper processing is related to the process of re-pulping the under-sized paper into pulps to be inserted in the papermaking system. Several pulp treatments like deinking, removal of coating materials and discharging the fillers from pulp systems are needed in order to fulfil the requirements for identified paper products. For instance, the production of soft, thin and absorbent tissue paper needs less non-fibre elements in the paper formation. Therefore, higher residue levels come from coating materials, inks and various inorganic fillers as well. Paper production requires virgin pulps and/or recycled pulps and minerals. The minerals comprise of fillers, coaters and binders. The blending of pulps and non-pulps is crucial in order to gain better formation of paper. In this phase, the residues are both either under or over-sized paper and minerals.

## Effluent Treatment and Energy Production

Effluent treatment involved the treatment of used process water that comes out from each stage in the pulp and paper production. This industry utilizes a huge amount of water along the processes. Waste water



treatment plants are one of the mandatory facilities to treat the used water which combining mechanical, chemical and biological aspects which finally resulted in effluent treatment sludge as its residue. Hence, Simão et al. (2017) studied new alternative materials for clinkerization by using lime mud, biomass ashes and waste water treatment plants sludge and proved that these residues are potential use as alternative materials for clinker production. In addition, Jaria et al. (2017) applied sludge as raw materials to produce carbon adsorbents which benefit the strategy in waste management system of pulp and paper industry. Another interesting finding is obtained by Patel et al. (2017) whom applied biological treatment to the industry effluent by oleaginous yeast that was integrated with production of biodiesel. The biodiesel can be used as sustainable transportation fuel.



**Fig. 1.** The production phases in a pulp and paper industries.

Most of the pulp and paper residues from all stages of production are used as biofuels. Therefore, the mills can self-support it needs or even sold externally in terms of electricity and heat. The residue appears in this stage is ash resulted from the combustion of biofuels.

### Value-able Residues Benefit Pulp and Paper Industries

By applying these value-able residues, the industries can assist the reduction of negative impacts on the environment and also to promote the global bio-economy as well (Silvio, 2015). Koutinas et al. (2014) focused on the potential in utilizing residues such as from pulp and paper industry in order to produce of chemicals and biopolymers via microbial bioconversion.



**Fig. 2.** The black liquor extracted after chemical pulping process which has high lignin content, potential for various bio-products.

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# Green Alternative of Biomass Pretreatment for Bioethanol Production

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## Introduction

In general, bioethanol production from lignocellulosic biomass requires three basic steps; pretreatment, saccharification (cellulose hydrolysis) and fermentation (Figure 1). Pretreatment is the main step which may bring domino effect to the subsequent steps for bioethanol production (Maurya et al., 2015). This initial pretreatment step is essential to open up the complex structure of lignocellulosic biomass.

Lignocellulosic biomass is composed of three primary polymers which are cellulose, hemicellulose and lignin that intricate together to form heteropolymer. Cellulose and hemicellulose are the vital parts that contributed to the fermentable sugars production prior to bioethanol fermentation. However, lignin component resided in the biomass act as a shield that protect the cellulose and hemicellulose. Lignin is also well known for its recalcitrant compounds that are resistant for

biodegradation (Ceballos et al., 2015). Physicochemical pretreatment is the most common method used to pretreat lignocellulosic biomass. Nevertheless, chemical utilization in this method generates chemical waste that need to be further treated. Biological pretreatment is one of the environmental friendly approaches for effective delignification (Sindhu et al., 2016). In this mini review, type of biological pretreatment and fungal pretreatment are discussed.

## Type of Biological Pretreatment

The aim of biological pretreatment of lignocellulosic biomass is to delignify the biomass and increase the accessibility of holocellulose for further applications. Comparison of delignification method of lignocellulosic biomass is summarized in Table 1. Enzymatic pretreatment requires purification step of ligninolytic enzymes before applying to the biomass and this contribute to the high cost of this pretreatment. Although, fungal pretreatment takes a long time to delignify the biomass but the pretreatment cost is still considered low. Laccase mediated system (LMS) is similar to enzymatic pretreatment method with addition of mediator. Mediator acts as an electron transfer to oxidise non-phenolic structure in lignin (Rich et al., 2016). Integrated fungal fermentation (IFF) involves a fungus or consortium of fungi that are able to convert lignocellulosic biomass into ethanol directly. This fermentation does not require any other pretreatments or microorganisms to produce ethanol.

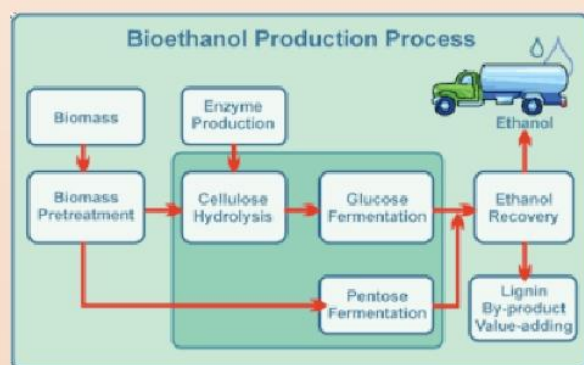


Fig. 1. Bioethanol production process from biomass

Source: <https://www.gns.cri.nz>

Table 1. Comparison of delignification method of lignocellulosic biomass

Delignification Method	Delignification	Sugar losses	Duration	Economic	Environmental Impact
Enzymatic	High	Low	2-48 h	High cost	Positive
Fungal	High	Low	6-45 days	Low cost	Positive
LMS	High	Low	2-48 h	High cost	Depends on the mediator
IFF	Medium	Some	1-12 weeks	Low cost	Positive

Source: Plácido and Capareda, 2015



## Fungal Pretreatment

Fungi are the most widely used for delignification of lignocellulosic biomass in biological pretreatment (Figure 2). Fungi are categorized into three types of wood decay; soft-rot fungi, brown-rot fungi and white-rot fungi (Wan and Li, 2012; Hamed, 2013). White-rot fungi is recognized by its capability to produce ligninolytic enzymes. The enzymes are secreted out directly from the tip of the hyphae that penetrate into the substrate system. This phenomenon enhances the catalytic reactions of the enzymes and increases the nutrient accessibility from the substrate particle to the fungal cell (Mitchell et al., 2006). In contrast, the development of bacteria and yeast are only on the exposed surface of the substrate particle (Figure 3). The spaces between the bacterial cells are occupied by water which contribute to the thick paste texture of the biofilm.



Fig. 2. Wheat straw colonised with different fungi

Source: <https://www.wur.nl>

The environmental factors of fungal pretreatment could remarkably influence delignification of lignocellulosic biomass in the pretreatment system. Incubation temperature, biomass amount, initial pH of nutrient supplied to the system, initial moisture content and fungal inoculum are the crucial factors that are necessary in fungal pretreatment (Rouches et al., 2016). Furthermore, different biomass and fungi utilized in fungal pretreatment have different favorable conditions. Thus, an optimal environment for delignification needs to be investigated and established depending on the type of biomass.

## Conclusions

Biological pretreatment particularly fungal pretreatment has a great potential to pretreat lignocellulosic biomass as it resembled the natural condition for fungal growth. This type of pretreatment may reduce the cost of bioethanol production and may even offer a chemical-free pretreatment process. Therefore, biological pretreatment process should be investigated further to examine the potential gaps of this system.

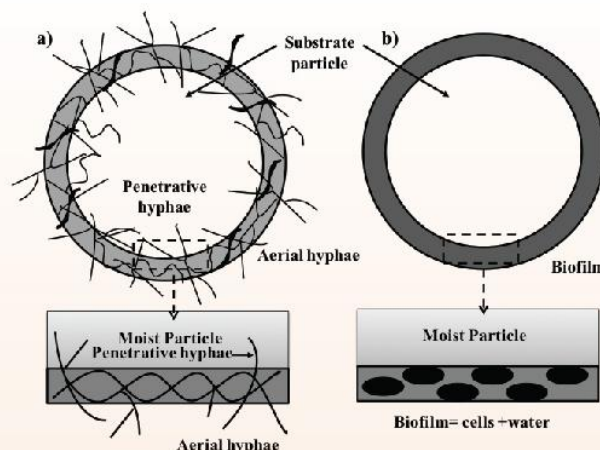


Fig. 3. Difference between (a) fungi and (b) bacteria growth pattern in biological pretreatment

(Source: Mitchell et al., 2006)

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# Hydrothermal and Wet Disk Milling Pretreatment for Biosugar and Nanofiber Production From Oil Palm Mesocarp Fiber

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## Introduction

Selection of suitable pretreatment is necessary to get rid of biomass recalcitrance before saccharification for bioethanol and biofuels production (Weiqi et al., 2013). Recently, pretreatment involving hot compressed water (HCW), liquid hot water (LHW), steam, and superheated steam (SHS) are gaining interest. These treatments are environmentally friendly and time-saving for enzymatic saccharification of natural biomass (Yu et al., 2011; Weiqi et al., 2013).

Recently, wet disk milling (WDM) has been used to produce relatively low levels of inhibitors and increased the degree of defibrillation which created more space between microfibrils, thus enhanced the enzymatic hydrolysis of the fiber (Lee et al., 2010; Zhang et al., 2013). Wet disk milling should be combined with other treatments to facilitate the enzyme accessibility of the fiber (Gao et al., 2012). The combination of hydrothermal (LHW and or HCW) with WDM pretreatment on rice straw (Hideno et al., 2012) and eucalyptus (Weiqi et al., 2013) have shown an improvement of sugar yield compared to hydrothermal pretreatment alone.

Therefore, in this work, we investigate the suitability of individual hydrothermal and WDM pretreatment alone and its combination on OPMF to understand the mechanism involved for each method used that affects biomass structure and cellulose properties Figure 1.

Individual hydrothermal (SHS and HCW) and WDM pretreatment and their combinations have resulted in morphological changes of OPMF as evaluated by SEM. Figure 2a shows that the untreated OPMF has a rigid and intact surface which impedes the penetration of degradation enzymes to the targeted compounds. A small morphological alteration was observed after being treated by SHS at 200°C, 60 min Figure 2b. In contrast, Figure 2c showed a higher degree of surface morphology alteration when OPMF was pretreated with HCW, whereas efficient dissolution of hemicellulose may result in peeling-off of outer layer of fiber (Zakaria et al., 2014b). Wet disk milling was performed to reduce particle size and increased specific surface area. Figure 2d shows the SEM image of WDM treated-OPMF samples after 20 operation cycles. From Figure 2e-f, there is no significant difference from combined hydrothermal (SHS and HCW) and WDM in comparison to WDM pretreatment alone. Serial dilution was performed, washed several times with ethanol as described in the methodology section to observe the differences between SHS and HCW-WDM pretreatment. The degree of defibrillation and particle size reduction played a critical part to enhance the conversion of hydrolysed sugars from lignocellulosic material. From the morphological analysis, defibrillation of OPMF occurred rapidly as the amount of operation cycle of WDM increased. Well-defibrillated fibers with a diameter size smaller than 50 nm were observed for OPMF treated

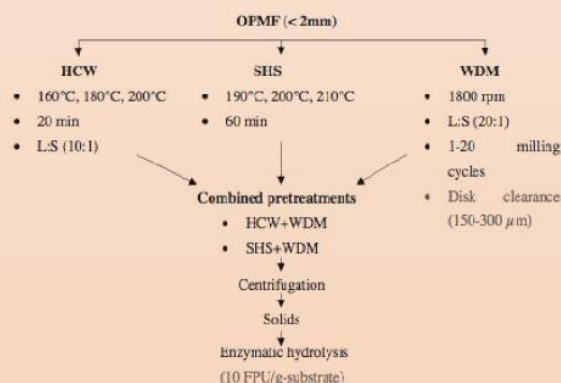
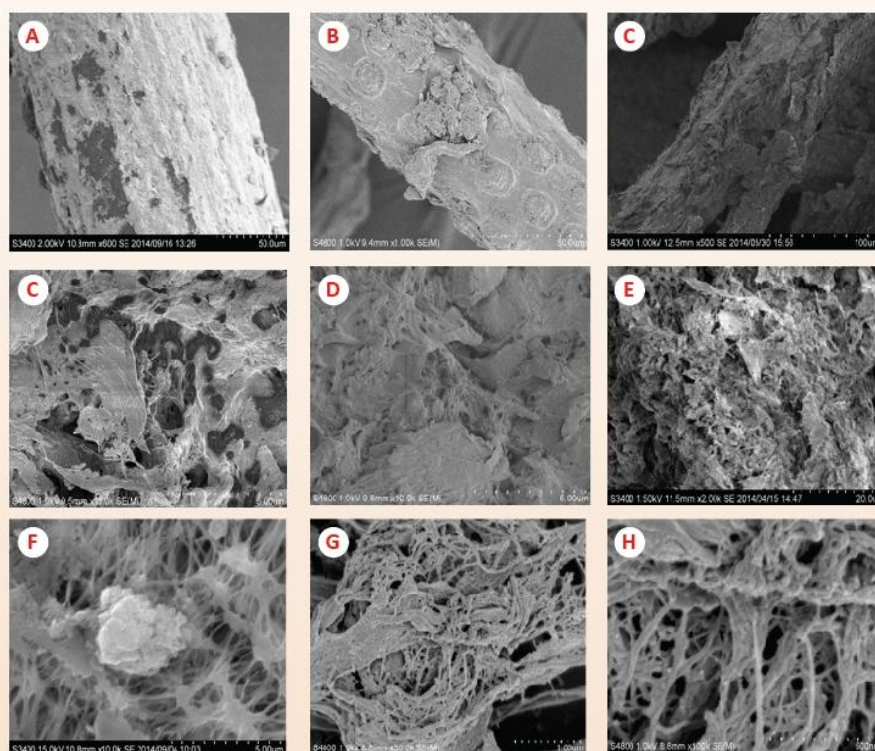


Fig. 1. Schematic diagram of pretreatments on OPMF samples for biosugars and nanofibers production.



with HCW as shown in Figure 2h-i. These results indicate the defibrillation of OPMF by HCW pretreatment is more pronounced than defibrillation by SHS pretreatment Figure 2g probably due to greater hemicellulose removal, which resulted in increased specific surface area of the particles. Partial removal of hemicellulose and alteration or migration of lignin from the cellulose-hemicellulose-lignin matrix may have caused OPMF to be more ductile and led to loosening packing of cellulose microfibrils (Lee et al., 2010). Thus, it will ease the WDM pretreatment by reducing the particle size and increased the efficiency of hydrolytic enzyme penetration to the fiber (Weiqi et al., 2013).



**Fig. 2.** a) Untreated OPMF, b) SHS (200°C, 60 min)-treated, c) HCW (200°C, 60 min)-treated, d) WDM-treated, e) SHS (200°C, 60 min)-WDM<sub>cycle9</sub>-treated, f) HCW (200°C, 60 min)-WDM<sub>cycle9</sub>-treated, g) diluted (0.01%) SHS (200°C, 60 min)-WDM<sub>cycle9</sub>-treated, h) diluted (0.01%) HCW (200°C, 20 min)-WDM<sub>cycle9</sub>-treated, i) enlarge image of (h)

Table 1 shows the comparative analysis of yield of hydrolyzed sugars and energy consumption from combined WDM with HCW pretreatments at different pretreatment severities with other studies. Wet disk milling pretreatment alone required about 18.9 MJ/kg of OPMF and recorded higher in comparison to rice straw, sugarcane bagasse and sugarcane straw (Hideno et al., 2009; Silva et al., 2010). Therefore, WDM pretreatment required lower energy consumption compared to ball milling pretreatment (Zakaria et al., 2014a; Zakaria et al., 2014b). It was observed that the energy requirement was decreased when OPMF was induced with hydrothermal pretreatment before WDM treatment, which resulted in energy consumption of 17.5 MJ/kg of

OPMF when pretreated with HCW at 200°C, 20 min). The yield of hydrolysed sugars correlated with the WDM processing cycles. Based on the current study, the energy consumption depended on the types of pretreatment, as partial removal of hemicellulose and migration of lignin are sufficient to weaken the matrix of the lignocellulosic network between cellulose microfibrils. It was also observed that the higher amount of energy consumption of WDM depended on the viscosity of the sample where HCW-treated OPMF was found to have the higher degree of viscosity than SHS-treated OPMF. By considering the higher specific surface area and degree of defibrillation from the HCW-WDM process, lower enzyme loading may apply.



**Table 1.** Comparative analysis of yield of hydrolyzed sugars and energy consumption from SHS and HCW at different treatment severities with other studies.

Sample	Yield of glucose,% (g/g-substrate)	of	Energy consumption (MJ/kg biomass)	References
OPMF WDM <sub>9cycle</sub>	30.2 ± 2.4		18.9	This study
HCW <sub>180°C, 20 min</sub> + WDM <sub>9cycle</sub>	86.2 ± 1.4		14.9	This study
HCW <sub>200°C, 20 min</sub> + WDM <sub>9cycle</sub>	91.1 ± 4.3		17.5	This study
WDM <sub>10cycle</sub> -rice straw	78.5 ± 5.6		5.4	Hideno et al. (2009)
WDM <sub>10cycle</sub> -sugarcane bagasse	31.5 ± 1.7		10.6	Silva et al. (2010)
WDM <sub>10cycle</sub> -sugarcane straw	56.1 ± 0.5		14.8	Silva et al. (2010)
LHWP <sub>180°C, 20 min</sub> + WDM <sub>15cycle</sub> -eucalyptus	91.6			Weiqi et al. (2013)
HCW <sub>135°C, 60 min</sub> + WDM <sub>15cycle</sub> -rice straw	90.0			Hideno et al. (2012)

\* WDM= wet disk milling, SHS= superheated steam, HCW= hot compressed water, and LHWP= liquid hot water pretreatment.

## Conclusions

Hydrothermal pretreatment alone showed an increase in degree of enzymatic digestibility compared to untreated OPMF. Hemicellulose removal was more pronounced in HCW, and subsequent WDM treatment has promoted defibrillation of cellulose microfibril, hence increased specific surface area. Furthermore, combined HCW and WDM offered shorter milling cycles and lower power consumption with more than 98% of glucose yield. To the best of our knowledge, this is the first report of eco-friendly combined pretreatment using hydrothermal and WDM to increase the enzymatic efficiency of OPMF and cost efficient for nanofiber production.

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# Reducing Ash Related Operation Problems of Oil Palm Biomass for Combustion Applications using Leaching Techniques

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## Introduction

The major problem during combustion of lignocellulosic biomass is the generation of ash which reduces the efficiency of the process. A majority of agricultural by-products contain high amount of ash, and thus, is responsible for the lower combustion efficiency when used for bioenergy applications. Although representing only a minor proportion by weight, ash appears to be a major determinant in the combustion behaviour of lignocellulosic material. The usage of high ash content biomass for heat and electricity generation may lead to various ash-related problems. The main cause of these problems is the high alkaline content (e.g. K, Na, S and Cl) and consequently the low melting temperature (Bernhardt et al, 2011; Liu and Bi, 2011). These alkali and alkaline elements, foul heat transfer surfaces, participate in slag formation in grate-fired units and contribute to the formation of fluidized bed agglomerates. When the combustion temperature exceeds the melting point of ash, it resulted in unwanted deposits and corrosion in energy conversion systems. These ash forming elements may give rise to molten phases during combustion which produce sticky ash particles that adhere to heat transfer surfaces (Werklin et al, 2005). Besides, high ash content also tends to lower the heating values of the raw materials by virtue of not being a contributor to the fuel heating value (Jenkins et al, 1998). The result is an increase in operating and maintenance costs and reduced conversion efficiency of the combustion systems.

Due to the disadvantages attributed by the high content of ash in lignocellulosic biomass, a number of authors have explored several methods to remove ash forming elements from biomass prior to combustion (Dayton et al, 1999; Sears and Walker, 1999; Cui et al, 2010). Leaching methods have been proven effective in removing ash forming elements from coal and recently this method being introduced to the biomass. Leaching is the process of removing inorganic, organic contaminants or radionuclides elements prior to fuel

utilization. These elements are released from the biomass into the liquid phase under the influence of mineral dissolution and desorption. Most biological organic and inorganic substances occur in a mixture of different components in biomass. In order to separate the desired solute constituent and to remove an undesirable solute component from the biomass, normally the biomass is brought into direct contact with liquid. The biomass and liquid are in contact and the solute or solutes can diffuse from the solid into the solvent, resulting in separation of the components originally in the biomass.

The proper selection of ash forming elements leaching treatments needs to be evaluated on a case-by-case basis as it highly depends on the ash removal effectiveness of different treatment method, and the effect of these treatments leading to organic degradation of the lignocellulosic biomass. The following work aims at evaluating the effectiveness of leaching method on removing ash forming elements and to determine the effects of leaching agent (water and acetic acid) on ash melting of oil palm biomass. Ash melting temperature is one of the most important parameters which should be used to characterize the fuel as it affects the design of boiler (temperature control). Thus, how the ash sintering and molten indices relate to the ash melting temperature was discussed in this study.

## Leaching Process

Empty fruit bunch and oil palm trunk (oil palm biomass) were subjected to various leaching temperature and reaction time with water and acetic acid (1M) as extraction solution. Leaching was performed on the lignocellulosic biomass with three different reaction times (30 min, 60 min and 120 min) at room temperature ( $27 \pm 2$  °C). 10 g samples were weighed and



placed in a 200 ml conical flask. 100 ml of water/ acetic acid were earlier heated to the selected leaching temperature and poured into the conical flask which contained the weight samples. The mixture was gently stirred to ensure the sample was fully submerged in the extraction solution. Leaching was carried in a constant temperature by placing the conical flask in a water bath regulated at the selected leaching temperature. After the leaching, the solutions were filtered and washed with 100 ml distilled water. The leached samples were oven dried at 105 °C over 24 h for further evaluation.

### Ash Melting Characteristic at Different Combustion Temperature

During combustion, ash related operation problems are to be expected for the ash fusion classes 'molten' and 'strongly sintered', while 'loose' or 'slightly sintered' ash should cause no or less problems. The lignocellulosic biomass was prepared into ash. Low-temperature ash of the lignocellulosic biomass was prepared in crucibles holding approximately 10 g of samples each. The crucibles were placed in a muffle furnace heated to 550 °C and kept at this temperature for 6 hours. Low-temperature ash samples (0.2 g) were weighed in small ceramic crucibles and heated in a muffle furnace for two hours with the selected combustion temperature (700 °C, 800 °C, 900 °C and 1000 °C) for two hours. As shown in Table 1, the ash samples were classified into one of the four ash fusion classes of a classification scheme adapted from Tonn et al. (2012) and Steenari et al. (2009).

**Table 1.** Macroscopic and microscopic characteristics of ash fusion classes

Ash fusion class	Ash sintering characteristics
(1) Loose	Macroscopic: ash loose, no evidence of sintering Stereo microscope: intact organogenic structure, no or only few small molten vesicles visible.
(2) Slightly sintered	Macroscopic: ash slightly sintered, manual disintegration easy Stereo microscope: intact organogenic structure, its surfaces partly or completely sintered, larger molten vesicles visible
(3) Strongly sintered	Macroscopic: ash strongly sintered, manual disintegration difficult Stereo microscope: majority of ash molten, but organogenic structure till distinctly visible, structure of ash still porous

(4) Molten	Macroscopic: ash molten, manual disintegration not possible Stereo microscope: no or only few remnants of organogenic structure visible, ash compact with molten phase largely flown into the pores of the original structure.
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(Source: Tonn, 2012; Steenari, 2009)

As tabulated in Table 2, increasing the combustion temperature from 700 °C to 1000 °C increased the sintering degree of the untreated lignocellulosic ash. Water and acetic acid leaching was sufficient to improve the classification of most of these biomass samples by at least one class. At 700 °C untreated OPT samples show no or slight sintering tendency. EFB sintered as a whole with certain hardness and even crushed it is not easy to become powder. The structure of the ashes still porous but molten formation was observed all over the material grain surface. When the combustion temperature increased to 800 °C, the sintering degree of the oil palm biomass increased as well. EFB ash was molten; ash particles closely connected into a solid structure and no sign of biomass ash debris. OPT was classified as "strongly sintered" under the ash fusion classes. The ash formed into a hard and dense sediment, thus, segregation was difficult. Combustion temperature at 900 °C further increased the sintering degree. EFB and OPT were overall melted, the sediments were tightly combined and disintegration was impossible. Ash from biomass made of untreated EFB and OPT tended to melt at least partly at 900 °C. EFB ash was molten at temperature as low as 700 °C. After water leaching treatment, OPT were classified loose or slightly sintered at temperature 1000 °C and could be considered safe for combustion.

**Table 2.** Ash melting characteristics after water leaching and acetic acid leaching<sup>1</sup>

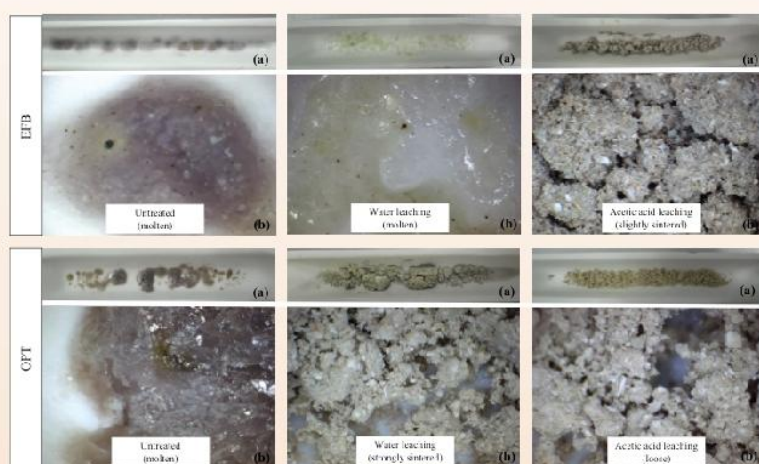
EFB				
700	Strongly sintered	loose	loose	
800	molten	Strongly sintered	loose	
900	molten	molten	loose	
1000	molten	molten	Slightly sintered	
OPT				
700	Strongly sintered	loose	loose	
800	Strongly sintered	loose	loose	
900	molten	Strongly sintered	loose	
1000	molten	Strongly sintered	loose	

(Source: Tonn, 2012; Steenari, 2009)



Figure 1 show the melting characteristic of ash at 1000 °C for untreated oil palm biomass and after the oil palm biomass were leached with water (25 °C for 120 mins) and acetic acid (25 °C for 120 mins). As the temperature increases to 1000 °C, the untreated EFB and OPT samples were completely melted, particles closely connected into a solid molten structure with smooth surface. Whereas, the leached biomass ash heated at 1000 °C fell into 'loose' or 'slightly sintered' classes except EFB treated with water leaching treatment as

shown in Figure 1. Acetic acid leaching treatment improve the ash melting classification of EFB to slightly sintered at 1000 °C but water leaching treated EFB was highly sintered and molten at 900 °C and 1000 °C (Figure 1), respectively. Even though the EFB showed significant decrease in ash content using water leaching method, the concentrations of alkali species is still sufficient to cause a reduction in ash melting temperatures when compared to the acetic acid leached EFB.



**Fig. 1.** Ash formation of EFB (top row) and OPT (bottom row) ash under combustion temperature at 1000°C (a) macroscopic view (b) microscopic view (40X)

## Conclusion

The extent of each elements removed using water as the leaching agent was associated with the amount of water-soluble elements; the higher the water soluble content, the higher the efficiency. Using the method established in this research, the selected oil palm biomass can be prepared for combustion with the assurance that ash forming elements have been reduced sufficiently to safeguard against ash production and slagging in biomass boiler. However, further process development and optimization required to confirm technical and economic feasibility. In general, when designing an industrial scale leaching facility,

several factors that may inhibit the feasibility of the leaching process include: (i) cost and energy for size reduction; (ii) water requirement; (iii) dewatering of the leached biomass; and (iv) treatment and disposal of the leachate. Further studies on the technical feasibility of the proposed lignocellulosic biomass leaching technique, including further modelling and scale-up, and the building of a pilot-scale plant are recommended to demonstrate the technical and economic potential for leaching process.

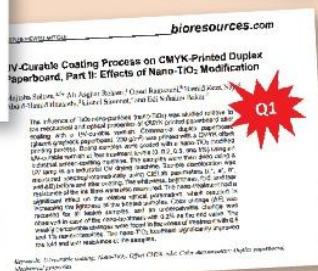
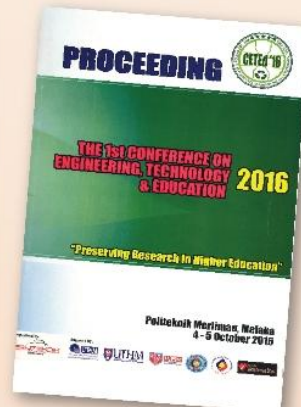
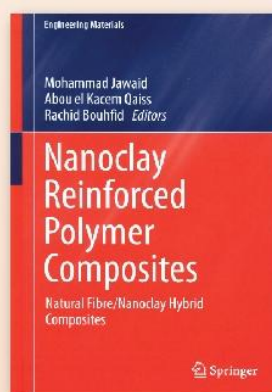
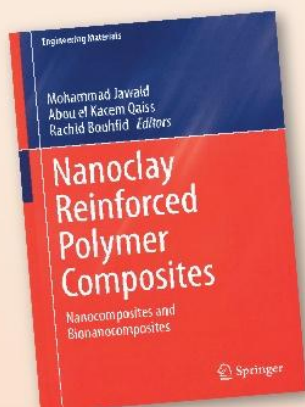
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## Achievements 2016

No	Item	Achievements
1	Publications in SCOPUS/WOS/ERA <ul style="list-style-type: none"> <li>Citation</li> <li>Journals</li> <li>Conference proceeding</li> </ul>	3003 104(Q1+Q2=64) 8
2	Publications in Others Journals	15
3	Research books <ul style="list-style-type: none"> <li>Books</li> <li>Chapter in books</li> </ul>	4 4
4	Research Grant <ul style="list-style-type: none"> <li>Public</li> <li>Private</li> </ul>	RM 3,970,000 RM 100,000.00
5	PI Private	1
6	Innovation <ul style="list-style-type: none"> <li>Paten filed</li> <li>Others IP</li> </ul>	3 2





## Awards 2016

No	Researcher/Staff/Student Name	Name of Award	Conferring Body
<b>INTERNATIONAL</b>			
1	Prof. Ir. Mohd Sapuan Salit	Outstanding Technical Paper Award Based on Published Journal 2016	SAE International
2	Assoc. Prof. Dr. Wan Zuhainis Saad	Glocalink Award	Tech Plan Demo Day In Singapore
3	Chen Jia Tian (Brenna) (PhD student, Programme: Bioresource Management)	Champion of AIRBUS Start-Up Event 2017	AIRBUS



## NATIONAL

1	Prof. Ir. Mohd Sapuan Salit	Buku Terbitan Luar Negara Terbaik	Anugerah Buku Negara 2017
2	Assoc. Prof. Dr. Wan Zuhainis Saad	Grand Winner	Tech Planter Demo Day in Malaysia 2017





## STUDENTS GRADUATED IN 2016

## DOCTOR OF PHILOSOPHY



Name : Norul Izani Md Allwi  
 Matrix No : GS23951  
 Field of Studies : Biocomposite Technology  
 Thesis Title : Effects of Oil Palm Empty Fruit Bunch Pre Treatments on Medium Density Fiberboard Performances  
 Supervisor : Prof. Dr. Paridah Md Tahir



Name : Seyedfariborz Hashemidizaji  
 Matrix No : GS33035  
 Field of Studies : Biocomposite Technology  
 Thesis Title : Evaluation of Behaviors of Voids and Their Effect on Mechanical Properties of Pultruded Hybrid Kenaf/Glass Fiber Reinforced Unsaturated Polymer Composites  
 Supervisor : Prof. Dr. Paridah Md Tahir



Name : Madhavan Balan Nair  
 Matrix No : GS30195  
 Field of Studies : Nature Tourism  
 Thesis Title : Multi-Criteria Decision Making Analysis for Responsible Management of Marine Protected Area in Semporna Sabah, Malaysia  
 Supervisor : Assoc. Prof. Dr. Sridar A/L Ramachandran

## MASTER



Name : Nor Fadhli Farhana A. Rahman  
 Matrix No : GS32669  
 Field of Studies : Biocomposite Technology  
 Thesis Title : Strength and Dimensional Stability of Pehenolic-Treated Bamboo Laminated Panel for Structural Application  
 Supervisor : Prof. Dr. Paridah Md Tahir



Name : Mohd Fadhil Ahmad  
 Matrix No : GS23345  
 Field of Studies : Biocomposite Product Design  
 Thesis Title : Development of Kenaf-Reinforced Plaster Composite for Three-Dimensional Printing System in Rapid Prototyping Technology  
 Supervisor : Prof. Dr. Rahinah Ibrahim



Name : Wan Rafiekal Wan Abdul Rahim  
 Matrix No : GS36336  
 Field of Studies : Bioresource Management  
 Thesis Title : Assessment of *Bambusa vulgaris* as a Potensial Phytoremediation Agent for Heavy Metals  
 Supervisor : Assoc. Prof. Dr. Hazandy Abdul Hamid





Name : Ahmad Khuzairi Sudari  
 Matrix No : GS37096  
 Field of Studies : Biocomposite Technology  
 Thesis Title : Effect of Cationic, Anionic and Non-Ionic Surfactants on the Properties of HDPE/LDPE/Cellulose Biocomposites  
 Supervisor : Assoc. Prof. Dr. Edi Syams Zainudin



Name : Abdul Latib Senin  
 Matrix No : GS31979  
 Field of Studies : Bioresource Management  
 Thesis Title : Growth and Physiological Characteristics of Acacia Species in a Progeny Trial  
 Supervisor : Assoc. Prof. Dr. Hazandy Abdul Hamid



Name : Riri Rimbun Anggih Chaidir  
 Matrix No : GS28050  
 Field of Studies : Forest is Disturbance Impact Evaluation  
 Thesis Title : Spatial Distribution of Ectomycorrhizal and Saprophytic Fungi In Relation with *Shorea Leprosula* Miq. Seedling Survival in Dipterocarp Forest  
 Supervisor : Prof. Dr. Ahmad Ainuddin Nuruddin



Name : Farah Hanan Abd Malek  
 Matrix No : GS31264  
 Field of Studies : Biocomposite  
 Thesis Title : Effects of Fibre Ratio and Additives on Properties of Pultruded Kenaf/Glass Fibres Phenolic Hybrid Composites  
 Supervisor : Assoc. Prof. Dr. Edi Syams Zainudin



Name : Yap Mei Ling  
 Matrix No : GS37147  
 Field of Studies : BIOREM  
 Thesis Title : Growth, Physiology and Anatomical Characteristics of Air-Layered *Azadirachta excelsa* (Jack) Jacobs  
 Supervisor : Assoc. Prof. Dr. Hazandy Abdul Hamid



Name : Munieleswar Raju  
 Matrix No : GS30896  
 Field of Studies : Nature Tourism  
 Thesis Title : Guest's Satisfaction Towards Service Quality Provided by Homestay in Selangor, Malaysia  
 Supervisor : Assoc. Prof. Dr. Nitty Hirawaty Kamaruzaman



## SITE VISIT TO MORINGA OLEIFERA PLANTATION

Date : 12 January 2017

Venue : Bentong, Pahang

A group of researchers from Laboratory of BIOREM conducted a site visit to the Moringa oleifera tree plantation in Bentong, Pahang. This visit is an invitation from Upayapadu (M) Sdn. Bhd., the company that operates this plantation aimed at obtaining consultation and advisory services from the researchers regarding the development of Standard Operating Procedure (SOP) for Moringa oleifera plantation. The company is determined to seek standardized procedures that are recognized as organic based farming. Both parties, UPM and payapadu (M) Sdn. Bhd. have signed the consultancy and services agreement on 6th April 2017 for cooperation in developing the SOP and at the same time further enhance networking and research on Moringa tree.



## ROUNDTABLE DISCUSSION BETWEEN UPM-CIRAD-ASAIHL-UNIVERSITY MONTPELLIER

Date : 2 February 2017

Venue : Office of the Deputy Vice Chancellor (Research & Innovation), UPM

A roundtable discussion between UPM-CIRAD-ASAIHL-UNI MOTPELLIER was organized by Institute of Tropical Forestry and Forest Products (INTROP), on 2<sup>nd</sup> February 2017. The roundtable discussion was attend by 26 participants who came from various agencies such as ASAIHL, University of Montpellier, CIRAD, Sarawak Tropical Peat Research Institute, The National University of Malaysia (UKM) and 12 of the faculties from UPM. This roundtable discussion is proposed to present the project and the platform, the CIRAD dynamic, and the ASAIHL vision. The objective of this discussion is to build synergy between ASAIHL, CIRAD and University Montpellier. The synergy leads to a network of excellence, under the shape of a Regional Platform or Centre of Excellence in research, capacity building and cooperation between Asian Universities and continental Europe. Outcome of this discussion is proposed to present the project the platform, the CIRAD dynamic the ASAIHL vision, participations of selected UPM researchers/institute/faculties, ASAIHL universities probably FRIM, MADI and UKM.





## PROGRAM JOM KURUS 1 INTROP 2017

Date: 8 February - 19 May 2017

Venue: INTROP, UPM

The program was aimed to encourage INTROP staffs to practice a healthy lifestyle. Among activities that have been carried out throughout the program were zumba for women and playing badminton for men. A weight loss competition was also held in two categories, men and women. The initial weight was taken on 8th February 2017. On that day a Dietitian Officer from Faculty of Medicine and Health Sciences, UPM, Ms. A'isyah Zafirah Abdul A'zim was invited to give a talk on healthy diet. The final weight was taken on 19th May 2017 and again a Dietitian Officer from the Faculty of Medicine and Health Sciences, UPM, Ms. Norhazwani Che Lah was invited to give a talk on special Ramadan diet. At the end of the program, the male category won by Mr. Hasnan Mat Isa with 7.6 kg lost and women's category won by Dr. Ainun Zuriyati Mohamed @ Asa'ari with 2.3 kg lost.



## INTERNSHIP LYCÉE FRANÇAIS DE KUALA LUMPUR (FRENCH SCHOOL OF KUALA LUMPUR)

Date: 20-24 February 2017

Venue: INTROP, UPM

INTROP was honored to receive 2 brilliant students from Lycée Français Kuala Lumpur (LFKL), a French international school. The objective for LFKL sent them was to train as internship student. Anais Dupuis, 15, and Clementine Nouvellon, 16 both had their internship at different department – CoE Biomass Valorisation and Laboratory of Pulp & Paper, respectively. They were stationed by their own interest and choice after brief by research officer and head of laboratory.

Anais Dupuis very interested in computer technology, supervised by Candice Ong Chu Lee (PhD Student) to train her using open-source software such as R – mathematical software – and GRASS GIS – geographical information system software. Then she able to generate graph and map mapping based on data she had with this two software. On the other hand, Clementine interested in laboratory work. She learnt how to make paper from the various plant's fiber. Throughout the process, she identified that not only one method to produce paper like a process called 'mechanical pulping'. There are chemical pulping and hybrid pulping as well.





## KISAS RESEARCH WORK FOR MALAYSIAN INTERNATIONAL YOUNG INVESTORS OLYMPIAD (MIYIO) 2017

Date: 22 February - 8 March 2017

Venue: INTROP, UPM

Kolej Islam Sultan Ahmad Shah (KISAS), Klang, Selangor repeated their series of successful achievement by winning 2 Silver Awards at Malaysian International Young Investors Olympiad (MIYIO) 2017 on 14-16 April 2017. The successful glory continues at Innovation Design Research International Symposium (IDRIS 2017), 23-25 April 2017 which witnessed KISAS team excellent potential by winning 4 awards – 1 Double Gold Award, 1 Gold Award, 1 Silver Award and 1 Special Award. Their research which was closely monitored by INTROP technical advisors from Pulp & Paper and Biocomposites Program headed by Dr. Ainun Zuriyati Mohamed, focused on the development of kapok. The research has been done at INTROP on 22 February until 8 March 2017. 'Kapok Paper as Potential Application in High Durability Specialty Paper' and took high attention by the recognized evaluators and audience. KISAS which was officially announced as Sekolah Angkat INTROP since 2015 is hoped to keep up the outstanding progress.



## SAFETY AWARENESS TALK: NEVER TRUST FIRE

Date: 5 May 2017

Venue: INTROP, UPM

The Occupational Safety & Health Committee (JKKP-INTROP) has invited the Fire Prevention Association Kuala Lumpur to deliver a safety talk on fire awareness at home, vehicle and office.

The talk was held at INTROP Meeting Room and attended by 28 INTROP staffs. Among the topics covered by the speaker are:

- Understand the short-circuit causes and how to overcome them.
- Know the cause of flammable vehicles and how to save yourself when dealing with such situations
- Loss of life caused by the toxic smoke generated from the fire
- Learn about fire prevention and safety tips including the guidance to save yourself from the building being burned.
- Introduction to equipment and devices that can detect and control fire early.





## TECHNICAL VISIT TO BANGKOK, THAILAND

Date : 18 -19 May 2017

Venue : Phoenix Pulp and Paper Public Company Limited, and Kasetsart University, Bangkok, Thailand

A delegation accompanied by four researchers from Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia was visited Phoenix Pulp and Paper Public Company (PPPC) Limited, Khon Kean, Thailand on 18 May 2017. The main objective of the visit was to discuss the ideas of utilizing the Eucalyptus tree bark for value added product and adhesive for wood based panels. PPPC will be supplied the raw material (Eucalyptus bark) and research will be conducted by UPM. The study will be started on August 2017.

PPPC is supplying the raw material of Eucalyptus bark to INTROP UPM for research purpose starting from August 2017.

INTROP researchers also visited a new Wood Composite Laboratory at Kasetsart University (KU), Bangkok. KU has a well-established wood composite and pulp and paper laboratories facilitated with advanced equipment. The laboratories also have produced paper using lab-scale apparatus and have a good conditioning room for paper testing.

This visit had opened a great opportunity for the researchers to discuss and share on the new technologies, current and potential projects. Hence, more collaboration and networking could be developed with Thailand pulp industry and Kasetsart University in the future.



## 1ST INTERNATIONAL SYMPOSIUM ON NANOCELLULOSIC MATERIALS

Date: 20 – 22 May 2017

Venue: Hangzhou, China

The 1st International Symposium on Nanocellulosic Materials (ISNCM) was organized by The Nanocellulose and Materials Committee of the China Technical Association of Paper Industry (NMC of CTAPI) aimed at gathering experts, researchers and private sectors involving in nanocellulosic materials development. The symposium consisted of 11 technical sessions and was attended by more than 250 participants from all over the world. Plenary lectures were given by Emeritus Prof. Derek Gray (University of McGill, Canada), Dr Xingyu Jiang (NMC of CTAPI, China), Dr Lixian Xu (Sappi Biotech, the Netherlands) and Prof. Orlando Rojas (Aalto University, Finland). 14 invited talks were given during the symposium, and one of the talks was given by Assoc. Prof. Dr Hidayah Ariffin (UPM, Malaysia) with the title Palm Oil Mill Biorefinery for the Production of Cellulose Nanofiber. The symposium reached its target in gathering the experts in nanocellulose for exchanging ideas; as many high quality papers were being presented during the conference, followed by close discussion among the researchers.





## ADVANCED COURSE ON BIOMECHANICS OF THE TREES

Date: 5 – 9 June 2017

Venue: Pistoia, Italy

The course is organized by the Department of AgriFood Production and Environmental Science in cooperation with the Italian Society of Arboriculture and the Italian Society of Horticulture. The course focus on advanced knowledge and training related to plant physiology and biomechanics with special focus on plant stability. The speakers are from various backgrounds of education, expertise and research field such as wind damage risk to trees and forests (Dr. Barry Gardiner), the dynamics of wind-tree interactions and thigmomorphogenesis (Dr. Bruno Moulia), anatomy of branch junctions and natural bracing in trees (Dr. Duncan Slater), tree risk and structure analysis on likelihood of failure (Prof. Brian Kane), tree biology and tree biomechanics (Prof. Frank Telewski) and pruning strategies leading to enhanced tree stability (Dr. Gilman Edward).



## 4TH INTERNATIONAL SYMPOSIUM ON APPLIED ENGINEERING AND SCIENCES (SAES 2016), AND TECHNICAL VISIT TO KYUSHU INSTITUTE OF TECHNOLOGY (KYUTECH)

Date : 15 – 21 December 2016

Venue : KYUTECH, Kitakyushu, Japan

Symposium on Applied Engineering and Sciences (SAES) is a yearly meeting which involved management, staff and students from UPM and KYUTECH. As a result of collaboration in between UPM and KYUTECH, a total of 170 participants had attended SAES2016 at KYUTECH, Tobata campus with the theme “Towards Strengthening Malaysia-Japan Research Collaboration”. Seven INTROP staff and 10 INTROP postgraduate students had attended the SAES2016. Researchers and students were able to exchange knowledge and experiences with other participants. Besides attending symposium, participants from INTROP participated in a technical visit to KYUTECH Laboratories at Wakamatsu campus, Yaskawa Electrical Co. (manufacturer of servos, motion controllers, industrial robots and etc.) and Toyota Motor Kyushu, Inc., a car manufacturing plant.





## New Member



**Name** : Dr. Rozihawati Zahari  
**Post** : Post-Doctoral  
**Email** : rozihawati@upm.edu.my/rozihawaitzahari@yahoo.com  
**Field of Specialization** : Plant Pathology, Microclimate Forest

***Achievement at international level:***

3 scientific papers, 10 conference papers and 3 awards

***Recent research projects:***

Characterization of Carbon and Greenhouse Gas Emissions of Repeated Burnt Peat Swamp Forest in Peninsular Malaysia.

***How do you feel to be a part of INTROP's family?***

I would say that I feel happy and grateful thank to INTROP because chosen me as one of the INTROP members. Joining INTROP is a great chance for me to extend my knowledge in microclimate forest field.

***What are your future strategies as a Post-Doc in INTROP?***

I will focus on research projects and contribute to the INTROPs objectives by suggesting more research papers for publication, publish patent and will try guide post-graduate students. Furthermore, I would like to target awards for my research project.

***What is your opinion on INTROP's working environment?***

I really enjoy working in INTROP due to has friendly staffs, great teamwork and provides a good environment to work.

***How do you see INTROP in 5 years?***

INTROP's working environment has good tolerance, dedication and great teamwork. It is reasonable to INTROP becoming the international centre and leader in biocomposites, natural fibre and forest management.



## Wood and Biofiber International Conference 2017 (WOBIC 2017)

Wood and biofibers are vital biomaterials for all aspects of human beings life. Such materials are used in varieties of application such as making ropes, buildings and automotive applications as well as extraction of bioproducts for health care and food applications. Recently, the developments of wood and biofiber products have been rising with the increase of environmental concern. The biomaterials are renewable and environmentally friendly having large diversities of applications. **Wood and Biofiber International Conference (WOBIC2 017)** will be held on **21<sup>st</sup> to 23<sup>rd</sup> November 2017** in Hotel Bangi - Putrajaya, Malaysia. The conference will be an immediate assistance to those involved in the development of wood and biofiber products research and industry including researchers, inventors, educators, suppliers, and engineers. **WOBIC 2017** is organized by Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, Serdang, Malaysia.

This conference was previously named as the International Conference on Kenaf and Allied Fibers (ICKAF), which is held every 4 years by carrying on the tradition of the international conference which was first organized in 2009. INTROP is recognizing the value of a holistic approach to sustainable wood and biofiber production in order to meet the needs of identified final products. A strategic decision has been made to change the name of the conference by expanding its scope on other fibers not only kenaf, and ascertains the evolution and significance of the wood and biofiber sector in the global economy.

**WOBIC 2017** seeks to gather industry and academia in order to discuss the latest developments in wood and biofiber, from upstream agricultural-related topic to downstream fiber processing and product advancement, as well as the socio-economic impact of these commodities.

The theme of **WOBIC 2017** is 'Lignocellulose for Future Bioeconomy' which covers all aspects of wood and biofibers activities. The conference covers a wide range of topics related to the theme for further scientific investigation, engineering, technical education & research, product development, prototyping, industry experience and economic.

Specific areas of interest include, but are not limited to:

- Wood Technology and Application
- Bioproducts (Bioenergy, Biochar, Biocompost)
- Bioresource Management, Economic and Policy
- Environment and Life Cycle Analysis
- Biopolymer and Derivatives
- Biocomposite Technology
- Bionanomaterials
- Pulp and Paper Technology
- Textile Composites

It is high hope that WOBIC 2017 may success and benefit all participants which is parallel to the global demand and needs to date.

### ORGANIZING SECRETARIAT

Institute of Tropical Forestry and Forest Products (INTROP)  
Universiti Putra Malaysia  
43400 UPM Serdang Selangor,  
MALAYSIA

Email: [wobic.introp@upm.edu.my](mailto:wobic.introp@upm.edu.my)



## Speakers for WOBIC 2017

### KEYNOTE SPEAKERS



**PROF. DR. SABU THOMAS**  
Mahatma Gandhi University, India  
Presentation Title:  
Engineering at the Nanoscale: A Strategy for Developing High Performance Functional Bio-Materials Based on Nanocellulose



**PROFESSOR EMERITUS DR DEREK GRAY**  
McGill University, Montreal, QC, Canada  
Presentation Title:  
Lignocellulose In A Sustainable Bioeconomy

### PLENARY SPEAKERS



**PROF. DR. HYUN-JOONG KIM**  
Seoul National University, Republic of Korea  
Presentation Title:  
Issues and Challenges of Bio-based Resin Commercialization in the 21<sup>st</sup> Century

### SESSION INVITED SPEAKERS



**PROF. DR. MOHD ALI HASSAN**  
Universiti Putra Malaysia, Malaysia  
Presentation Title:  
Oil Palm Biomass Biorefinery for Future Bioeconomy



**DR. VIJAYA SUBRAMANIAM**  
Malaysian Palm Oil Board (MPOB), Malaysia  
Presentation Title:  
Carbon Footprint Reduction Practices in the Malaysian Oil Palm Industry



**DR. SATOSHI HIRATA**  
Advanced Industrial Science and Technology (AIST), Japan  
Presentation Title:  
R&D and industrialization of cellulose nanofibrils in Japan



**DR. JAN E.G. VAN DAM**  
Wageningen UR, Netherlands  
Presentation Title:  
Biopolymer Innovations and Products Development in The Netherlands



**PROF. DR. MOHD SHAHWAHID OTHMAN**  
Universiti Putra Malaysia, Malaysia  
Presentation Title:  
Environmental and economic sustainability of Kenaf as Bio-materials in the Malaysian Automotive Industry



**PROF. DR. LIJUN WANG**  
Zhejiang University of Science and Technology/ National Eng. & Tech. Research Center for Paper Chemicals, China  
Presentation Title:  
Design of Total Chemistry Management System for Paper Mills in China



**PROF. DR. -ING. HAIRUL ABRAL**  
Andalas University, Indonesia  
Presentation Title:  
Vibration Duration Effect of Ultrasound Applied to Gelatinized Biocomposite on Its Mechanical Properties



**PROF. DR. PARIDAH MD TAHIR**  
Universiti Putra Malaysia, Malaysia (INTROP),  
Presentation Title:  
Cross Laminated Structures from Tropical Bioresources



## Equipment/Services Available at INTROP (Laboratory of Biocomposite)

No	Equipment	Application	Person In charge	Contact No
1	BRABENDER Internal Mixer	To melt-mix polymer samples with natural/synthetic fillers at low volume.	Ms. Ana Salleza Md. Salleh	03-8947 1885
2	Thermoplastic Compression Moulding (40 tonne)	To melt-compress plastic/composite samples at low pressure.	Ms. Ana Salleza Md. Salleh	03-8947 1885
3	Hot Press (100 tonne)	To compress wood/composite samples at high pressure.	Ms. Ana Salleza Md. Salleh	03-8947 1885
4	Twin Screw Extruder	To melt-mix polymer samples with natural/synthetic fillers at high volume.	Ms. Ana Salleza Md. Salleh	03-8947 1885
5	Various chipper and milling machines	To chip and grind wood and fiber sample	Ms. Ana Salleza Md. Salleh	03-8947 1885
6	Injection Moulding	To inject polymer/composite samples into a mould cavity.	Ms. Ana Salleza Md. Salleh	03-8947 1885
7	Universal Testing Machine (UTM) (30 kN)	To determine tensile/flexural properties of polymer/composite samples.	Mr. Mohd Lufti Mohd Tawil	03-8946 9615
8	Thermal Gravimetric Analyzer (TGA)	To determine thermal decomposition of samples.	Mr. Mohd Lufti Mohd Tawil	03-8946 9615
9	Differential Scanning Calorimeter (DSC)	To determine thermal behaviours of samples.	Mr. Mohd Lufti Mohd Tawil	03-8946 9615
10	Dynamic Mechanical Analyzer (DMA)	To determine mechanical-thermal properties of samples.	Mr. Mohd Lufti Mohd Tawil	03-8946 9615
11	Thermal Mechanical Analyzer (TMA)	To determine thermal-mechanical behaviours of samples.	Mr. Mohd Lufti Mohd Tawil	03-8946 9615
12	Dynamic Mechanical Analyzer (DMA)	To determine impact properties of polymer/composite samples.	Mr. Mohd Lufti Mohd Tawil	03-8946 9615
13	Digital Image Analyzer	To visualize fibre/composite sample at low magnification (40x).	Mr. Mohd Lufti Mohd Tawil	03-8946 9615
14	Freezer Mill / Cryocrusher(excluding liquid nitrogen)	To crush leaf/fibre samples via cryogenic process.	Ms. Ana Salleza Md. Salleh	03-8947 1885



Universal Testing Machine



OSB Resin Mixer



Injection Moulding Machine



Optical Microscope



Compression Moulding Machine



## Equipment/Services Available at INTROP (Laboratory of Biopolymer and Devivatives)

No	Equipment	Application	Person In charge	Contact No
1	Gas Chromatography Mass Spectrometry (GCMS)	Characterization of sample in components in samples (e.g: fatty acids, organic acids, biodiesel (FAME))	Mdm. Nor Azizah Haron	03-8947 1887
2	Pulp Digester	To convert wood/non-wood into pulp	Mdm. Nazlia Girun	03-8946 7009
3	Papermaking instruments (handsheet former)	To convert pulp into paper/board	Mdm. Nazlia Girun	03-8946 7009
4	Beater (PFI mill)	To beat pulp	Mdm. Nazlia Girun	03-8946 7009
5	Pulp Viscometer	To find the viscosity of pulp	Mdm. Nazlia Girun	03-8946 7009
6	Paper/board tensile machine	To find the strength of paper/paperboard	Mdm. Nazlia Girun	03-8946 7009
7	Chemical compositional analysis	To measure the composition of cellulose, hemicellulose and lignin	Mdm. Nazlia Girun	03-8946 7009



Beater (PFI Mill)



Canadian Standard Feeness



Disintegrator



Pulp Viscometer



Handsheet Former



Gas Chromatography Mass Spectrometry (GCMS)





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