PROPERTIES OF SUGAR PALM NANOCELLULOSE FIBRE-REINFORCED BIOPOLYMER COMPOSITE

AHMAD ILYAS BIN RUSHDAN

IPTPH 2019 2

PROPERTIES OF SUGAR PALM NANOCELLULOSE FIBRE-REINFORCED BIOPOLYMER COMPOSITE

By

AHMAD ILYAS BIN RUSHDAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

January 2019

DEDICATION

To Al-Quran, the greatest source of knowledge

Bring me sheets of iron" - until, when he had leveled [them] between the two mountain walls, he said, "Blow [with bellows]," until when he had made it [like] fire, he said, "Bring me, that I may pour over it molten copper." (Al-Kahf:Verse 96)

&

To my beloved father and mother for their invaluable sacrifices, encouragements and support throughout my life

&

To my beloved wife for her love, patience and understanding

&

To my beloved daughter and son

&

To my awesome 13 siblings

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

PROPERTIES OF SUGAR PALM NANOCELLULOSE FIBRE-REINFORCED BIOPOLYMER COMPOSITE

By

AHMAD ILYAS BIN RUSHDAN

January 2019

Chairman : Mohd Sapuan Bin Salit, PhD
Faculty : Institute of Tropical Forestry and Forest Products

The robust economic growth and rapid development as well as population growth in Malaysia have increased the amount of plastic waste generation by households, industry and trade sectors. The National Strategic Master Plan 2005 estimated that a total of 31,500 tonnes of solid wastes generated per day by 2020. To resolve the ongoing problems caused by non-biodegradable plastics, natural biopolymers which are also environmental friendly plastic have been investigated as potential alternatives to replace conventional plastic. Starch is one of the most widely available biopolymers for packaging application as well as potential alternative to non-biodegradable plastics as it is affordable, wide availability, biodegradable and renewable. The major challenges for the development of starches as packaging films are the shortcomings related to brittleness, processability, high moisture sensitivity, and poor mechanical and water barrier properties. In order to transform native sugar palm starch (SPS) into high performance thermoplastic starch for packaging application, sugar palm nanocrystalline cellulose (SPNCCs) and sugar palm nanofibrillated cellulose (SPNFCs) were extracted from sugar palm fibre (SPF) and utilized to reinforce the matrix of SPS. The SPNCCs and SPNFCs were isolated using chemical (acid hydrolysis) and mechanical (high pressurized homogenization) treatments, respectively. The characterization of SPNCCs and SPNFCs was performed using TEM, FESEM, AFM, DP, TGA, DSC, DMA, FTIR, BET, XRD, zeta potential, chemical composition, density, and moisture content. From the implemented experiment, the dimension of the obtained SPNCCs and SPNFCs was in nanometer range in the form of needle-like and thread-like particles shapes, respectively, with less aggregated in suspension and high thermal stability which was attributed to their high crystallinity and stiffness. The SPNCCs presented a high crystallinity value of 85.9%, length (L) of around 130 ± 30 nm and the average diameter (D) of 9 ± 1.96 nm with yield value of 29%. Meanwhile the SPNFCs presented a high crystallinity value of 81.2%, length (L) of around several micrometers and average diameter (D) 5.5 ± 0.99 nm with yield value of 92%. SPNCCs and SPNFCs reinforced SPS composite film were developed using solution casting method. The effects of different SPNCCs and SPNFCs concentrations (0 – 1.0 wt. %) on the physical, mechanical, biodegradability, thermal and water barrier properties of nanocomposite

films were evaluated. The addition of the concentration of sugar palm nanocellulose from 0.1 to 1.0 % significantly improves the water barrier and mechanical properties of the reinforced SPS nanocomposite films compared to control SPS films. It was incredible to note that the SPNCCs reinforced SPS nanocomposite films showed an increase in Young's modulus and tensile strength from 54 to 178.83 MPa and 4.80 to 11.47 MPa with increasing nanofillers concentration from 0 to 1.0 wt %, respectively. Whereas for SPNFCs reinforced SPS nanocomposites, the films showed an increase in Young's modulus and tensile strength from 54 to 121.26 MPa and 4.80 to 10.68 MPa with increasing nanofillers concentration from 0 to 1.0 wt %, respectively. The addition of SPNCCs and SPNFCs within SPS nanocomposites reduced the films solubility from 33.36 % (neat film) to 14.76 % and 18.60, respectively, which proved that the films have good water stability. Moreover, sugar palm nanocellulose reinforced sugar palm starch nanocomposite was anticipated to have good interfacial adhesion to improve the water barrier and mechanical properties and biocompatibility. The development of such fully biodegradable packaging films is important in the effort to address the ongoing environmental problems and gradually substitute the widely used conventional packaging materials.

Abstrak tesis yang dikemukan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

CIRI-CIRI SERAT ENAU NANOSELLULOSA MEMPERKUKUHKAN KANJI BIOPOLIMER KOMPOSIT

Oleh

AHMAD ILYAS BIN RUSHDAN

Januari 2019

Pengerusi : Mohd Sapuan Bin Salit, PhD
Fakulti : Institut Perhutanan Tropika dan Produk Hutan

Pertumbuhan ekonomi dan pembangunan yang pesat serta peningkatan jumlah penduduk di Malaysia telah meningkatkan jumlah pengeluaran sisa plastik oleh sektor isi rumah, industri dan perdagangan. Menurut Pelan Induk Strategik Kebangsaan 2005, sebanyak 31,500 tan sisa pepejal dijangka dijana setiap hari menjelang tahun 2020. Untuk menyelesaikan masalah-masalah ini yang disebabkan oleh plastik yang bersifat tidak biodegradasi, biopolimer semulajadi yang juga plastik mesra alam dilihat sebagai alternatif yang berpotensi untuk menggantikan plastik konvensional. Kanji adalah salah satu daripada biopolimer yang berpotensi menggantikan plastik bukan biodegradasi sebagai pembungkusan makanan kerana ia mudah didapati, murah, terbiodegradasi dan sumbernya adalah daripada bahan yang boleh diperbaharui. Cabaran utama untuk membangunkan kanji sebagai filem pembungkusan adalah kekurangannya yang berkaitan dengan sifat rapuh, kebolehprosesan, kepekaan kelembapan yang tinggi, serta sifat mekanikal dan ciri penghalang air yang lemah. Untuk mengubah kanji enau (SPS) ke kanji termoplastik berprestasi tinggi untuk aplikasi pembungkusan, selulosa nanokristal enau (SPNCCs) dan selulosa nanofibrilasi enau (SPNFCs) diekstrak daripada gentian enau (SPF) dan digunakan untuk mengukuhkan matriks kanji SPS. SPNCCs diekstrak menggunakan kaedah kimia (asid hidrolisis), manakala SPNFCs diekstrak menggunakan kaedah mekanik (homogenisasi bertekanan tinggi). Pencirian SPNCCs dan SPNFCs dikaji menggunakan analisis TEM, FESEM, AFM, DP, TGA, DSC, DMA, FTIR, BET, XRD, potensi zeta, komposisi kimia, ketumpatan, dan kandungan kelembapan. Daripada eksperimen yang telah dijalankan, dimensi SPNCCs dan SPNFCs yang diperolehi berada dalam pelbagai ukuran nanometer, dan masing-masing berbentuk seperti jarum dan benang. Selain itu SPNCCs dan SPNFCs dilihat tidak bergumpal, serta mempunyai kestabilan haba yang tinggi yang dikaitkan dengan sifat kristal yang tinggi. SPNCCs menunjukkan nilai kristal 85.9%,mempunyai saiz panjang (L) bersamaan 130 ± 30 nm dan purata diameter (D) bersamaan 9 ± 1.96 nm dengan nilai hasil 29%. Sementara itu, SPNFC menunjukkan nilai kristal yang tinggi iaitu 81.2%, mempunyai saiz panjang (L) sekitar beberapa mikrometer dan purata diameter (D) bersamaan 5.5 ± 0.99 nm dengan nilai hasil 92%. SPNCCs dan SPNFCs yang dihasilkan seterusnya dimasukkan ke dalam filem SPS dengan menggunakan kaedah penuangan cairan. Kesan

kepekatan SPNCCs dan SPNFCs yang dimasukkan ke dalam filem SPS (0 - 1.0 wt.%) dapat dilihat dengan mengkaji sifat fizikal, mekanikal, biodegradasi, haba dan halangan air daripada filem nanocomposit telah dihasilkan. Penambahan berat nanoselulosa enau dari 0.1 hingga 1.0 wt. % kedalam filem SPS dilihat meningkatkan sifat mekanikal dan penghalang air dengan ketara berbanding dengan filem SPS yang tidak dicampur nanocelulosa. SPS/SPNCCs nanokomposit menunjukkan peningkatan dalam kekuatan modulus dan kekuatan tegangan daripada 54 MPa kepada 178.83 MPa dan 4.80 MPa kepada 11.47 MPa dengan peningkatan kepekatan nanofiller dari 0 hingga 1.0%. Manakala bagi filem SPS/SPNFCs nanokomposit, ia juga menunjukkan peningkatan dalam kekuatan modulus dan kekuatan tegangan dari 54 MPa hingga 121.26 MPa dan 4.80 MPa hingga 10.68 MPa dengan peningkatan kepekatan nanofiller dari 0 hingga 1.0 wt%. Penambahan SPNCCs dan SPNFCs ke dalam filem SPS juga dilihat mengurangkan kelarutan filem daripada 33.36% (filem terkawal) kepada 14.76% dan 18.60, yang membuktikan bahawa filem mempunyai kestabilan air yang baik. Tambahan pula, filem nanoselulosa enau memperkuatkan kanji SPS nanokomposit dilihat mempunyai hubung-kait lekatan yang baik bagi meningkatkan sifat halangan air, sifat mekanikal dan biokompatibiliti. Pengembangan filem pembungkusan yang bersifat biodegradasi adalah penting dalam usaha menangani masalah kerosakan alam sekitar yang berleluasa dan ia dapat direalisasikan secara beransur-ansur dengan menggantikan bahan pembungkusan konvensional yang digunakan secara meluas dengan filem nanoselulosa enau memperkuatkan kanji enau biopolimer nanokomposit.

ACKNOWLEDGEMENTS

In the name of Allah, the Most Gracious, the Most Merciful

Highest gratitude to Allah swt for granting me the strength, resilient, and knowledge to complete this thesis. The accomplishment of this thesis would not have materialized without His blessing and guidance. My deepest appreciation goes to my kind supervisor Professor Ir. Dr. Mohd. Sapuan Salit for his immense support and enthusiastic supervision throughout my PhD program. I was greatly inspired to explore the world of research and writing under his supervision. Besides that, I would like to express my sincere appreciation for the guidance and coaching of my co-supervisors, Associate Professor Dr. Edi Syams Zainudin (Department of Mechanical and Manufacturing Engineering, UPM) and Dr. Mohamad Ridzwan Ishak (Department of Aerospace Engineering, UPM).

I would like to convey my great appreciation to Universiti Putra Malaysia for the financial support provided through Universiti Putra Malaysia Graduate Research Fellowship (GRF) scholarship, Universiti Putra Malaysia Grant scheme Hi-COE (6369107) and Fundamental Research Grant Scheme (FRGS): FRGS/1/2017/TK05/UPM/01/1 (5540048).

I owe a special thanks to my dear wife Siti Nur Atikah Mahamud (Ummu Adam) for her continuous support and sacrifice throughout my study. To my beloved father (Dr. Rushdan Ibrahim) and mother (Norlaila Yusof) for the motivations and continuous prayer for my success in this world and in the hereafter. Special credit to my daughter (Ainul Mardhiah) and son (Adam) for providing a cheerful environment during my study period. Thanks to my siblings, Mariam, Muhammad Faruq, Abdul Fattah, Ibrahim, Fatimah, Aisyah, Sumaiyah, Umar, Khadijah, Amalina, Sarah and Syuaib, for their constant moral support. It's my fortune to cheerfully acknowledge the support of my entire family members including my in-laws.

I am thankful to all staff in Faculty of Engineering and Institute of Tropical and Forestry Product (INTROP) for their help and guidance. Last but not least, my thanks goes to all those people who knowingly or unknowingly helped me in the successful completion of this work such as the likes of Dr. Muhammed Lamin Sanyang (Gambian), Dr. Ridhwan Jumaidin (Malaysian), Muhammad Huzaifah, Mohd Adrinata, Noor Azammi, Mohd Supian, Mohd Radzi, Nuzaimah (PhD student, Malaysian), Muhammad Ammar and many others.

JazakAllahu Khairan!

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Mohd Sapuan bin Salit, PhD
Professor, Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Edi Syams bin Zainudin, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohamad Ridzwan bin Ishak, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia
Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: _______________ Date: ________________

Name and Matrix No.: Ahmad Ilyas bin Rushdan; GS46982

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ___________________________
Name of
Chairman of
Supervisory
Committee: Professor Ir. Dr. Mohd Sapuan Bin Salit

Signature: ___________________________
Name of
Member of
Supervisory
Committee: Associate Professor Dr. Edi Syams Bin Zainudin

Signature: ___________________________
Name of
Member of
Supervisory
Committee: Dr. Mohamad Ridzwan Bin Ishak

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AFM	Atomic force microscopy
ANOVA	Analysis Of Variance
ASTM	American Society for Testing and Materials
DMA	Dynamic mechanical analysis
DP	Degree of polymerization
DSC	Differential Scanning Calorimetry
FESEM	Field emission scanning electron microscope
FESEM	Field Emission Scanning Electron Microscope
FTIR	Fourier Transform Infrared
HAS	High amylose starch
MFC	Microfibrillated cellulose
PBAT	Poly(butylene adipate-co-terephthalate)
PHB	Polyhydroxybutyrate
PLA	Poly (lactic acid)
PP	Polypropylene
PVOH	Polyvinyl alcohol
RH	Relative humidity
SPATF	Sugar palm acid treated fibre
SPC	Sugar palm cellulose
SPF	Sugar palm fibre
SPNCCs	Sugar palm nanocrystalline cellulose
SPNFCs	Sugar palm nanofibrillated cellulose
SPS	Sugar palm starch
TGA	Thermal-gravimetric analysis
TPCS	Thermoplastic cassava starch
TPS	Thermoplastic Starch
UV	Ultraviolet
W	Weight
WS	Water solubility
WVP	Water vapor permeability
XRD	X-ray diffraction

LIST OF SYMBOLS

α	Alpha
A	Area
L/D	Aspect ratio
D	Coefficient of diffusion
C	Concentration
X_c	Crystallinity index
^{o}	Degree
^oC	Degree celcius
Φ	Degree of entanglement
ρ	Density
D	Diameter
x	Distances
E_f	Effectiveness of the dispersion
M_∞	Equilibrium water sorption
w_2	Final weight
T_g	Glass transition
g	Gram
Hz	Hertz
h	Hour
w_1	Initial weight
η	Intrinsic viscosity
kV	Kilo volt
λ	Lambda
L	Length
Tr	Light transmittance
$Tan\ \delta$	Loss factor
E''	Loss modulus
T_{Max}	Maximum weight-loss rate
MPa	Mega pascal
m	Meter
μg	Microgram
μm	Micrometer
mm	Milimeter
mL	Millimeter
mV	Millivolt
M_w	Molecular weight
nm	Nanometer
N	Newton

T_{Onset}	Onset temperature
P	Partial pressure
I_{am}	Peak intensities of amorphous
I_{002}	Peak intensities of crystalline
T_p	Peak temperature
%	Percentage
π	Radian
Sc	Solid content
E'	Storage modulus
E'_g	Storage modulus at glass phase
E'_r	Storage modulus at rubber phase
θ	Theta
d	Thickness
t	Time
R	Universal gas constant
v	Volume
V_f	Volume fraction of the nanofiller
M_f	Weight final
M_i	Weight initial
W_L	Weight loss
$wt.\%$	Weight percentage

CHAPTER 1

INTRODUCTION

1.1 Background

Cellulose possesses high mechanical strength and good thermal resistance properties. It sources from natural fibres such as sugar palm, roselle, cotton, wood, sisal, flax, hemp, jute, ramie, oil palm, kenaf and coir (Razali et al., 2015). The development of nanosized particles from renewable source as reinforcing materials in nanocomposites has become interest of researchers. Nanocellulose is stiff nanometric particles and biodegradable materials from cellulose biopolymer. Nanocellulose can be categorized into nanocrystalline cellulose (NCC), nanofibrillated cellulose (NFC) and bacterial cellulose (BC). The categorization depends on their physical characteristics of dimension, size and stiffness. Cellulose can be processed into nanocellulose by mechanical or chemical treatment.The low cost of cellulose due to its availability and abundance in nature that make it as a bio-fillers in polymer matrixes (Lin, & Dufresne, 2014).

Nanocellulose is widely utilized to develop nanocomposites or polymer composites because of its low density, high thermal stability, high tensile strength, biocompatibility and biodegradability. Nanocellulose reinforced nanocomposites are environmentally friendly materials that are known as green composites (Eichhornet al., 2010). They can be applied in various industries such as food packaging, automotive, furniture, construction and biomedical (Lin & Dufresne, 2014). Nanocellulose is discerned as one of the promising reinforcing agents of bionanocomposite owing to the interaction between the nano-sized components that form a percolated network connected by hydrogen bonding.

Sugar palm tree is one of the versatile trees due to almost all parts of the tree can be utilized. It mostly grown in tropical countries covers as wide as South Asia to South East Asia and up to North Australia (Ishak et al., 2013). It serves as a potential sources of starch and natural fibre which are collected from stem and leaves, respectively, for developing green composite materials. Previous studies by the authors (Sanyang, Sapuan, Jawaid, Ishak, & Sahari, 2016b) have done on the mechanical, thermal, physical and water barrier properties of plasticizer sugar palm starch films for food packaging applications. The results gained from these previous studies suggest upgrading the mechanical and water vapor barrier properties of sugar palm starch films to further improve their performance.

There are very little or no studies have been reported on the isolation and characterization of NCCs and NFCs from sugar palm fibre. Therefore, the objective of the current study was to extract nanocrystalline cellulose from sugar palm fibres and incorporate the sugar palm-derived cellulose into sugar palm starch as reinforcement material to improve the mechanical and water vapor barrier properties of sugar palm based composite films.

1.2 Problem Statements

Single-use consumer packaging materials produced from non-biodegradable plastics represent huge volume of the size of a typical landfills. It is believed that the amount of packaging wastes generated in industrialized countries in a single day is sufficient to fill up a space equivalent to the Sears Tower, Chicago, USA, which was once the tallest building in the world (Imam et al., 2008). In view of the numerous environmental problems posed by petroleum-based plastics, governments of many developed countries enacted environmental policies that will help mitigate the current scenario (Sanyang, Ilyas, Sapuan, & Jumaidin, 2018). Most of these laws are constituted to device means of minimizing the use of non-biodegradable plastics, which continued to accumulate in landfills or disposed in water bodies, which eventually pose serious impact on marine life. This provides an excellent opportunity for biobased plastics to be adopted for the replacement of petroleum-based plastics in the packaging industry. Due to the unsustainable waste disposal in landfills, governments of several nations established laws to promote the use of recyclable and/or biobased green products (Sanyang et al., 2018). Take the case of the 'producer pays' principle, it was designed to encourage manufacturers to take responsibility for their products throughout their whole life cycle (Fowler et al., 2006). Such laws will not only stimulate enhancement of product recyclability, but will also offer better opportunities for the utilization of biobased materials as raw material for the manufacturing of these products. In the case of Selangor state (Malaysia), the initiation of 'Selangor no plastic bag day' every Saturday', which was launched in 2010 has motivated the public to resort to recyclable bags and also promotes the use of environmentally friendly plastics made from biobased resources. The campained had assisted in saving about 5 million plastic bags within 2 years (2010 – 2012). Thus, the state government was planning to extend the campaign to three days, weekly. More and more countries and states follow in the banning of grocery plastic bags, which are responsible for the so called 'white pollution' across the globe (Nampoothiri, Nair, & John, 2010). Most recently, Selangor state had totally ban free plastic bags effective from 1st January 2017. The state compelled business operators to adhere to Selangor's policy to discourage the use of plastic bags and polystyrene boxes from January 1st (2017) or face a maximum RM1000 fine. These activities provided biobased plastics the opportunity to gradually substitute conventional plastics.

To overcome the dependence on petroleum-based polymers, attempts were made in this work to utilize 100% renewable and biodegradable biopolymer from sugar palm tree. Sugar palm is a multipurpose tree found in most South East Asian countries and it is regarded as a potential source of natural fibre and biopolymer. However, such a bio-source is still underutilized and, thus, very limited studies have been reported related to their development as a green packaging material. Hence, sugar palm starch (SPS) was modified and employed in the current study to develop fully biodegradable films and nanocomposite films as environmentally friendly packaging material for the food industry. However, sugar palm starch like most other biopolymers is hydrophilic in nature due to either their hydroxyl or polar groups. The major challenges for the development of starches as packaging films are the shortcomings related to brittleness, processability, high moisture sensitivity, quick retrogradation, poor mechanical and barrier properties (Sanyang, Sapuan, Jawaid, Ishak, & Sahari, 2016d). In order to transform native sugar palm starch into high performance thermoplastic starch for packaging application, the aforementioned drawbacks can be addressed by reinforcing

SPS with nanocellulose isolated from sugar palm fibre. Owing to the nanoscale size nature and high aspect ratio of nanocelluloses, they are not only provide excellent mechanical properties compared to neat SPS and SPS reinforced with microsized fillers, but they also demonstrated excellent combination of optical, electrical, thermal, magnetic, and other physic-chemical properties (Dufresne, 2013). Besides, the incorporation of sugar palm nanocellulose within sugar palm starch also was done to investigate the potential of utilizing starch as biopolymer and the starch/ nanocellulose bionanocomposites properties for high-end applications. To the best of our knowledge, no work has been carried out on the isolation of sugar palm nanocellulose and its use in reinforcing polymer nanocomposite films.

1.3 Research Objectives

The research objectives can be specified into:

1 To characterize cellulose from sugar palm fibre (*Arenga Pinnata*) via delignification and mercerization treatment.
2 To characterize sugar palm nanocrystalline cellulose (SPNCCs) from sugar palm fibre (*Arenga Pinnata*) via acid hydrolysis treatment.
3 To characterize sugar palm nanofibrillated cellulose (SPNFCs) from sugar palm fibre (*Arenga Pinnata*) via high pressurize homogenization mechanical treatment.
4 To determine and analyze the effect of SPNCCs and SPNFCs loading on the physical, chemical, mechanical, thermal, biodegradability and morphological properties of sugar palm nanocrystalline cellulose reinforced sugar palm starch composites for packaging purposes.

1.4 Significance of study

1 The findings from the current study are expected to enrich the knowledge in developing high performance biodegradable polymer derived from sugar palm starch reinforced nanocellulose for food packaging application.
2 The development of biodegradable polymer with enhanced properties in this study is expected to aid in addressing the environmental problems regarding the alternative materials for petroleum based polymer.
3 The problems associated with petroleum based polymer such as environmental pollution during the production and disposal can be alleviated by using a 100% biodegradable polymer films, where the matrix (SPS) and the nanofibre (sugar palm nanocellulose) are both from a single source (sugar palm tree).
4 Besides, this research also utilizes the sugar palm tree for yielding starch and fibre for the development of the composites. Hence, it adds more value for the sugar palm tree other than producing the sugar.
5 In term of waste management issue, this research provides platform for utilizing wastes from agricultural products into nanofibres and biopolymers, which also turns waste into wealth.
6 The successful development of such green materials from sugar palm tree would provide opportunities to improve the standard of living of the sugar palm tree

farmers in Malaysia by generating non-food source of economic development for rural areas.

7 This research may also add to the effort to uncover the potential of using sugar palm starch and fibre in developing green products; else, such abundant bioresources may be underutilized.

1.5 Scope of study

In this study, sugar palm fibre (SPF) and sugar palm starch (SPS) were manually extracted from the sugar palm tree. Then, the sugar palm cellulose (SPC) were extracted from sugar palm fibres and the yield was optimized using delignification and mercerization process. The chemical composition and structural morphology of the obtained cellulose was characterized through chemical composition testing and field emission scanning electron microscope (FESEM), respectively. The best SPC fibres with outstanding functional properties was spotted out for further modification. Later the best properties of the obtained cellulose was then undergo hydrolysis process (sulphuric acid solution) and mechanical process (high pressurize homogenization) to isolate sugar palm nanocrystalline cellulose (SPNCCs) and sugar palm nanofibrillated cellulose (SPNFCs), respectively. Characterization of their physical, chemical, thermal and structural properties were performed.

Thermoplastic sugar palm starch was developed by using solution casting method with the addition of glycerol and sorbitol. The characterized nanocellulose (SPNCCs and SPNFCs) were used as reinforcement for SPS films to improve the matrix properties. Thus, the effect of sugar palm nanocellulose loading (0 – 1.0 wt %) on the physical, mechanical and water barrier properties of SPS based composite films was carried out.

1.6 Structure of thesis

The structure of this thesis is in accordance with the alternative thesis format of Universiti Putra Malaysia which is based on the publications of this study. Each research chapter represent a separate study that has its own: ‘Introduction’, ‘Materials and method’, ‘Results and discussion’, and ‘Conclusions’. The details of the structure are presented below.

Chapter 1

The problems that initiate this research and the research objectives were clearly highlighted in this chapter. The significance of this work and the scope of study were also elaborated within the chapter.

Chapter 2

This chapter presents a comprehensive literature review on the areas related to the topic of this thesis. In addition, the research gaps obtained from the review were also clarified within the chapter.

Chapter 3
This chapter presents the methodology used in this study for the preparation of materials, testing procedure, and data collection.

Chapter 4
This chapter presents the first article entitled "**Effect of delignification on the physical, thermal, chemical, and structural properties of sugar palm fibre**". In this article, the characteristics of the raw sugar palm fibres, and treated fibres were investigated.

Chapter 5
This chapter presents the second article entitled "**Isolation and characterization of nanocrystalline cellulose from sugar palm fibres (*Arenga pinnata*)**". In this article, the characteristics of the nanocrystalline cellulose were investigated.

Chapter 6
This chapter present the third article entitled "**Development and characterization of sugar palm nanocrystalline cellulose reinforced sugar palm starch bionanocomposites**". In this article, the effect of nanocrystalline cellulose loading (0 – 1.0 wt%) on the mechanical, chemical, physical, water barrier properties, thermal, and biodegradation properties of sugar palm nanocrystalline cellulose reinforced starch bionanocomposites were investigated.

Chapter 7
This chapter presents the forth article entitled "**Sugar palm nanofibrillated cellulose (*Arenga pinnata* (*Wurmb.*) *Merr*): Effect of cycles on their yield, physic-chemical, morphological and thermal behavior)**". In this article, the characteristics of the nanofibrillated cellulose were investigated.

Chapter 8
This chapter present the fifth article entitled "**Water transport properties of bio-nanocomposites reinforced by sugar palm (*Arenga pinnata*) nanofibrillated cellulose**". In this article, SPNFCs with three different sizes based on cycling time (5, 10 and 15 cycles denoted as SPS/SPNFCs-5C, SPS/SPNFCs-10C, and SPS/SPNFCs-15C) that were incorporated into SPS plasticizers were investigated.

Chapter 9
This chapter present the additional results of this research including the analysis and presentation of data, the discussion of results, and the correlation between the findings.

Chapter 10
This chapter presents the overall conclusions from the whole study as well as future recommendations for further improvement of this study.

REFERENCES

Abdalla, F., Megat, M., Sapuan, M., & Bb, S. (2008). Determination of volume fraction values of filament wound glass and carbon fiber reinforced composites. *ARPN J Eng Appl Sci*, *3*(4), 7–11.

Abdollahi, M., Alboofetileh, M., Rezaei, M., & Behrooz, R. (2013). Comparing physico-mechanical and thermal properties of alginate nanocomposite films reinforced with organic and/or inorganic nanofillers. *Food Hydrocolloids*, *32*(2), 416–424.

Abdul Khalil, H. P. S., Bhat, A. H., & Yusra, A. F. I. (2012). Green composites from sustainable cellulose nanofibrils: A review. *Carbohydrate Polymers*, *87*(2), 963–979.

Abitbol, T., Rivkin, A., Cao, Y., Nevo, Y., Abraham, E., Ben-Shalom, Shoseyov, O. (2016). Nanocellulose, a tiny fiber with huge applications. *Current Opinion in Biotechnology*, *39*(I), 76–88.

Abraham, E., Deepa, B., Pothen, L. A., Cintil, J., Thomas, S., John, M. J., Narine, S. S. (2013). Environmental friendly method for the extraction of coir fibre and isolation of nanofibre. *Carbohydrate Polymers*, *92*(2), 1477–1483.

Abral, H., Anugrah, A. S., Hafizulhaq, F., Handayani, D., Sugiarti, E., & Muslimin, A. N. (2018). Effect of nanofibers fraction on properties of the starch based biocomposite prepared in various ultrasonic powers. *International Journal of Biological Macromolecules*, *116*, 1214–1221.

Abral, H., Dalimunthe, M. H., Hartono, J., Efendi, R. P., Asrofi, M., Sugiarti, E., Kim, H. J. (2018). Characterization of tapioca starch biopolymer composites reinforced with micro scale water hyacinth fibers. *Starch/Staerke*, *70*(7–8), 1–8.

Abral, H., Lawrensius, V., Handayani, D., & Sugiarti, E. (2018). Preparation of nano-sized particles from bacterial cellulose using ultrasonication and their characterization. *Carbohydrate Polymers*, *191*(September 2017), 161–167.

Abushammala, H., Hashaikeh, R., & Cooney, C. (2012). Microcrystalline cellulose powder tableting via networked cellulose-based gel material. *Powder Technology*, *217*, 16–20.

Agrebi, F., Ghorbel, N., Rashid, B., Kallel, A., & Jawaid, M. (2018). Influence of treatments on the dielectric properties of sugar palm fiber reinforced phenolic composites. *Journal of Molecular Liquids*, *263*, 342–348.

Akhlaghi, S. P., Berry, R. C., & Tam, K. C. (2013). Surface modification of cellulose nanocrystal with chitosan oligosaccharide for drug delivery applications. *Cellulose*, *20*(4), 1747–1764.

Akil, H. M., Omar, M. F., Mazuki, A. A. M., Safiee, S., Ishak, Z. A. M., & Abu Bakar, A. (2011). Kenaf fiber reinforced composites: A review. *Materials and Design*, *32*(8–9), 4107–4121.

Alain, D., Danièle, D., & Michel, R. V. (2000). Cellulose microfibrils from potato tuber cells: Processing and characterization of starch-cellulose microfibril composites. *Journal of Applied Polymer Science*, *76*(14), 2080–2092.

Alemdar, A., & Sain, M. (2008). Isolation and characterization of nanofibers from agricultural residues - Wheat straw and soy hulls. *Bioresource Technology*, *99*(6), 1664–1671.

Allen, L. V, & Ansel, H. C. (2011). *Ansel ' s Pharmaceutical Dosage Forms and Drug Delivery Systems* (8th ed.). New Delhi: Wolter Kluwer Publishers.

Alvarez, V. A., Ruseckaite, R. A., & Vázquez, A. (2006). Degradation of sisal fibre/Mater Bi-Y biocomposites buried in soil. *Polymer Degradation and Stability*, *91*(12), 3156–3162.

Alves, C., Ferrão, P. M. C., Silva, A. J., Reis, L. G., Freitas, M., Rodrigues, L. B., & Alves, D. E. (2010). Ecodesign of automotive components making use of natural jute fiber composites. *Journal of Cleaner Production*, *18*(4), 313–327.

Amin, S., Rajabnezhad, S., & Kohli, K. (2009). Hydrogels as potential drug delivery systems. *Scientific Research and Essay*, *4*(11), 1175–1183.

Angellier, H., Molina-Boisseau, S., Dole, P., & Dufresne, A. (2006). Thermoplastic starch−waxy maize starch nanocrystals nanocomposites. *Biomacromolecules*, *7*(2), 531–539.

Anglès, M. N., & Dufresne, A. (2001). Plasticized starch/tunicin whiskers nanocomposite materials. 2. Mechanical behavior. *Macromolecules*, *34*(9), 2921–2931.

Aqil, M., Sultana, Y., & Ali, A. (2003). Matrix type transdermal drug delivery systems of metoprolol tartrate: in vitro characterization. *Acta Pharmaceutica (Zagreb, Croatia)*, *53*, 119–125.

Asadi, A., Miller, M., Sultana, S., Moon, R. J., & Kalaitzidou, K. (2016). Introducing cellulose nanocrystals in sheet molding compounds (SMC). *Composites Part A: Applied Science and Manufacturing*, *88*, 206–215.

Asrofi, M., Abral, H., Putra, Y. K., Sapuan, S. M., & Kim, H. J. (2018). Effect of duration of sonication during gelatinization on properties of tapioca starch water hyacinth fiber biocomposite. *International Journal of Biological Macromolecules*, *108*, 167–176.

ASTM D1103-60. (1977). Method of test for alpha-cellulose in wood. USA: American Society for Testing and Materials.

ASTM D1104-56. (1978). Method of test for holocellulose in wood. USA: American Society for Testing and Materials.

Azeredo, H. M. C., Mattoso, L. H. C., Wood, D., Williams, T. G., Avena-Bustillos, R. J., & McHugh, T. H. (2009). Nanocomposite edible films from mango puree reinforced with cellulose nanofibers. *Journal of Food Science*, *74*(5).

Azizi Samir, M. A. S., Alloin, F., & Dufresne, A. (2005). Review of recent research into cellulosic whiskers, their properties and their application in nanocomposite field. *Biomacromolecules*, *6*(2), 612–626.

Babaee, M., Jonoobi, M., Hamzeh, Y., & Ashori, A. (2015). Biodegradability and mechanical properties of reinforced starch nanocomposites using cellulose nanofibers. *Carbohydrate Polymers*, *132*(3), 1–8.

Bachtiar, D., Salit, M. S., Zainudin, E., Abdan, K., & Dahlan, K. Z. H. M. (2011). Effects of alkaline treatment and a compatibilizing agent on tensile properties of sugar palm fibrereinforced high impact polystyrene composites. *BioResources*, *6*(4), 4815–4823.

Bachtiar, D., Sapuan, S. M. M., & Hamdan, M. M. M. (2008). The effect of alkaline treatment on tensile properties of sugar palm fibre reinforced epoxy composites. *Materials & Design*, *29*(7), 1285–1290.

Balakrishnan, P., Sreekala, M. S., Kunaver, M., Huskić, M., & Thomas, S. (2017). Morphology, transport characteristics and viscoelastic polymer chain confinement in nanocomposites based on thermoplastic potato starch and cellulose nanofibers from pineapple leaf. *Carbohydrate Polymers*, *169*, 176–188.

Beck-Candanedo, S., Roman, M., & Gray, D. G. (2005). Effect of reaction conditions on the properties and behavior of wood cellulose nanocrystal suspensions. *Biomacromolecules*, *6*(2), 1048–1054.

Beck, S., Bouchard, J., & Berry, R. (2013). Control of nanocrystalline cellulose film iridescence wavelength. Washington, DC, U.S. Retrieved from https://www.google.com/patents/US8530005

Beckermann, G. W., & Pickering, K. L. (2008). Engineering and evaluation of hemp fibre reinforced polypropylene composites: Fibre treatment and matrix modification. *Composites Part A: Applied Science and Manufacturing*, *39*(6), 979–988.

Besbes, I., Rei, M., & Boufi, S. (2011). Nanofibrillated cellulose from alfa , eucalyptus and pine fibres : preparation , characteristics and reinforcing potential. *Carbohydrate Polymers*, *86*(3), 1198–1206.

Bhatnagar, A. (2005). Processing of cellulose nanofiber-reinforced composites. *Journal of Reinforced Plastics and Composites*, *24*(12), 1259–1268.

Bhattacharya, D., Germinario, L. T., & Winter, W. T. (2008). Isolation, preparation and characterization of cellulose microfibers obtained from bagasse. *Carbohydrate Polymers*, *73*(3), 371–377.

Bilbao-Sainz, C., Bras, J., Williams, T., Sénechal, T., & Orts, W. (2011). HPMC reinforced with different cellulose nano-particles. *Carbohydrate Polymers*, *86*(4), 1549–1557.

Bledzki, A. K., & Gassan, J. (1999). Composites reinforced with cellulose based fibers. *Progress in Polymer Science*, *24*(2), 221–274.

Bondeson, D., Mathew, A., & Oksman, K. (2006). Optimization of the isolation of nanocrystals from microcrystalline cellulose by acid hydrolysis. *Cellulose*, *13*(2), 171–180.

Börjesson, M., & Westman, G. (2015). Crystalline Nanocellulose — preparation, modification, and properties. In *Cellulose - Fundamental Aspects and Current Trends* (pp. 159–191). InTech.

Bourtoom, T., & Chinnan, M. S. (2008). Preparation and properties of rice starch–chitosan blend biodegradable film. *LWT - Food Science and Technology*, *41*(9), 1633–1641.

Braun, B., Dorgan, J. R., & Chandler, J. P. (2008). Cellulosic nanowhiskers. theory and application of light scattering from polydisperse spheroids in the rayleigh−gans−debye regime. *Biomacromolecules*, *9*(4), 1255–1263.

Brinchi, L., Cotana, F., Fortunati, E., & Kenny, J. M. (2013). Production of nanocrystalline cellulose from lignocellulosic biomass: Technology and applications. *Carbohydrate Polymers*, *94*(1), 154–169.

Brito, B. S. L., Pereira, F. V., Putaux, J.-L., & Jean, B. (2012). Preparation, morphology and structure of cellulose nanocrystals from bamboo fibers. *Cellulose*, *19*(5), 1527–1536.

Brown, E. E., Hu D., Abu Lail, N., & Zhang, X. (2013). Potential of nanocrystalline cellulose–fibrin nanocomposites for artificial vascular graft applications. *Biomacromolecules*, *14*(4), 1063–1071.

Burgueño, R., Quagliata, M. J., Mohanty, A. K., Mehta, G., Drzal, L. T., & Misra, M. (2005). Hybrid biofiber-based composites for structural cellular plates. *Composites Part A: Applied Science and Manufacturing*, *36*(5), 581–593.

Cao, X., Chen, Y., Chang, P. R., Muir, A. D., & Falk, G. (2008). Starch-based nanocomposites reinforced with flax cellulose nanocrystals. *Express Polymer Letters*, *2*(7), 502–510.

Cao, X., Chen, Y., Chang, P. R., Stumborg, M., & Huneault, M. A. (2008). Green composites reinforced with hemp nanocrystals in plasticized starch. *Journal of Applied Polymer Science*, *109*(6), 3804–3810.

Cao, X., Xu, C., Wang, Y., Liu, Y., Liu, Y., & Chen, Y. (2013). New nanocomposite materials reinforced with cellulose nanocrystals in nitrile rubber. *Polymer Testing*, *32*(5), 819–826.

Chang, P. R., Jian, R., Zheng, P., Yu, J., & Ma, X. (2010). Preparation and properties of glycerol plasticized-starch (GPS)/cellulose nanoparticle (CN) composites. *Carbohydrate Polymers*, *79*(2), 301–305.

Chauve, M., Barre, L., Tapin-lingua, S., Perez, S., Decottignies, D., Perez, S., & Ferreira, N. L. (2013). Evolution and impact of cellulose architecture during enzymatic hydrolysis by fungal cellulases. *Advances in Biosciences and Biotechnology'*, *4*, 1095–1109.

Chen, D., Lawton, D., Thompson, M. R., & Liu, Q. (2012). Biocomposites reinforced with cellulose nanocrystals derived from potato peel waste. *Carbohydrate Polymers*, *90*(1), 709–716.

Chen, W., Yu, H., Liu, Y., Chen, P., Zhang, M., & Hai, Y. (2011). Individualization of cellulose nanofibers from wood using high-intensity ultrasonication combined with chemical pretreatments. *Carbohydrate Polymers*, *83*(4), 1804–1811.

Chen, Y., Liu, C., Chang, P. R., Cao, X., & Anderson, D. P. (2009). Bionanocomposites based on pea starch and cellulose nanowhiskers hydrolyzed from pea hull fibre: Effect of hydrolysis time. *Carbohydrate Polymers*, *76*(4), 607–615.

Cherian, B. M., Leão, A. L., de Souza, S. F., Thomas, S., Pothan, L. A., & Kottaisamy, M. (2010). Isolation of nanocellulose from pineapple leaf fibres by steam explosion. *Carbohydrate Polymers*, *81*(3), 720–725.

Corrêa, A. C., de Morais Teixeira, E., Pessan, L. A., & Mattoso, L. H. C. (2010). Cellulose nanofibers from curaua fibers. *Cellulose*, *17*(6), 1183–1192.

Coscia, M. G., Bhardwaj, J., Singh, N., Santonicola, M. G., Richardson, R., Thakur, V. K., & Rahatekar, S. (2018). Manufacturing & characterization of regenerated cellulose/curcumin based sustainable composites fibers spun from environmentally benign solvents. *Industrial Crops and Products*, *111*(September 2017), 536–543.

Cristaldi, G., Latteri, A., Recca, G., & Cicala, G. (2010). Composites based on natural fibre fabrics. In *Woven fabric engineering 17* (pp. 317–342).

Dalmas, F., Cavaillé, J. Y., Gauthier, C., Chazeau, L., & Dendievel, R. (2007). Viscoelastic behavior and electrical properties of flexible nanofiber filled polymer nanocomposites. Influence of processing conditions. *Composites Science and Technology*, *67*(5), 829–839.

Dash, R., & Ragauskas, A. J. (2012). Synthesis of a novel cellulose nanowhisker-based drug delivery system. *RSC Advances*, *2*(8), 3403.

de Mesquita, J. P., Donnici, C. L., & Pereira, F. V. (2010). Biobased nanocomposites from layer-by-layer assembly of cellulose nanowhiskers with chitosan. *Biomacromolecules*, *11*(2), 473–480.

de Morais Teixeira, E., Bondancia TJ, Teodoro KBR, Correˆa AC, Marconcini JM, & Mattoso LHC. (2011). Sugarcane bagasse whiskers : Extraction and characterizations. *Ind Crops Prod*, *33*(63), 66.

Deepa, B., Abraham, E., Cherian, B. M., Bismarck, A., Blaker, J. J., Pothan, L. A., Kottaisamy, M. (2011). Structure, morphology and thermal characteristics of banana nano fibers obtained by steam explosion. *Bioresource Technology*, *102*(2), 1988–1997.

Denisov, A. Y., Kloser, E., Gray, D. G., & Mittermaier, A. K. (2010). Protein alignment using cellulose nanocrystals: practical considerations and range of application. *Journal of Biomolecular NMR*, *47*(3), 195–204.

Dias, A. B., Müller, C. M. O., Larotonda, F. D. S., & Laurindo, J. B. (2011). Mechanical and barrier properties of composite films based on rice flour and cellulose fibers. *LWT - Food Science and Technology*, *44*(2), 535–542.

Dong, S., & Roman, M. (2007). Fluorescently labeled cellulose nanocrystals for bioimaging applications. *Journal of the American Chemical Society*, *129*(45), 13810–13811.

Dorigato, A., Morandi, S., & Pegoretti, A. (2011). Effect of nanoclay addition on the fiber/matrix adhesion in epoxy/glass composites. *Journal of Composite Materials*, *46*(12), 1439–1451.

Dufresne, A. (2000). Cellulose microfibrils from potato tuber cells : Processing and characterization of starch – cellulose microfibril composites. *Polymer*, *76*(14), 2080–2092.

Dufresne, A. (2013). Nanocellulose: A new ageless bionanomaterial. *Materials Today*, *16*(6), 220–227.

Dugan, J. M., Gough, J. E., & Eichhorn, S. J. (2013). Bacterial cellulose scaffolds and cellulose nanowhiskers for tissue engineering. *Nanomedicine*, *8*(2), 287–298.

Duncan, T. V. (2011). Applications of nanotechnology in food packaging and food safety: Barrier materials, antimicrobials and sensors. *Journal of Colloid and Interface Science*, *363*(1), 1–24.

Eichhorn, S. J., Dufresne, A., Aranguren, M., Marcovich, N. E., Capadona, J. R., Rowan, S. J., Peijs, T. (2010). Review: current international research into cellulose nanofibres and nanocomposites. *Journal of Materials Science*, *45*(1), 1–33.

Einstein, A. (1956). Investigations on the theory of brownian motion.

Eyholzer, C., Borges de Couraça, A., Duc, F., Bourban, P. E., Tingaut, P., Zimmermann, T., Oksman, K. (2011). Biocomposite hydrogels with carboxymethylated, nanofibrillated cellulose powder for replacement of the nucleus pulposus. *Biomacromolecules*, *12*(5), 1419–1427.

Faix, O., Lin, S., & Dence, C. (1992). Fourier transform infrared spectroscopy. In Methods in lignin chemistry. *Springer-Verlag*, 83–109.

Fan, L. T., Lee, Y.-H., & Beardmore, D. H. (1980). Mechanism of the enzymatic hydrolysis of cellulose: Effects of major structural features of cellulose on enzymatic hydrolysis. *Biotechnology and Bioengineering*, *22*(1), 177–199.

Fan, M., Dai, D., & Huang, B. (2012). *Fourier Transform - Materials Analysis*. (S. Salih, Ed.).

Faruk, O., Bledzki, A. K., Fink, H.-P., & Sain, M. (2012). Biocomposites reinforced with natural fibers: 2000–2010. *Progress in Polymer Science*, *37*(11), 1552–1596.

Favier, V., Canova, G. R., Cavaillé, J. Y., Chanzy, H., Dufresne, A., & Gauthier, C. (1995). Nanocomposite materials from latex and cellulose whiskers. *Polymers for Advanced Technologies*, *6*(5), 351–355.

Fengel, D., & Ludwig, M. (1991). Possibilities and limits of FTIR spectroscopy characterization of the cellulose. *Das Papier*, *45*(2), 45–51.

Ferrer, A., Filpponen, I., Rodríguez, A., Laine, J., & Rojas, O. J. (2012). Valorization of residual empty palm fruit bunch fibers (epfbf) by microfluidization: Production of nanofibrillated cellulose and EPFBF nanopaper. *Bioresource Technology*, *125*, 249–255.

Fishman, M., Coffin, D., Konstance, R., & Onwulata, C. (2000). Extrusion of pectin/starch blends plasticized with glycerol. *Carbohydrate Polymers*, *41*(4), 317–325.

Flauzino Neto, W. P., Silvério, H. A., Dantas, N. O., & Pasquini, D. (2013). Extraction and characterization of cellulose nanocrystals from agro-industrial residue – Soy hulls. *Industrial Crops and Products*, *42*, 480–488.

Follain, N., Belbekhouche, S., Bras, J., Siqueira, G., Marais, S., & Dufresne, A. (2013). Water transport properties of bio-nanocomposites reinforced by *Luffa cylindrica* cellulose nanocrystals. *Journal of Membrane Science*, *427*, 218–229.

Fortunati, E., Puglia, D., Monti, M., Peponi, L., Santulli, C., Kenny, J. M., & Torre, L. (2013). Extraction of cellulose nanocrystals from *phormium tenax* fibres. *Journal of Polymers and the Environment*, *21*(2), 319–328.

Frenot, A., Henriksson, M. W., & Walkenström, P. (2007). Electrospinning of cellulose-based nanofibers. *Journal of Applied Polymer Science*, *103*(3), 1473–1482.

Frost, K., Kaminski, D., Kirwan, G., Lascaris, E., & Shanks, R. (2009). Crystallinity and structure of starch using wide angle X-ray scattering. *Carbohydrate Polymers*, *78*(3), 543–548.

Garcia de Rodriguez, N. L., Thielemans, W., & Dufresne, A. (2006). Sisal cellulose whiskers reinforced polyvinyl acetate nanocomposites. *Cellulose*, *13*(3), 261–270.

George, J., Ramana, K. V., Bawa, A. S., & Siddaramaiah. (2011). Bacterial cellulose nanocrystals exhibiting high thermal stability and their polymer nanocomposites.

International Journal of Biological Macromolecules, *48*(1), 50–57.

Gohel, M. C., Parikh, R. K., Brahmbhatt, B. K., & Shah, A. R. (2007). Study of coat quality of tablets coated by an on-line Supercell coater. *AAPS PharmSciTech*, *8*(1), E1–E7.

Gurunathan, T., Mohanty, S., & Nayak, S. K. (2015). A review of the recent developments in biocomposites based on natural fibres and their application perspectives. *Composites Part A: Applied Science and Manufacturing*, *77*, 1–25.

Habibi, Y., Mahrouz, M., & Vignon, M. R. (2009). Microfibrillated cellulose from the peel of prickly pear fruits. *Food Chemistry*, *115*(2), 423–429.

Habibi, Y., & Vignon, M. R. (2008). Optimization of cellouronic acid synthesis by TEMPO-mediated oxidation of cellulose III from sugar beet pulp. *Cellulose*, *15*(1), 177–185.

Hagiwara, Y., Putra, A., Kakugo, A., Furukawa, H., & Gong, J. P. (2010). Ligament-like tough double-network hydrogel based on bacterial cellulose. *Cellulose*, *17*(1), 93–101.

Hai, L. Van, Park, H. J., & Seo, Y. B. (2013). Effect of PFI mill and valley beater refining on cellulose degree of polymerization, alpha cellulose contents, and crystallinity of wood and cotton fibers. *Journal of Korea Technical Association of the Pulp and Paper Industry*, *45*(4), 27–33.

Henriksson, M., & Berglund, L. A. (2007). Structure and properties of cellulose nanocomposite films containing melamine formaldehyde. *Journal of Applied Polymer Science*, *106*(4), 2817–2824.

Herrick, F. W., Casebier, R. L., Hamilton, J. K., & Sandberg, K. R. (1983). Microfibrillated cellulose: morphology and accessibility. *J. Appl. Polym. Sci.: Appl. Polym. Symp.*, *37*(9), 797–813.

Hietala, M., Mathew, A. P., & Oksman, K. (2013). Bionanocomposites of thermoplastic starch and cellulose nanofibers manufactured using twin-screw extrusion. *European Polymer Journal*, *49*(4), 950–956.

Hoover, R., Hughes, T., Chung, H. J., & Liu, Q. (2010). Composition, molecular structure, properties, and modification of pulse starches: A review. *Food Research International*, *43*(2), 399–413.

Hubbell, C. A., & Ragauskas, A. J. (2010). Effect of acid-chlorite delignification on cellulose degree of polymerization. *Bioresource Technology*, *101*(19), 7410–7415.

Hussain, F. (2006). Polymer-matrix nanocomposites, processing, manufacturing, and application: An overview. *Journal of Composite Materials*, *40*(17), 1511–1575.

Huzaifah, M. R. M., Sapuan, S. M., Leman, Z., Ishak, M. R., & Maleque, M. A. (2017). A review of sugar palm (*Arenga pinnata*): application, fibre characterisation and composites. *Multidiscipline Modeling in Materials and Structures*, *13*(4), 678–698.

Ilyas, R. A., Sapuan, S. M., & Ishak, M. R. (2018). Isolation and characterization of nanocrystalline cellulose from sugar palm fibres (*Arenga Pinnata*). *Carbohydrate Polymers*, *181*, 1038–1051.

Ilyas, R. A., Sapuan, S. M., Ishak, M. R., & Zainudin, E. S. (2017). Effect of delignification on the physical, thermal, chemical, and structural properties of sugar palm fibre. *BioResources*, *12*(4), 8734–8754.

Ilyas, R. A., Sapuan, S. M., Ishak, M. R., & Zainudin, E. S. (2018a). Development and characterization of sugar palm nanocrystalline cellulose reinforced sugar palm starch bionanocomposites. *Carbohydrate Polymers*, *202*, 186–202.

Ilyas, R. A., Sapuan, S. M., Ishak, M. R., & Zainudin, E. S. (2018b). Sugar palm nanocrystalline cellulose reinforced sugar palm starch composite: Degradation and water-barrier properties. *IOP Conference Series: Materials Science and Engineering*, *368*(1), 012006.

Ilyas, R. A., Sapuan, S. M., Ishak, M. R., & Zainudin, E. S. (2018c). Water Transport Properties of Bio-Nanocomposites Reinforced by Sugar Palm (*Arenga Pinnata*) Nanofibrillated Cellulose. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences Journal*, *51*(2), 234–246.

Ilyas, R. A., Sapuan, S. M., Ishak, M. R., & Zainudin, E. S. (2019). Sugar palm nanofibrillated cellulose (*Arenga pinnata (Wurmb.) Merr*): Effect of cycles on their yield, physic-chemical, morphological and thermal behavior. *International Journal of Biological Macromolecules*, *123*, 379–388. https://doi.org/10.1016/j.ijbiomac.2018.11.124

Ilyas, R. A., Sapuan, S. M., Ishak, M. R., Zainudin, E. S., & Atikah, M. S. N. (2018a). Characterization of sugar palm nanocellulose and its potential for reinforcement with a starch-based composite. In *Sugar Palm Biofibers, Biopolymers, and Biocomposites* (1st ed., pp. 189–220). First edition. | Boca Raton, FL : CRC Press/Taylor & Francis Group, 2018.: CRC Press.

Ilyas, R. A., Sapuan, S. M., Ishak, M. R., Zainudin, E. S., & Atikah, M. S. N. (2018b). Nanocellulose reinforced starch polymer composites : a review of preparation, properties and application. In *Proceeding: 5th International Conference on Applied Sciences and Engineering (ICASEA, 2018)* (pp. 325–341). Capthorne Hotel, Cameron Highlands, Malaysia.

Ilyas, R. A., Sapuan, S. M., Sanyang, M. L., & Ishak, M. R. (2016). Nanocrystalline cellulose reinforced starch-based nanocomposite: A review. In *5th Postgraduate Seminar on Natural Fiber Composites* (pp. 82–87). Serdang, Selangor: Universiti Putra Malaysia.

Ilyas, R. A., Sapuan, S. M., Sanyang, M. L., Ishak, M. R., & Zainudin, E. S. (2018). Nanocrystalline cellulose as reinforcement for polymeric matrix nanocomposites and its potential applications: A Review. *Current Analytical Chemistry*, *14*(3), 203–225.

Ishak, M. R., Leman, Z., Sapuan, S. M., Rahman, M. Z. A., & Anwar, U. M. K. (2011). Effects of impregnation time on physical and tensile properties of impregnated sugar palm (*Arenga pinnata*) fibres. *In Key Engineering Materials*, *471*, 1147–1152.

Ishak, M. R., Leman, Z., Sapuan, S. M., Salleh, M. Y., & Misri, S. (2009). Effect of sea water treatment on the impact and flexural strength of sugar palm fibre reinforced epoxy composites. *International Journal of Mechanical and Materials Engineering (IJMME)*, *4*(3), 316–320.

Ishak, M. R., Sapuan, S. M., Leman, Z., Rahman, M. Z. A., Anwar, U. M. K., & Siregar, J. P. (2013). Sugar palm (*Arenga pinnata*): Its fibres, polymers and composites. *Carbohydrate Polymers*, *91*(2), 699–710.

Ishak, M. R., Sapuan, S. M., Leman, Z., Rahman, M. Z. A., & Anwar, U. M. K. (2012). Characterization of sugar palm (*Arenga pinnata*) fibres tensile and thermal properties. *Journal of Thermal Analysis and Calorimetry*, *109*(2), 981–989.

Islam, M. T., Alam, M. M., & Zoccola, M. (2013). Review on modification of nanocellulose for application in composites. *International Journal of Innovative Research in Science, Engineering and Technology*, *2*(10), 5444–5451.

ISO 5264-2. (2002). Pulps — Laboratory beating — Part 2: PFI mill method.

ISO 5351:2004(E). (2004). Pulps — Determination of limiting viscosity number in cupri-ethylenediamine (CED) solution. *International Standard*.

Jackson, J. K., Letchford, K., Wasserman, B. Z., Ye, L., Hamad, W. Y., & Burt, H. M. (2011). The use of nanocrystalline cellulose for the binding and controlled release of drugs. *International Journal of Nanomedicine*, *6*, 321–330.

Johnson, R. K., Zink-Sharp, A., Renneckar, S. H., & Glasser, W. G. (2009). A new bio-based nanocomposite: Fibrillated TEMPO-oxidized celluloses in hydroxypropylcellulose matrix. *Cellulose*, *16*(2), 227–238.

Jonoobi, M., Oladi, R., Davoudpour, Y., Oksman, K., Dufresne, A., Hamzeh, Y., & Davoodi, R. (2015). Different preparation methods and properties of nanostructured cellulose from various natural resources and residues: a review. *Cellulose*, *22*(2), 935–969.

Jorfi, M., & Foster, E. J. (2015). Recent advances in nanocellulose for biomedical applications. *Journal of Applied Polymer Science*, *132*(14), 1-19.

Joseph R . Robinson, & Lee, V. H. . L. . (1987). *Controlled drug delivery fundamentals and application* (2nd ed). New York: Marcel Dekker.

Joshi, A. A., & Duriez, X. (2004). Added functionality excipients: an answer to challenging formulations. *Pharmaceutical Technology*, *22*, 12–19.

Julien, S., Chornet, E., & Overend, R. P. (1993). Influence of acid pretreatment (H_2SO_4, HCl, HNO_3) on reaction selectivity in the vacuum pyrolysis of cellulose. *Journal of Analytical and Applied Pyrolysis*, *27*(1), 25–43.

Jumaidin, R., Sapuan, S. M., Jawaid, M., Ishak, M. R., & Sahari, J. (2016). Effect of seaweed on physical properties of thermoplastic sugar palm starch/agar composites. *Journal Of Mechanical Engineering and Sciences*, *10*(3), 2214–2225.

Karimi, S., Tahir, P., Dufresne, A., Karimi, A., & Abdulkhani, A. (2014). A comparative study on characteristics of nanocellulose reinforced thermoplastic starch biofilms prepared with different techniques. *Nordic Pulp & Paper Research Journal*, *29*(1), 41–45.

Karimi, S., Tahir, P. M., Karimi, A., Dufresne, A., & Abdulkhani, A. (2014). Kenaf bast cellulosic fibers hierarchy: A comprehensive approach from micro to nano. *Carbohydrate Polymers*, *101*(1), 878–885.

Kaushik, A., Singh, M., & Verma, G. (2010). Green nanocomposites based on thermoplastic starch and steam exploded cellulose nanofibrils from wheat straw. *Carbohydrate Polymers*, *82*(2), 337–345.

Kazayawoko, M., Balatinecz, J. J., & Woodhams, R. T. (1997). Diffuse reflectance fourier transform infrared spectra of wood fibers treated with maleated polypropylenes. *Journal of Applied Polymer Science*, *66*(6), 1163–1173.

Keshk, S., Suwinarti, W., & Sameshima, K. (2006). Physicochemical characterization of different treatment sequences on kenaf bast fiber. *Carbohydrate Polymers*, *65*(2), 202–206.

Khalil, H. P. S. A., Davoudpour, Y., Islam, M. N., Mustapha, A., Sudesh, K., Dungani, R., & Jawaid, M. (2014). Production and modification of nanofibrillated cellulose using various mechanical processes: A review. *Carbohydrate Polymers*, *99*, 649–665.

Khan, A., Khan, R. A., Salmieri, S., Le Tien, C., Riedl, B., Bouchard, J., Lacroix, M. (2012). Mechanical and barrier properties of nanocrystalline cellulose reinforced chitosan based nanocomposite films. *Carbohydrate Polymers*, *90*(4), 1601–1608.

Kiatkamjornwong, S., Sonsuk, M., Wittayapichet, S., Prasassarakich, P., & Vejjanukroh, P.-C. (1999). Degradation of styrene-g-cassava starch filled polystyrene plastics. *Polymer Degradation and Stability*, *66*(3), 323–335.

Kim, D.-Y., Nishiyama, Y., Wada, M., & Kuga, S. (2001). High-yield carbonization of cellulose by sulfuric acid impregnation. *Cellulose*, *8*(1), 29–33.

Klemm, D., Kramer, F., Moritz, S., Lindström, T., Ankerfors, M., Gray, D., & Dorris, A. (2011). Nanocelluloses: A new family of nature-based materials. *Angewandte Chemie - International Edition*, *50*(24), 5438–5466.

Klemm, D., Schumann, D., Udhardt, U., & Marsch, S. (2001). Bacterial synthesized cellulose - artificial blood vessels for microsurgery. *Progress in Polymer Science (Oxford)*, *26*(9), 1561–1603.

Kolakovic, R., Peltonen, L., Laukkanen, A., Hellman, M., Laaksonen, P., Linder, M. B., Laaksonen, T. (2013). Evaluation of drug interactions with nanofibrillar cellulose. *European Journal of Pharmaceutics and Biopharmaceutics*, *85*(3 PART B), 1238–1244.

Koronis, G., Silva, A., & Fontul, M. (2013). Green composites: A review of adequate materials for automotive applications. *Composites Part B: Engineering*, *44*(1), 120–127.

Kovacs, T., Naish, V., O'Connor, B., Blaise, C., Gagné, F., Hall, L., Hall L. (2010). An ecotoxicological characterization of nanocrystalline cellulose (NCC). *Nanotoxicology*, *4*(3), 255–270.

Kumar, R., Mago, G., Balan, V., & Wyman, C. E. (2009). Physical and chemical characterizations of corn stover and poplar solids resulting from leading pretreatment technologies. *Bioresource Technology*, *100*(17), 3948–3962.

Kvien, I., Sugiyama, J., Votrubec, M., & Oksman, K. (2007). Characterization of starch based nanocomposites. *Journal of Materials Science*, *42*(19), 8163–8171.

Lee, S. Y., Chun, S. J., Kang, I. A., & Park, J. Y. (2009). Preparation of cellulose nanofibrils by high-pressure homogenizer and cellulose-based composite films. *Journal of Industrial and Engineering Chemistry*, *15*(1), 50–55.

Leman, Z., Sapuan, S. M., Azwan, M., Ahmad, M. M. H. M., & Maleque, M. A. (2008). The effect of environmental treatments on fiber surface properties and tensile strength of sugar palm fiber-reinforced epoxy composites. *Polymer - Plastics Technology and Engineering*, *47*(6), 606–612.

Leman, Z., Sapuan, S. M., Ishak, M. R., & Ahmad, M. M. H. M. (2010). Pre-treatment by water retting to improve the interfacial bonding strength of sugar palm fibre. *Polymers from Renewable Resources*, *1*(1).

Li, M., Wang, L. J., Li, D., Cheng, Y. L., & Adhikari, B. (2014). Preparation and characterization of cellulose nanofibers from de-pectinated sugar beet pulp. *Carbohydrate Polymers*, *102*(1), 136–143.

Li, R., Fei, J., Cai, Y., Li, Y., Feng, J., & Yao, J. (2009). Cellulose whiskers extracted from mulberry : A novel biomass production. *Carbohydrate Polymers*, *76*(1), 94–99.

Lin, N., & Dufresne, A. (2013). Supramolecular hydrogels from in situ host − guest inclusion between chemically modified cellulose nanocrystals and cyclodextrin. *Biomacromolecules*, *14*, 871–880.

Lin, N., & Dufresne, A. (2014). Nanocellulose in biomedicine: Current status and future prospect. *European Polymer Journal*, *59*, 302–325.

Lin, N., Huang, J., Chang, P. R., Feng, L., & Yu, J. (2011). Effect of polysaccharide nanocrystals on structure, properties, and drug release kinetics of alginate-based microspheres. *Colloids and Surfaces B: Biointerfaces*, *85*(2), 270–279.

Lipinski, C. (2009). Poor aqueous solubility – an industry wide problem in drug discovery american. *American Pharmaceutical Review*, 38–40.

Liu, D., Zhong, T., Chang, P. R., Li, K., & Wu, Q. (2010). Starch composites reinforced by bamboo cellulosic crystals. *Bioresource Technology*, *101*(7), 2529–2536.

Liu, Y., Wang, J., Zheng, Y., & Wang, A. (2012). Adsorption of methylene blue by kapok fiber treated by sodium chlorite optimized with response surface methodology. *Chemical Engineering Journal*, *184*, 248–255.

Llanos, J. H. R., & Tadini, C. C. (2017). Preparation and characterization of bio-nanocomposite films based on cassava starch or chitosan, reinforced with montmorillonite or bamboo nanofibers. *International Journal of Biological Macromolecules*.

Lu, P., & Hsieh, Y. (2012). Preparation and characterization of cellulose nanocrystals from rice straw. *Carbohydrate Polymers*, *87*(1), 564–573.

Lu, Y., Weng, L., & Cao, X. (2005). Biocomposites of plasticized starch reinforced with cellulose crystallites from cottonseed linter. *Macromolecular Bioscience*, *5*(11), 1101–1107.

Lu, Y., Weng, L., & Cao, X. (2006). Morphological, thermal and mechanical properties of ramie crystallites—reinforced plasticized starch biocomposites. *Carbohydrate Polymers*, *63*(2), 198–204.

Luz, S. M., Caldeira-Pires, A., & Ferrão, P. M. C. (2010). Environmental benefits of substituting talc by sugarcane bagasse fibers as reinforcement in polypropylene composites: Ecodesign and LCA as strategy for automotive components. *Resources, Conservation and Recycling*, *54*(12), 1135–1144.

Ma, X., Yu, J., & Kennedy, J. F. (2005). Studies on the properties of natural fibers-reinforced thermoplastic starch composites. *Carbohydrate Polymers*, *62*(1), 19–24.

Madhavan Nampoothiri, K., Nair, N. R., & John, R. P. (2010). An overview of the recent developments in polylactide (PLA) research. *Bioresource Technology*, *101*(22), 8493–8501.

Mahmoud, K. A., Male, K. B., Hrapovic, S., & Luong, J. H. T. (2009). Cellulose nanocrystal/gold nanoparticle composite as a matrix for enzyme immobilization. *ACS Applied Materials & Interfaces*, *1*(7), 1383–1386.

Mahmoud, K. A., Mena, J. A., Male, K. B., Hrapovic, S., Kamen, A., & Luong, J. H. T.

(2010). Effect of surface charge on the cellular uptake and cytotoxicity of fluorescent labeled cellulose nanocrystals. *ACS Applied Materials & Interfaces, 2*(10), 2924–2932.

Majeed, K., Jawaid, M., Hassan, A., Abu Bakar, A., Abdul Khalil, H. P. S., Salema, A. A., & Inuwa, I. (2013). Potential materials for food packaging from nanoclay/natural fibres filled hybrid composites. *Materials & Design*, *46*, 391–410.

Marchessault, R. H., Morehead, F. F., & Walter, N. M. (1959). Liquid crystal systems from fibrillar polysaccharides. *Nature*, *184*(4686), 632–633.

Martin JD, Clift E, Foster, J., Vanhecke, D., Studer, D., Wick, P., Weder, C. (2011). Investigating the interaction of cellulose nanofibers derived from cotton with a sophisticated 3d human lung cell coculture. *Biomacromolecules*, *12*(10), 3666–3673.

Mathew, A. P., Thielemans, W., & Dufresne, A. (2008). Mechanical properties of nanocomposites from sorbitol plasticized starch and tunicin whiskers. *Journal of Applied Polymer Science*, *109*(6), 4065–4074.

Meneguin, A. B., Ferreira Cury, B. S., dos Santos, A. M., Franco, D. F., Barud, H. S., & da Silva Filho, E. C. (2017). Resistant starch/pectin free-standing films reinforced with nanocellulose intended for colonic methotrexate release. Carbohydrate Polymers, 157, 1013–1023.

Miller, M. (2016). Nano-cellulose reinforced sheet molding compounds for automotive composite manufacturing. (Doctoral dissertation, Georgia Institute of Technology).

Mogea, J., Seibert, B., & Smits, W. (1991). Multipurpose palms: the sugar palm (*Arenga pinnata (Wurmb) Merr.*). *Agroforestry Systems*, *13*(2), 111–129.

Mohammed, A. A., Bachtiar, D., Rejab, M. R. M., Jiang, X. X., Abas, F. O., Abass, R. U., Siregar, J. P. (2018). Effects of KMnO4 treatment on the flexural, impact, and thermal properties of sugar palm fiber-reinforced thermoplastic polyurethane composites. *Jom*, *70*(7), 1326–1330.

Mohammed, A. A., Bachtiar, D., Rejab, M. R. M., & Siregar, J. P. (2018). Effect of microwave treatment on tensile properties of sugar palm fibre reinforced thermoplastic polyurethane composites. *Defence Technology*, *14*(4), 287–290.

Mohanty, A. K., Misra, M., & Drzal, L. T. (2005). *Natural fibers, biopolymers, and biocomposites*. Boca Raton: CRC Press.

Mohanty, A. K., Misra, M., & Hinrichsen, G. (2000). Biofibres, biodegradable polymers and biocomposites: An overview. *Macromolecular Materials and Engineering*, *276–277*, 1–24.

Moon, R. J., Martini, A., Nairn, J., Simonsen, J., & Youngblood, J. (2011). Cellulose nanomaterials review: structure, properties and nanocomposites. *Chemical Society Reviews, 40*(7), 3941.

Morais, J. P. S., Rosa, M. D. F., De Souza Filho, M. de sá M., Nascimento, L. D., Do Nascimento, D. M., & Cassales, A. R. (2013). Extraction and characterization of nanocellulose structures from raw cotton linter. *Carbohydrate Polymers*, *91*(1), 229–235.

Morán, J. I., Alvarez, V. A., Cyras, V. P., & Vázquez, A. (2008). Extraction of cellulose and preparation of nanocellulose from sisal fibers. *Cellulose*, *15*(1), 149–159.

N., E., Jane, Z., & K., R. (2012). Image Watermarking in Higher-Order Gradient Domain. In *Advances in Wavelet Theory and Their Applications in Engineering, Physics and Technology*. InTech.

Naduparambath, S., T.V., J., Shaniba, V., M.P., S., Balan, A. K., & Purushothaman, E. (2018). Isolation and characterisation of cellulose nanocrystals from sago seed shells. *Carbohydrate Polymers*, *180*, 13–20.

Nasri-Nasrabadi, B., Behzad, T., & Bagheri, R. (2014). Preparation and characterization of cellulose nanofiber reinforced thermoplastic starch composites. *Fibers and Polymers*, *15*(2), 347–354.

Ndazi, B. S., Nyahumwa, C., & Tesha, J. (2007). Chemical and thermal stability of rice husks against alkali treatment. *BioResources*, *3*(4), 1267–1277.

Ng, H.-M. M., Sin, L. T., Tee, T. T., Bee, S. T., Hui, D., Low, C. Y., & Rahmat, A. R. R. (2015). Extraction of cellulose nanocrystals from plant sources for application as reinforcing agent in polymers. *Composites Part B: Engineering*, *75*, 176–200.

Nguyen, T., Zavarin, E., & Barrall, E. M. (1981). Thermal Analysis of Lignocellulosic Materials. *Journal of Macromolecular Science, Part C*, *20*(1), 1–65.

Nicolais, L. (2011). *Wiley Encyclopedia of Composites*. Hoboken, NJ, USA: John Wiley & Sons, Inc.

Njugunaa J., Pielichowskib K., & Alcocka J.R. (2007). Epoxy-based fibre reinforced nanocomposites: current status. *Advanced Engineering Materials*, *9*(10), 835–847.

Noshirvani, N., Ghanbarzadeh, B., Fasihi, H., & Almasi, H. (2016). Starch-PVA nanocomposite film incorporated with cellulose nanocrystals and MMT: A comparative study. *International Journal of Food Engineering*, *12*(1), 37–48.

Oommen, Z., Groeninckx, G., & Thomas, S. (2000). Dynamic mechanical and thermal properties of physically compatibilized natural rubber/poly(methyl methacrylate) blends by the addition of natural rubber-graft- poly(methyl methacrylate). *Journal of Polymer Science Part B: Polymer Physics*, *38*(4), 525–536.

Oshkovr, S. A., Taher, S. T., Oshkour, A. A., Ariffin, A. K., & Azhari, C. H. (2013). Finite element modelling of axially crushed silk/epoxy composite square tubes.

Composite Structures, *95*, 411–418.

Othman, A. R., & Haron, N. H. (1992). Potensi industri kecil tanaman enau. *FRIM report*, *60*, 7–18.

Ouatmane, A., Provenzano, M. M. R., A., O., Provenzano, M. M. R., Hafidi, M., & Senesi, N. (2000). Compost maturity assessment using calorimetry, spectroscopy and chemical analysis. *Compost Science & Utilization*, *8*(2), 124–134.

Pääkkö, M., Vapaavuori, J., Silvennoinen, R., Kosonen, H., Ankerfors, M., Lindström, T., Ikkala, O. (2008). Long and entangled native cellulose I nanofibers allow flexible aerogels and hierarchically porous templates for functionalities. *Soft Matter*, *4*(12), 2492.

Pandele, A. M., Neacsu, P., Cimpean, A., Staras, A. I., Miculescu, F., Iordache, A., Toader, O. D. (2018). Cellulose acetate membranes functionalized with resveratrol by covalent immobilization for improved osseointegration. *Applied Surface Science*, *438*, 2–13.

Park, S. U., Lee, B. K., Kim, M. S., Park, K. K., Sung, W. J., Kim, H. Y., Park, D. H. (2014). The possibility of microbial cellulose for dressing and scaffold materials. *International Wound Journal*, *11*(1), 35–43.

Pedrazzoli, D., Pegoretti, A., & Kalaitzidou, K. (2014). Synergistic effect of exfoliated graphite nanoplatelets and short glass fiber on the mechanical and interfacial properties of epoxy composites. *Composites Science and Technology*, *98*, 15–21.

Pegoretti, T. D. S., Mathieux, F., Evrard, D., Brissaud, D., & Arruda, J. R. D. F. (2014). Use of recycled natural fibres in industrial products: A comparative LCA case study on acoustic components in the Brazilian automotive sector. *Resources, Conservation and Recycling*, *84*, 1–14.

Pelissari, F. M., Andrade-Mahecha, M. M., Sobral, P. J. do A., & Menegalli, F. C. (2017). Nanocomposites based on banana starch reinforced with cellulose nanofibers isolated from banana peels. *Journal of Colloid and Interface Science*, *505*, 154–167.

Pérez, S., Baldwin, P. M., & Gallant, D. J. (2009). *Structural Features of Starch Granules I. Starch* (Third Edit). Elsevier Inc.

Petersen, N., & Gatenholm, P. (2011). Bacterial cellulose-based materials and medical devices: current state and perspectives. *Applied Microbiology and Biotechnology*, *91*(5), 1277–1286.

Petersson, L., Mathew, A. P., & Oksman, K. (2009). Dispersion and properties of cellulose nanowhiskers and layered silicates in cellulose acetate butyrate nanocomposites. *Journal of Applied Polymer Science*, *112*(4), 2001–2009.

Plackett. (2014). A review of nanocellulose as a novel vehicle for drug delivery. *Nordic Pulp and Paper Research Journal*, *29*(01), 105–118.

Radzi, A. M., Sapuan, S. M., Jawaid, M., & Mansor, M. R. (2017). Influence of fibre contents on mechanical and thermal properties of roselle fibre reinforced polyurethane composites. *Fibers and Polymers*, *18*(7), 1353–1358.

Ramires, E. C., & Dufresne, A. (2011). A review of cellulose nanocrystals and nanocomposites. *Tappi Journal*, *10*(4), 9–16.

Ray, D., & Sarkar, B. K. (2001). Characterization of alkali-treated jute fibers for physical and mechanical properties. *Journal of Applied Polymer Science*, *80*(7), 1013–1020.

Razali, N., Salit, M. S., Jawaid, M., Ishak, M. R., & Lazim, Y. (2015). A study on chemical composition, physical, tensile, morphological, and thermal properties of roselle fibre: Effect of fibre maturity. *BioResources*, *10*(1), 1803–1823.

Razali, N., Sapuan, S. M., & Razali, N. (2018). Mechanical properties and morphological analysis of roselle/sugar palm fiber reinforced vinyl ester hybrid composites. In *Natural Fibre Reinforced Vinyl Ester and Vinyl Polymer Composites* (pp. 169–180). Elsevier.

Reddy, M. M., Vivekanandhan, S., Misra, M., Bhatia, S. K., & Mohanty, A. K. (2013). Biobased plastics and bionanocomposites: Current status and future opportunities. *Progress in Polymer Science*, *38*(10–11), 1653–1689.

Revol, J. F., Godbout, D. L., & Gray, D. G. (1997). Solidified liquid crystals of cellulose with optically variable properties. Washington, DC, US.

Rhim, J.-W., & Ng, P. K. W. (2007). Natural biopolymer-based nanocomposite films for packaging applications. *Critical Reviews in Food Science and Nutrition*, *47*(4), 411–433.

Rindlava, Å., Hulleman, S. H. D., & Gatenholma, P. (1997). Formation of starch films with varying crystallinity. *Carbohydrate Polymers*, *34*(1–2), 25–30.

Roman, M. (2015). Toxicity of cellulose nanocrystals: A review. *Industrial Biotechnology*, *11*(1), 25–33.

Roman, M., & Winter, W. T. (2004). Effect of sulfate groups from sulfuric acid hydrolysis on the thermal degradation behavior of bacterial cellulose. *Biomacromolecules*, *5*(5), 1671–1677.

Rong, M. Z., Zhang, M. Q., Liu, Y., Yang, G. C., & Zeng, H. M. (2001). The effect of fiber treatment on the mechanical properties of unidirectional sisal-reinforced epoxy composites. *Composites Science and Technology*, *61*(10), 1437–1447.

Rosa, M. F. M., Medeiros, E. S., Malmonge, J. A. J., Gregorski, K. S., Wood, D. F., Mattoso, L. H. C., Imam, S. H. (2010). Cellulose nanowhiskers from coconut husk fibers: Effect of preparation conditions on their thermal and morphological behavior. *Carbohydrate Polymers*, *81*(1), 83–92.

Sahari, J., Salit, M. S., Zainudin, E. S., & Maleque, M. A. (2014). Degradation characteristics of SPF/SPS biocomposites fabrication of SPF/SPS biocomposites. *Fibres and Textiles in Eastern Europe*, *22*(5107), 96–98.

Sahari, J., Sapuan, S. M., Ismarrubie, Z. N., & Rahman, M. Z. (2012). Physical and chemical properties of different morphological parts of sugar palm fibres. *Fibres and Textiles in Eastern Europe*, *91*(2), 21–24.

Sahari, J., Sapuan, S. M., Ismarrubie, Z. N., & Rahman, M. Z. a. (2011). Investigation on bending strength and stiffness of sugar palm fibre from different parts reinforced unsaturated polyester composites. *Key Engineering Materials*, *471–472*.

Sahari, J., Sapuan, S. M., Zainudin, E. S., & Maleque, M. A. (2013a). Effect of water absorption on mechanical properties of sugar palm fibre reinforced sugar palm starch (SPF/SPS) biocomposites. *Journal of Biobased Materials and Bioenergy*, *7*(1), 90–94.

Sahari, J., Sapuan, S. M., Zainudin, E. S., & Maleque, M. A. (2013b). Mechanical and thermal properties of environmentally friendly composites derived from sugar palm tree. *Materials & Design*, *49*(2), 285–289.

Sahari, J., Sapuan, S. M., Zainudin, E. S., & Maleque, M. A. (2013c). Thermo-mechanical behaviors of thermoplastic starch derived from sugar palm tree (*Arenga pinnata*). *Carbohydrate Polymers*, *92*(2), 1711–1716.

Samir, A., Alloin, F., Paillet, M., & Dufresne, A. (2004). Tangling effect in fibrillated cellulose reinforced nanocomposites. *Macromolecules*, *37*, 4313–4316.

Samir, A., Alloin, F., Sanchez, J., Kissi, N. El, & Dufresne, A. (2004). Preparation of cellulose whiskers reinforced nanocomposites from an organic medium suspension. *Macromolecules*, *37*, 1386–1393.

Sanyang, M. L., Ilyas, R. A., Sapuan, S. M., & Jumaidin, R. (2018). Sugar palm starch-based composites for packaging applications. In *Bionanocomposites for Packaging Applications* (pp. 125–147). Cham: Springer International Publishing.

Sanyang, M. L., Sapuan, S. M., Jawaid, M., Ishak, M. R., & Sahari, J. (2015a). Effect of glycerol and sorbitol plasticizers on physical and thermal properties of sugar palm starch based films. *Recent Advances in Environment, Ecosystems and Development Effect*, 157–162.

Sanyang, M. L., Sapuan, S. M., Jawaid, M., Ishak, M. R., & Sahari, J. (2015b). Effect of plasticizer type and concentration on dynamic mechanical properties of sugar palm starch based films. *International Journal of Polymer Analysis and Characterization*, *5341*, 150622104055002.

Sanyang, M. L., Sapuan, S. M., Jawaid, M., Ishak, M. R., & Sahari, J. (2016a). Development and characterization of sugar palm starch and poly(lactic acid) bilayer films. *Carbohydrate Polymers*, *146*, 36–45.

Sanyang, M. L., Sapuan, S. M., Jawaid, M., Ishak, M. R., & Sahari, J. (2016b). Effect of sugar palm-derived cellulose reinforcement on the mechanical and water barrier properties of sugar palm starch biocomposite films. *BioResources*, *11*(2), 4134–4145.

Sanyang, M. L., Sapuan, S. M., Jawaid, M., Ishak, M. R., & Sahari, J. (2016c). Recent developments in sugar palm (*Arenga pinnata*) based biocomposites and their potential industrial applications: A review. *Renewable and Sustainable Energy Reviews*, *54*, 533–549.

Sanyang, M. L., Sapuan, S. M., Jawaid, M., Ishak, M. R., & Sahari, J. (2016d). Recent developments in sugar palm (*Arenga pinnata*) based biocomposites and their potential industrial applications: A review. *Renewable and Sustainable Energy Reviews*, *54*, 533–549.

Sapuan, S. M., Ilyas, R. A., Ishak, M. R., Leman, Z., Huzaifah, M. R. M., Ammar, I. M., & Atikah, M. S. N. (2018). Development of sugar palm–based products: A community project. In *Sugar Palm Biofibers, Biopolymers, and Biocomposites* (1st ed., pp. 245–266). First edition. Boca Raton, FL : CRC Press/Taylor & Francis Group, 2018.: CRC Press.

Savadekar, N. R., & Mhaske, S. T. (2012). Synthesis of nano cellulose fibers and effect on thermoplastics starch based films. *Carbohydrate Polymers*, *89*(1), 146–151.

Savastano, H., Warden, P. ., & Coutts, R. S. . (2000). Brazilian waste fibres as reinforcement for cement-based composites. *Cement and Concrete Composites*, *22*(5), 379–384.

Saxena, A., Elder, T. J., Kenvin, J., & Ragauskas, A. J. (2010). High oxygen nanocomposite barrier films based on xylan and nanocrystalline cellulose. *Nano-Micro Letters*, *2*(4), 235–241.

Segal, L., Creely, J. J., Martin, A. E., & Conrad, C. M. (1959). An empirical method for estimating the degree of crystallinity of native cellulose using the x-ray diffractometer. *Textile Research Journal*, *29*(10), 786–794.

Shafizadeh, F., & Chin, P. P. S. (1977). Thermal deterioration of wood. In Goldstein IS (Ed.), *Wood technology: chemical aspects* (pp. 57–81). ACS Symposium Series 43.

Sharif Hossain, A. B. M., Ibrahim, N. A., & AlEissa, M. S. (2016). Nano-cellulose derived bioplastic biomaterial data for vehicle bio-bumper from banana peel waste biomass. *Data in Brief*, *8*, 286–294.

Sheltami, R. M., Abdullah, I., Ahmad, I., Dufresne, A., & Kargarzadeh, H. (2012). Extraction of cellulose nanocrystals from mengkuang leaves (*Pandanus tectorius*). *Carbohydrate Polymers*, *88*(2), 772–779.

Silvério, H. A., Flauzino Neto, W. P., Dantas, N. O., & Pasquini, D. (2013). Extraction and characterization of cellulose nanocrystals from corncob for application as reinforcing agent in nanocomposites. *Industrial Crops and Products*, *44*, 427–436.

Singh, J., Tripathi, K. P., & Sakya, T. R. (1993). Effect of penetration enhancers on the in vitro transport of ephedrine through rat skin and human epidermis from matrix based transdermal formulations. *Drug Development and Industrial Pharmacy*, *19*(13), 1623–1628.

Siqueira, G., Bras, J., & Dufresne, A. (2010). Cellulosic bionanocomposites: A review of preparation, properties and applications. *Polymers*, *2*(4), 728–765.

Slavutsky, A. M., & Bertuzzi, M. A. (2014). Water barrier properties of starch films reinforced with cellulose nanocrystals obtained from sugarcane bagasse. *Carbohydrate Polymers*, *110*, 53–61.

Soares, S., Camino, G., & Levchik, S. (1995). Comparative study of the thermal decomposition of pure cellulose and pulp paper. *Polymer Degradation and Stability*, *49*(2), 275–283.

Song, Y. K., Leng Chew, I. M., Yaw Choong, T. S., & Tan, K. W. (2016). Nanocrystalline cellulose, an environmental friendly nanoparticle for pharmaceutical application – A quick study. *MATEC Web of Conferences*, *60*, 01006.

Sonia, A., Priya Dasan, K., & Alex, R. (2013). Celluloses microfibres (CMF) reinforced poly (ethylene-co-vinyl acetate) (EVA) composites: Dynamic mechanical, gamma and thermal ageing studies. *Chemical Engineering Journal*, *228*, 1214–1222.

Stevens, E. S. (2002). *Green plastics: an introduction to the new science of biodegradable plastics*. Princeton, New Jersey: Princeton University Press.

Sun, R. C., & Tomkinson, J. (2002). Comparative study of organic solvent-soluble and water-soluble lipophilic extractives from wheat straw 2: spectroscopic and thermal analysis. *Journal of Wood Science*, *48*(3), 222–226.

Syafri, E., Kasim, A., Abral, H., & Asben, A. (2018). Cellulose nanofibers isolation and characterization from ramie using a chemical-ultrasonic treatment. *Journal of Natural Fibers*, *00*(00), 1–11.

Syafri, E., Kasim, A., Abral, H., Sudirman, Sulungbudi, G. T., Sanjay, M. R., & Sari, N. H. (2018). Synthesis and characterization of cellulose nanofibers (CNF) ramie reinforced cassava starch hybrid composites. *International Journal of Biological Macromolecules*, *120*, 578–586.

T 203 cm-99. (1999). Alpha-, beta- and gamma-cellulose in pulp. *Tappi*.

T 222 om-02. (2006). Acid-insoluble lignin in wood and pulp. *Tappi*.

T230 om-08. (2013). Viscosity of pulp (capillary viscometer method). *Tappi*.

Tahri, N., Bahafid, W., Sayel, H., & El Ghachtouli, N. (2013). Biodegradation: Involved microorganisms and genetically engineered microorganisms. In *Biodegradation - Life of Science*. InTech.

Talib, R. A., Tawakkal, I. S. M. A., & Khalina, A. (2011). The influence of mercerised kenaf fibres reinforced polylactic acid composites on dynamic mechanical analysis. *Key Engineering Materials*, *471–472*, 815–820.

Tan, I. S., & Lee, K. T. (2014). Enzymatic hydrolysis and fermentation of seaweed solid wastes for bioethanol production: An optimization study. *Energy*, *78*, 53–62.

Tawakkal, I. S. M. a. ., Talib, R. a. ., Abdan, K., & Ling, C. N. (2012). Mechanical and physical properties of kenaf-derived cellulose (KDC)-filled polylactic acid (PLA) composites. *BioResources*, *7*(2), 1643–1655.

Tee, Y. B., Talib, R. a., Abdan, K., Chin, N. L., Basha, R. K., & Md Yunos, K. F. (2013). Thermally grafting aminosilane onto kenaf-derived cellulose and its influence on the thermal properties of poly(lactic acid) composites. *BioResources*, *8*(3), 4468–4483.

Teixeira, E. de M., Pasquini, D., Curvelo, A. A. S. S., Corradini, E., Belgacem, M. N., & Dufresne, A. (2009). Cassava bagasse cellulose nanofibrils reinforced thermoplastic cassava starch. *Carbohydrate Polymers*, *78*(3), 422–431.

Thakur, M. K., Gupta, R. K., & Thakur, V. K. (2014). Surface modification of cellulose using silane coupling agent. *Carbohydrate Polymers*, *111*(2), 849–855.

Thakur, V. K., Singha, A. S., & Thakur, M. K. (2012). Biopolymers based green composites: mechanical, thermal and physico-chemical characterization. *Journal of Polymers and the Environment*, *20*(2), 412–421.

Thakur, V. K., Singha, A. S., & Thakur, M. K. (2013). Synthesis of natural cellulose-based graft copolymers using methyl methacrylate as an efficient monomer. *Advances in Polymer Technology*, *32*(S1), E741–E748.

Ticoalu, A., Aravinthan, T., & Cardona, F. (2010). Experimental investigation into gomuti fibres / polyester composites. In *21st Australasian Conference on the Mechanics of Structures and Materials (ACMSM 21)* (pp. 451–456). Melbourne, Australia: CRC Press/ Balkema.

Ticoalu, A., Aravinthan, T., & Cardona, F. (2013). A review on the characteristics of gomuti fibre and its composites with thermoset resins. *Journal of Reinforced Plastics and Composites*, *32*(2), 124–136.

Tonoli, G. H. D. H. D., Teixeira, E. M. M., Corrêa, A. C. C., Marconcini, J. M. M., Caixeta, L. A. A., Pereira-Da-Silva, M. A. A., & Mattoso, L. H. C. H. C. (2012). Cellulose micro/nanofibres from eucalyptus kraft pulp: Preparation and properties. *Carbohydrate Polymers*, *89*(1), 80–88.

Tonoli, G. H. D., Joaquim, A. P., Arsène, M.-A., Bilba, K., & Savastano, H. (2007). Performance and durability of cement based composites reinforced with refined sisal pulp. *Materials and Manufacturing Processes*, *22*(2), 149–156.

Trache, D., Hussin, M. H., Haafiz, M. K. M., & Thakur, V. K. (2017). Recent progress in cellulose nanocrystals: Sources and production. *Nanoscale*, *9*(5), 1763–1786.

Tunc, S., Angellier, H., Cahyana, Y., Chalier, P., Gontard, N., & Gastaldi, E. (2007). Functional properties of wheat gluten/montmorillonite nanocomposite films processed by casting. *Journal of Membrane Science*, *289*(1–2), 159–168.

Valdebenito, F., Pereira, M., Ciudad, G., Azocar, L., Briones, R., & Chinga-Carrasco, G. (2017). On the nanofibrillation of corn husks and oat hulls fibres. *Industrial Crops and Products*, *95*, 528–534.

Vergnaud, J. M. (1991). Liquid transport processes in polymeric materials: modeling and industrial applications. *Prentice Hall*.

Vilay, V., Mariatti, M., Mat Taib, R., & Todo, M. (2008). Effect of fiber surface treatment and fiber loading on the properties of bagasse fiber-reinforced unsaturated polyester composites. *Composites Science and Technology*, *68*(3–4), 631–638.

Villanova, J. C. O., Ayres, E., Carvalho, S. M., Patrício, P. S., Pereira, F. V., & Oréfice, R. L. (2011). Pharmaceutical acrylic beads obtained by suspension polymerization containing cellulose nanowhiskers as excipient for drug delivery. *European Journal of Pharmaceutical Sciences*, *42*(4), 406–415.

Wan, Y. Z., Luo, H., He, F., Liang, H., Huang, Y., & Li, X. L. (2009). Mechanical, moisture absorption, and biodegradation behaviours of bacterial cellulose fibre-reinforced starch biocomposites. *Composites Science and Technology*, *69*(7–8), 1212–1217.

Wang, Y., Cao, X., & Zhang, L. (2006). Effects of cellulose whiskers on properties of soy protein thermoplastics. *Macromolecular Bioscience*, *6*(7), 524–531.

Wang, Y., & Chen, L. (2011). Impacts of nanowhisker on formation kinetics and properties of all-cellulose composite gels. *Carbohydrate Polymers*, *83*(4), 1937–1946.

Wang, Y., Wei, X., Li, J., Wang, F., Wang, Q., & Kong, L. (2013). Homogeneous isolation of nanocellulose from cotton cellulose by high pressure homogenization. *Journal of Materials Science and Chemical Engineering*, *1*, 49–52.

Wang, Y., Wei, X., Li, J., Wang, F., Wang, Q., Zhang, Y., & Kong, L. (2017). Homogeneous isolation of nanocellulose from eucalyptus pulp by high pressure homogenization. *Industrial Crops and Products*, *104*(March), 237–241.

Wang Yueping, Wang Ge, Cheng Haitao, Tian Genlin, Liu Zheng, Xiao Qun Feng, … Gao Xushan. (2010). Structures of Bamboo Fiber for Textiles. *Textile Research Journal*, *80*(4), 334–343.

Wilhelm, H. M., Sierakowski, M. R., Souza, G. P., & Wypych, F. (2003). Starch films reinforced with mineral clay. *Carbohydrate Polymers*, *52*(2), 101–110.

Wise, L. E., Murphy, M., & D'Addieco, A. A. (1946). Chlorite, holocellulose, its fractionation and bearing on summative wood analysis and on studies on the hemicellulose. *Paper Trade Journal*, *122*(2), 35–43.

Witik, R. A., Payet, J., Michaud, V., Ludwig, C., & Månson, J. A. E. (2011). Assessing the life cycle costs and environmental performance of lightweight materials in automobile applications. *Composites Part A: Applied Science and Manufacturing*, *42*(11), 1694–1709.

Wróblewska-Krepsztul, J., Rydzkowski, T., Borowski, G., Szczypiński, M., Klepka, T., & Thakur, V. K. (2018). Recent progress in biodegradable polymers and nanocomposite-based packaging materials for sustainable environment. *International Journal of Polymer Analysis and Characterization*, *23*(4), 383–395.

Xiang, C., Taylor, A. G., Hinestroza, J. P., & Frey, M. W. (2013). Controlled release of nonionic compounds from poly(lactic acid)/cellulose nanocrystal nanocomposite fibers. *Journal of Applied Polymer Science*, *127*(1), 79–86.

Xiang, Q., Lee, Y. Y., Pettersson, P. O., & Torget, R. W. (2003). Heterogeneous aspects of acid hydrolysis of α-cellulose. In *Biotechnology for Fuels and Chemicals* (pp. 505–514). Totowa, NJ: Humana Press.

Xiao, B., Sun, X. ., & Sun, R. (2001). Chemical, structural, and thermal characterizations of alkali-soluble lignins and hemicelluloses, and cellulose from maize stems, rye straw, and rice straw. *Polymer Degradation and Stability*, *74*(2), 307–319.

Yang, H., Yan, R., Chen, H., Lee, D. H., & Zheng, C. (2007). Characteristics of hemicellulose, cellulose and lignin pyrolysis. *Fuel*, *86*(12–13), 1781–1788.

Yang, S., Tang, Y., Wang, J., Kong, F., & Zhang, J. (2014). Surface treatment of cellulosic paper with starch-based composites reinforced with nanocrystalline cellulose. *Industrial & Engineering Chemistry Research*, *53*(36), 13980–13988.

Yang, Y., Boom, R., Irion, B., van Heerden, D. J., Kuiper, P., de Wit, H., Wit, H. De. (2012). Recycling of composite materials. *Chemical Engineering and Processing: Process Intensification*, *51*, 53–68.

Yasim-Anuar, T. A. T., Ariffin, H., Norrrahim, M. N. F., & Hassan, M. A. (2017). Factors affecting spinnability of oil palm mesocarp fiber cellulose solution for the production of microfiber. *Bioresources*, *12*(1), 715–734.

Zainuddin, S. Y. Z., Ahmad, I., Kargarzadeh, H., Abdullah, I., & Dufresne, A. (2013). Potential of using multiscale kenaf fibers as reinforcing filler in cassava starch-kenaf biocomposites. *Carbohydrate Polymers*, *92*(2), 2299–2305. 6

Zhang, X., Huang, J., Chang, P. R., Li, J., Chen, Y., Wang, D., Chen, J. (2010). Structure and properties of polysaccharide nanocrystal-doped supramolecular hydrogels based on Cyclodextrin inclusion. *Polymer*, *51*(19), 4398–4407.

Zhong, Y., & Li, Y. (2014). Effects of glycerol and storage relative humidity on the properties of kudzu starch-based edible films. *Starch/Staerke*, *66*(5–6), 524–532.

Zhou, C., Wu, Q., Yue, Y., & Zhang, Q. (2011). Application of rod-shaped cellulose nanocrystals in polyacrylamide hydrogels. *Journal of Colloid and Interface Science*, *353*(1), 116–123.

Zimmermann, T., Bordeanu, N., & Strub, E. (2010). Properties of nanofibrillated cellulose from different raw materials and its reinforcement potential. *Carbohydrate Polymers*, *79*(4), 1086–1093.

Żuchowska, D., Steller, R., & Meissner, W. (1998). Structure and properties of degradable polyolefin-starch blends. *Polymer Degradation and Stability*, *60*(2–3), 471–480.

Zuluaga, R., Putaux, J.-L. L., Restrepo, A., Mondragon, I., & Gañán, P. (2007). Cellulose microfibrils from banana farming residues: isolation and characterization. *Cellulose*, *14*(6), 585–592.