UNIVERSITI PUTRA MALAYSIA

CHARACTERIZATION OF OIL PALM (Elaeis guineensis Jacq.) EMPTY FRUIT BUNCH FIBRE FILLED POLYBUTYLENE SUCCINATE AND TAPIOCA STARCH BIOCOMPOSITES

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IPTPH 2021 8

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By

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May 2021

Chairman : Professor Ts. Khalina binti Abdan, PhD
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In Malaysia, the production of biodegradable food packaging is not well established. Biodegradable polymers only were used in high-end products such as in medical instruments. This is due to the high cost of the raw materials caused industries are not interested to invest in the development of biodegradable food packaging. The major challenges for the development of biodegradable polymer as food packaging are the shortcomings related to brittleness and processability. In meantime, this research was come out with an alternative to replace conventional plastic and overcome the drawbacks of the biodegradable polymer by substitute a certain percentage of polymer with tapioca starch and natural fibre from oil palm.

EFB fibre was added at 10 to 50wt% fibre loading. The percentage of water absorption of the samples increased maximum by 10.15% for 50wt% fibre loading and reached the equilibrium of absorption on day 8. The same trends were observed for water vapour permeability as the reading was increased as the EFB fibre loading increased. It was incredible to note that increasing the EFB fibre up to 20 wt.% and 30 wt.%, showed an increase in tensile strength from 14.27MPa to 16.16MPa and tensile modulus from 2965.81MPa to 3177.19MPa. The flexural strength was increased from 17.15MPa to 35.16MPa. However, the thermal stability of the composites decreased by 12.65°C as the fibre loading increased.

The composites with 20-30 wt.% of fibre loading exhibited good physical and mechanical properties, respectively. Increasing trends in the performance of tensile strength and flexural properties were shown for the glycerol loadings up to 10 wt% by 45% and 31.25% respectively. The addition of glycerol in the composite from 7.5-15% significantly improves the flexibility of the composite as the elongation at break increase from 6.12% to 14.21%. Besides, thermal stability for composite with 10.wt% glycerol

loading shows the highest thermal stability. This is due to better interfacial bonding and interaction between PBS, starch and fibre compounding. In rheological testing was showed the viscosity for all fibre loading in the composite was reduced as an increase in shear rate. The composites showed a shear-thinning behaviour thus, showed a non-Newtonian behaviour.

Due to calendaring machine capacity and limitation, 20 wt.% of EFB fibre loading and 10 wt.% glycerol content were chosen as a final formulation. Two technique of thermoforming process were evaluated to thermoform the composite into a food packaging tray. The hot press technique was showed higher tensile strength compare with the vacuum forming method. In terms of strength, this development of food packaging is competitive with the current food packaging. Hence, the development of fully biodegradable food packaging is important in the effort to address the ongoing environmental problems and gradually substitute the widely used conventional packaging materials.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENCIRIAN GENTIAN KELAPA SAWIT (*Elaeis guineensis* Jacq.) DIPENUHI POLY BUTYLENE SUCCINATE DAN KANJI UBI BIOKOMPOSIT

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Di Malaysia penghasilan bungkusan plastik yang bersifat biodegradasi tidak mapan. Polimer yang mempunyai sifat biodegradasi hanya digunakan untuk produk yang mahal seperti dalam peralatan perubatan. Hal ini disebabkan kos bahan mentah yang tinggi dan menyebabkan pihak industri tidak berminat untuk melabur dalam pembangunan pembungkusan makanan yang mempunyai sifat biodegradasi. Cabaran utama untuk pembangunan biodegradsi polimer sebagai pembungkusan makanan adalah kekurangan yang berkaitan dengan kerapuhan dan kebolehprosesan. Sementara itu, penyelidikan ini dibuat sebagai alternatif untuk menggantikan plastik konvensional dan mengatasi kekurangan polimer yang dapat terurai dengan menggantikan peratusan polimer tertentu dengan kanji ubi kayu dan gentian tandan kosong kelapa sawit.

Muatan gentian tandan kosong kelapa sawit ditambahkan pada muatan daripada 10 hingga 50wt% peratus berat. Peratus penyerapan air meningkat sebanyak 10.15% apabila muatan gentian tandan kosong sawit meningkat pada 50wt% muatan peratus berat dan mencapai keseimbangan penyerapan pada hari ke-8. Kecenderungan yang sama diperhatikan untuk kebolehtelapan wap air ketika bacaanya meningkat apabila muatan serat gentian tandan kosong sawit meningkat. Peningkatan serat gentian tandan kosong sawit untuk 20% berat dan 30% berat, menunjukkan peningkatan kekuatan tegangan dari 14.27MPa menjadi 16.16MPa dan modulus tegangan dari 2965.81MPa hingga 3177.19MPa. Kekuatan lenturan meningkat dari 17.15MPa menjadi 35.16MPa. Walau bagaimanapun, kestabilan terma komposit menurun sebanyak 12.65 °C dengan peningkatan beban serat gentian.

Komposit dengan 20-30% berat serat masing-masing menunjukkan sifat fizikal dan mekanikal yang baik. Peningkatan dalam prestasi kekuatan tegangan sebanyak 10% dan sifat lenturan sebanyak 31.25% telah dicerap untuk muatan gliserol sehingga 10% berat. Penambahan gliserol dalam komposit dari 7.5-15% secara telah meningkatkan

fleksibiliti komposit kerana pemanjangan meningkat dari 6.12% menjadi 14.21%. Selain itu, kestabilan terma untuk komposit dengan 10% berat gliserol menunjukkan kestabilan terma tertinggi. Ini disebabkan oleh ikatan kimia antara bahan dan interaksi yang lebih baik antara polimer, kanji dan gentian. Dalam pengujian reologi menunjukkan kelikatan untuk semua berat gentian pada komposit berkurang apabila peningkatan pada kadar ricih. Komposit menunjukkan tingkah laku penipisan ricih, menunjukkan sifat non-Newtonian.

Disebabkan kapasiti mesin yang dihadkan, 20% berat serat EFB dan 10% kandungan gliserol dipilih sebagai formulasi akhir. Dua teknik proses pembentukan terma dinilai untuk membentuk komposit ke dalam bungkusan makanan. Teknik tekan panas menunjukkan kekuatan tegangan yang lebih tinggi dibandingkan dengan kaedah pembentuk vakum. Dari segi kekuatan, penghasilan pembungkusan makanan ini kompetitif dengan pembungkusan makanan semasa. Penghasilan 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 konventional yang digunakan secara meluas.

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

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LIST OF ABREVIATIONS

ASTM	American Society for Testing and Materials
EFB	Empty Fruit Bunch
CO_2	Carbon Dioxide
DTG	Derivative Thermo-gravimetry
FTIR	Fourier Transform Infrared Spectroscopy
G	Gram
HDPE	High Density Polyethylene
IR	Infrared
KF	Kenaf Fibre
MC	Moisture Content
OPEFB	Oil Palm Empty Fruit Bunch
OH	Hydroxyl Group
PALF	Pineapple Leaf Fibre
PBS	Polybutylene Succinate
PLA	Polylactic Acid
PE	Polyethylene
PP	Polypropylene
PU	Polyurethene
PS	Polystyrene
PCL	Polycaprolactone
PHA	Polyhaydroxyalkanoates
SEM	Scanning Electron Microscopy
T_g	Glass Transition Temperature
TGA	Thermal-gravimetric Analysis
USA	United States America
WA	Water Absorption
WVP	Water Vapour Permeability
wt.%	Weight percentage

LIST OF UNIT

°C	Degree celcius
°C/min	Degree celcius per minute
°	Degree
GPa	Gigapascal
gsm	gram square meter
tex	gram per 1000 meters
g/cm^3	gram per cubic centimeter
J/m	Joule per meter
kJ	kilo Joule
kN	kilo Newtons
Kg/m^3	Kilogram per cubic meter
MPa	Megapascal
ms^{-1}	meter per second
µ	micro
mm	millimeter
min	minute
τ	Shear stress
γ	Shear rate
%	Percentage
cm^{-1}	per centimeter
rpm	rotation per minute

CHAPTER 1

INTRODUCTION

1.1 Background

Plastics are chemically synthesized polymer via polymerization from petroleum products containing long chains of monomers. The plastics industry has existed over the last 60–70 years. Plastics have great properties such as versatility, low weight, durability, and low costs (Chidambarampadmavathy *et al*., 2017). The growing of environmental burden and awareness is forcing the industries to pursue more eco-friendly materials for their products. There has been a significant focus within the scientific, industrial and environmental communities on the use of eco-friendly products with terms such as renewable, recyclable, sustainable and biodegradable (Boz, Korhonen & Koelsch, 2020).

Thermoplastic polyesters are produced from non-degradable fossil-based materials. Its properties lead to the accumulation of plastic waste and petrochemical feedstock degradation (Folino *et al*., 2020). The growing of environment concern and awareness are derived industries from seeking more eco-friendly material. The thermoplastic polymer is a type of plastic polymer with the properties of a polymer resin. This material becomes soft when heated and can be moulded to any desired shape and scale. When it is cooled, it becomes hard and rigid and remains in the developed shape and size. Recently, biodegradable polymers have gained a great deal of interest due to their wide variety of applications in environmentally friendly goods. Polymers have begun to replace current materials in every aspect of life due to its properties. The growing issue of non-biodegradable plastics has increased the need to replace into biodegradable materials and optimize the use and disposal of traditional plastics.

A biodegradable polymer such as polybutylene succinate (PBS), polycaprolactone (PCL) and polylactic acid (PLA) was attracted tremendous attention due to their economic competitiveness. Besides that, the selection of polymer depends on the requirements for specific applications and performances. Biopolymer had been studied by researchers as a potential matrix for compostable and eco-friendly composite (Balart *et al*., 2020). Facilitate biodegradable material in composites, PBS is often used as a matrix. PBS is a biopolymer that has been extensively studied primarily due to its excellent mechanical properties and processing capabilities. PBS was polymerized from butanediol and succinic acid, which may soon both be available from bio-based renewable resources (Han *et al*., 2019; Su *et al*., 2019). PBS exhibits good storage modulus and flexural properties compared to other biodegradable polymers and naturally degraded in nature. The utilization of PBS can minimize environmental plastic load in a landfill (Mazhandu *et al*., 2020). PBS now had become one of the most promising polymers for both wide applications especially as an alternative in the packaging industry and also an idea to replace conventional synthetic polymers (Nakajima *et al*., 2017). However, it has some drawbacks such as brittleness and low impact strength (Huang *et al*., 2018). As a result, the production of bio-based natural fibre composites has been established and were used in many application. The use of natural fibres materials able to reduce the cost of material and consequently modify the chosen properties as well as the rates of degradation. As far as the matter is concerned, when comparing the copolymerization and modification process with the blending of biodegradable polymers, the latter was found to be a much simpler method as well as the best approach to obtain the desired properties. (Meereboer *et al.*, 2020).

Natural fibre composites are simply planted fibres, embedded in a thermoplastic polymer. The density of these natural fibres is close to that of their plastic counterparts, which are typically 40% to 50% lower than the density of glass fibres. (Pecas *et al.*, 2018). Polymeric materials may then be reinforced or filled without having a noticeable effect on their density. Several types of natural fibres, such as kenaf fibre, oil palm fibre, sugar palm fibre, pineapple leaf fibre, banana fibre, flax, hemp, sisal, coir and jute fibre, have attracted the attention of scientists and technologists for their widespread applications (Madhu *et al*., 2018). These fibres are used to reinforce thermoplastic polymer matrices such as polystyrene (PS), polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC) and polyurethane (PU). Due to its lightweight and eco-friendly properties, natural fibres also was chosen as based biocomposite are centre of attraction for industries over traditional composites (Mohammed *et al*., 2017). Oil palm plantation produces about 55 tons of dry matter in the form of fibrous biomass annually while yielding 5.5 tons of oil. The calorific value of oil palm residues in Malaysia varies between 18 to 21 MJ/kg on a dry basis. Lignocellulosic fibres of oil palm can be extracted from the trunk, frond, fruit mesocarp and empty fruit bunches (EFBs) of oil palm trees which has good mechanical properties (Hamzah *et al*., 2019). Therefore, the insertion of natural fibres in a polymer will enhance the properties of composite for future applications.

1.2 Problem Statement

The challenges in the food packaging industry today is to produce food packaging, which is environmentally friendly to avoid negative impacts on human wellbeing. Disposal of food packaging from synthetic plastics makes an additional contribution to the carbon dioxide emissions in the atmosphere, which contributes to global warming. In view of the numerous environmental problems posed by petroleum-based plastics, the government of many developed countries enacted policies that will help mitigate the current scenario (Sanyang *et al*., 2018). In Malaysia, biodegradable materials especially in the food packaging industry are not well established. It costs 20 – 50% more to produce bio-plastic compare with synthetic plastic. Therefore, biodegradable polymers only were used in high-end products such as in medical instruments and pharmaceutical fields (Teixeira *et al*., 2021). Due to the high cost of the raw materials caused industries are not interested to invest in the development of biodegradable food packaging. Besides that, biodegradable plastic needs costly industrial processors and composters, especially those that require high industrial-scale temperatures to be broken down. Apart from cost, there is a need for the availability of equipment, which may be a problem for the industry.

To overcome the dependence on petroleum-based polymers, attempts were made in this work to utilize 100% renewable and biodegradable materials. From a previous study, research was conducted to evaluate the blending of biodegradable polymer with starch or natural fibres by using extrusion, melt blending, solvent casting or injection moulding in lab-scale capacity (Nazrin *et al*., 2020, Fahrngruber *et al*., 2020). However, such a bio-sourced is still underutilized and thus, very limited studies have been reported related to their development as green packaging materials. Hence, in this research, natural fibres and starch were employed in the current study to develop fully biodegradable food packaging materials. In terms of processing, this research was upscale the material's capacity by using industrial extrusion and calendaring machine. This provides an excellent opportunity for researchers and industry as a reference for the future development of biodegradable food packaging. The positive results from previous research have encouraged this research to be done on broader scale for countering conventional polymer based plastic packaging.

In the previous research, polylactic acid (PLA) was a chosen biodegradable polymer that has a high potential to replace current synthetic food packaging. PLA is a commercially and environmentally interesting biopolymer and possesses unique characteristics, including rigidity, good transparency, good processability and glossy appearance (Siakeng *et al*., 2018). However, PLA processing temperature is very high, which is 160°C and required a longer processing time. Other than that, PLA also has a serious limitation on its brittleness, poor toughness, slow degradation rate and poor thermal stability, which limits its extensive application (Nofar *et al*., 2019).

In response to these problems associated with plastic waste, this research was used PBS as the main biodegradable polymer due to rarely research on these materials for commercial food packaging application. PBS melting point is 115°C which is lower compare with PLA. These properties could save on industrial processing while it takes a shorter time to melts and blends with other material. PBS was also easy to process and handling while mixing with other materials. In terms of brittleness, PBS is more rigid but slightly brittle due to its production from petroleum-based. PBS also has good thermal stability and excellent mechanical properties (Matos *et al.*, 2020). However, blending PBS alone caused the PBS unable to extrude and reshape into food packaging due to less flexibility and brittleness. Therefore, it was suggested to compound with other materials to overcome this drawback. Tapioca starch is a readily available source of renewable energy and can be obtained from various by-products of cultivation and harvesting industrialization of raw materials. Starch is one of the most promising natural polymers because of its inherent biodegradability and abundance. However, the starch itself was brittle and difficult to process. Therefore mixing starch with PBS has the potential to overcome this drawback. Empty fruit bunch (EFB) fibre is a versatile lignocellulosic fibre that is abundant and was extracted from an oil palm tree. EFB fibre was used as reinforcement or filler for both thermoplastic and thermosetting polymer to combine become composite material. (Pecas *et al*., 2018).

In this research, PBS was filled with starch, EFB fibre and glycerol to produce a composite sheet for food packaging application. Proper mixing of PBS, starch, EFB fibre and glycerol able to develop biodegradable food packaging materials which have the potential to substitute current synthetic food packaging in the market. The key requirements of composites for food packaging materials are non-toxic or harmful, standard rigidity and stiffness with acceptable barrier properties. These can be achieved by an innovative formulation of a significant amount of weight. This bio-composite has potential application in the development of biodegradable food tray.

1.3 Research Hypothesis

From this research, the utilization of PBS, natural fibres, starch and glycerol composite would lead to the fabrication of bio-composites for biodegradable food tray application to resolve on issues of synthetic food packaging.

1.4 Research Objectives

Main objective: The aim for this research is to investigate the performance of EFB fibre filled polybutylene succinate and tapioca starch bio composite for potential on development of biodegradable food packaging.

<u>Specific Objectives</u>

1. To determine the effect of starch filled polybutylene succinate on its chemical, thermal, physical, mechanical and morphological properties.
2. To investigate the effect of different loading Empty Fruit Bunch (EFB) fibre filled with PBS and starch on chemical, thermal, physical, mechanical and morphological properties.
3. To examine the effect of glycerol content on PBS/Starch/EFB Fibre bio composite on its chemical, thermal, physical, mechanical and morphological properties.
4. To determine the rheological behaviour of PBS/Starch/EFB Fibre bio composite.

1.5 Significance of Study

1. The development of biodegradable materials which expected to aids in addressing environmental issues regarding substitution of plastic based products.
2. Development of novel composites from PBS, EFB fibre and starch to produce food packaging tray.
3. This study also employs method processing to produce biodegradable food packaging tray

1.6 Scope and Limitation

In this study, pure starch that was purchased in Vietnam has properties easy to trap moisture and solidify when mixing with PBS at a certain temperature. Therefore, pure starch was excluded for mixing with PBS and unable to characterize properties of PBS and pure starch compound. PBS, starch and natural fibre are hydrophilic in nature. Therefore, the materials need to oven-dry before processing.

Second, pores on the composite sheet surface were detected, causing an oxygen transmission rate for investigating barrier properties unable to carry out. The presence of pores on the composite causing the reading of oxygen in and out are at the same rate. Therefore, in future work, it was suggested to laminate the composite to improve the barrier properties of the composite.

Third, fibre loading was set at a maximum limit to 20wt% due to easy processing and limitation of industrial extruder machine. This industrial extruder consisted of 4 feeders of different capacities. Feeder 1 is the main feeder that can fit materials up to 50%, feeder 2 up to 30%, feeder 3 and feeder 4 only can feed 20% of the total material. However, during producing composite sheet using an extruder, only two feeders were used which are feeder 1 for PBS and feeder 3 for a dry mix of starch/EFB fibre and glycerol due to feeder 2 is unable to operate. The composite sheet was developed by using an industrial calendaring machine. The characterize of the starch and EFB fibre as filler for PBS to improve the matrix properties. Thus, the effect of starch and fibre loading on the chemical, physical, mechanical and morphological properties of the composite was carried out.

1.7 Thesis Outline

This thesis is structured into five chapters. The first chapter contains an overview of biodegradable polymer and natural fibres, the significance of the research, highlights of the research problems, research hypothesis and finally, the objectives, scope, and limitations of the research. Chapter two is an overview of the literature on natural fibres filled composites by focusing on EFB fibre composites and biodegradable polymer. Chapter three presents the overall research methodology for the overall structure of the research work. This chapter describes the materials, a specific approach in designing and planning the experimental design, experimental test procedures and standards. The following chapter four presents the results and discussion of the research works. Finally, chapter five presents a summary of the research findings and recommendations for future works.

REFERENCES

Abdul Hadi, N., Wiege, B., Stabenau, S., Marefati, A., & Rayner, M. (2020). Comparison of Three Methods to Determine the Degree of Substitution of Quinoa and Rice Starch Acetates, Propionates, and Butyrates: Direct Stoichiometry, FTIR, and 1H-NMR. *Foods*, *9*(1), 83.

Adilah, A. N., Jamilah, B., Noranizan, M., & Hanani, Z. N. (2018). Utilization of mango peel extracts on the biodegradable films for active packaging. *Food packaging and shelf life*, *16*, 1-7.

Ahmad Saffian, H., Abdan, K., Ali Hassan, M., & Ibrahim, A. (2017). Characterization, morphology, and biodegradation of bioplastic fertilizer (B p F) composites made of poly (Butylene succinate) blended with oil palm biomass and fertilizer. Polymer Composites, 38(11), 2577-2583.

Aisyah, H. A., Paridah, M. T., Sapuan, S. M., Khalina, A., Berkalp, O. B., Lee, S. H., ... & Ilyas, R. A. (2019). Thermal properties of woven kenaf/carbon fibre-reinforced epoxy hybrid composite panels. *International Journal of Polymer Science*, *2019*.

Akampumuza, O., Wambua, P. M., Ahmed, A., Li, W., & Qin, X. H. (2017). Review of the applications of biocomposites in the automotive industry. *Polymer Composites*, *38*(11), 2553-2569.

AL-Oqla, F. M., & Omari, M. A. (2017). Sustainable biocomposites: challenges, potential and barriers for development *Green biocomposites* (pp. 13-29): Springer.

Alcazar-Alay, S. C., & Meireles, M. A. A. (2015). Physicochemical properties, modifications and applications of starches from different botanical sources. Food Science and Technology, 35(2), 215-236.

Aldas, M., Pavon, C., López-Martínez, J., & Arrieta, M. P. (2020). Pine Resin Derivatives as Sustainable Additives to Improve the Mechanical and Thermal Properties of Injected Moulded Thermoplastic Starch. *Applied Sciences*, *10*(7), 2561.

Alshehrei, F. (2017). Biodegradation of synthetic and natural plastic by microorganisms. Journal of Applied & Environmental Microbiology, 5(1), 8-19.

Amin, A. M. M., Sauid, S. M., Musa, M., & Hamid, K. H. K. (2017). The effect of glycerol content on mechanical properties, surface morphology and water absorption of thermoplastic films from tacca leontopetaloides starch. *Journal of technology 79*(5-3).

Amir, N., Abidin, K. A. Z., & Shiri, F. B. M. (2017). Effects of fibre configuration on mechanical properties of banana fibre/PP/MAPP natural fibre reinforced polymer composite. *Procedia engineering*, *184*, 573-580.

Anstey, A., Muniyasamy, S., Reddy, M. M., Misra, M., & Mohanty, A. (2014). Processability and biodegradability evaluation of composites from poly (butylene succinate)(PBS) bioplastic and biofuel co-products from Ontario. Journal of Polymers and the Environment, 22(2), 209-218.

Anuar, N. I. S., Zakaria, S., Gan, S., Chia, C. H., Wang, C., & Harun, J. (2019). Comparison of the morphological and mechanical properties of oil Palm EFB fibres and kenaf fibres in nonwoven reinforced composites. *Industrial Crops and Products*, *127*, 55-65.

Anuar, N. I. S., Zakaria, S., Kaco, H., Hua, C. C., Chunhong, W., & Abdullah, H. S. (2018). Physico-mechanical, chemical composition, thermal degradation and crystallinity of oil palm empty fruit bunch, kenaf and polypropylene fibres: A comparatives study. *Sains Malaysiana*, *47*(4), 839-851.

Arib, R., Sapuan, S., Ahmad, M., Paridah, M., & Zaman, H. K. (2006). Mechanical properties of pineapple leaf fibre reinforced polypropylene composites. *Materials & Design*, *27*(5), 391-396.

Ariffin, A., & Ahmad, M. (2011). single screw extruder in particulate filler composite. *Polymer-Plastics Technology and Engineering*, *50*(4), 395-403.

Ardi, M. S., Aroua, M. K., & Hashim, N. A. (2015). Progress, prospect and challenges in glycerol purification process: A review. Renewable and Sustainable Energy Reviews, 42, 1164-1173.

Ashori, A. (2008). Wood–plastic composites as promising green-composites for automotive industries! *Bioresource technology*, *99*(11), 4661-4667.

Asim, M., Abdan, K., Jawaid, M., Nasir, M., Dashtizadeh, Z., Ishak, M., & Hoque, M. E. (2015). A review on pineapple leaves fibre and its composites. *International Journal of Polymer Science*, *2015*.

Asim, M., Jawaid, M., Abdan, K., & Ishak, M. R. (2016). Effect of alkali and silane treatments on mechanical and fibre-matrix bond strength of kenaf and pineapple leaf fibres. *Journal of Bionic Engineering*, *13*(3), 426-435.

Asim, M., Saba, N., Jawaid, M., & Nasir, M. (2018). Potential of natural fiber/biomass filler-reinforced polymer composites in aerospace applications. In *Sustainable composites for aerospace applications* (pp. 253-268). Woodhead Publishing.

ASTM D1895-17,Standarad Test Methods for Apparent Density,Bulk Factor,and Pourability of Plastic Materials,*ASTM International*, West Conshohocken, PA, 2017.

ASTM D638-14, Standarad Test Methods for Tensile Properties of Plastic ,*ASTM International* , West Conshohocken, PA, 2014.

ASTM D790-17, Standarad Test Methods for Flexural Properties of Plastic ,ASTM International , West Conshohocken, PA, 2017.

ASTM E1131-08(2014), Standarad Test Methods for Compositional Analysis by Thermogravimety, ASTM International , West Conshohocken, PA, 2014.

ASTM F 1249-06 Standard Test Method for Water Vapor Transmission Rate Through Plastic Film and Sheeting Using a Modulated Infrared Sensor, ASTM International , West Conshohocken, PA, 2006.

ASTM D570-98, Standard Test Method for Water Absorption of plastics. American Society for Testing and Materials, New York, 1998.

ASTM D4440-15, Standard Test Method for Plastics: Dynamic Mechanical Properties Melt Rheology, ASTM International, West Conshohocken, PA, 2015.

ASTM D882-18, Standard Test Method for Tensile Properties of Thin Plastic Sheeting, ASTM International, West Conshohocken, PA, 2018.

Ayana, B., Suin, S., & Khatua, B. B. (2014). Highly exfoliated eco-friendly thermoplastic starch (TPS)/poly (lactic acid)(PLA)/clay nanocomposites using unmodified nanoclay. *Carbohydrate polymers*, *110*, 430-439.

Ayrilmis, N., Kariz, M., Kwon, J. H., & Kuzman, M. K. (2019). Effect of printing layer thickness on water absorption and mechanical properties of 3D-printed wood/PLA composite materials. *The International Journal of Advanced Manufacturing Technology*, *102*(5), 2195-2200.

Basavegowda, N., Mandal, T. K., & Baek, K. H. (2020). Bimetallic and trimetallic nanoparticles for active food packaging applications: A review. *Food and Bioprocess Technology*, *13*(1), 30-44.

Bagnato, G., Iulianelli, A., Sanna, A., & Basile, A. (2017). Glycerol production and transformation: a critical review with particular emphasis on glycerol reforming reaction for producing hydrogen in conventional and membrane reactors. *Membranes*, *7*(2), 17.

Balart, R., Montanes, N., Dominici, F., Boronat, T., & Torres-Giner, S. (2020). Environmentally Friendly Polymers and Polymer Composites.

Ballesteros-Mártinez, L., Pérez-Cervera, C., & Andrade-Pizarro, R. (2020). Effect of glycerol and sorbitol concentrations on mechanical, optical, and barrier properties of sweet potato starch film. *NFS Journal*, *20*, 1-9.

Basiak, E., Lenart, A., & Debeaufort, F. (2018). How glycerol and water contents affect the structural and functional properties of starch-based edible films. *Polymers*, *10*(4), 412.

Berthet, M.-A., Angellier-Coussy, H., Chea, V., Guillard, V., Gastaldi, E., & Gontard, N. (2015). Sustainable food packaging: Valorising wheat straw fibres for tuning PHBV-based composites properties. *Composites Part A: Applied Science and Manufacturing*, *72*, 139-147.

Bertoft, E. (2017). Understanding starch structure: Recent progress. *Agronomy*, *7*(3), 56.

Beg, M. D. H., Kormin, S., Bijarimi, M., & Zaman, H. U. (2018). Preparation and characterization of low-density Polyethylene/Thermoplastic starch composites. *Advances in Polymer Technology*, *35*(1).

Battegazzore, D., Noori, A., & Frache, A. (2019). Natural wastes as particle filler for poly (lactic acid)-based composites. *Journal of Composite Materials*, *53*(6), 783-797.

Bharathi, S. V., Rohini, B., Moses, J. A., & Anandharamakrishnan, C. (2019). Nanocomposite for Food Packaging. In *Food Nanotechnology* (pp. 275-307). CRC Press.

Bhattacharjee, S. K., Chakraborty, G., Kashyap, S. P., Gupta, R., & Katiyar, V. (2021). Study of the thermal, mechanical and melt rheological properties of rice straw filled poly (butylene succinate) bio-composites through reactive extrusion process. *Journal of Polymers and the Environment*, *29*(5), 1477-1488.

Bi, S., Tan, B., Soule, J. L., & Sobkowicz, M. J. (2018). Enzymatic degradation of poly (butylene succinate-co-hexamethylene succinate). *Polymer Degradation and Stability*, *155*, 9-14.

Bilo, F., Pandini, S., Sartore, L., Depero, L. E., Gargiulo, G., Bonassi, A., & Bontempi, E. (2018). A sustainable bioplastic obtained from rice straw. Journal of Cleaner Production, 200, 357-368.

Biagiotti, J., Puglia, D., & Kenny, J. M. (2014). A review on natural fibre-based composites-part I: structure, processing and properties of vegetable fibres. *Journal of Natural Fibers, 1*(2), 37-68.

Bocz, K., Szolnoki, B., Marosi, A., Tábi, T., Wladyka-Przybylak, M., & Marosi, G. (2014). Flax fibre reinforced PLA/TPS biocomposites flame retarded with multifunctional additive system. *Polymer Degradation and Stability*, *106*, 63-73.

Bourmaud, A., Åkesson, D., Beaugrand, J., Le Duigou, A., Skrifvars, M., & Baley, C. (2016). Recycling of L-Poly-(lactide)-Poly-(butylene-succinate)-flax biocomposite. *Polymer degradation and stability*, *128*, 77-88.

Boz, Z., Korhonen, V., & Koelsch Sand, C. (2020). Consumer considerations for the implementation of sustainable packaging: A review. *Sustainability*, *12*(6), 2192.

Brebu, M. (2020). Environmental Degradation of Plastic Composites with Natural Fillers—A Review. Polymers, 12(1), 166.

Byun, M. Y., Kim, J. S., Baek, J. H., Park, D. W., & Lee, M. S. (2019). Liquid-Phase Hydrogenation of Maleic Acid over Pd/Al2O3 Catalysts Prepared via Deposition–Precipitation Method. Energies, 12(2), 284.

Calabia, B. P., Ninomiya, F., Yagi, H., Oishi, A., Taguchi, K., Kunioka, M., & Funabashi, M. (2013). Biodegradable poly (butylene succinate) composites reinforced by cotton fiber with silane coupling agent. Polymers, 5(1), 128-141.

Cazón, P., Vázquez, M., & Velazquez, G. (2018). Novel composite films based on cellulose reinforced with chitosan and polyvinyl alcohol: Effect on mechanical properties and water vapour permeability. *Polymer Testing*, *69*, 536-544.

Cao, Y., Zhang, J., Feng, J., & Wu, P. (2011). Compatibilization of immiscible polymer blends using graphene oxide sheets. *Acs Nano*, *5*(7), 5920-5927.

Cha, J., Chung, D., Seib, P., Flores, R., & Hanna, M. (2001). Physical properties of starch-based foams as affected by extrusion temperature and moisture content. *Industrial Crops and Products, 14*(1), 23-30.

Chandran, S., Shanks, R., & Thomas, S. (2014). Polymer blends.

Chanakaewsomboon, I., Tongurai, C., Photaworn, S., Kungsanant, S., & Nikhom, R. (2020). Investigation of saponification mechanisms in biodiesel production: Microscopic visualization of the effects of FFA, water and the amount of alkaline catalyst. Journal of Environmental Chemical Engineering, 8(2), 103538.

Chamas, A., Moon, H., Zheng, J., Qiu, Y., Tabassum, T., Jang, J. H., & Suh, S. (2020). Degradation rates of plastics in the environment. *ACS Sustainable Chemistry & Engineering*, *8*(9), 3494-3511.

Chan, J. X., Wong, J. F., Hassan, A., & Zakaria, Z. (2021). Bioplastics from agricultural waste. In *Biopolymers and Biocomposites from Agro-Waste for Packaging Applications* (pp. 141-169). Woodhead Publishing.

Chen, X., Guo, L., Du, X., Chen, P., Ji, Y., Hao, H., & Xu, X. (2017). Investigation of glycerol concentration on corn starch morphologies and gelatinization behaviours during heat treatment. *Carbohydrate polymers, 176*, 56-64.

Chen, L., Tian, Y., Sun, B., Cai, C., Ma, R., & Jin, Z. (2018). Measurement and characterization of external oil in the fried waxy maize starch granules using ATR-FTIR and XRD. *Food chemistry*, *242*, 131-138.

Cheng, X. Q., Konstas, K., Doherty, C. M., Wood, C. D., Mulet, X., Xie, Z., ... & Lau, C. H. (2017). Hyper-cross-linked additives that impede aging and enhance permeability in thin polyacetylene films for organic solvent nanofiltration. *ACS applied materials & interfaces*, *9*(16), 14401-14408.

Cheng, J., Wang, H., Kang, S., Xia, L., Jiang, S., Chen, M., & Jiang, S. (2019). An active packaging film based on yam starch with eugenol and its application for pork preservation. Food Hydrocolloids, 96, 546-554.

Cheremisinoff, N. P. (2018). *Introduction to polymer rheology and processing*. Crc Press.

Chidambarampadmavathy, K., Karthikeyan, O. P., & Heimann, K. (2017). Sustainable bio-plastic production through landfill methane recycling. *Renewable and Sustainable Energy Reviews, 71*, 555-562.

Ching, Y. C., & Ng, T. S. (2014). Effect of preparation conditions on cellulose from oil palm empty fruit bunch fiber. *BioResources*, *9*(4), 6373-6385.

Chuang, L., Panyoyai, N., Shanks, R. A., & Kasapis, S. (2017). Effect of salt on the glass transition of condensed tapioca starch systems. Food chemistry, 229, 120-126.

Clarizio, S., & Tatara, R. (2012). Tensile strength, elongation, hardness, and tensile and flexural moduli of PLA filled with glycerol-plasticized DDGS. *Journal of Polymers and the Environment*, *20*(3), 638-646.

Corre. L, D., Bras, J., & Dufresne, A. (2010). Starch nanoparticles: a review. Biomacromolecules, 11(5), 1139-1153.

Cornejo-Ramírez, Y. I., Martínez-Cruz, O., Del Toro-Sánchez, C. L., Wong-Corral, F. J., Borboa-Flores, J., & Cinco-Moroyoqui, F. J. (2018). The structural characteristics of starches and their functional properties. *CyTA-Journal of Food*, *16*(1), 1003-1017.

Cui, D., Liu, M., Liang, R., & Bi, Y. (2007). Synthesis and optimization of the reaction conditions of starch sulfates in aqueous solution. Starch-Stärke, 59(2), 91-98.

Dankar, I., Haddarah, A., Omar, F. E., Pujolà, M., & Sepulcre, F. (2018). Characterization of food additive-potato starch complexes by FTIR and X-ray diffraction. *Food chemistry*, *260*, 7-12.

Danso, H. (2017). Properties of coconut, oil palm and bagasse fibres: as potential building materials. *Procedia Engineering*, *200*, 1-9.

Davachi, S. M., Heidari, B. S., Hejazi, I., Seyfi, J., Oliaei, E., Farzaneh, A., & Rashedi, H. (2017). Interface modified polylactic acid/starch/poly ε-caprolactone antibacterial nanocomposite blends for medical applications. Carbohydrate polymers, 155, 336-344.

De Moraes Crizel, T., Costa, T. M. H., de Oliveira Rios, A., & Flôres, S. H. (2016). Valorization of food-grade industrial waste in the obtaining active biodegradable films for packaging. *Industrial Crops and Products*, *87*, 218-228.

DeArmitt, C., & Rothon, R. (2016). Particulate fillers, selection and use in polymer composites. *Encyclopedia of polymers and composites (Springer-Verlag Heidelberg, Berlin, 2015)*, 1-19.

Deeyai, P., Suphantharika, M., Wongsagonsup, R., & Dangtip, S. (2013). Characterization of modified tapioca starch in atmospheric argon plasma under diverse humidity by FTIR spectroscopy. *Chinese Physics Letters, 30*(1), 018103.

Di Lorenzo, M. L., Androsch, R., & Righetti, M. C. (2017). Low-temperature crystallization of poly (butylene succinate). *European Polymer Journal, 94*, 384-391.

Din, M. I., Ghaffar, T., Najeeb, J., Hussain, Z., Khalid, R., & Zahid, H. (2020). Potential perspectives of biodegradable plastics for food packaging application-review of properties and recent developments. *Food Additives & Contaminants: Part A, 37*(4), 665-680.

Dirim, S. N., Özden, H. Ö., Bayındırlı, A., & Esin, A. (2004). Modification of water vapour transfer rate of low density polyethylene films for food packaging. *Journal of Food Engineering, 63*(1), 9-13.

Domene-López, D., García-Quesada, J. C., Martin-Gullon, I., & Montalbán, M. G. (2019). Influence of starch composition and molecular weight on physicochemical properties of biodegradable films. *Polymers, 11*(7), 1084.

Dong, H., & Vasanthan, T. (2020). Effect of phosphorylation techniques on structural, thermal, and pasting properties of pulse starches in comparison with corn starch. Food Hydrocolloids, 106078.

Duanmu, J., Gamstedt, E. K., Pranovich, A., & Rosling, A. (2010). Studies on mechanical properties of wood fiber reinforced cross-linked starch composites made from enzymatically degraded allylglycidyl ether-modified starch. Composites Part A: Applied Science and Manufacturing, 41(10), 1409-1418.

Dungani, R., Aditiawati, P., Aprilia, S., Yuniarti, K., Karliati, T., Suwandhi, I., & Sumardi, I. (2018). Biomaterial from Oil Palm Waste: Properties, Characterization and Applications. *Palm Oil*, 31.

Egharevba, H. O. (2019). Chemical properties of starch and its application in the food industry. In *Chemical properties of starch* (p. 63). IntechOpen.

Engel, J. B., Ambrosi, A., & Tessaro, I. C. (2019). Development of biodegradable starch-based foams incorporated with grape stalks for food packaging. *Carbohydrate polymers*, *225*, 115234.

Esmaeili, M., Pircheraghi, G., & Bagheri, R. (2017). Optimizing the mechanical and physical properties of thermoplastic starch via tuning the molecular microstructure through co-plasticization by sorbitol and glycerol. *Polymer international*, *66*(6), 809-819.

Fahrngruber, B., Fortea-Verdejo, M., Wimmer, R., & Mundigler, N. (2020). Starch/poly (butylene succinate) compatibilizers: effect of different reaction-approaches on the properties of thermoplastic starch-based compostable films. Journal of Polymers and the Environment, 28(1), 257-270.

Farahnaky, A., Saberi, B., & Majzoobi, M. (2013). Effect of glycerol on physical and mechanical properties of wheat starch edible films. *Journal of Texture Studies*, *44*(3), 176-186.

Fallon, J. J., McKnight, S. H., & Bortner, M. J. (2019). Highly loaded fiber filled polymers for material extrusion: A review of current understanding. *Additive Manufacturing*, *30*, 100810.

Ferreira, A., Alves, V., & Coelhoso, I. (2016). Polysaccharide-based membranes in food packaging applications. *Membranes*, *6*(2), 22.

Ferri, J. M., Fenollar, O., Jorda-Vilaplana, A., García-Sanoguera, D., & Balart, R. (2018). Effect of miscibility on mechanical and thermal properties of poly (lactic acid)/polycaprolactone blends. *Polymer International*, *65*(4), 453-463.

Folino, A., Karageorgiou, A., Calabrò, P. S., & Komilis, D. (2020). Biodegradation of wasted bioplastics in natural and industrial environments: A review. *Sustainability*, *12*(15), 6030.

Formela, K., Zedler, Ł., Hejna, A., & Tercjak, A. (2018). Reactive extrusion of bio-based polymer blends and composites-Current trends and future developments. *Express Polymer Letters*, *12*(1).

Frollini, E., Bartolucci, N., Sisti, L., & Celli, A. (2013). Poly (butylene succinate) reinforced with different lignocellulosic fibers. Industrial Crops and Products, 45, 160-169.

Gadhave, R. V., Das, A., Mahanwar, P. A., & Gadekar, P. T. (2018). Starch based bio-plastics: the future of sustainable packaging.

Gao, J., Vasanthan, T., Hoover, R., & Li, J. (2012). Structural modification of waxy, regular, and high-amylose maize and hulless barley starches on partial acid hydrolysis and their impact on physicochemical properties and chemical modification. *Starch-Stärke*, *64*(4), 313-325.

Gao, C., Pollet, E., & Avérous, L. (2017). Properties of glycerol-plasticized alginate films obtained by thermo-mechanical mixing. *Food hydrocolloids*, *63*, 414-420.

Garcia, M. A. V. T., Garcia, C. F., & Faraco, A. A. G. (2020). Pharmaceutical and biomedical applications of native and modified starch: A review. *Starch-Stärke*, *72*(7-8), 1900270.

Gautam, N., & Kaur, I. (2013). Soil burial biodegradation studies of starch grafted polyethylene and identification of Rhizobium meliloti therefrom. *Journal of Environmental Chemistry and Ecotoxicology*, *5*(6), 147-158.

Georgousopoulou, I.-N., Vouyiouka, S., Dole, P., & Papaspyrides, C. D. (2016). Thermo-mechanical degradation and stabilization of poly (butylene succinate). *Polymer degradation and stability*, *128*, 182-192.

Gaenssle, A. L., van der Maarel, M. J., & Jurak, E. (2020). Reliability factor for identification of amylolytic enzyme activity in the optimized starch-iodine assay. *Analytical biochemistry*, *597*, 113696.

Gigli, M., Fabbri, M., Lotti, N., Gamberini, R., Rimini, B., & Munari, A. (2016). Poly (butylene succinate)-based polyesters for biomedical applications: A review. *European Polymer Journal*, *75*, 431-460.

Ginzburg, V. V. (2005). Influence of nanoparticles on miscibility of polymer blends. A simple theory. *Macromolecules*, *38*(6), 2362-2367.

Gu, X., Xu, T., & Ni, F. (2014). Rheological behavior of basalt fiber reinforced asphalt mastic. *Journal of Wuhan University of Technology-Mater. Sci. Ed.*, *29*(5), 950-955.

Gumede, T. P., Luyt, A. S., & Muller, A. J. (2018). Review on PCL, PBS, and PCL/PBS blends containing carbon nanotubes.

Guillard, V., Gaucel, S., Fornaciari, C., Angellier-Coussy, H., Buche, P., & Gontard, N. (2018). The next generation of sustainable food packaging to preserve our environment in a circular economy context. *Frontiers in nutrition*, *5*, 121.

Gutiérrez, T. J. (2018). Biodegradability and compostability of food nanopackaging materials. *Composite materials for food packaging*, 269-296.

Guo, R., Azaiez, J., & Bellehumeur, C. (2005). Rheology of fiber filled polymer melts: Role of fiber-fiber interactions and polymer-fiber coupling. *Polymer Engineering & Science*, *45*(3), 385-399.

Gupta, M. K., Srivastava, R. K., & Bisaria, H. (2015). Potential of jute fibre reinforced polymer composites: a review. International Journal of Fiber and Textile Research, 5(3), 30-38.https://www.zionmarketresearch.com/report/packaging-materials-market, 2021.

Hamzah, N., Tokimatsu, K., & Yoshikawa, K. (2019). Solid fuel from oil palm biomass residues and municipal solid waste by hydrothermal treatment for electrical power generation in Malaysia: A review. *Sustainability*, *11*(4), 1060.

Han, J. H. (2005). *Innovations in food packaging*: Elsevier.

Han, J., Shi, J., Xie, Z., Xu, J., & Guo, B. (2019). Synthesis, Properties of Biodegradable Poly (Butylene Succinate-co-Butylene 2-Methylsuccinate) and Application for Sustainable Release. Materials, 12(9), 1507.

Han, J. W., Ruiz-Garcia, L., Qian, J. P., & Yang, X. T. (2018). Food packaging: A comprehensive review and future trends. *Comprehensive Reviews in Food Science and Food Safety*, *17*(4), 860-877.

Harmaen, A. S., Khalina, A., Azowa, I., Hassan, M. A., Tarmian, A., & Jawaid, M. (2015). Thermal and biodegradation properties of poly (lactic acid)/fertilizer/oil palm fibers blends biocomposites. *Polymer Composites*, *36*(3), 576-583.

Hassan, N. A. A., Ahmad, S., Chen, R. S., & Shahdan, D. (2020). Cells analyses, mechanical and thermal stability of extruded polylactic acid/kenaf bio-composite foams. *Construction and Building Materials*, *240*, 117884.

Horstmann, S. W., Lynch, K. M., & Arendt, E. K. (2017). Starch characteristics linked to gluten-free products. *Foods*, *6*(4), 29.

Hoffmann, G. A., Wienke, A., Reitberger, T., Franke, J., Kaierle, S., & Overmeyer, L. (2020). Thermoforming of planar polymer optical waveguides for integrated optics in smart packaging materials. *Journal of Materials Processing Technology*, *285*, 116763.

Hsieh, C. F., Liu, W., Whaley, J. K., & Shi, Y. C. (2019). Structure, properties, and potential applications of waxy tapioca starches–A review. Trends in Food Science & Technology, 83, 225-234.

Huang, Z., Qian, L., Yin, Q., Yu, N., Liu, T., & Tian, D. (2018). Biodegradability studies of poly (butylene succinate) composites filled with sugarcane rind fiber. *Polymer Testing*, *66*, 319-326.

Huang, J., Wei, M., Ren, R., Li, H., Liu, S., & Yang, D. (2017). Morphological changes of blocklets during the gelatinization process of tapioca starch. *Carbohydrate polymers*, *163*, 324-329.

Huang, S., Chao, C., Yu, J., Copeland, L., & Wang, S. (2021). New insight into starch retrogradation: the effect of short-range molecular order in gelatinized starch. *Food Hydrocolloids*, 106921.

Hyvarinen, M., Jabeen, R., & Kärki, T. (2020). The Modelling of Extrusion Processes for Polymers—A Review. *Polymers*, *12*(6), 1306.

Ibrahim, B., & Fakhre, N. (2019). Crown ether modification of starch for adsorption of heavy metals from synthetic wastewater. *International journal of biological macromolecules*, *123*, 70-80.

Ibrahim, I. D., Jamiru, T., Sadiku, R. E., Kupolati, W. K., Agwuncha, S. C., & Ekundayo, G. (2015). The use of polypropylene in bamboo fibre composites and their mechanical properties–A review. Journal of Reinforced Plastics and Composites, 34(16), 1347-1356.

Ibrahim, N. A., Yunus, W. M. Z. W., Othman, M., Abdan, K., & Hadithon, K. A. (2010). Poly (lactic acid)(PLA)-reinforced kenaf bast fiber composites: the effect of triacetin. *Journal of reinforced plastics and composites*, *29*(7), 1099-1111.

Ibrahim, H., Mehanny, S., Darwish, L., & Farag, M. (2018). A comparative study on the mechanical and biodegradation characteristics of starch-based composites reinforced with different lignocellulosic fibers. Journal of Polymers and the Environment, 26(6), 2434-2447.

Imre, B., & Pukanszky, B. (2013). Compatibilization in bio-based and biodegradable polymer blends. *European Polymer Journal, 49*(6), 1215-1233.

Ishak, Z. I., Sairi, N. A., Alias, Y., Aroua, M. K. T., & Yusoff, R. (2017). A review of ionic liquids as catalysts for transesterification reactions of biodiesel and glycerol carbonate production. *Catalysis Reviews*, *59*(1), 44-93.

Jamaluddin, N., Razaina, M., & Ishak, Z. M. (2016). Mechanical and morphology behaviours of polybutylene (succinate)/thermoplastic polyurethaneblend. *Procedia Chemistry, 19,* 426-432.

Janssen, L. P. B. M., & Moscicki, L. (2006). Thermoplastic starch as packaging material. Acta Sci. Pol., Technica Agraria, 5(1), 19-25.

Jawaid, M., & Khalil, H. A. (2011). Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review. *Carbohydrate polymers*, *86*(1), 1-18.

Jawaid, M., Khalil, H. A., Khanam, P. N., & Bakar, A. A. (2011). Hybrid composites made from oil palm empty fruit bunches/jute fibres: Water absorption, thickness swelling and density behaviours. *Journal of Polymers and the Environment*, *19*(1), 106-109.

Jariyasakoolroj, P., & Chirachanchai, S. (2015). Silane modified starch for compatible reactive blend with poly (lactic acid). *Carbohydrate polymers*, *106*, 255-263.

Jeong, S.-W. (2019). Shear Rate-Dependent Rheological Properties of Mine Tailings: Determination of Dynamic and Static Yield Stresses. *Applied Sciences, 9*(22), 4744.

Jem, K. J., & Tan, B. (2020). The development and challenges of poly (lactic acid) and poly (glycolic acid). *Advanced Industrial and Engineering Polymer Research*, *3*(2), 60-70.

Jiang, S., Yang, Y., Ge, S., Zhang, Z., & Peng, W. (2018). Preparation and properties of novel flame-retardant PBS wood-plastic composites. *Arabian journal of chemistry*, *11*(6), 844-857.

Jiang, T., Duan, Q., Zhu, J., Liu, H., & Yu, L. (2020). Starch-based biodegradable materials: Challenges and opportunities. *Advanced Industrial and Engineering Polymer Research*, *3*(1), 8-18.

Jiang, Y., & Loos, K. (2016). Enzymatic synthesis of biobased polyesters and polyamides. *Polymers*, *8*(7), 243.

Jiang, X., Yu, Y., Guan, Y., Liu, T., Pang, C., Ma, J., & Gao, H. (2020). Random and multiblock PBS copolyesters based on a rigid diol derived from naturally occurring camphor: Influence of chemical microstructure on thermal and mechanical properties. *ACS Sustainable Chemistry & Engineering*, *8*(9), 3626-3636.

Jumaidin, R., Khiruddin, M. A. A., Saidi, Z. A. S., Salit, M. S., & Ilyas, R. A. (2020). Effect of cogon grass fibre on the thermal, mechanical and biodegradation properties of thermoplastic cassava starch biocomposite. *International journal of biological macromolecules*, *146*, 746-755.

Kaewtatip, K., Poungroi, M., Holló, B., & Szécsényi, K. M. (2014). Effects of starch types on the properties of baked starch foams. *Journal of Thermal Analysis and Calorimetry*, *115*(1), 833-840.

Kamarudin, S. H., Abdullah, L. C., Aung, M. M., Ratnam, C. T., & Jusoh, E. R. (2018). A study of mechanical and morphological properties of PLA based biocomposites prepared with EJO vegetable oil based plasticiser and kenaf fibres. *Materials Research Express*, *5*(8), 085314.

Kang, K. H., Han, S. J., Lee, J. W., Kim, T. H., & Song, I. K. (2016). Effect of boron content on 1, 4-butanediol production by hydrogenation of succinic acid over Re-Ru/BMC (boron-modified mesoporous carbon) catalysts. *Applied Catalysis A: General*, *524*, 206-213.

Kasmi, N., Majdoub, M., Papageorgiou, G. Z., & Bikiaris, D. N. (2018). Synthesis and crystallization of new fully renewable resources-based copolyesters: Poly (1, 4-cyclohexanedimethanol-co-isosorbide 2, 5-furandicarboxylate). *Polymer degradation and stability*, *152*, 177-190.

Koto, N., & Soegijono, B. (2019, March). Analysis of Damage Area of Fiberglass/Polyester Bi-Panel Composite With Tapioca Starch Filler Through a Ballistic Test. In *Journal of Physics: Conference Series* (Vol. 1191, No. 1, p. 012055). IOP Publishing.

Khan, B., Bilal Khan Niazi, M., Samin, G., & Jahan, Z. (2017). Thermoplastic starch: a possible biodegradable food packaging material—a review. Journal of Food Process Engineering, 40(3), e12447.

Khai, K. H., Putra, A., & Selamat, M. Z. (2017). Oil palm empty fruit bunch fibres as sustainable acoustic absorber. *Applied Acoustics*, *119*, 9-16.

Khalil, H. A., Jawaid, M., & Bakar, A. A. (2011). Woven hybrid composites: water absorption and thickness swelling behaviours. *BioResources, 6*(2), 1043-1052.

Khalil, H. A., Saurabh, C. K., Syakir, M. I., Fazita, M. N., Bhat, A., Banerjee, A., & Tahir, P. M. (2019). Barrier properties of biocomposites/hybrid films. In *Mechanical and physical testing of biocomposites, fibre-reinforced composites and hybrid composites* (pp. 241-258). Woodhead Publishing.

Khanam, P. N., Khalil, H. A., Reddy, G. R., & Naidu, S. V. (2011). Tensile, flexural and chemical resistance properties of sisal fibre reinforced polymer composites: effect of fibre surface treatment. *Journal of Polymers and the Environment*, *19*(1), 115-119.

Khatoon, S., Sreerama, Y., Raghavendra, D., Bhattacharya, S., & Bhat, K. (2009). Properties of enzyme modified corn, rice and tapioca starches. *Food research international*, *42*(10), 1426-1433.

Kim, J., & Hwangbo, H. (2019). Real-time early warning system for sustainable and intelligent plastic film manufacturing. *Sustainability*, *11*(5), 1490.

Kim, S. (2018). Enhancing bioethanol productivity using alkali-pretreated empty palm fruit bunch fiber hydrolysate. *BioMed research international*, *2018*.

Kizil, R., Irudayaraj, J., & Seetharaman, K. (2002). Characterization of irradiated starches by using FT-Raman and FTIR spectroscopy. *Journal of agricultural and food chemistry, 50*(14), 3912-3918.

Krishnan, P. (2016). Rheology of Epoxy/Rubber Blends.

Kumar, R., Ul Haq, M. I., Raina, A., & Anand, A. (2019). Industrial applications of natural fibre-reinforced polymer composites–challenges and opportunities. International Journal of Sustainable Engineering, 12(3), 212-220.

Lafleur, P. G., & Vergnes, B. (2016). *Polymer extrusion*: John Wiley & Sons.

Lau, K. T., Hung, P. Y., Zhu, M. H., & Hui, D. (2018). Properties of natural fibre composites for structural engineering applications. Composites Part B: Engineering, 136, 222-233.

Lavorgna, M., Piscitelli, F., Mangiacapra, P., & Buonocore, G. G. (2010). Study of the combined effect of both clay and glycerol plasticizer on the properties of chitosan films. *Carbohydrate polymers*, *82*(2), 291-298.

Lee, C., Sapuan, S., & Hassan, M. (2018). Thermal analysis of kenaf fiber reinforced floreon biocomposites with magnesium hydroxide flame retardant filler. *Polymer Composites, 39*(3), 869-875.

Lee, C., Sapuan, S., Lee, J., & Hassan, M. (2016). Mechanical properties of kenaf fibre reinforced floreon biocomposites with magnesium hydroxide filler. *Journal of Mechanical Engineering and Sciences, 10*(3), 2234-2248.

Lee, J. K., & Han, C. D. (2000). Evolution of polymer blend morphology during compounding in a twin-screw extruder. *Polymer, 41*(5), 1799-1815.

Lee, S. Y. (2012). Residence time distribution of tapioca starch-poly (lactic acid)-Cloisite 10A nanocomposite foams in an extruder. Pertanika Journal of Science and Technology, 20(1), 103-108.

Lee, C. H., Khalina, A., & Lee, S. H. (2021). Importance of interfacial adhesion condition on characterization of plant-fiber-reinforced polymer composites: a review. *Polymers*, *13*(3), 438.

Liang, Z., Pan, P., Zhu, B., Dong, T., & Inoue, Y. (2016). Mechanical and thermal properties of poly (butylene succinate)/plant fiber biodegradable composite. Journal of applied polymer science, 115(6), 3559-3567.

Li, J., Luo, X., Lin, X., & Zhou, Y. (2013). Comparative study on the blends of PBS/thermoplastic starch prepared from waxy and normal corn starches. *Starch-Stärke, 65*(9-10), 831-839.

Li, Y.-D., Zeng, J.-B., Wang, X.-L., Yang, K.-K., & Wang, Y.-Z. (2008). Structure and properties of soy protein/poly (butylene succinate) blends with improved compatibility. *Biomacromolecules, 9*(11), 3157-3164.

Li, M., Pu, Y., Thomas, V. M., Yoo, C. G., Ozcan, S., Deng, Y., & Ragauskas, A. J. (2020). Recent advancements of plant-based natural fiber–reinforced composites and their applications. *Composites Part B: Engineering*, 108254.

Liu, R., Morrell, J. J., & Yan, L. (2018). Thermogravimetric analysis studies of thermally-treated glycerol impregnated poplar wood. *BioResources*, *13*(1), 1563-1575.

Liu, H., Adhikari, R., Guo, Q., & Adhikari, B. (2013). Preparation and characterization of glycerol plasticized (high-amylose) starch–chitosan films. *Journal of Food Engineering, 116*(2), 588-597.

Liu, L., Yu, J., Cheng, L., & Qu, W. (2009). Mechanical properties of poly (butylene succinate)(PBS) biocomposites reinforced with surface modified jute fibre. *Composites Part A: Applied Science and Manufacturing*, *40*(5), 669-674.

Liu, L., Yu, J., Cheng, L., & Yang, X. (2009). Biodegradability of poly (butylene succinate)(PBS) composite reinforced with jute fibre. *Polymer Degradation and Stability, 94*(1), 90-94.

Liu, W., Mohanty, A. K., Askeland, P., Drzal, L. T., & Misra, M. (2004). Influence of fiber surface treatment on properties of Indian grass fiber reinforced soy protein based biocomposites. *Polymer*, *45*(22), 7589-7596.

Likittheerakarn, S. U. P. P. A. W. A. T., Kurdpradid, S. U. P. A. W. A. D. E. E., Smittipornpun, N. A. N. T. H. A. P. O. N., & Sritapunya, T. (2017). Comparison of mechanical properties of biocomposites between polybutylene succinate/corn silk and polybutylene succinate/cellulose extracted from corn silk. In *Key Engineering Materials* (Vol. 737, pp. 275-280). Trans Tech Publications Ltd.

Liminana, P., Garcia-Sanoguera, D., Quiles-Carrillo, L., Balart, R., & Montanes, N. (2018). Development and characterization of environmentally friendly composites from poly (butylene succinate)(PBS) and almond shell flour with different compatibilizers. Composites Part B: Engineering, 144, 153-162.

Liminana, P., Garcia-Sanoguera, D., Quiles-Carrillo, L., Balart, R., & Montanes, N. (2019). Optimization of maleinized linseed oil loading as a biobased compatibilizer in poly (butylene succinate) composites with almond shell flour. Materials, 12(5), 685.

Lu, Y., Wu, C., & Xu, S. (2018). Mechanical, thermal and flame retardant properties of magnesium hydroxide filled poly (vinyl chloride) composites: The effect of filler shape. *Composites Part A: Applied Science and Manufacturing*, *113*, 1-11.

Lu, Z.-H., Donner, E., Yada, R. Y., & Liu, Q. (2016). Physicochemical properties and in vitro starch digestibility of potato starch/protein blends. *Carbohydrate polymers*, *154*, 214-222.

Madhu, P., Sanjay, M. R., Senthamaraikannan, P., Pradeep, S., Saravanakumar, S. S., & Yogesha, B. (2018). A review on synthesis and characterization of commercially available natural fibers: Part-I. *Journal of Natural Fibers*.

Mahmood, K., Kamilah, H., Shang, P. L., Sulaiman, S., & Ariffin, F. (2017). A review: Interaction of starch/non-starch hydrocolloid blending and the recent food applications. Food bioscience, 19, 110-120.

Mahmoudi Yayshahri, A., Peighambardoust, S. J., & Shenavar, A. (2019). Impact, thermal and biodegradation properties of high impact polystyrene/corn starch blends processed via melt extrusion. *Polyolefins Journal*, *6*(2), 151-158.

Mahjoub, R., Bin Mohamad Yatim, J., & Mohd Sam, A. R. (2013). A review of structural performance of oil palm empty fruit bunch fiber in polymer composites. Advances in Materials Science and Engineering, 2013.

Mano, J. F., Koniarova, D., & Reis, R. (2003). Thermal properties of thermoplastic starch/synthetic polymer blends with potential biomedical applicability. *Journal of materials science: Materials in medicine, 14*(2), 127-135.

Manson, J. A. (2012). *Polymer blends and composites*: Springer Science & Business Media.

Malkin, A. Y., & Isayev, A. I. (2017). *Rheology: concepts, methods, and applications*. Elsevier.

Maran, J. P., Sivakumar, V., Thirugnanasambandham, K., & Sridhar, R. (2014). Degradation behavior of biocomposites based on cassava starch buried under indoor soil conditions. *Carbohydrate polymers, 101*, 20-28.

Mariani, P., Allganer, K., Oliveira, F., Cardoso, E. J. B. N., & Innocentini-Mei, L. H. (2009). Effect of soy protein isolate on the thermal, mechanical and morphological properties of poly (ε-caprolactone) and corn starch blends. *Polymer testing, 28*(8), 824-829.

Marichelvam, M. K., Jawaid, M., & Asim, M. (2019). Corn and rice starch-based bio-plastics as alternative packaging materials. *Fibers*, *7*(4), 32.

Markovic, G., & Visakh, P. (2017). Recent Developments in Polymer Macro, Micro and Nano Blends.

Marvizadeh, M. M., Oladzadabbasabadi, N., Nafchi, A. M., & Jokar, M. (2017). Preparation and characterization of bionanocomposite film based on tapioca starch/bovine gelatin/nanorod zinc oxide. *International journal of biological macromolecules, 99*, 1-7.

Masina, N., Choonara, Y. E., Kumar, P., du Toit, L. C., Govender, M., Indermun, S., & Pillay, V. (2017). A review of the chemical modification techniques of starch. *Carbohydrate polymers, 157*, 1226-1236.

Matignon, A., & Tecante, A. (2017). Starch retrogradation: From starch components to cereal products. Food Hydrocolloids, 68, 43-52.

Matos Costa, A. R., Crocitti, A., Hecker de Carvalho, L., Carroccio, S. C., Cerruti, P., & Santagata, G. (2020). Properties of Biodegradable Films Based on Poly (butylene Succinate)(PBS) and Poly (butylene Adipate-co-Terephthalate)(PBAT) Blends. *Polymers, 12*(10), 2317.

Maubane, L., Ray, S. S., & Jalama, K. (2017). The effect of starch amylose content on the morphology and properties of melt-processed butyl-etherified starch/poly [(butylene succinate)-co-adipate] blends. *Carbohydrate polymers, 155*, 89-100.

Mazhandu, Z. S., Muzenda, E., Mamvura, T. A., & Belaid, M. (2020). Integrated and Consolidated Review of Plastic Waste Management and Bio-Based Biodegradable Plastics: Challenges and Opportunities. Sustainability, 12(20), 8360.

McCool, R., & Martin, P. J. (2010). The role of process parameters in determining wall thickness distribution in plug-assisted thermoforming. Polymer Engineering & Science, 50(10), 1923-1934.

Mehdizadeh, T., Tajik, H., Rohani, S. M. R., & Oromiehie, A. R. (2012). Antibacterial, antioxidant and optical properties of edible starch-chitosan composite film containing *Thymus kotschyanus essential oil.* Paper presented at the Veterinary Research Forum.

Meng, R., Wu, Z., Xie, H. Q., Xu, G. X., Cheng, J. S., & Zhang, B. (2020). Preparation, characterization, and encapsulation capability of the hydrogel cross-linked by esterified tapioca starch. *International journal of biological macromolecules*, *155*, 1-5.

Meereboer, K. W., Misra, M., & Mohanty, A. K. (2020). Review of recent advances in the biodegradability of polyhydroxyalkanoate (PHA) bioplastics and their composites. *Green Chemistry*, *22*(17), 5519-5558.

Mello, L. R., & Mali, S. (2014). Use of malt bagasse to produce biodegradable baked foams made from cassava starch. Industrial Crops and Products, 55, 187-193.

Merieux, J., Hurley, S., Lubrecht, A., & Cann, P. (2000). Shear-degradation of grease and base oil availability in starved EHL lubrication *Tribology series* (Vol. 38, pp. 581-588): Elsevier.

Miles, I. S., & Zurek, A. (1988). Preparation, structure, and properties of two-phase co-continuous polymer blends. *Polymer Engineering & Science, 28*(12), 796-805.

Mishra, M. (2015). Encapsulation via Hot-Melt Extrusion *Handbook of Encapsulation and Controlled Release* (pp. 237-258): CRC Press.

Miculescu, F., Maidaniuc, A., Voicu, S. I., Thakur, V. K., Stan, G. E., & Ciocan, L. T. (2017). Progress in hydroxyapatite–starch based sustainable biomaterials for biomedical bone substitution applications. ACS Sustainable Chemistry & Engineering, 5(10), 8491-8512.

Mikulionok, I., Gavva, O., & Kryvoplias-Volodina, L. (2018). Modeling the process of polymers processing in twin-screw extruders. *Восточно-Европейский журнал передовых технологий*, (4 (5)), 35-44.

Minchenkov, K., Vedernikov, A., Safonov, A., & Akhatov, I. (2021). Thermoplastic Pultrusion: A Review. *Polymers, 13*(2), 180.

Mohammed, L., Ansari, M. N., Pua, G., Jawaid, M., & Islam, M. S. (2015). A review on natural fiber reinforced polymer composite and its applications. *International Journal of Polymer Science, 2015*.

Monroy, Y., Rivero, S., & García, M. A. (2018). Microstructural and techno-functional properties of cassava starch modified by ultrasound. *Ultrasonics sonochemistry, 42*, 795-804.

Moorthy, S. N. (2002). Physicochemical and functional properties of tropical tuber starches: a review. *Starch-Stärke, 54*(12), 559-592.

Morales, R. A., Candal, M. V., Santana, O. O., Gordillo, A., & Salazar, R. (2014). Effect of the thermoforming process variables on the sheet friction coefficient. *Materials & Design, 53*, 1097-1103.

Mochane, M. J., Magagula, S. I., Sefadi, J. S., & Mokhena, T. C. (2021). A Review on Green Composites Based on Natural Fiber-Reinforced Polybutylene Succinate (PBS). *Polymers*, *13*(8), 1200.

Moeini, A., Mallardo, S., Cimmino, A., Dal Poggetto, G., Masi, M., Di Biase, M., ... & Santagata, G. (2020). Thermoplastic starch and bioactive chitosan sub-microparticle biocomposites: Antifungal and chemico-physical properties of the films. *Carbohydrate polymers*, *230*, 115627.

Mohammadinejad, R., Karimi, S., Iravani, S., & Varma, R. S. (2016). Plant-derived nanostructures: types and applications. *Green Chemistry, 18*(1), 20-52.

Munthoub, D. I., & Rahman, W. (2011). Tensile and water absorption properties of biodegradable composites derived from cassava skin/polyvinyl alcohol with glycerol as plasticizer. *Sains Malaysiana, 40*(7), 713-718.

Muthuraj, R., Misra, M., & Mohanty, A. K. (2018). Biodegradable compatibilized polymer blends for packaging applications: A literature review. *Journal of Applied Polymer Science*, *135*(24), 45726.

Muthuraj, R., Misra, M., & Mohanty, A. K. (2014). Biodegradable Poly (butylene succinate) and Poly (butylene adipate-co-terephthalate) Blends: Reactive Extrusion and Performance Evaluation. Journal of Polymers and the Environment, 22(3), 336-349.

Muller, J., Gonzalez-Martinez, C., & Chiralt, A. (2017). Combination of poly (lactic) acid and starch for biodegradable food packaging. Materials, 10(8), 952.

Nagalakshmaiah, M., Afrin, S., Malladi, R. P., Elkoun, S., Robert, M., Ansari, M. A., & Karim, Z. (2019). Biocomposites: present trends and challenges for the future. In Green Composites for Automotive Applications (pp. 197-215). Woodhead Publishing.

Nardi, V. G. (2018). A numerical study of particles settling in power law fluids using lattice-Boltzmann method (Universidade Tecnológica Federal do Paraná).

Nakajima, H., Dijkstra, P., & Loos, K. (2017). The recent developments in biobased polymers toward general and engineering applications: Polymers that are upgraded from biodegradable polymers, analogous to petroleum-derived polymers, and newly developed. *Polymers, 9*(10), 523.

Nam, T. H., Ogihara, S., Nakatani, H., Kobayashi, S., & Song, J. I. (2012). Mechanical and thermal properties and water absorption of jute fiber reinforced poly (butylene succinate) biodegradable composites. *Advanced composite materials, 21*(3), 241-258.

Nanni, A., Cancelli, U., Montevecchi, G., Masino, F., Messori, M., & Antonelli, A. (2021). Functionalization and use of grape stalks as poly (butylene succinate)(PBS) reinforcing fillers. *Waste Management*, *126*, 538-548.

Nazrin, A., Sapuan, S. M., & Zuhri, M. Y. M. (2020). Mechanical, Physical and Thermal Properties of Sugar Palm Nanocellulose Reinforced Thermoplastic Starch (TPS)/Poly (Lactic Acid)(PLA) Blend Bionanocomposites. Polymers, 12(10), 2216.

Nassar, M. M., Arunachalam, R., & Alzebdeh, K. I. (2017). Machinability of natural fiber reinforced composites: a review. *The International Journal of Advanced Manufacturing Technology*, *88*(9-12), 2985-3004.

Ncube, L. K., Ude, A. U., Ogunmuyiwa, E. N., Zulkifli, R., & Beas, I. N. (2020). Environmental Impact of Food Packaging Materials: A Review of Contemporary Development from Conventional Plastics to Polylactic Acid Based Materials. *Materials*, *13*(21), 4994.

Nghiem, N., Kleff, S., & Schwegmann, S. (2017). Succinic acid: technology development and commercialization. *Fermentation*, *3*(2), 26.

Nguong, C., Lee, S., & Sujan, D. (2016). A review on natural fibre reinforced polymer composites. Paper presented at the Proceedings of world academy of science, engineering and technology.

Niranjana Prabhu, T., & Prashantha, K. (2018). A review on present status and future challenges of starch based polymer films and their composites in food packaging applications. Polymer Composites, 39(7), 2499-2522.

Nilagiri, K. B., & Ramesh, T. (2018). Role, effect, and influences of micro and nano-fillers on various properties of polymer matrix composites for microelectronics: a review. *Polymers for Advanced Technologies*, *29*(6), 1568-1585.

Norizan, M. N., Abdan, K., Salit, M. S., & Mohamed, R. (2017). Physical, mechanical and thermal properties of sugar palm yarn fibre loading on reinforced unsaturated polyester composites. *Journal of Physical Science*, *28*(3), 115-136.

Norrrahim, M. N. F., Ariffin, H., Yasim-Anuar, T. A. T., Hassan, M. A., Nishida, H., & Tsukegi, T. (2018, June). One-pot nanofibrillation of cellulose and nanocomposite production in a twin-screw extruder. In IOP Conf. Ser. Mater. Sci. Eng. (Vol. 368, pp. 1-9).

Nofar, M., Sacligil, D., Carreau, P. J., Kamal, M. R., & Heuzey, M. C. (2019). Poly (lactic acid) blends: Processing, properties and applications. International journal of biological macromolecules, 125, 307-360.

Nordin, N., Othman, S. H., Rashid, S. A., & Basha, R. K. (2020). Effects of glycerol and thymol on physical, mechanical, and thermal properties of corn starch films. *Food Hydrocolloids*, *106*, 105884.

Nomanbhay, S., Hussein, R., & Ong, M. Y. (2018). Sustainability of biodiesel production in Malaysia by production of bio-oil from crude glycerol using microwave pyrolysis: a review. *Green Chemistry Letters and Reviews*, *11*(2), 135-157.

Nurazzi, N. M., Asyraf, M. R. M., Khalina, A., Abdullah, N., Aisyah, H. A., Rafiqah, S., . & Sapuan, S. M. (2021). A review on natural fiber reinforced polymer composite for bullet proof and ballistic applications. *Polymers*, *13*(4), 646.

Oh, S. M., Choi, H. D., Choi, H. W., & Baik, M. Y. (2020). Starch Retrogradation in Rice Cake: Influences of Sucrose Stearate and Glycerol. *Foods*, *9*(12), 1737.

Onoja, E., Chandren, S., Razak, F. I. A., Mahat, N. A., & Wahab, R. A. (2019). Oil palm (Elaeis guineensis) biomass in Malaysia: the present and future prospects. *Waste and Biomass Valorization*, *10*(8), 2099-2117.

Okoye, P. U., Abdullah, A. Z., & Hameed, B. H. (2017). A review on recent developments and progress in the kinetics and deactivation of catalytic acetylation of glycerol—A byproduct of biodiesel. *Renewable and Sustainable Energy Reviews*, *74*, 387-401.

Otto, S., Strenger, M., Maier-Nöth, A., & Schmid, M. (2021). Food packaging and sustainability–Consumer perception vs. correlated scientific facts: A review. *Journal of Cleaner Production*, 126733.

Pak, E. S., Ghaghelestani, S. N., & Najafi, M. A. (2020). Preparation and characterization of a new edible film based on Persian gum with glycerol plasticizer. *Journal of Food Science and Technology*, *57*(9), 3284-3294.

Pantani, R., & Sorrentino, A. (2013). Influence of crystallinity on the biodegradation rate of injection-moulded poly (lactic acid) samples in controlled composting conditions. *Polymer degradation and stability*, *98*(5), 1089-1096.

Pang, Z., Xu, R., Luo, T., Che, X., Bansal, N., & Liu, X. (2019). Physiochemical properties of modified starch under yogurt manufacturing conditions and its relation to the properties of yogurt. *Journal of food engineering*, *245*, 11-17.

Pappu, A., Pickering, K. L., & Thakur, V. K. (2019). Manufacturing and characterization of sustainable hybrid composites using sisal and hemp fibres as reinforcement of poly (lactic acid) via injection moulding. *Industrial Crops and Products*, *137*, 260-269.

Pathak, V. M. (2017). Review on the current status of polymer degradation: a microbial approach. Bioresources and Bioprocessing, 4(1), 15.

Pecas, P., Carvalho, H., Salman, H., & Leite, M. (2018). Natural fibre composites and their applications: a review. Journal of Composites Science, 2(4), 66.

Pemberton, R., Summerscales, J., & Graham-Jones, J. (Eds.). (2018). *Marine composites: design and performance*. Woodhead Publishing.

Pickering, K. L., Efendy, M. A., & Le, T. M. (2016). A review of recent developments in natural fibre composites and their mechanical performance. *Composites Part A: Applied Science and Manufacturing, 83*, 98-112.

Platnieks, O., Gaidukovs, S., Barkane, A., Sereda, A., Gaidukova, G., Grase, L., ... & Laka, M. (2020). Bio-based poly (butylene succinate)/microcrystalline cellulose/nanofibrillated cellulose-based sustainable polymer composites: Thermo-mechanical and biodegradation studies. *Polymers*, *12*(7), 1472.

Poli, P. A. K. (2013). Effect of maleated compatibiliser (PBS-g-MA) addition on the flexural properties and water absorption of poly (butylene succinate)/kenaf bast fibre composites. *Sains Malaysiana*, *42*(4), 435-441.

Pourfarzad, A., Yousefi, A., & Ako, K. (2021). Steady/dynamic rheological characterization and FTIR study on wheat starch-sage seed gum blends. *Food Hydrocolloids, 111*, 106380.

Pozo, C., Rodriguez-Llamazares, S., Bouza, R., Barral, L., Castano, J., Muller, N., & Restrepo, I. (2018). Study of the structural order of native starch granules using combined FTIR and XRD analysis. Journal of Polymer Research, 25(12), 266.

Polman, E. M., Gruter, G. J. M., Parsons, J. R., & Tietema, A. (2020). Comparison of the aerobic biodegradation of biopolymers and the corresponding bioplastics: A review. Science of The Total Environment, 141953.

Pradima, J., & Kulkarni, M. R. (2017). Review on enzymatic synthesis of value added products of glycerol, a by-product derived from biodiesel production. *Resource-Efficient Technologies*, *3*(4), 394-405.

Preechawong, D., Peesan, M., Supaphol, P., & Rujiravanit, R. (2004). Characterization of starch/poly (ε-caprolactone) hybrid foams. *Polymer testing*, *23*(6), 651-657.

Putro, J. N., Ismadji, S., Gunarto, C., Soetaredjo, F. E., & Ju, Y. H. (2020). A study of anionic, cationic, and nonionic surfactants modified starch nanoparticles for hydrophobic drug loading and release. *Journal of Molecular Liquids*, *298*, 112034.

Qi, Q., Hong, Y., Zhang, Y., Gu, Z., Cheng, L., Li, Z., & Li, C. (2020). Combinatorial effect of fermentation and drying on the relationship between the structure and expansion properties of tapioca starch and potato starch. *International journal of biological macromolecules*, *145*, 965-973.

Qin, L., Qiu, J., Liu, M., Ding, S., Shao, L., Lü, S.,Fu, X. (2011). Mechanical and thermal properties of poly (lactic acid) composites with rice straw fiber modified by poly (butyl acrylate). *Chemical Engineering Journal, 166*(2), 772-778.

Quispe, C. A., Coronado, C. J., & Carvalho Jr, J. A. (2016). Glycerol: Production, consumption, prices, characterization and new trends in combustion. Renewable and sustainable energy reviews, 27, 475-493.

Radzuan, N. A. M., Sulong, A. B., Mamat, M. R., Tharazi, I., Tholibon, D., Dweiri, R., & Hammadi, M. S. (2018). Kenaf Reinforced PLA Composite Thermoforming: A Numerical Simulation. International Journal of Integrated Engineering, 10(5).

Raigond, P., Ezekiel, R., & Raigond, B. (2016). Resistant starch in food: a review. Journal of the Science of Food and Agriculture, 95(10), 1968-1978.

Rajan, V. P., & Curtin, W. A. (2015). Rational design of fiber-reinforced hybrid composites: A global load sharing analysis. Composites Science and Technology, 117, 199-207.

Rajak, D. K., Pagar, D. D., Menezes, P. L., & Linul, E. (2019). Fiber-reinforced polymer composites: Manufacturing, properties, and applications. Polymers, 11(10), 1667.

Ramadan, M. F., & Sitohy, M. Z. (2020). Phosphorylated starches: Preparation, properties, functionality, and techno-applications. *Starch-Stärke*, *72*(5-6), 1900302.

Razak, N., & Kalam, A. (2012). Effect of OPEFB size on the mechanical properties and water absorption behaviour of OPEFB/PPnanoclay/PP hybrid composites. *Procedia Engineering*, *41*, 1593-1599.

Razali, N., & Abdullah, A. Z. (2017). Production of lactic acid from glycerol via chemical conversion using solid catalyst: A review. *Applied Catalysis A: General*, *543*, 234-246.

Robeson, L. M. (2007). Polymer blends. *A Comprehensive Review*.

Rodrigues, A., Bordado, J. C., & Santos, R. G. D. (2017). Upgrading the glycerol from biodiesel production as a source of energy carriers and chemicals—A technological review for three chemical pathways. *Energies*, *10*(11), 1817.

Rueda, M. M., Auscher, M. C., Fulchiron, R., Perie, T., Martin, G., Sonntag, P., & Cassagnau, P. (2017). Rheology and applications of highly filled polymers: A review of current understanding. *Progress in Polymer Science*, *66*, 22-53.

Saba, N., Tahir, P. M., & Jawaid, M. (2014). A review on potentiality of nano filler/natural fiber filled polymer hybrid composites. *Polymers*, *6*(8), 2247-2273.

Saba, N., & Jawaid, M. (2017). Epoxy resin based hybrid polymer composites. In *Hybrid polymer composite materials* (pp. 57-82). Woodhead Publishing.

Saffian, H. A., Abdan, K., Hassan, M. A., Ibrahim, N. A., & Jawaid, M. (2016). Characterisation and biodegradation of poly (lactic acid) blended with oil palm biomass and fertiliser for bioplastic fertiliser composites. BioResources, 11(1), 2055-2070.

Sahari, J., Sapuan, S., Zainudin, E. S., & Maleque, M. A. (2013). *Flexural and impact properties of biopolymer derived from sugar palm tree.* Paper presented at the Advanced Materials Research.

Sahu, P., & Gupta, M. K. (2020). Water absorption behavior of cellulosic fibres polymer composites: A review on its effects and remedies. *Journal of Industrial Textiles*, 1528083720974424.

Sarasini, F. (2017). Thermoplastic biopolymer matrices for biocomposites. In *Biocomposites for High-Performance Applications* (pp. 81-123). Woodhead Publishing.

Santagata, G., Valerio, F., Cimmino, A., Dal Poggetto, G., Masi, M., Di Biase, M., . . . Evidente, A. (2017). Chemico-physical and antifungal properties of poly (butylene succinate)/cavoxin blend: Study of a novel bioactive polymeric based system. *European Polymer Journal, 94*, 230-247.

Santana, R. F., Bonomo, R. C. F., Gandolfi, O. R. R., Rodrigues, L. B., Santos, L. S., dos Santos Pires, A. C., ... & Veloso, C. M. (2018). Characterization of starch-based bioplastics from jackfruit seed plasticized with glycerol. *Journal of food science and technology*, *55*(1), 278-286.

Sanyang, M. L., Sapuan, S. M., Jawaid, M., Ishak, M. R., & Sahari, J. (2015). Effect of glycerol and sorbitol plasticizers on physical and thermal properties of sugar palm starch based films. In *Proceedings of the 13th International Conference on Environment, Ecosystems and Development (EED '15)* (p. 157).

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

Sanyang, M. L., Ilyas, R., Sapuan, S., & Jumaidin, R. (2018). Sugar palm starch-based composites for packaging applications *Bionanocomposites for packaging applications* (pp. 125-147): Springer.

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

Sanchez-Safont, E. L., Aldureid, A., Lagarón, J. M., Gamez-Perez, J., & Cabedo, L. (2018). Biocomposites of different lignocellulosic wastes for sustainable food packaging applications. Composites Part B: Engineering, 145, 215-225.

Sarifuddin, N., Ismail, H., & Ahmad, Z. (2013). The Effect of Kenaf Core Fibre Loading on Properties of Low Density Polyethylene/Thermoplastic Sago Starch/Kenaf Core Fiber Composites. *Journal of Physical Science*, *24*(2).

Salem, I. A. S., Rozyanty, A. R., Betar, B. O., Adam, T., Mohammed, M., & Mohammed, A. M. (2017, October). Study of the effect of surface treatment of kenaf fiber on chemical structure and water absorption of kenaf filled unsaturated polyester composite. In *Journal of Physics: Conference Series* (Vol. 908, No. 1, p. 012001). IOP Publishing.

Siakeng, R., Jawaid, M., Ariffin, H., & Sapuan, S. M. (2018, June). Thermal properties of coir and pineapple leaf fibre reinforced polylactic acid hybrid composites. In IOP Conference Series: Materials Science and Engineering (Vol. 368, No. 1, p. 012019). IOP Publishing.

Siyamak, S., Ibrahim, N. A., Abdolmohammadi, S., Yunus, W. M. Z. B. W., & Rahman, M. Z. A. (2012). Enhancement of mechanical and thermal properties of oil palm empty fruit bunch fiber poly (butylene adipate-co-terephtalate) biocomposites by matrix esterification using succinic anhydride. *Molecules*, *17*(2), 1969-1991.

Sisti, L., Totaro, G., & Marchese, P. (2016). PBS makes its entrance into the family of biobased plastics. *Biodegradable and biobased polymers for environmental and biomedical applications*, *1*, 225-273.

Scarfato, P., Di Maio, L., & Incarnato, L. (2015). Recent advances and migration issues in biodegradable polymers from renewable sources for food packaging. *Journal of Applied Polymer Science*, *132*(48).

Schuller, C., Panozzo, D., Grundhofer, A., Zimmer, H., Sorkine, E., & Sorkine-Hornung, O. (2016). Computational thermoforming. *ACM Transactions on Graphics (TOG), 35*(4), 43.

Semkiv, M., Dmytruk, K., Abbas, C., & Sibirny, A. (2017). Biotechnology of Glycerol Production and Conversion in Yeasts *Biotechnology of Yeasts and Filamentous Fungi* (pp. 117-148): Springer.

Senthilkumar, K., Saba, N., Rajini, N., Chandrasekar, M., Jawaid, M., Siengchin, S., & Alotman, O. Y. (2018). Mechanical properties evaluation of sisal fibre reinforced polymer composites: a review. *Construction and Building Materials*, *174*, 713-729.

Sharma, A. K., Tiwari, A. K., & Dixit, A. R. (2016). Rheological behaviour of nanofluids: a review. *Renewable and Sustainable Energy Reviews, 53*, 779-791.

Shah, U., Naqash, F., Gani, A., & Masoodi, F. A. (2016). Art and science behind modified starch edible films and coatings: a review. Comprehensive reviews in Food science and food safety, 15(3), 568-580.

Shamsuri, A. A. (2020). Compatibilization effect of ionic liquid-based surfactants on physicochemical properties of PBS/rice starch blends: An initial study. *Materials*, *13*(8), 1885.

Shesan, O. J., Stephen, A. C., Chioma, A. G., Neerish, R., & Rotimi, S. E. (2019). Fiber-matrix relationship for composites preparation. *Renewable and Sustainable Composites. London*, 1-30.

Shariatinia, Z., & Fazli, M. (2015). Mechanical properties and antibacterial activities of novel nanobiocomposite films of chitosan and starch. *Food Hydrocolloids*, *46*, 112-124.

Shanmugam, K., Doosthosseini, H., Varanasi, S., Garnier, G., & Batchelor, W. (2019). Nanocellulose films as air and water vapour barriers: A recyclable and biodegradable alternative to polyolefin packaging. *Sustainable Materials and Technologies*, *22*, e00115.

Shi, K., Liu, Y., Hu, X., Su, T., Li, P., & Wang, Z. (2018). Preparation, characterization, and biodegradation of poly (butylene succinate)/cellulose triacetate blends. *International journal of biological macromolecules*, *114*, 373-380.

Shivaraju, V. K., & Vallayil Appukuttan, S. (2019). The influence of bound water on the FTIR characteristics of starch and starch nanocrystals obtained from selected natural sources. Starch‐Stärke, 71(5-6), 1700026.

Shokoohi, S., & Arefazar, A. (2009). A review on ternary immiscible polymer blends: morphology and effective parameters. *Polymers for Advanced Technologies*, *20*(5), 433-447.

Shukri, R., & Shi, Y. C. (2017). Structure and pasting properties of alkaline-treated phosphorylated cross-linked waxy maize starches. Food chemistry, 214, 90-95.

Shumigin, D., Tarasova, E., Krumme, A., & Meier, P. (2011). Rheological and mechanical properties of poly (lactic) acid/cellulose and LDPE/cellulose composites. *Materials Science*, *17*(1), 32-37.

Siracusa, V. (2012). Food packaging permeability behaviour: A report. *International Journal of Polymer Science*, *2012*.

Siracusa, V., Rocculi, P., Romani, S., & Dalla Rosa, M. (2008). Biodegradable polymers for food packaging: a review. *Trends in Food Science & Technology*, *19*(12), 634-643.

Siracusa, V. (2019). Microbial degradation of synthetic biopolymers waste. *Polymers*, *11*(6), 1066.

Soatthiyanon, N., Aumnate, C., & Srikulkit, K. (2020). Rheological, tensile, and thermal properties of poly (butylene succinate) composites filled with two types of cellulose (kenaf cellulose fiber and commercial cellulose). *Polymer Composites*, *41*(7), 2777-2791.

Song, H., & Lee, S. Y. (2016). Production of succinic acid by bacterial fermentation. *Enzyme and microbial technology*, *39*(3), 352-361.

Soykeabkaew, N., Thanomsilp, C., & Suwantong, O. (2015). A review: Starch-based composite foams. Composites Part A: Applied Science and Manufacturing, 78, 246-263.

Someya, Y., Nakazato, T., Teramoto, N., & Shibata, M. (2017). Thermal and mechanical properties of poly (butylene succinate) nanocomposites with various organo-modified montmorillonites. *Journal of applied polymer science, 91*(3), 1463-1475.

Srivastava, P., Bano, K., Zaheer, M. R., & Kuddus, M. (2018). Biodegradable Smart Biopolymers for Food Packaging: Sustainable Approach Toward Green Environment. In Bio-based Materials for Food Packaging (pp. 197-216). Springer, Singapore.

Stevens, C. V. (2021). *Bio-Based Packaging: Material, Environmental and Economic Aspects*. John Wiley & Sons.

Su, S., Kopitzky, R., Tolga, S., & Kabasci, S. (2019). Polylactide (PLA) and its blends with poly (butylene succinate)(PBS): A brief review. Polymers, 11(7), 1193.

Sukan, A. (2015). Dual biopolymer production and separation from cultures of *Bacillus spp* (Doctoral dissertation, University of Westminster).

Supthanyakul, R., Kaabbuathong, N., & Chirachanchai, S. (2016). Random poly (butylene succinate-co-lactic acid) as a multi-functional additive for miscibility, toughness, and clarity of PLA/PBS blends. *Polymer, 105*, 1-9.

Suchao-in, K., Koombhongse, P., & Chirachanchai, S. (2014). Starch grafted poly (butylene succinate) via conjugating reaction and its role on enhancing the compatibility. *Carbohydrate polymers*, *102*, 95-102.

Suriyatem, R., Auras, R. A., & Rachtanapun, P. (2018). Improvement of mechanical properties and thermal stability of biodegradable rice starch–based films blended with carboxymethyl chitosan. *Industrial crops and products*, *122*, 37-48.

Tao, H. H., Snaddon, J. L., Slade, E. M., Henneron, L., Caliman, J. P., & Willis, K. J. (2018). Application of oil palm empty fruit bunch effects on soil biota and functions: a case study in Sumatra, Indonesia. *Agriculture, ecosystems & environment*, *256*, 105-113.

Tan, H., Aziz, A. A., & Aroua, M. (2013). Glycerol production and its applications as a raw material: A review. *Renewable and Sustainable Energy Reviews, 27*, 118-127.

Tang, X., & Alavi, S. (2017). Recent advances in starch, polyvinyl alcohol based polymer blends, nanocomposites and their biodegradability. *Carbohydrate polymers, 85*(1), 7-16.

Teck Kim, Y., Min, B., & Won Kim, K. (2014). Chapter 2—General characteristics of packaging materials for food system A2—Han, Jung H. *Innovations in food packaging. Second Edition San Diego: Academic Press*, 13A35.

Teixeira, E. d. M., De Campos, A., Marconcini, J., Bondancia, T., Wood, D., Klamczynski, A., Glenn, G. (2014). Starch/fiber/poly (lactic acid) foam and compressed foam composites. *RSC Advances*, *4*(13), 6616-6623.

Teixeira, S., Eblagon, K. M., Miranda, F., R Pereira, M. F., & Figueiredo, J. L. (2021). Towards Controlled Degradation of Poly (Lactic) Acid in Technical Applications. C, 7(2), 42.

Teixeira, A. S., Deladino, L., Garcia, M. A., Zaritzky, N. E., Sanz, P. D., & Molina-García, A. D. (2018). Microstructure analysis of high pressure induced gelatinization of maize starch in the presence of hydrocolloids. *Food and Bioproducts Processing*, *112*, 119-130.

Thyavihalli Girijappa, Yashas Gowda, Sanjay Mavinkere Rangappa, Jyotishkumar Parameswaranpillai, and Suchart Siengchin. "Natural fibers as sustainable and renewable resource for development of eco-friendly composites: a comprehensive review." *Frontiers in Materials* 6 (2019): 226.

Then, Y. Y., Ibrahim, N. A., Zainuddin, N., Ariffin, H., Yunus, W., & Zin, W. M. (2013). Oil palm mesocarp fiber as new lignocellulosic material for fabrication of polymer/fiber biocomposites. *International Journal of Polymer Science, 2013*.

Thomazine, M., Carvalho, R. A., & Sobral, P. J. (2015). Physical properties of gelatin films plasticized by blends of glycerol and sorbitol. *Journal of Food Science, 70*(3), E172-E176.

Thirmizir, M. A., Ishak, Z. M., Taib, R. M., Sudin, R., & Leong, Y. W. (2011). Mechanical, water absorption and dimensional stability studies of kenaf bast fibre-filled poly (butylene succinate) composites. Polymer-Plastics Technology and Engineering, 50(4), 339-348.

Tserki, V., Matzinos, P., Pavlidou, E., Vachliotis, D., & Panayiotou, C. (2006). Biodegradable aliphatic polyesters. Part I. Properties and biodegradation of poly (butylene succinate-co-butylene adipate). *Polymer degradation and stability, 91*(2), 367-376.

Tran, N. H. A., Brünig, H., Auf der Landwehr, M., & Heinrich, G. (2018). Controlling micro-and nanofibrillar morphology of polymer blends in low-speed melt spinning process. Part III: Fibrillation mechanism of PLA/PVA blends along the spinline. *Journal of Applied Polymer Science*, *133*(48).

Uesaka, T., Ogata, N., Nakane, K., Shimizu, K., & Ogihara, T. (2002). Structure and physical properties of cellulose acetate/poly (butylene succinate) blends containing a transition metal alkoxide. *Journal of Applied Polymer Science, 83*(8), 1750-1758.

Velmathi, S., Nagahata, R., Sugiyama, J. i., & Takeuchi, K. (2005). A Rapid Eco-Friendly Synthesis of Poly (butylene succinate) by a Direct Polyesterification under Microwave Irradiation. *Macromolecular rapid communications, 26*(14), 1163-1167.

Verma, A., Joshi, K., Gaur, A., & Singh, V. K. (2018). Starch-jute fiber hybrid biocomposite modified with an epoxy resin coating: fabrication and experimental characterization. *Journal of the Mechanical Behavior of Materials*, *27*(5-6).

Villacres, R. A. E., Flores, S. K., & Gerschenson, L. N. (2014). Biopolymeric antimicrobial films: Study of the influence of hydroxypropyl methylcellulose, tapioca starch and glycerol contents on physical properties. *Materials Science and Engineering: C, 36*, 108-117.

Visakh, P., Srikaeo, K., Ghasemlou, M., Sahari, J., Calado, V., de Carvalho, A. J. F., . Yang, H. (2015). *Starch-based blends, composites and nanocomposites*: Royal Society of Chemistry.

Visan, A. I., Popescu-Pelin, G., & Socol, G. (2021). Degradation Behavior of Polymers Used as Coating Materials for Drug Delivery—A Basic Review. *Polymers*, *13*(8), 1272.

Vlachopoulos, J., & Strutt, D. (2003). *The role of rheology in polymer extrusion.* Paper presented at the New Technology for Extrusion Conference. Milan, Italy. Nov.

Vytejckova, S., Vapenka, L., Hradecky, J., Dobias, J., Hajslova, J., Loriot, C.,& Poustka, J. (2017). Testing of polybutylene succinate based films for poultry meat packaging. Polymer Testing, 60, 357-364.

Wang, H., Sun, X., & Seib, P. (2002). Mechanical properties of poly (lactic acid) and wheat starch blends with methylenediphenyl diisocyanate. *Journal of Applied Polymer Science, 84*(6), 1257-1262.

Wang, N., Yu, J., Chang, P. R., & Ma, X. (2008). Influence of formamide and water on the properties of thermoplastic starch/poly (lactic acid) blends. *Carbohydrate polymers, 71*(1), 109-118.

Wang, Q., Shi, A., & Shah, F. (2019). Rheology instruments for food quality evaluation *Evaluation Technologies for Food Quality* (pp. 465-490): Elsevier.

Wang, S. Q. (2018). *Nonlinear polymer rheology*. Wiley, Hoboken, NJ.

Wang, S., Li, C., Copeland, L., Niu, Q., & Wang, S. (2015). Starch retrogradation: A comprehensive review. Comprehensive Reviews in Food Science and Food Safety, 14(5), 568-585.

Warren, F. J., Gidley, M. J., & Flanagan, B. M. (2016). Infrared spectroscopy as a tool to characterise starch ordered structure—a joint FTIR–ATR, NMR, XRD and DSC study. *Carbohydrate polymers, 139*, 35-42.

Wei, H. (2021). Optimisation on thermoforming of biodegradable poly (lactic acid)(PLA) by numerical modelling. *Polymers*, *13*(4), 654.

White, R. P., Lipson, J. E., & Higgins, J. S. (2012). New correlations in polymer blend miscibility. *Macromolecules, 45*(2), 1076-1084.

Whitney, K., Reuhs, B. L., Martinez, M. O., & Simsek, S. (2016). Analysis of octenylsuccinate rice and tapioca starches: Distribution of octenylsuccinic anhydride groups in starch granules. *Food chemistry, 211*, 608-615.

Wiercigroch, E., Szafraniec, E., Czamara, K., Pacia, M. Z., Majzner, K., Kochan, K., & Malek, K. (2017). Raman and infrared spectroscopy of carbohydrates: A review. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *185*, 317-335.

Work, W., Horie, K., Hess, M., & Stepto, R. (2004). Definition of terms related to polymer blends, composites, and multiphase polymeric materials (IUPAC Recommendations 2004). *Pure and applied chemistry, 76*(11), 1985-2007.

Woodard, L. N., & Grunlan, M. A. (2018). Hydrolytic degradation and erosion of polyester biomaterials.

Wu, C.-S., Liao, H.-T., & Jhang, J.-J. (2013). Palm fibre-reinforced hybrid composites of poly (butylene succinate): characterisation and assessment of mechanical and thermal properties. *Polymer bulletin, 70*(12), 3443-3462.

Wu, J., Chen, S., Ge, S., Miao, J., Li, J., & Zhang, Q. (2013). Preparation, properties and antioxidant activity of an active film from silver carp (Hypophthalmichthys molitrix) skin gelatin incorporated with green tea extract. *Food Hydrocolloids, 32*(1), 42-51.

Xie, M., Duan, Y., Li, F., Wang, X., Cui, X., Bacha, U.,& Zhao, Z. (2017). Preparation and characterization of modified and functional starch (hexadecyl corboxymethyl starch) ether using reactive extrusion. Starch-Stärke, 69(5-6), 1600061.

Xiong, H., Hamila, N., & Boisse, P. (2019). Consolidation modeling during thermoforming of thermoplastic composite prepregs. *Materials*, *12*(18), 2853.

Xiong, J., Li, Q., Shi, Z., & Ye, J. (2017). Interactions between wheat starch and cellulose derivatives in short-term retrogradation: Rheology and FTIR study. *Food Research International*, *100*, 858-863.

Xu, J., & Guo, B. H. (2010). Poly (butylene succinate) and its copolymers: research, development and industrialization. *Biotechnology journal, 5*(11), 1149-1163.

Yan, L., Chouw, N., & Yuan, X. (2012). Improving the mechanical properties of natural fibre fabric reinforced epoxy composites by alkali treatment. Journal of Reinforced Plastics and Composites, 31(6), 425-437.

Yazid, N. S. M., Abdullah, N., Muhammad, N., & Matias-Peralta, H. M. (2018). Application of starch and starch-based products in food industry. Journal of Science and Technology, 10(2).

Yang, Y., Vervust, T., Dunphy, S., Van Put, S., Vandecasteele, B., Dhaenens, K., ... & Vanfleteren, J. (2018). 3D Multifunctional Composites Based on Large-Area Stretchable Circuit with Thermoforming Technology. *Advanced Electronic Materials*, *4*(8), 1800071.

Yang, Z., Xu, X., Singh, R., de Campo, L., Gilbert, E. P., Wu, Z., & Hemar, Y. (2019). Effect of amyloglucosidase hydrolysis on the multi-scale supramolecular structure of corn starch. *Carbohydrate polymers*, *212*, 40-50.

Ye, J., Hu, X., Luo, S., Liu, W., Chen, J., Zeng, Z., & Liu, C. (2018). Properties of starch after extrusion: a review. *Starch-Stärke*, *70*(11-12), 1700110.

Yee, Y. Y., Ching, Y. C., Rozali, S., Hashim, N. A., & Singh, R. (2016). Preparation and characterization of poly (lactic acid)-based composite reinforced with oil palm empty fruit bunch fiber and nanosilica. BioResources, 11(1), 2269-2286.

Ying-Chen, Z., Hong-Yan, W., & Yi-Ping, Q. (2010). Morphology and properties of hybrid composites based on polypropylene/polylactic acid blend and bamboo fiber. *Bioresource Technology*, *101*(20), 7944-7950.

Yokohara, T., Nobukawa, S., & Yamaguchi, M. (2011). Rheological properties of polymer composites with flexible fine fibers. *Journal of Rheology*, *55*(6), 1205-1218.

Yu, L., Dean, K., & Li, L. (2006). Polymer blends and composites from renewable resources. *Progress in polymer science*, *31*(6), 576-602.

Yu, L., Ke, S., Zhang, Y., Shen, B., Zhang, A., & Huang, H. (2011). Dielectric relaxations of high-k poly (butylene succinate) based all-organic nanocomposite films for capacitor applications. *Journal of materials research*, *26*(19), 2493-2502.

Yu, S., Ma, Y., & Sun, D.-W. (2009). Impact of amylose content on starch retrogradation and texture of cooked milled rice during storage. *Journal of Cereal Science*, *50*(2), 139-144.

Yun, I. S., Hwang, S. W., Shim, J. K., & Seo, K. H. (2016). A study on the thermal and mechanical properties of poly (butylene succinate)/thermoplastic starch binary blends. *International Journal of Precision Engineering and Manufacturing-Green Technology*, *3*(3), 289-296.

Yusof, N. S. B., Sapuan, S. M., Sultan, M. T. H., & Jawaid, M. (2020). Conceptual design of oil palm fibre reinforced polymer hybrid composite automotive crash box using integrated approach. *Journal of Central South University*, *27*(1), 64-75.

Yusoff, N. H., Pal, K., Narayanan, T., & de Souza, F. G. (2021). Recent trends on bioplastics synthesis and characterizations: Polylactic acid (PLA) incorporated with tapioca starch for packaging applications. *Journal of Molecular Structure*, *1232*, 129954.

Zainudin, E. S., Yan, L. H., Haniffah, W. H., Jawaid, M., & Alothman, O. Y. (2014). Effect of coir fiber loading on mechanical and morphological properties of oil palm fibers reinforced polypropylene composites. Polymer Composites, 35(7), 1418-1425.

Zain, G., Nada, A. A., El-Sheikh, M. A., Attaby, F. A., & Waly, A. I. (2018). Superabsorbent hydrogel based on sulfonated-starch for improving water and saline absorbency. *International journal of biological macromolecules*, *115*, 61-68.

Zarski, A., Bajer, K., & Kapuśniak, J. (2021). Review of the most important methods of improving the processing properties of starch toward non-food applications. *Polymers*, *13*(5), 832.

Zeng, J.-B., Li, Y.-D., Zhu, Q.-Y., Yang, K.-K., Wang, X.-L., & Wang, Y.-Z. (2009). A novel biodegradable multiblock poly (ester urethane) containing poly (L-lactic acid) and poly (butylene succinate) blocks. *Polymer*, *50*(5), 1178-1186.

Zenkiewicz, M., & Richert, J. (2008). Permeability of polylactide nanocomposite films for water vapour, oxygen and carbon dioxide. *Polymer Testing*, *27*(7), 835-840.

Zhang, M., & Thomas, N. L. (2010). Preparation and properties of polyhydroxybutyrate blended with different types of starch. Journal of applied polymer science, 116(2), 688-694.

Zhang, N., Liu, X., Yu, L., Shanks, R., Petinaks, E., & Liu, H. (2013). Phase composition and interface of starch–gelatin blends studied by synchrotron FTIR micro-spectroscopy. *Carbohydrate polymers*, *95*(2), 649-653.

Zhang, Z.-X., Gao, C., Xin, Z. X., & Kim, J. K. (2012). Effects of extruder parameters and silica on physico-mechanical and foaming properties of PP/wood-fiber composites. *Composites part B: engineering*, *43*(4), 2047-2057.

Zhang, S., Li, Z., Lin, L., Zhang, L., & Wei, C. (2019). Starch Components, Starch Properties and Appearance Quality of Opaque Kernels from Rice Mutants. *Molecules*, *24*(24), 4580.

Zhang, S., He, Y., Yin, Y., & Jiang, G. (2019). Fabrication of innovative thermoplastic starch bio-elastomer to achieve high toughness poly (butylene succinate) composites. *Carbohydrate polymers*, *206*, 827-836.

Zhu, T., Jackson, D. S., Wehling, R. L., & Geera, B. (2008). Comparison of amylose determination methods and the development of a dual wavelength iodine binding technique. Cereal Chemistry, 85(1), 51-58.

Zia-ud-Din, Xiong, H., & Fei, P. (2017). Physical and chemical modification of starches: A review. *Critical reviews in food science and nutrition*, *57*(12), 2691-2705.

Zuo, Y., Gu, J., Yang, L., Qiao, Z., Tan, H., & Zhang, Y. (2016). Preparation and characterization of dry method esterified starch/polylactic acid composite materials. *International journal of biological macromolecules*, *64*, 174-180.

Zwawi, M. (2021). A Review on Natural Fiber Bio-Composites; Surface Modifications and Applications. *Molecules*, *26*(2), 404.

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LIST OF PUBLICATIONS

Journal Papers

Ayu, R. S., Khalina, A., Harmaen, A. S., Zaman, K., Jawaid, M., & Lee, C. H. (2018). Effect of modified tapioca starch on mechanical, thermal, and morphological properties of PBS blends for food packaging. *Polymers*, *10*(11), 1187.

Ayu, R. S., Khalina, A., Harmaen, A. S., Zaman, K., Nurrazi, N. M., Isma, T., & Lee, C. H. (2020). Effect of Empty Fruit Brunch reinforcement in PolyButylene-Succinate/Modified Tapioca Starch blend for Agricultural Mulch Films. *Scientific reports*, *10*(1), 1-7.

Ayu, R. S., Khalina, A., Harmaen, A. S., Zaman, K., Isma, T., Liu, Q.,& Lee, C. H. (2020). Characterization study of empty fruit bunch (EFB) fibers reinforcement in poly (Butylene) succinate (PBS)/starch/glycerol composite sheet. *Polymers*, *12*(7), 1571.

Ayu, R, S., Khalina, A., Harmaen, A. S., Tawakkal, I. A., Zaman, K., Asim, M.,& Lee, C. H. (2021). A Review on Properties and Application of Bio-Based Poly (Butylene Succinate). *Polymers*, *13*(9), 1436.

Book Chapter

Ayu, R. S., Khalina (2021). Biopolymer and Biocomposite From Agro-Waste For Packaging Material. Elsevier, Chapter 4: Effect of different Polybutylene succinate and starch formulation on food tray by thermoforming process

Ayu Rafiqah, S., Khalina, A., Zaman, K., Tawakkal, I. S. M. A., Harmaen, A. S., & Nurrazi, N. M. (2021). Bioplastics: The Future of Sustainable Biodegradable Food Packaging. *Bio-based Packaging: Material, Environmental and Economic Aspects*, 335-351.

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