



UNIVERSITI PUTRA MALAYSIA

***UTILIZATION OF JACKFRUIT WASTE FOR THE PRODUCTION OF
ACTIVE EDIBLES FILMS***

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PRODUCTION OF ACTIVE EDIBLES FILMS**

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APPROVAL SHEET

This project report attached here, entitle “**UTILIZATION OF JACKFRUIT WASTE FOR THE PRODUCTION OF ACTIVE EDIBLES FILMS**” prepared and submitted by **UMMI AMIRAH BINTI ABD SUKOR** in partial fulfilment of the requirements for the degree of Bachelor of Process and Food Engineering is hereby accepted.

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ABSTRACT

This research was aimed to utilize jackfruit waste, particularly jackfruit skin and straw for the production of edible films. The effect of tapioca starch and plasticizer contents of the jackfruit waste based films was investigated in this study. The jackfruit straw and starch (JSt/starch) films and jackfruit skin and starch (JSk/starch) films were prepared by casting technique followed by drying the films at 50°C for 24 hours. Jackfruit straw and skin films with various tapioca starch contents (3-5g) and plasticizer (0-40%) loadings impose towards physical properties (thickness and color), FTIR spectra and mechanical properties where the highest values of TS of were 4.52 MPa (JSt/starch) and 4.51 MPa (JSk/starch) at 6:4 ratio. A fixed jackfruit waste to starch ratio of 6:4 for both jackfruit straw and skin was compared in term of mechanical and physical properties.

The film with 6g of jackfruit straw or skin incorporated with 4g of starch (6:4) had been used as the controlled film based on the tensile strength (TS) and Yong's Modulus (YM) value obtained from the tensile test. In addition, the mechanical properties of JSt/starch and JSk/starch films with increase loading of plasticizer (sorbitol) of 15%, 25%, 40% concentration were investigated. The addition of plasticizer had influenced the physical and mechanical properties of the films. The plasticized JSt/starch film demonstrated a much lower TS. In the meantime, JSk/starch film shows that the higher the plasticizer load, the lower the TS. This is due to plasticizers that act as spacers between the polymer chains, reduce brittleness by reducing the intermolecular forces between adjacent polymer chains and improve flexibility and extensibility.

Infrared spectral analysis of starch, JSt and JSt/starch film was measured using a Shimadzu IR Prestige Fourier Transform Infrared (FTIR) spectrophotometer. The sharp peak absorption is seen at approximately 1631 cm^{-1} of natural starch film, which was similar to OH vibration absorbed in starch film. Major changes in the band associated with -OH groups occur. New hydrogen bonding could be interpreted in the JSt/starch film from the -OH (absorbed water) group peak, which shifts to 1587 cm^{-1} with a wider band than the native starch film. The JSt/starch and native JSt film at 1741 cm^{-1} showed a new and prominent peak, indicating the stretching vibration of $\text{C}=\text{O}$ attributes to the carbonyl group which is the ester carbonyl group of pectin.

Moreover, this research also was aimed to utilize jackfruit waste containing tapioca starch for the production of active edible films. The addition of a natural agent, particularly thymol as antimicrobial agent at a fixed 3% concentration was investigated. The result demonstrated that thymol was able to be released from the JSk/starch films and act as active agent based on the positive zone of inhibition result.

ABSTRAK

Kajian ini bertujuan untuk menggunakan sisa nangka terutama kulit nangka dan jerami untuk menghasilkan filem yang boleh dimakan. Kesan kanji ubi kayu dan kandungan pemplastik pada filem berasaskan buangan nangka telah disiasat dalam kajian ini. Filem JSt/kanji dan JSk /kanji disediakan dengan teknik pemutus diikuti dengan mengeringkan filem pada 50° C selama 24 jam. Filem jerami dan filem kulit dengan pelbagai kandungan kanji ubi kayu (3-5g) dan pemplastik (0-40%) dikenakan ke atas sifat fizikal (ketebalan dan warna), spektrum FTIR dan sifat mekanik di mana nilai tertinggi TS adalah 4.52 MPa JSt / kanji) dan 4.51 MPa (JSk / kanji) pada nisbah 6: 4. Nisbah sisa nangka tetap kepada kanji sebanyak 6: 4 untuk kedua-dua jerami nangka dan kulit dibandingkan dari segi sifat mekanikal dan fizikal.

Filem yang mengandungi 6g jerami atau kulit yang digabungkan dengan 4g kanji (6:4) telah digunakan sebagai filem terkawal berdasarkan kekuatan tegangan (TS) dan nilai Modulus Yong (YM) yang didapati dari ujian tegangan. Di samping itu, sifat mekanikal filem JSt/kanji dan JSk/kanji dengan peningkatan beban pemplastik (sorbitol) sebanyak 15%, 25%, kepekatan 40% disiasat. Penambahan pemplastik telah mempengaruhi sifat-sifat fizikal dan mekanik filem. Filem JSt/kanji plastik mempunyai TS yang lebih rendah. Sementara itu, filem JSk/kanji menunjukkan bahawa semakin tinggi beban pemplastik, semakin rendah TS. Ini disebabkan oleh pelekat yang bertindak sebagai penjarak di antara rantai polimer, mengurangkan kelembutan dengan mengurangkan daya antara polimer antara rantai polimer dan meningkatkan fleksibiliti dan meluas.

Analisis spektrum inframerah kanji, filem JSt dan JSt/kanji diukur dengan menggunakan spektrofotometer *Shimadzu IR Prestige Fourier transform infrared* (FTIR). Penyerapan puncak yang tajam dilihat pada kira-kira 1631 cm^{-1} filem kanji semulajadi, yang serupa dengan getaran OH yang diserap dalam filem kanji. Perubahan utama dalam kumpulan yang berkaitan dengan -OH berlaku. Ikatan hidrogen baru boleh ditafsirkan dalam filem JSt/kanji dari puncak kumpulan -OH (air yang diserap), yang beralih kepada 1587 cm^{-1} dengan jalur yang lebih luas daripada filem kanji asli. JSt/kanji dan filem JSt asli pada 1741 cm^{-1} menunjukkan puncak baru dan menonjol, menunjukkan getaran regangan bagi $\text{-C}=\text{O}$ atribut kepada kumpulan karbonil yang merupakan kumpulan ester karbonyl pektin.

Selain itu, kajian ini juga bertujuan untuk menggunakan sisa nangka yang mengandungi kanji ubi kayu untuk pengeluaran filem yang boleh dimakan aktif. Penambahan agen semula jadi terutamanya thymol sebagai agen antimikrobial pada kepekatan 3% tetap disiasat. Hasilnya menunjukkan bahawa thymol dapat dibebaskan dari filem JSk / kanji dan bertindak sebagai agen aktif berdasarkan keputusan yang positif bagi zon perencatan.

TABLE OF CONTENTS

APPROVAL SHEET	ii
PERMISSION LETTER	iii
ACKNOWLEDGEMENT	iv
ABSTRACT	v
ABSTRAK	vii
TABLE OF CONTENTS	ix
LIST OF TABLES	xi
LIST OF FIGURES	xii
LIST OF ABBREVIATIONS	xiv
CHAPTER 1 INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement	3
1.3 Objectives	4
CHAPTER 2 LITERATURE REVIEW	5
2.1 Introduction	5
2.2 Biodegradable polymer	6
2.3 Starch-based edible films	7
2.4 Jackfruits	10
2.5 Plasticizer	12
2.6 Thymol	12
2.7 Physical Properties	13
2.7.1 Film Thickness	13
2.7.2 Colour	13
2.8 Mechanical Properties	14
2.9 FTIR Analysis – Infrared Spectroscopy	16
2.10 Antimicrobial Activity	17
CHAPTER 3 METHODOLOGY	18

3.1 Introduction	18
3.2 Materials	20
3.3 Preparation of Jackfruit Straw and Skin Powder	20
3.4 Preparation of Films	20
3.5 Characterisation of Jackfruit Waste/Starch Films	23
3.5.1 Physical properties	23
3.5.2 Mechanical properties	24
3.5.3 FTIR Analysis - Infrared Spectroscopy	24
3.5.4 Antimicrobial Test	24
CHAPTER 4 RESULT AND DISCUSSION	25
4.1 Mechanical Properties of Jackfruit Waste Based Films: Effect of Starch Content	25
4.2 Mechanical Properties of Jackfruit Waste Based Films: Effect of Plasticizer Content	30
4.3 Physical Properties of Jackfruit Waste Based Films: Effect of Starch and Plasticizer Contents	33
4.3.1 Thickness of Films	33
4.3.2 Films Colour	36
4.4 FTIR Spectra Analysis	40
4.5 Antimicrobial Analysis	42
CHAPTER 5 CONCLUSIONS.....	43
REFERENCES.....	45
APPENDICES A: EQUIPMENT	53
APPENDICES B: DATA ANALYSIS	58

LIST OF TABLES

Table 1: The current study of biodegradable film with starch as main polymer	10
Table 2: Formulations of JS films	21
Table 3: Thickness of JSt/starch and JSk/starch films at different starch contents.	34
Table 4: Thickness of JSk/starch and JSt/starch film at ratio of 6:4 with different loading of plasticizer	36
Table 5: Images of JSt/starch and JSk/starch (6:4) of non-plasticized (0%) and plasticized film (25%).	39

LIST OF FIGURES

Figure 1: Classification of biodegradable polymers (Source: Trinetta and State, 2016)	7
Figure 2: (a) Amylose is a linear α -D- glucose unit chain combined with α -1,4-glycosidic bonds, (b) Because of the bonding of hydrogen, amylose develops a spiral structure containing six glucose units per turn. (Source: Smith, 2016)	8
Figure 3: Branching representation in amylopectin and glycogen. Both amylopectin and glycogen contain branch points that are connected with α -1,6 links. (Source: Smith, 2016)	9
Figure 4: Jackfruit	11
Figure 5: A stress–strain curve for polymer film undergoing tensile strain testing (Source: Lim and Hoag, 2013).	15
Figure 6: Process Flow Diagram	19
Figure 7: Flow chart of film preparation	22
Figure 8(a): Mechanical properties of JSt/starch films at jackfruit straw to starch ratio of 5:5 and 6:4	27
Figure 8(b): Mechanical properties of JSk/starch films at jackfruit skin to starch ratio of 7:3 and 6:4	28
Figure 9: Mechanical properties of JSt/starch and JSk/starch films at ratio of 6:4	29

Figure 10: Tensile properties of JSt/starch and JSk/starch films at different loading of plasticizer: Tensile Strength, Elongation at Break and Young's Modulus 31

Figure 11: Colour analysis of JSt/starch and JSk/starch films at ratio of 6:4 with addition of plasticizer for different types of parameters: L*, a* and b* 37

Figure 12: FTIR spectra of (i) JSt/starch film at JSt and starch ratio of 4:6, (ii) native JSP film and (iii) native tapioca starch film. 41

Figure 13: Images of inhibitory zones of JSt/starch (left side) and JSk/starch (right side) incorporated with 3% thymol compared to control against test microorganisms, *E. coli*. 42

LIST OF ABBREVIATIONS

JS	Jackfruit
JSt	Jackfruit Straw
JSk	Jackfruit Skin
JSt/starch	Jackfruit Straw and starch film
JSk/starch	Jackfruit Skin and starch film
EAB	Elongation at break
TS	Tensile Strength
YM	Young's Modulus

CHAPTER 1

INTRODUCTION

1.1 Background

Packaging is a regulated system which provides goods for transport, distribution, storage, retail, and final use. Packaging protects its contents from contamination and spoilage, makes it easier to transport and store goods and provides uniform measuring of contents. In fact, packaging behaves as containment, protection, convenience and communication (Barlow and Morgan, 2013). Packaging of foods to be distinct, have three levels of packaging: primary, secondary and tertiary. However, packaging material derived from petroleum are not easily degradable and caused huge environment issue.

Packaging of environmental friendly are essential for solving this problem. Biodegradable packaging material needs to be developed especially in food packaging. Therefore, edible film is one alternative for food packaging due to its biodegradable and cost-efficient. Edible film is defined as a packaging material, which is a thin layer of edible biopolymers placed on or between food component (Espitia *et al.*, 2014). The use of edible films as primary packaging can potentially substitute standards packaging materials which able to decrease the overall consumption of

synthetic materials. Moreover, several active ingredients can be incorporated into the polymer matrix and consumed with the food, while enhancing safety, nutritional and sensory attributes.

In this case, starch are suitable material as the main matrix for edible films and it has been used to produce biodegradable films to replace plastic polymers partially due to its low cost and renewability (Xu *et al.*, 2005). It is a natural polymer consists of (1-4) linked α -D-glucopyranosyl units. In natural starch there are two types of chain: amylopectine and amylose.

The component for film-forming biopolymers is the proteins, polysaccharides, lipids, or a combination of these (Pablo, Jim and Ibarz, 2011). Jackfruit straw which is a waste jackfruit contain carbohydrates that consist of glucose, sucrose, fructose, starch, pectin and cellulose (Sarwar *et al.*, 2018). Jackfruit straw has the potential to be developed into edible films due to the presence of major compound namely starch and pectin which is a polysaccharide, a naturally occurring hydrophilic polysaccharide found in plant cell walls which has good film forming feature (Red, Murtius and Prastica, 2015).

At present, researchers have been focused on searching for new naturally occurring substances that act as possible alternatives sources of antioxidants and antimicrobials (Ponce *et al.*, 2008). Thymol is one of natural antimicrobial (AM) agent that possess the GRAS (Generally Recognized as Safe) status which indicated that it is safe of using for films in preventing the growth of foodborne pathogens or spoilage organisms. A report by Guarda and co-workers (2011) stated that thymol is a strong inhibitors of a broad variety of microorganisms. Thus, thymol is a suitable natural antimicrobial agent to be incorporated in edible film for antimicrobial food packaging.

1.2 Problem Statement

This study aimed at investigating the possibility of using the jackfruit waste such as straw and skin for the preparation of edible film. Jackfruit is grown in many countries including India, Myanmar, Malaysia, Indonesia, Brazil, Sri Lanka, Surinam, Australia, Caribbean islands and some African countries. During jackfruit processing, the whole organic product is used except the peel which contributes the major waste product. In fact, edible portions amount of jackfruit only up to 30-35% of the total weight and the rest is the jackfruit waste including seed, core, straw and skin (Saxena, Bawa and Raju, 2011). The presence of polysaccharides in jackfruit waste are important as the raw material to prepare edible films that can be used as packaging material for food preservation (Cazón *et al.*, 2017).

Biopolymers are increasingly gaining attention largely in response to the growing concerns about the sustainability of conventional polymers and the environmental pollution caused by plastic packaging waste treatment (Ingrao and Siracusa, 2017). By using a biodegradable polymer packaging material not only help in enhancing product shelf-life, but it is also reducing the overall carbon footprint related to food packaging (Fabra, López-Rubio and Lagaron, 2014).

1.3 Objectives

Objectives in this study are:

1. To investigate the effect of starch and plasticizer (sorbitol) contents on the mechanical and physical properties of jackfruit waste based edible films.
2. To evaluate the spectra analysis and antimicrobial activity of JSk/starch and JSt/starch films.



CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The main function of food packaging is to protect food from external influences and damage, contain food and provide nutritional materials and information to consumers (Barlow and Morgan, 2013). After use, food packaging must be released in a responsible manner to the environment. However, food packaging is a huge contributor to municipal solid waste (MSW) because food is the only product which consumed generally by every person practically three times a day (Marsh and Bugusu, 2007b). Therefore, packaging technology must be balanced with other issues especially in social and environmental awareness, and strict rules on pollutants and MSW (Marsh and Bugusu, 2007b).

In food packaging, plastics is the materials used generally besides glass, metals (aluminium, foils and laminates, tinfoil, and tin-free steel), paper and paperboards. In fact, plastic is derived from petroleum feedstock (Marsh and Bugusu, 2007a). Petrochemical based plastics such as polyethylene terephthalate (PET), polyvinyl chloride (PVC), polyethylene (PE), polypropylene (PP), polystyrene (PS), polyamide (PA) is relatively inexpensive and available, and is being increasingly used as a packaging material due to its excellent mechanical performance such as tensile and

tear strength, excellent barrier against oxygen, carbon dioxide, acid anhydride and aroma of compounds, and heat-resistant seal (Siracusa *et al.*, 2008). However, their use has to be restricted because they are not easily degradable. Petroleum-derived packaging materials have caused huge environmental negative effects such as natural resource depletion, energy crisis, and climate change and ecosystem issues (Sarwar *et al.*, 2018). Currently, there are more than 200 million tonnes of plastic consumption with a five percent increment annually, and it is the largest field of crude oil application (Siracusa *et al.*, 2008).

A lot of research has been done to develop food packaging materials that can easily degrade in the environment in order to meet the gradual demand for environmental safety and sustainability (Jayaramudu *et al.*, 2013). Therefore, biodegradable polymers are designed to decompose through the work of living organisms (Gross and Kalra, 2002). Hence, producing environmentally friendly products such as carbon dioxide, water, fertilizer (Marsh and Bugusu, 2007a).

2.2 Biodegradable polymer

Biodegradable polymers are polymers that are decomposed mainly into CO₂, CH₄, H₂O, inorganic compounds or biomass due to the enzymatic action of microorganisms (Peelman *et al.*, 2013). Despite the degradability and compostability of these biopolymers are important, but their mechanical and chemical properties are also important. In detail, the type of chemical bonds defines at what point the microorganism could biodegrade the material. Several synthetic polymers such as starch, cellulose, and natural carbon based polymers such as lignin are biodegradable and compostable (Siracusa *et al.*, 2008).

Biodegradable polymers are classified based on their synthesis process (see Figure 1): (1) Polymers obtained from agricultural products, (2) microorganisms, (3) chemical synthesis, and (4) biotechnology (Trinetta and State, 2016).

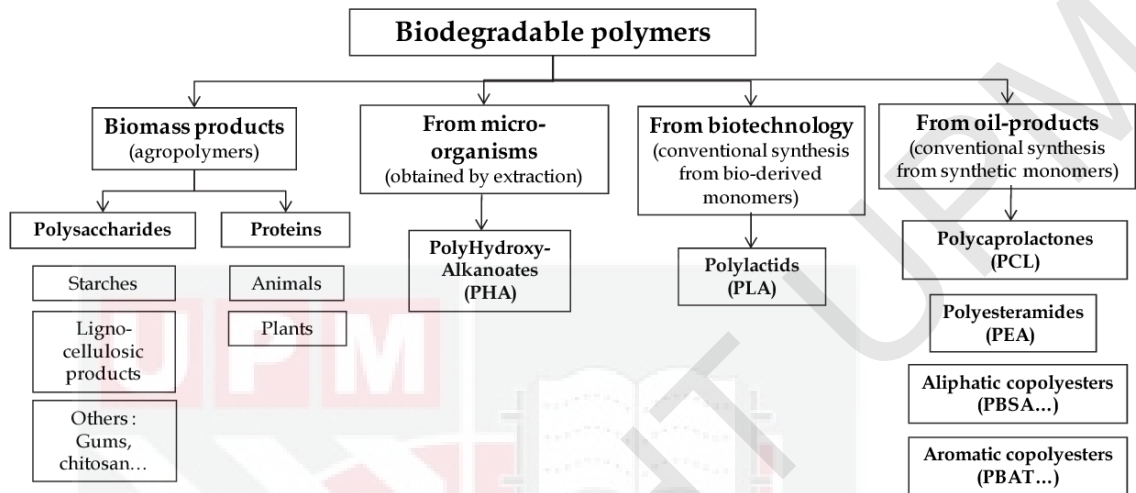


Figure 1: Classification of biodegradable polymers (Source: Trinetta and State, 2016)

2.3 Starch-based edible films

Edible film can be defined as a primary package made from biologically degradable polymers and food-grade additives. A thin layer of biodegradable material can be formed into a film and can be used as a food package without altering the original ingredients or method of treatment. Biodegradable films were used to protect and prolong the life of food products (Chiralt and Atar, 2016; Cazón *et al.*, 2017).

Furthermore, starch-based biopolymer can be produced by blending or mixing them with a synthetic polymer. Thus, miscibility, morphology, and the components and properties of these starches, can be easily and efficiently adjusted by changing the synthesis mixture (Gross and Kalra, 2002). The native starch is chemically composed of two main molecular macro elements 10% - 30% amylose and 70% - 90%

amylopectine. Amylose is an almost linear polymer of α -1,4 anhydroglucose units with an excellent ability to form film, making film strong, isotropic, odorless, tasteless and colorless (Alberto Jimenez, Maria Jose Fabra, Pau Talens, 2012). Experimental evidence shows that amylose is coiled like a spring with six glucose monomers per turn and is not a linear chain of glucose units.

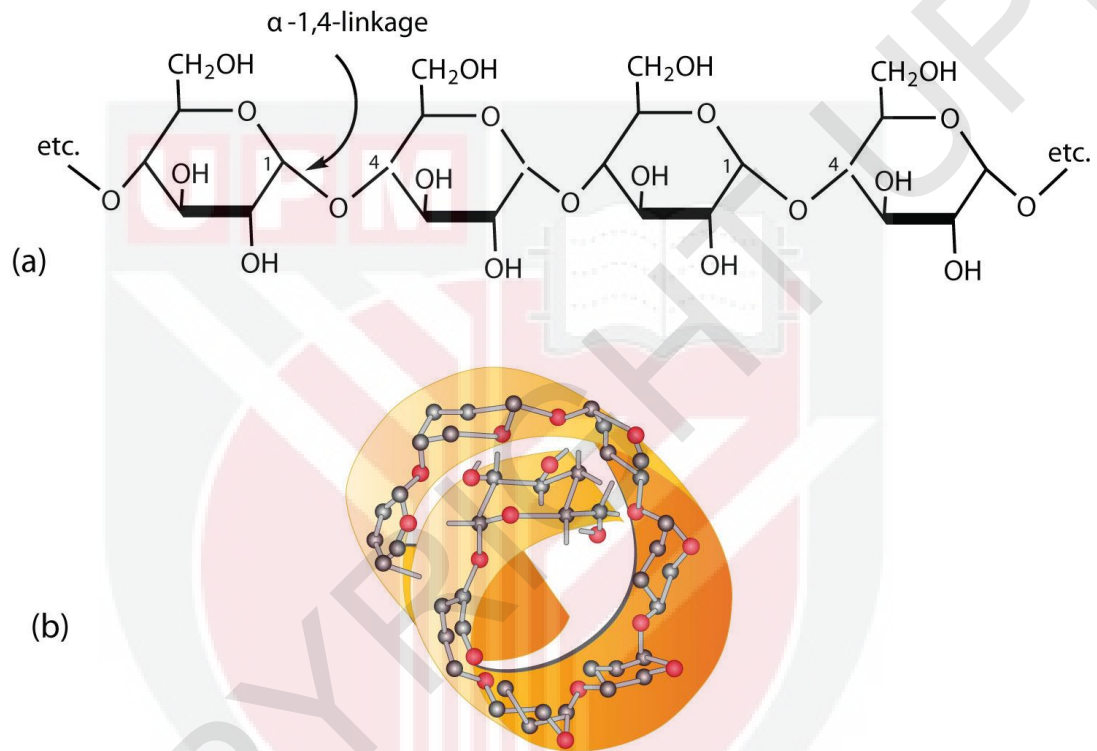


Figure 2: (a) Amylose is a linear α -D- glucose unit chain combined with α -1,4-glycosidic bonds, (b) Because of the bonding of hydrogen, amylose develops a spiral structure containing six glucose units per turn. (Source: Smith, 2016)

Amylopectin is a branched-chain polysaccharide consisting of glucose units bound mainly by α -1,4-glycosidic bonds but bound by α -1,6-glycosidic bonds which are the cause of branching. The amylopectin molecule may contain several thousand glucose units where branching points occur every 25 to 30 units. Amylopectin is a highly branched polymer with a very high molecular weight (5000–30,000 kg / mol), while amylose is a linear polysaccharide chain with a lower molecular size (20–800

kg / mol). Amylose accounts for about 20–25% of most granular starches therefore starch is a natural polymer that can readily be cast into films (Peressini *et al.*, 2003). However, the extensive use of starch film is limited due to their solubility in water and brittleness (Xu *et al.*, 2005). These can be improved by mixing either synthetic polymers in biodegradable materials or cellulose derivatives and proteins in edible packaging(Peressini *et al.*, 2003). The morphology and properties can be regulated easily and efficiently by changing the synthetic blend component and its miscibility with starch (Gross and Kalra, 2002).

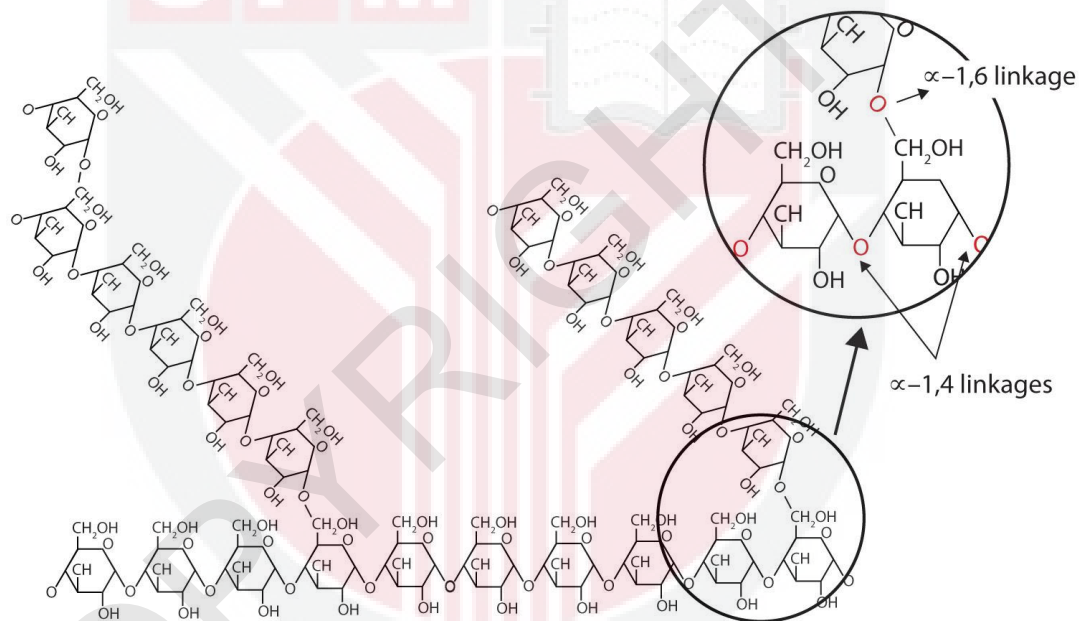


Figure 3: Branching representation in amylopectin and glycogen. Both amylopectin and glycogen contain branch points that are connected by α -1,6 links. (Source: Smith, 2016)

In addition, the most common type of naturally occurring biopolymer is starch that is also one of the most common sources of natural polysaccharides, which are renewable, inexpensive and widely available resources. Correspondingly, there have been numerous studies that investigate the properties of starch-based films.

Table 1: The current study of biodegradable film with starch as main polymer

Author	Polymer	Fruit Waste
Nascimento, Calado and Carvalho, 2012	Starch	Passion fruit mesocarp flour
Salehudin <i>et al.</i>, 2014	Starch	Empty Fruit Bunch (EFB) Cellulose Nanofiber
Luchese <i>et al.</i>, 2018	Cassava starch	Blueberry pomace
Nogueira <i>et al.</i>, 2019	Arrowroot starch	Blackberry pulp
Nouraddini, Esmaili and Mohtarami, 2018	Corn starch	Eggplant flour
Luchese <i>et al.</i>, 2017	Corn starch	Blueberry agro-industrial waste
Ali <i>et al.</i>, 2018	Starch	Pomegranate peel

2.4 Jackfruits

Jackfruit (*Artocarpus Heterophyllus*) belongs to genus *Artocarpus*, which includes species such as breadfruit (*Artocarpus altilis*), dugdug (*Artocarpus mariannensis*) and breadnut (*Artocarpus camansi*). Other than that, the other major species in the genus *Artocarpus* that popular in Malaysia is known as *champedak* (*Artocarpus integer*) (Saxena *et al.*, 2011). Jackfruit size is big and its weight can reach up to 50 kg with 90 cm long and 50 cm wide. Thus, jackfruit is known as the largest and heaviest tree – borne fruit. Generally, jackfruit can be processed into variety of products such as chips, fruit juice, sweets, syrups and jam (Saxena, Bawa and Raju, 2011).

Jackfruit consists of fruit pulp, seeds, straw and skin. In general, jackfruit wastes or by-products compositions have been reported up to 65 – 80% of the total weight of the fruit (Wignyanto, Rahmah and Margani, 2014). In addition, jackfruit waste skin and straw contains starch about 11.1% and 12.5% respectively which is important for film making (Subburamu *et al.*, 1992).

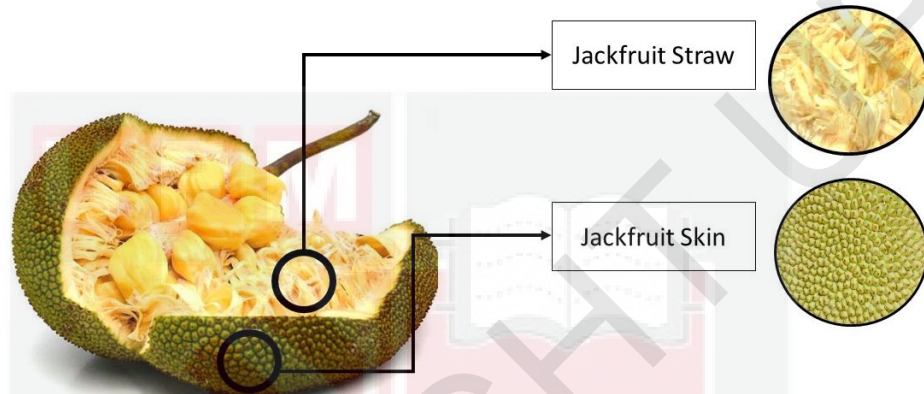


Figure 4: Jackfruit

Jackfruit straw is a jackfruit waste, peeled and does not contain seeds. It contains carbohydrates consisting of glucose, fructose, sucrose, starch, pectin and also contains considerably higher cellulose. Renewable resources of biopolymers include polysaccharides such as starch and pectin are naturally occurring hydrophilic polysaccharides found on plant cell walls, which have good film-forming properties (Neswati, Murtius and Prastica, 2015). The straw of jackfruit was known as coils, rags and streaks. A raw jackfruit straw was used in a dish in Malaysia. The straws are not sweet as the fruit, but rather sweet and somewhat fibrous with some resin. In addition, the jackfruit straw can be processed into jam (Sayuti, Azima and Marisa, 2015). In contrast, jackfruit skin production into edible film has not been extensively studied compared with jackfruit seed.

2.5 Plasticizer

Plasticizers commonly used in the production of films are defined as additives to soften the cast film, to improve flexibility and to overcome the fragility of the film. Plasticizers are an important class of non-volatile molecular weight compounds widely used in the polymer industries as additives. The main role of these materials is to improve the flexibility and processing of polymers by reducing the transition temperature of the second class, the temperature of the glass transition. IUPAC defines plastics as "a material or material embedded in a material (usually plastic or rubber) to increase flexibility, ease of use or use". These materials reduce the deformation resistance, hardness, density, viscosity and electrostatic charge of the polymer, with increased flexibility of the polymer chain, tensile strength and solid insulation (Vieira *et al.*, 2011).

Sorbitol is a type of polyol and is used in this experiment because of its nature. In fact, sorbitol was selected based on the following studies which mention that the active hydroxyl group of sorbitol is an effective plasticizer for some -OH or -NH-rich polymers such as plant proteins, chitosan, and starch (Mohsin, Hossin and Haik, 2011). Furthermore, sorbitol is non-toxic and could be used in some food contacting materials, making it a good choice to be used as food packaging materials (Tian *et al.*, 2017).

2.6 Thymol

Thymol is a carvacrol isomer that is a natural antimicrobial. Carvacrol is the main component of essential oils of oregano and thyme (*Thymus* and *Origanum* sp.) Thymol is also a white crystalline substance called 2-isopropyl-5-methylphenol. It gives a delightful aromatic odor. In relation, this compound is hydrophobic and is

likely to dilute between the lipid acyl chains in the hydrophobic domain of the cytoplasmic membrane of bacterial cells. Then it contains antimicrobial and antioxidant properties for a wide range of bacteria, mold and yeast. (Guarda et al., 2011; Tawakkal, 2016).

This phenolic compound (thymol) in essential oils is a hydrophobic compound that is probably dissolved in the hydrophobic domain of the bacterial cell cytoplasm between lipid acyl chains. Thymol used as antimicrobial agents has a high potential for expanding shelf life and enhancing food product safety. Antimicrobial activity of thymol against bacteria, mold and yeast was demonstrated (Guarda et al., 2011).

2.7 Physical Properties

2.7.1 Film Thickness

Thickness is an important parameter that can influence the product use of films. As a standard thickness requirement for edible film, films should have a thickness of less than 254 μm (Robertson, 2013; Neswati *et al.*, 2015).

2.7.2 Colour

Film color is one of the acceptability factors for consumers. Color attributes are of the utmost importance because they directly influence the acceptance of consumers. Film color parameters range from $L=0$ (black) to $L=100$ (white), $-a$ (green) to $+a$ (red) and $-b$ (blue) to $+b$ (yellowness) were measured using the Easy Math Colorimeter (HunterLab Color Reader) standard test method (ASTM D1925, 1995) (Chillo *et al.*, 2008; Gutierrez *et al.*, 2015; HunterLab, n.d.). The color difference (ΔE), measured by the magnitude of the resulting vector of the three components, which is:

ΔL : brightness difference

Δa : red – green chromaticity difference

Δb : yellow – blue chromaticity difference

The concentration of plasticizers used in edible film can also influence the color of the film. Moreover, Bourtoom(2008) stated that color change is attributed to the plasticizer concentration. The higher plasticizers used in film forming add to the yellowness ($+b$) (Risyon, 2014).

2.8 Mechanical Properties

In this study, the mechanical properties include tensile strength, Young's modulus and elongation in film breaks. The tensile strength of the films can be achieved through its tensile stress and strain curve. Tensile strength is measuring the force to pull something. In addition, the maximum tensile stress was achieved before the sample test specimen failed. The breaking point of the specimen is the test failure point (Risyon, 2014). As the loads continue to increase, the axial deflection of the specimen leads to a failure (break point). In the meantime, the tensile strain is the elongation of the test specimen measured when the break point was reached.

The Young's modulus or elastic modulus is one of the basic measurements of film rigidity. As the modulus of Young increases, the film rigidity also increases. The film thickness and the addition of plasticizers may also affect the young module. Figure 5 represents a stress– strain curve for polymer film subjected to stress testing. A stress– strain curve characterizes mechanical properties such as tensile strength, break load, elongation percentage, toughness, Young's modulus and the tensile strength ratio to Young's module. The elongation percentage can be calculated by

multiplying the load at break by 100. On the other hand, the Young's modulus (modulus of elasticity) can be measured from the slope of the first linear part of the pressure curve as shown in Figure 5 (indicated as A) where the film elastically deforms. Furthermore, the tensile strength is the breaking load when breaking force is divided by the initial film thickness and width shown in B in Figure 5.

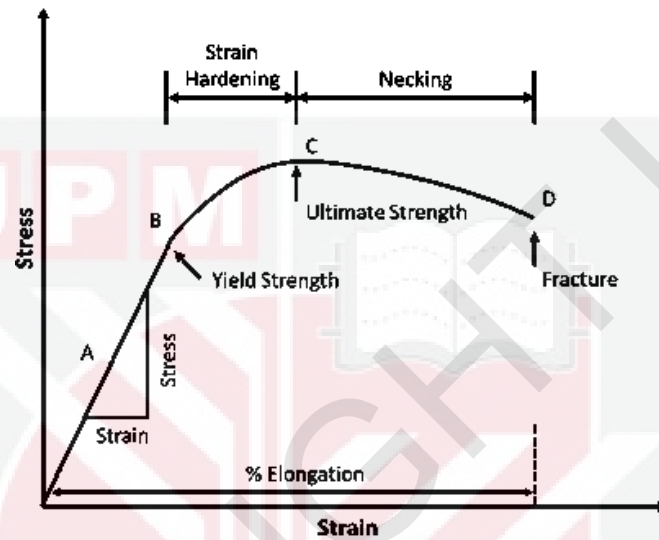


Figure 5: A stress–strain curve for polymer film undergoing tensile strain testing (Source: Lim and Hoag, 2013).

In general it has been found that the addition of a plasticizer reduces the tensile strength of the edible film. This was supported by the aforementioned studies that the addition of plasticizer weakens the hydrogen bonding interaction of starch molecules and can enhance molecular mobility. (Gutierrez *et al.*, 2015; Ooi *et al.*, 2012). The addition of sorbitol-plasticized film gives greater tensile strength. This is because of the molecular structure of sorbitol, which interacts with polymer starch chains when the molecular structure of sorbitol is identical to glucose units.

Adding a plasticizer such as glycerol or sorbitol also affects elongation at break and Young's modulus of the film (Tapia-Blácido, Sobral and Menegalli, 2011). Films without plasticizer are generally brittle and not elastic. The plasticizer is used to soften the cast film, thus increasing the flexibility of the film. Besides, it can loosen the molecular structure of the film without plasticizer and make it easier to move the polymer chain segment.

2.9 FTIR Analysis – Infrared Spectroscopy

Fourier Transform Infrared Spectroscopy (FTIR) provides basic information on the molecular structure of organic and inorganic components and provides the most versatile analytical techniques for non-destructive, chemical characterization of geological samples (Chen *et al.*, 2015). In FTIR analysis, IR radiation is absorbed when a photon transfers to a molecule and stimulates it to a higher energy level (Parikh and Chorover, 2005). The excited state results in the oscillation (i.e., stretching, bending, twisting, rocking, meandering and deformation out of the plane) of the molecular bonds that occur at different wavenumbers (or frequencies) in the IR region of the light spectrum. The intrinsic physicochemical properties of the corresponding molecule determine by the wavenumber of each IR absorption peak and diagnosis similar to that particular functional group's (e.g., C–H, O–H, C=O, etc.) (Chen *et al.*, 2015).

2.10 Antimicrobial Activity

Edible film can be used as a carrier for a variety of food additives, including various antimicrobial agents that can extend product life and reduce the risk of pathogen growth in food surfaces (Ryser, Cagri and Ustunol, 2004). The main advantage of antimicrobial is that barrier agents in these films can be specifically targeted at post-processing contaminants on food surfaces, with the antimicrobial dispersion rate into the product partly operated by the agents that are incorporated into the film. Antimicrobial dispersion through edible film is influenced by film type, hydrophilic nature, and storage condition (temperature, duration).

Zone of inhibition testing is one way of quantifying the ability of antibiotics to inhibit bacterial growth. The interpretation of the results of this test is based on model-dependent analysis, which assumes that antibiotics are free to spread into solid nutrient media (Bonev and Hooper, 2008). Besides other factors, such dissipative diffusion could result from antimicrobial interactions with the diffusion medium, antimicrobial degradation, bacterial film antimicrobial removal or other substrate loss during diffusion.

The effectiveness of antibiotics can be assessed by their ability to suppress or inhibit bacterial growth. Zone of inhibition method is commonly used to measure the growth. It involves antimicrobial sample to be placed on the surface agar plates seeded with the test bacterial strain. Diffusion of antibiotics from these sources to the agarose medium results in inhibition of bacterial growth near the source and the formation of distinct "zones" without bacterial lawn. The diameter of this zone increases with antibiotic concentration (Bonev and Hooper, 2008).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discuss about the selection of materials used and methodology to carry out the experiment. The steps of preparing jackfruit skin and straw film is also explained in this chapter. The methodology covered from the preparation of jackfruit skin and straw powder until to the preparation of jackfruit skin and straw films. JS/starch films were prepared by solvent casting technique using honey wax as mold release agent. The films were produced by combining tapioca starch and jackfruit skin / straw powder at different weight ratios (g:g) (5g JS: 5g starch, 6g JS: 4g starch, 7g JS: 3g starch). Next, 6g JS: 4g starch will be added with plasticizers, sorbitol at different loading (0%, 15%, 25%, 40%). Lastly, 3% of thymol concentration will be added at the last stage of film preparation for antimicrobial test. Figure 6 describes the process flow diagram of this study.

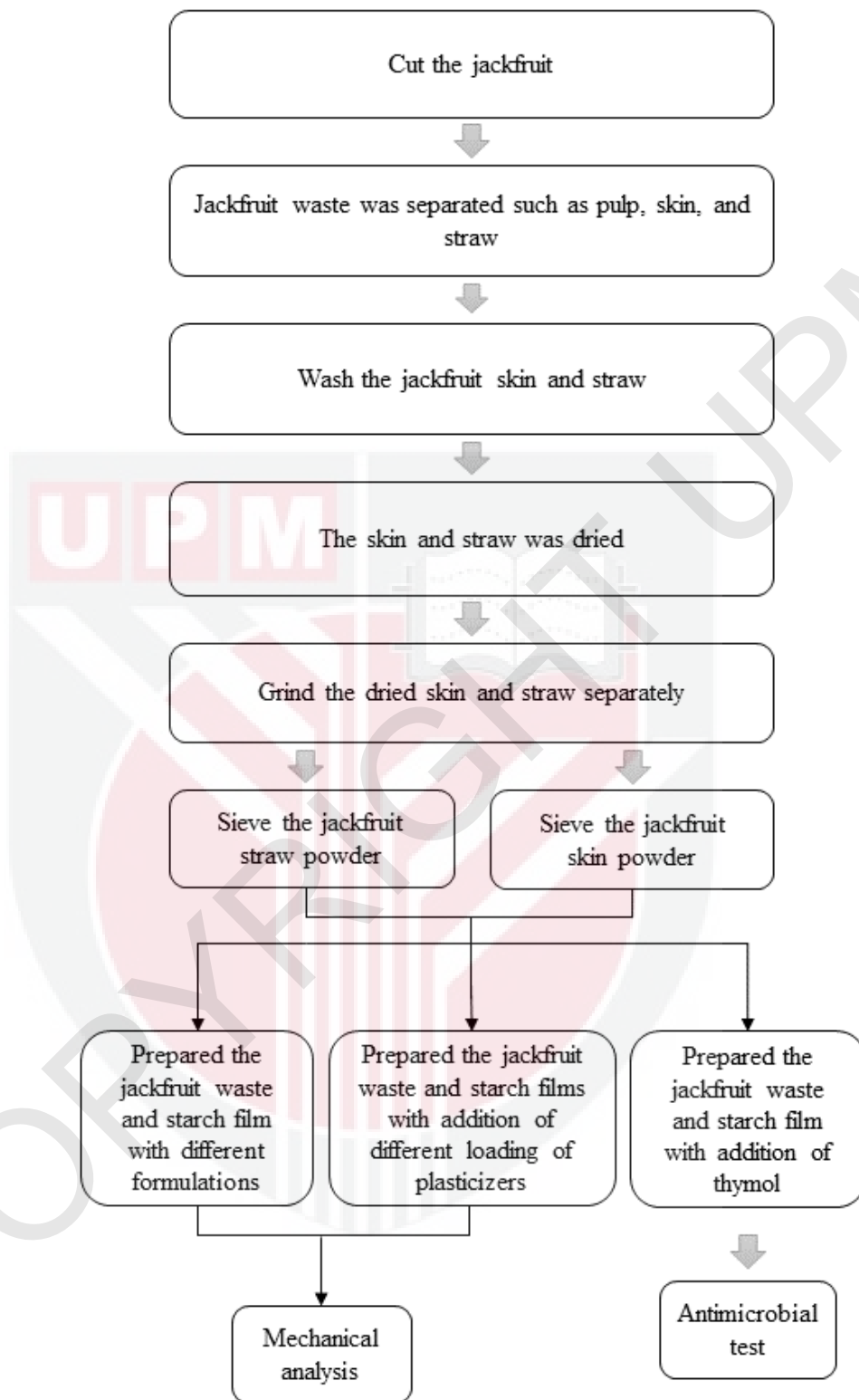


Figure 6: Process Flow Diagram

3.2 Materials

Tapioca starch was purchased from Thye Huat Chan Sdn. Bhd. and honey jackfruit was obtained from Pasar Borong Seri Kembangan, Selangor. Sorbitol as plasticizer were purchased from R&M Chemical Malaysia. Natural antimicrobial agent used is thymol were purchased from R&M Chemical Malaysia.

3.3 Preparation of Jackfruit Straw and Skin Powder

The jackfruit straw and skin were obtained from the fruit will go through the washing and cutting processes before dried in a drying oven at 60°C for 48 hours. Then, by using the electrical grinder, the straws and skin were grinded separately to form jackfruit straw powder and jackfruit skin powder. In the electrical grinder, both jackfruit straw powder and jackfruit skin powder were passed through a 0.25 mm mesh sieve size and collected.

3.4 Preparation of Films

There are three types of films used in this project. The first films are the jackfruit waste films with no addition of plasticizer or antimicrobial agent. This film act as a control to other films which were incorporated with plasticizer and antimicrobial. Types of films prepared:

Table 2: Formulations of JS films

Sample	JS Starch Powder (g)	JS Skin Powder (g)	Tapioca starch (g)	Sorbitol (g)	Thymol (g)
(a) JS formulations films (Jackfruit: Starch)					
5:5	5	-	5	-	-
6:4	6	-	4	-	-
7:3	7	-	3	-	-
5:5	-	5	5	-	-
6:4	-	6	4	-	-
7:3	-	7	3	-	-
(b) Films with different concentration of plasticizer (6JS:4S)					
0%	6	-	4	0	-
15%	6	-	4	0.15	-
25%	6	-	4	0.25	-
40%	6	-	4	0.4	-
0%	-	6	4	0	-
15%	-	6	4	0.15	-
25%	-	6	4	0.25	-
40%	-	6	4	0.4	-
(c) Films with Thymol					
3%	-	-	4	-	0.03
3%	-	-	4	-	0.03

Basically, the films was prepared by using technique called solvent casting. The starch and jackfruit powder were diluted using 200ml distilled water using 1:20 ratio (Jackfruit straw/skin powder to distilled water). The mixing solution was mixed homogeneously with a magnetic stirrer with a constant stirrer for 5 minutes. The mixture solution was then heated with a hot plate at 75 ° C for 15 minutes with continuous stir (Risyon, 2014; Neswati, Murtius and Prastica, 2015). The solution was cooled at room temperature and filtered by using tea filter or vacuum filter after being sonicated for 10 minutes. Next, the film solution was centrifuged at 500 rpm to precipitate undissolved substances. The natural antimicrobial agent, thymol at different concentrations (3%) is added before the solution temperature reach 75°C.

Next, a portion (50ml) of each film was casted on petri dish and dried at controlled temperature of 60°C for 48 hours using dry oven. The film was peeled off from the petri dish after stand for 10 minutes. Figure 7 summarized the film preparation in form of flow chart.

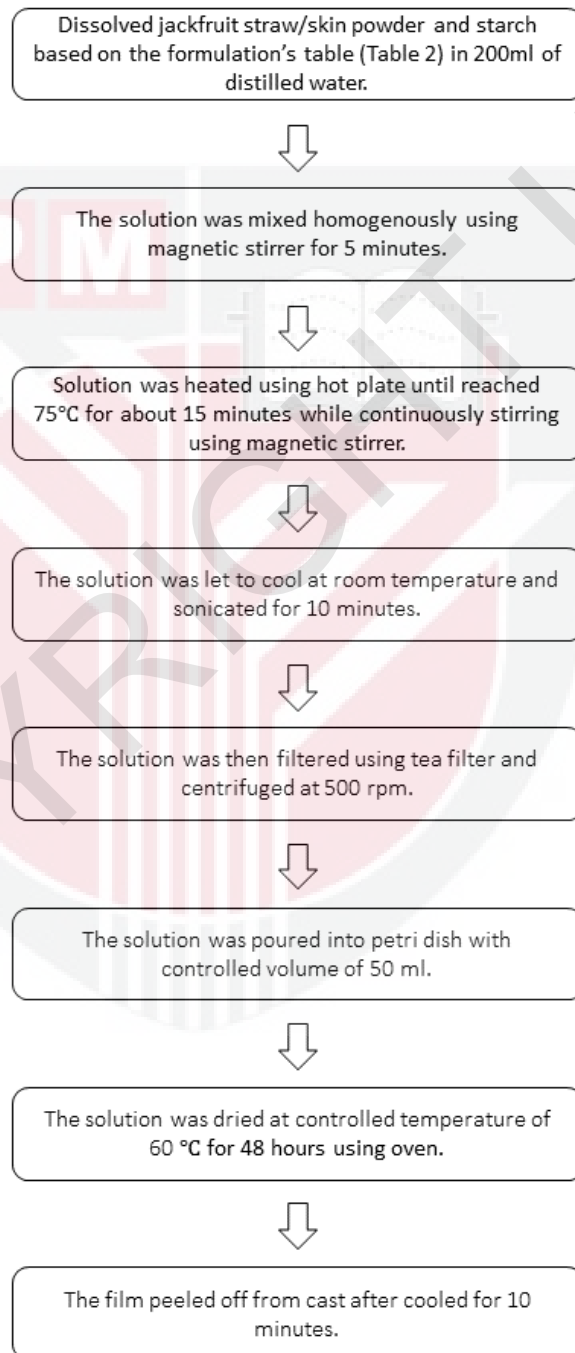


Figure 7: Flow chart of film preparation

3.5 Characterisation of Jackfruit Waste/Starch Films

3.5.1 Physical properties

Film Thickness

The thickness of the film at five different places were measured using a digital Vernier calliper with an accuracy of 0.001 mm. The values obtained were averaged and represented in mm (Risyon, 2014; Neswati, Murtius and Prastica, 2015).

Colour Test

JSP / starch film colour was measured using a Hunter Lab colorimeter (USP 1431 UltraScan Pro, USA) based on the CIE L*a*b* colour system, L*, a* and b*. L* describes the lightness from black to white, a* and b* describe the chromatic coordinates from -a*: green to+ a*: redness and from -b*: blueness to+ b*: yellowness. The film samples were first placed on the surface of a white standard plate with a value of L*= 97.39, a*= 0.03 and b*= 1.77 to calibrate the equipment (Gutierrez *et al.*, 2015). The measurements for each film were recorded in three different positions.

3.5.2 Mechanical properties

In order to determine tensile strength, Texture Analyser Testing Machine Model 3365 was used based on American Society of Testing and Material Standard Method (ASTM) D882-97 for mechanical test of the films. Rectangular shape with dimension of 100 x 15 mm was cut of the films. The initial gauge separation and the crosshead speed was set to 10 and 20 mm/min respectively. At room temperature, the test was conducted (Risyon, 2014)

3.5.3 FTIR Analysis - Infrared Spectroscopy

The infrared spectral analyses of the starch, JSP and JSP/starch films were measured using a Shimadzu IR Prestige Fourier transform infrared (FTIR) spectrophotometer with an attenuated total reflectance (ATR) attachment. All spectra were recorded in the range of 550– 4000 cm^{-1} with 4 cm^{-1} resolution and 32 scans recorded with Happ-Genzel apodization at each point. At least two random locations of the film were scanned for each sample.

3.5.4 Antimicrobial Test

Films were cut to a diameter of 1 cm and placed on PDA and osmophilic agar plates. Plates were incubated for 24 hours at 30°C, microorganism growth was observed around and under films and the inhibitory area was measured. The test was carried out in triplicate (Murtius and Rahmi, 2015) .

CHAPTER 4 RESULT AND DISCUSSION

4.1 Mechanical Properties of Jackfruit Waste Based Films: Effect of Starch Content

Mechanical properties show the strength of films and their ability to increase food mechanical integrity (Nouraddini, Esmaili and Mohtarami, 2018). The mechanical properties of the JSt/starch and JSk/starch films are shown in Figure 8(a) and Figure 8(b), respectively. Jackfruit straw film of 7:3 weight ratios had trouble in handling, due to higher loading of straw powder makes it become sticky. Oppositely, for jackfruit skin film, low loading of skin powder makes it become brittle. Thus, no result obtained for weight ratios of JSt/starch film at ratio of 7:3 and JSk/starch film at ratio of 5:5 due to its difficulty to handle.

There is a significant effect on the addition of starch loading on tensile strength. Result shows that JSt/starch films at weight ratios 5:5, had the highest values of tensile strength (TS), 4.52 MPa whereas JSt/starch film at weight ratio 6:4 was 1.87 MPa. At weight ratio of 6:4, JSk/starch film has higher TS value of 4.51 MPa compared to JSk/starch film at 7:3. This indicates that higher loading of starch gives higher tensile strength of film. This can be due to the presence of starch as polysaccharides, which generally increase the mechanical strength of the films (Prakash Maran *et al.*, 2013). The starch can provide a higher film rigidity due to its high intermolecular forces (Mali *et al.*, 2006).

Elongation at break (EaB) is an indication of the flexibility and stretch ability of the film (extensibility), which is determined at the point when the film breaks during tensile testing and is expressed as the percentage of change in the original length of the specimen between the film grips to stretch (extend) (Bourtoom and Chinnan, 2008). Based on Figure 8(a), JSt/starch films at weight ratio of 5:5 had a slightly higher value than weight ratio 6:4 of elongation at break which are 29.23% (5:5) and 26.82% (6:4). Whereas, the Eab value of JSk/starch films at weight ratio of 7:3 had a significant changes than weight ratio 6:4 which are 28.24% (7:3) and 21.45% (6:4). Noticed that the Eab value of JSk/starch decreases as TS value increased. It suit with the statement that starch loading leads to a stiffer and rigid film and not elastic film due to its high intermolecular forces (Mali *et al.*, 2006).

The jackfruit waste to starch ratio of 6:4 for both jackfruit straw and skin was selected as the main formulation in which to systematically investigate the mechanical properties of the films. Figure 9 shows the results of JSt/starch and JSk/starch films at weight ratios of 6:4. The result shows that JSk/starch film (4.51 MPa) have higher TS than JSt/starch film with the same loading of starch. It was assumed due to the presence of fiber as cellulose in the jackfruit skin films which result in stronger film (Mohd Na'im, 2018) It was reported that the jackfruit skin contains up to 50.13% of α -cellulose (Ahmad Marzuki, 2018). The Eab value was higher for JSt/starch film than JSk/starch film which are 26.82% and 21.45% respectively. It is assumed that there is not much natural fiber in the straw of the jackfruit as in the skin of the jackfruit Therefore, JSt/starch film exhibit a higher Eab value than JSk/starch film.

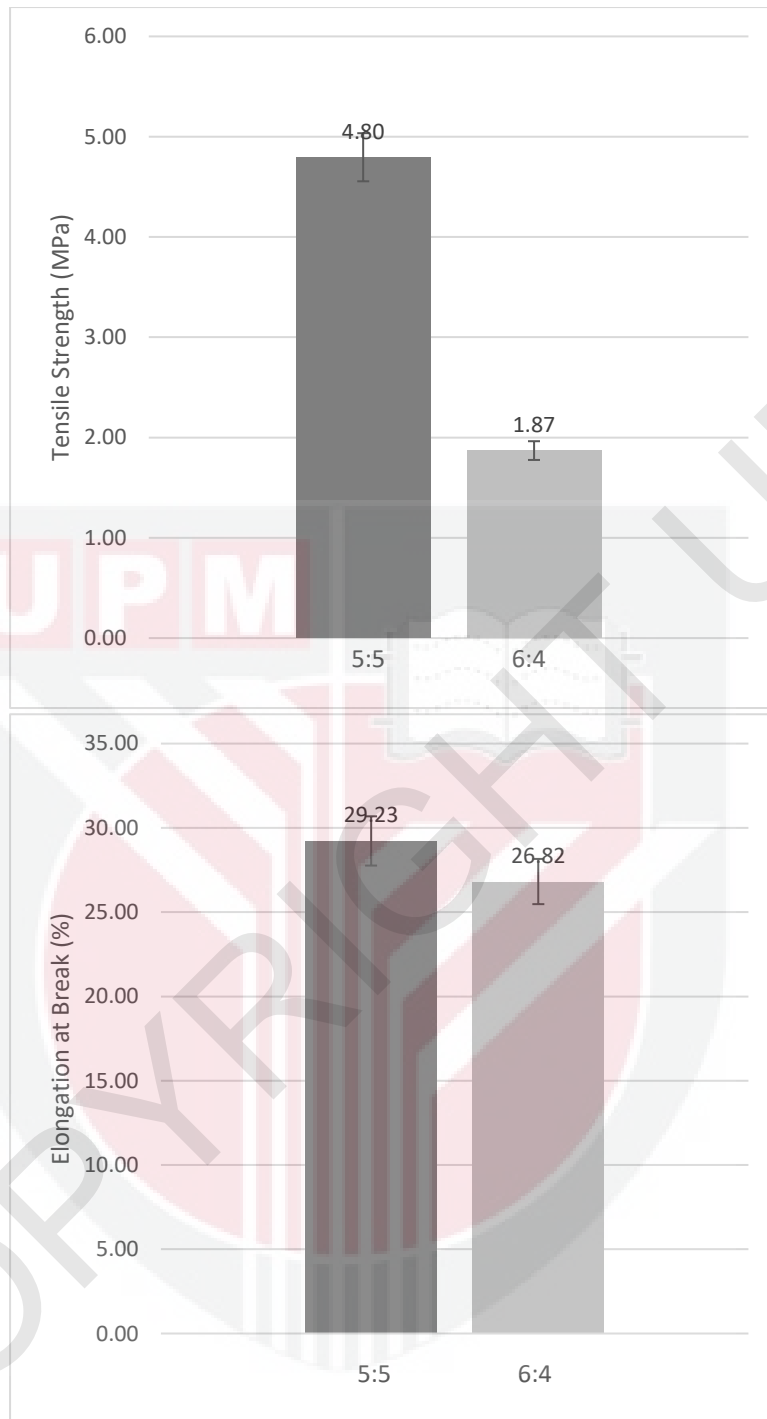


Figure 8(a): Mechanical properties of JSt/starch films at jackfruit straw to starch ratio of 5:5 and 6:4

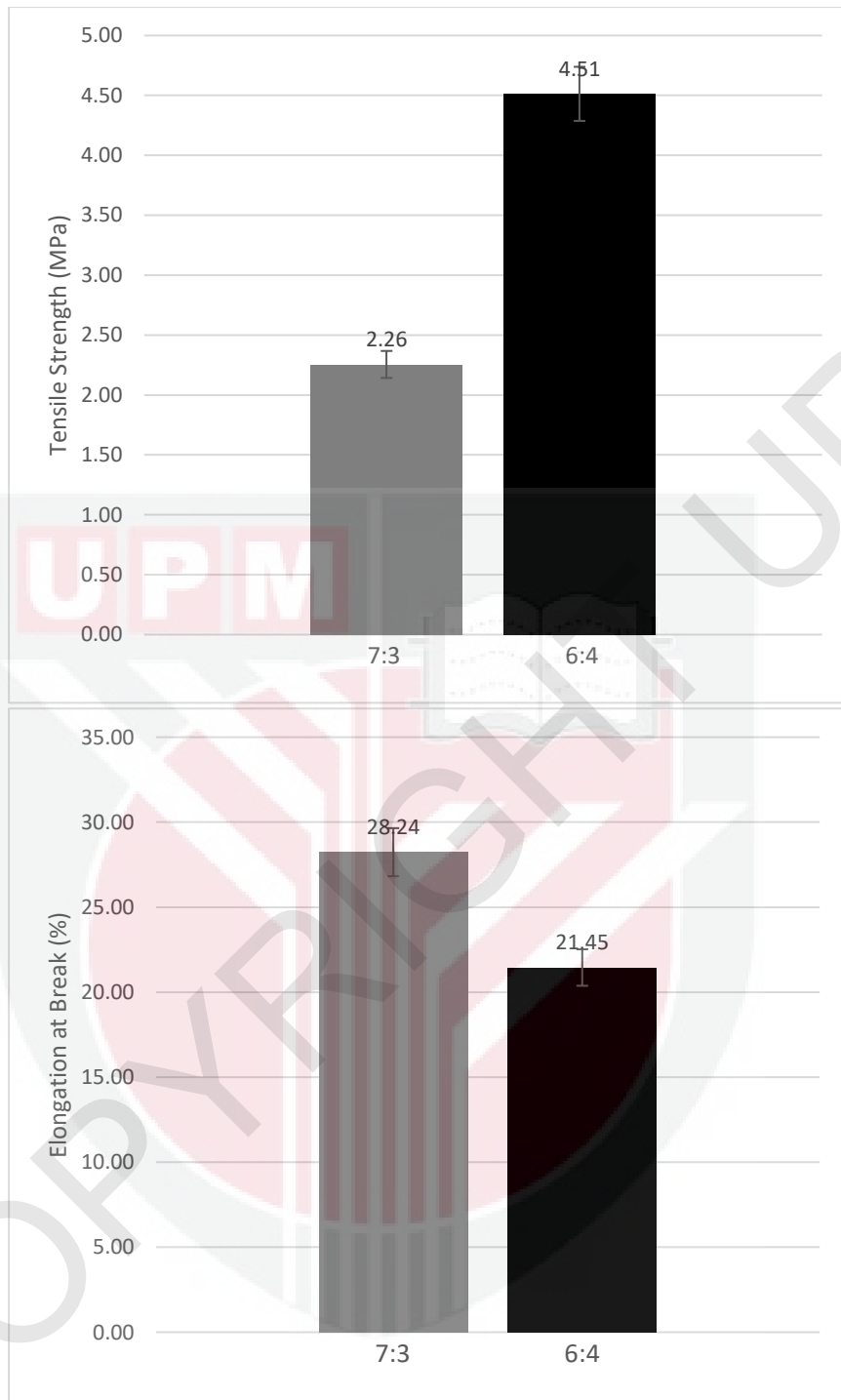


Figure 8(b): Mechanical properties of JSk/starch films at jackfruit skin to starch ratio of 7:3 and 6:4

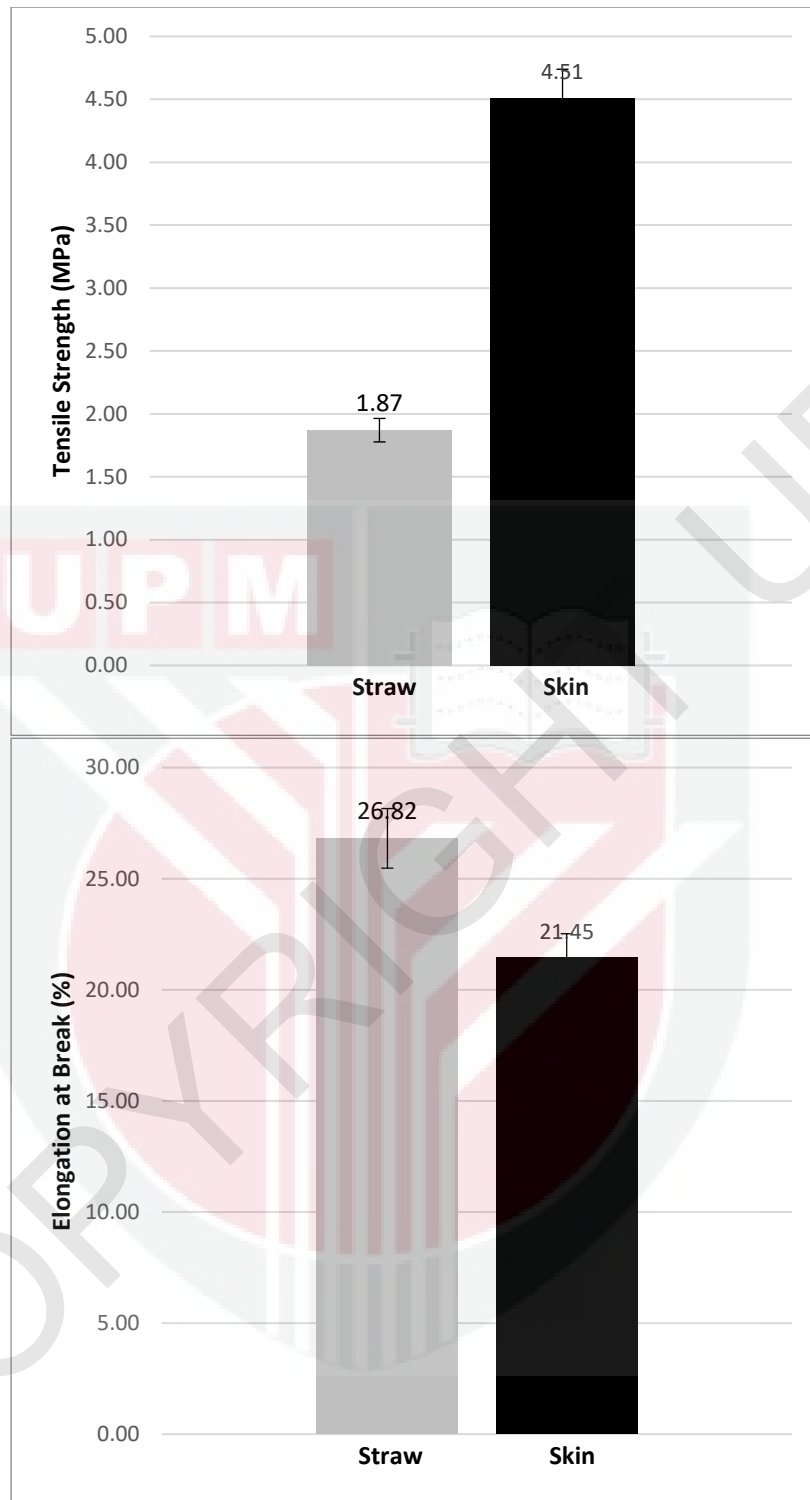


Figure 9: Mechanical properties of JSSt/starch and JSk/starch films at ratio of 6:4

4.2 Mechanical Properties of Jackfruit Waste Based Films: Effect of Plasticizer Content

Figure 10 presents the mechanical properties of plasticized JSt/starch and JSk/starch films with different loading of plasticizer. Noted that the highest value of TS was the film with zero loading of sorbitol for both JSk/starch and JSt/starch film which are 1.87 MPa for JSt/starch and 5.94 MPa for JSk/starch. The result shows that plasticized JSt/starch film demonstrated much lower tensile strength value for the overall film in the range of 0.17 MPa to 0.36 MPa. Meanwhile, plasticized JSk/starch film shows that the higher the sorbitol loading, the lower the TS which range between 3.60 MPa to 1.39 MPa. This is due to the presence of plasticizer in the film which reduces brittleness and enhances flexibility and extensibility by acting as spacers between polymer chains and reducing intermolecular forces between adjacent polymer chains (Prakash Maran *et al.*, 2013). Similar result was found by Mohd Nazri, (2017) who prepare jackfruit films containing starch at 4:6 ratio for plasticized films containing sorbitol.

As stated before, elongation at break (EAB) is an indication of the flexibility and stretch ability of the film. In Figure 10, the EAB value were significantly increased for both plasticized JSt/starch and JSk/starch films with highest EAB value of 35.48% (JSt/starch) and 36.82% (JSk/starch). JSt/starch plasticized films demonstrated a similar value of EAB with the range between 30.16% and 35.48%. However, plasticized JSk/starch film show a decreasing value of EAB as plasticizer loading increase. Noticed that the highest EAB value of plasticized JSk/starch film was at 15% of sorbitol loading and decrease to 32.39% and 22.09% for 25% and 40% of sorbitol loading respectively. This is the effect of plasticizer which have increase the flexibility of film by penetrating between polymer chains, weakening the interaction between

polymer materials as in polysaccharides and film proteins and enhancing their flexibility and extensibility (Suderman, Isa and Sarbon, 2018). Thus, result in higher Eab values and flexibility of films.

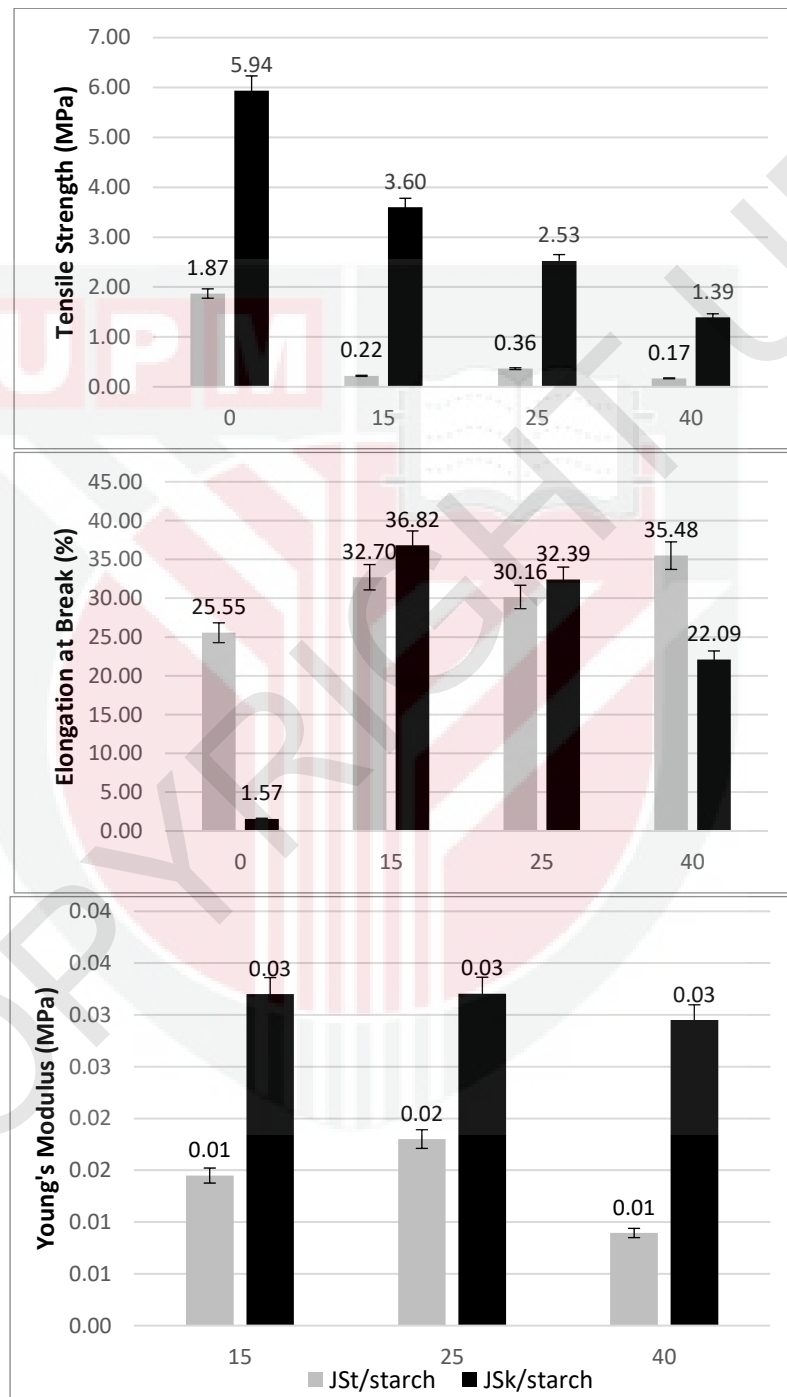


Figure 10: Tensile properties of JSk/starch and JSt/starch films at different loading of plasticizer: Tensile Strength, Elongation at Break and Young's Modulus

Young's modulus is the stress to strain ratio over the linear part of the stress-strain curve. It is the fundamental measure of film stiffness, as the Young modulus increases, the stiffness of the materials increases (Prakash Maran *et al.*, 2013). Both of the JSt/starch and JSk/starch film shows no significant change in YM value. The YM value of JSt/starch film possessed in between 0.01449 MPa to 0.01801 MPa. Whereas, JSk/starch film demonstrated slightly higher YM value in the range between 0.0295 MPa to 0.0320 MPa. The addition of plasticizer into the film is expected to significantly reduce the stiffness of JS films. The result showed that the lowest value of YM was plasticized JSt/starch film of 40% sorbitol loading which was 0.01 MPa. It is mainly due to addition of plasticizer which increased the film flexibility. By increasing the loading of plasticizers in the films can increase the molecular volume and reduce the hydrogen bond between polymer chains in JS films (Mali *et al.*, 2006). A similar observation was reported by Mohd Nazri, (2017) which show similar result in YM of plasticized jackfruit straw film containing tapioca starch at ratio of 4:6.

4.3 Physical Properties of Jackfruit Waste Based Films: Effect of Starch and Plasticizer Contents

4.3.1 Thickness of Films







Table 3 shows the thickness value of JSt/starch and JSk/starch films at different starch contents as well as the physical appearance of the films. It was found that the thickness of the films ranged between 0.167 mm to 0.098 mm. The films meet the standard requirement of JIS 1975 for edible film (Red, Murtius and Prastica, 2015). The calculated standard deviations of thickness averages are typical for edible films (Sobral *et al.*, 2001). It was found that the films of both jackfruit straw and skin containing tapioca starch were partially transparent, flexible and easily handled.

It was observed that the amount of starch content in the films show significant effect on the thickness of both JSt/starch and JSk/starch film. The JSk/starch films show a slight reduction in the thickness value (0.1137 to 0.0976 mm) with the reduction of the starch loading. However, the thickness of the JSt/starch film is increased (0.1298 to 0.1523 mm) with the reduction of the starch loading from 5g to 4g. It can be assumed that presence of natural starch in the jackfruit straw was higher than the jackfruit skin, which contributes to a slightly higher thickness (Murtius and Rahmi, 2015). Thus, it can be conclude that higher starch content (the combination of natural starch in the jackfruit straw and tapioca starch) leads to higher thickness value of films.

During the experiment, it was found that the thickness of JSk/starch film at ratio of 5:5 cannot be measured due to its brittleness and easily break (see Table 3). The brittleness of starch based films is due to the present of amylopectin in the starch. Starch usually contains 20 to 25% amylose and 75 to 80% amylopectin (Alberto Jimenez, Maria Jose Fabra, Pau Talens, 2012). Linear molecules of amylose that form

strong and flexible films, while branched films of amylopectin are weak and brittle (Peressini *et al.*, 2003). Meanwhile, the thickness of JSt/starch film at ratio of 7:3 was not able to be measured as it is hard to handle due to high stickiness (see Table 3). In this case, the formulation of jackfruit straw and starch ratio was not functional. This is because edible films are greatly influenced by parameters such as formulation, film-forming technology, solvent characteristics and additives (Peressini *et al.*, 2003).

Table 3: Thickness of JSt/starch and JSk/starch films at different starch contents.

Weight Ratios (g:g)	T _{avg} (mm)	Films
i) JSt / Starch		
5:5	0.1298 ± 0.005	
6:4	0.1523 ± 0.005	
7:3	<i>Sticky</i>	
ii) JSk / Starch		
5:5	<i>Brittle</i>	
6:4	0.1137 ± 0.005	
7:3	0.0976 ± 0.005	

The formulation of both JSt/starch and JSk/starch films was then fixed at ratio of 6:4 in which to systematically investigate the thickness of the films. It was observed that there was a significant change in thickness of JSt/starch and JSk/starch films film at different plasticizer contents. The film with no loading of plasticizer demonstrate a higher thickness value than plasticized films. This is due to the presence of plasticizer which reduces the viscosity of film, hence film solution can be uniformly spread onto casting plate resulted in lower thickness. According to Vieira, Da Silva, Dos Santos, & Beppu, (2011) , plasticizer reduce the deformation resistance, hardness, density, viscosity and electrostatic charge of the polymer, with increased flexibility of the polymer chain, tensile strength and solid insulation.

The thickness of plasticized JSt/starch films was higher which is in the range between 0.11 mm to 0.126 mm, than plasticized films of JSk/starch with the thickness between 0.084 mm to 0.0925 mm. This observation was similar to the previous section whereby higher starch content due to the combination of natural starch in the jackfruit straw and tapioca starch leads to higher thickness value of films. Interestingly, no significant changes on the thickness were observed for both plasticized JSt/starch and JSk/starch films with the addition of plasticizer from 15 to 40%. These current results are similar to (Mohd Nazri, 2017) who prepare jackfruit straw films containing tapioca starch at ratio of 4:6 in term of the thickness of plasticized jackfruit straw films using glycerol and sorbitol.

Table 4: Thickness of JSk/starch and JSt/starch film at ratio of 6:4 with different loading of plasticizer

Loading of Plasticizer (%)	Thickness (mm)	
	JSt/starch	JSk/starch
0	0.1523 ± 0.005	0.1137 ± 0.005
15	0.11 ± 0.005	0.084 ± 0.005
25	0.108 ± 0.005	0.094 ± 0.005
40	0.126 ± 0.005	0.0925 ± 0.005

4.3.2 Films Colour

Figure 11 shows the colour parameters of JSt/starch and JSk/starch films at a fixed ratio of 6:4 with the addition of 25% plasticizer and without plasticizer. L* described the brightness value of the product in the range from 0 (black) to 100 (white). It was observed that addition of plasticizer demonstrated a significant effect on the colour of the JSt/starch and JSk/starch films. Noted that there were significant difference of value L* for JSt/starch and JSk/starch film. Film without plasticizer have a higher lightness value (L*) which are 40 for JSt/starch and 39.69 for JSk/starch. The plasticized films exhibited similar L* value than the film without plasticizer. From the observation, generally JSk/starch film appears less brightness than JSt/starch film. JSt/starch film appeared to be light orange whereas JSk/starch film appeared to be dark orange from sight. According to Bourtoom and Chinnan (2008), the concentration of the plasticized film can influence the colour change.

The a* colour parameter is the red colour value (+) and green colour value (-). JSt/starch and JSk/starch without plasticizer shows a negative value a* colour parameter which indicate greenish in film. Compared with plasticized film, the a* value is higher and in positive value which indicates it have red colour of the film.

This result is similar to the findings by Mohd Nazri, (2017) for colour of plasticized jackfruit straw film containing tapioca starch at ratio of 4:6.

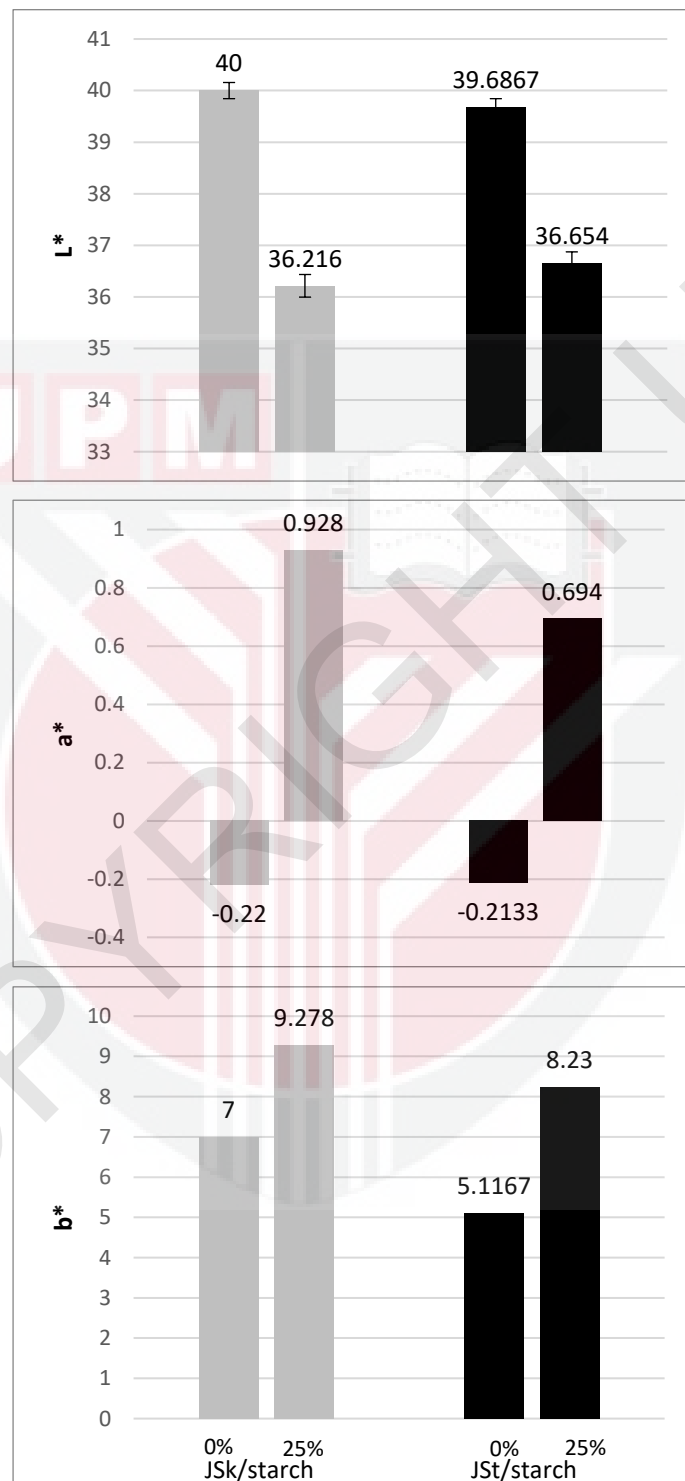






Figure 11: Colour analysis of JSt/starch and JSk/starch films at ratio of 6:4 with addition of plasticizer for different types of parameters: L*, a* and b*

The b^* colour parameter shows the yellow colour. The higher b^* value indicates yellow whereas opposite indicates blueish. It was found that a slight increase in b^* value of plasticized JSt/starch and JSk/starch film compared with film without plasticizer. No significant changes in b^* value compared with L^* and a^* value. From observation, both films of JSt/starch and JSk/starch appeared yellowish. Result show that JSt/starch film have high value of yellowish (b^*) than JSk/starch for both plasticized and without plasticizer film. This is due to the natural colour of the jackfruit straw itself which is yellow (Sayuti, Azima and Marisa, 2015). It had influenced the overall colour of the films. Moreover, a significant change on colour of the films was observed for plasticized JSt/starch and JSk/starch films than the films without plasticizer (see Table 5). The data for colour parameters of plasticized JSt/starch and JSk/starch films at different plasticizer content was not reported in this section due to no significant changes were observed.

Table 5: Images of JSt/starch and JSk/starch (6:4) of non-plasticized (0%) and plasticized film (25%).

Colour film	
(i) JSt/starch	
Non – plasticized film	Plasticized film
	
(ii) JSk/starch	
Non – plasticized film	Plasticized film
	

4.4 FTIR Spectra Analysis

The surface FTIR spectra of native JSt, native starch and JSt/starch films were obtained and are shown in Figure 12 in order to confirm the interaction between the jackfruit skin and starch on the film. In this section, the spectrum of JSk/starch film is not presented in the current result. It was found that the spectrum of JSt/starch film at JSt and starch ratio of 4:6 was similar to the spectrum of the native JSt film. A wide range of -OH groups was observed in the spectrum of all films in a region of approximately 3400 - 3300 cm^{-1} . This peak corresponds to the extended vibration of the -OH starch and pectin group, as in the JSt film. A peak at 2921 cm^{-1} is attributed to an asymmetrically vibration of the -CH band.

A sharp absorption peak at about 1631 cm^{-1} of the native starch film is observed, which corresponds to the -OH stretching vibration of absorbed water in the starch film. The existence of this was attributed to the vibration of water molecules absorbed in the non-crystalline starch region (Deeyai et al., 2013).

As shown in Figure 12, major changes in the band associated with -OH groups occur. For example, the presence of new hydrogen bonding in the JSt/starch film could be interpreted from the -OH(adsorbed water) group peak, which shifts to 1587 cm^{-1} with a broader band than native starch film (Liu et al., 2011).

Interestingly, a new and prominent peak was observed from the JSt/starch and native JSt film at 1741 cm^{-1} which indicates the stretching vibration of -C=O, attributes to the carbonyl group. According Proctor (2000), this band representing the ester carbonyl group of pectin at approximately 1760-1745 cm^{-1} . It was found that the existence of this peak was weak for JSt film and no peak presence in the starch film.

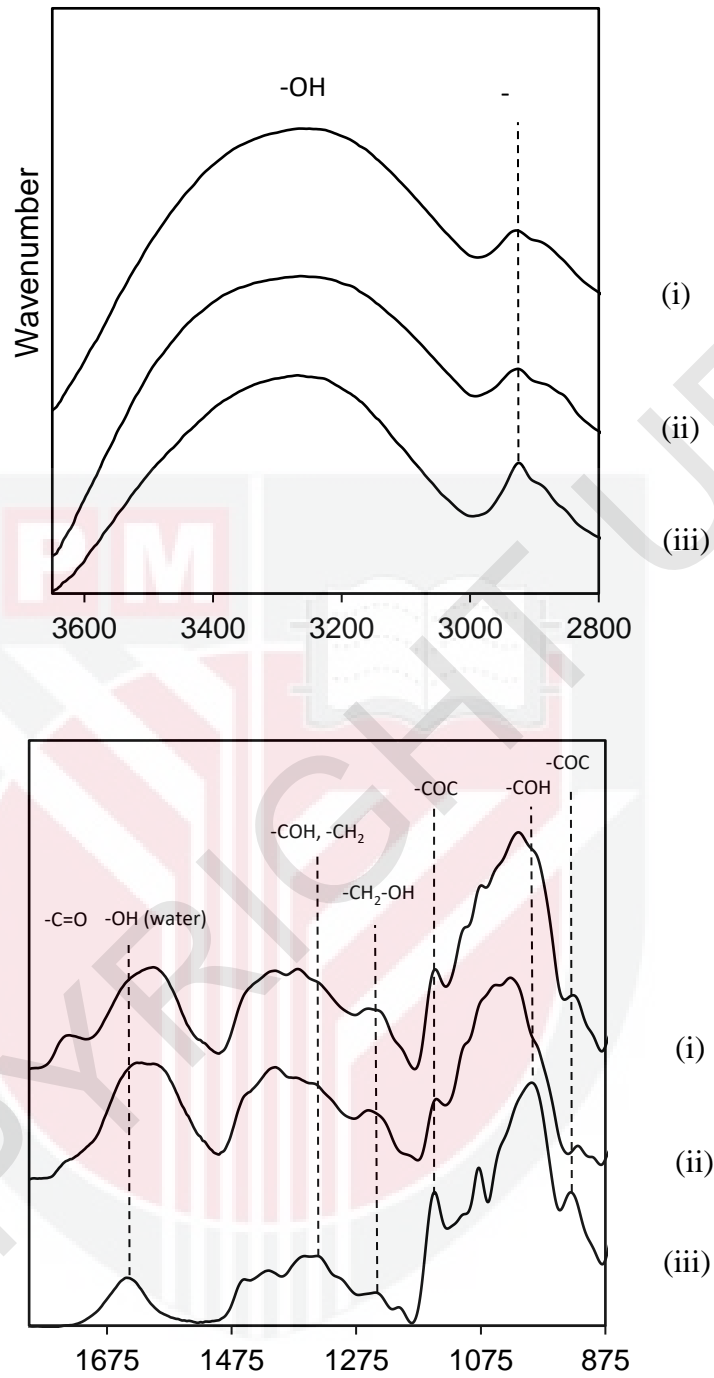


Figure 12: FTIR spectra of (i) JSt/starch film at JSt and starch ratio of 4:6, (ii) native JSP film and (iii) native tapioca starch film.

4.5 Antimicrobial Analysis

Thymol was incorporated to JSt/starch and JSk/starch films and were tested against microorganisms particularly *E. coli* for the zone of inhibition. Images of the inhibitory effect of JSt/starch and JSk/starch film incorporated with 3% of thymol against test microorganism, *E. coli* were shown in Figure 13. The zone of inhibition was observed to be slightly clearer in the JSk/starch film than JSt/starch films. This was due to thymol incorporated into the films diffused out to inhibit growth of microorganism. In the current study, mode of action of carvacrol was explained by Seydim & Sarikus, (2006) that it disintegrates the outer membrane of gram-negative bacteria, releasing lipopolysaccharides and increasing the permeability of the cytoplasmic membrane to ATP. Diffusion of antibiotics from these sources to the agarose medium results in inhibition of bacterial growth near the source and the formation of clear "zones" without bacterial lawn (Bonev and Hooper, 2008).

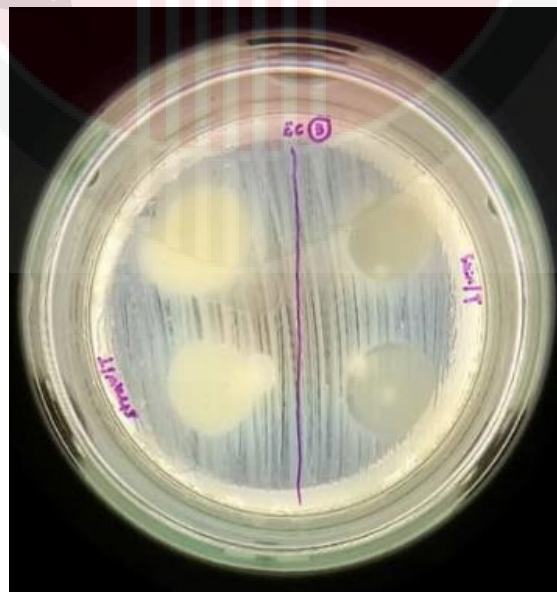


Figure 13: Images of inhibitory zones of JSt/starch (left side) and JSk/starch (right side) incorporated with 3% thymol compared to control against test microorganisms, *E. coli*.

CHAPTER 5 CONCLUSIONS

In this study, jackfruit straw and skin were used to prepare edible film with starch as main matrix. The different loadings of weight ratio for the JSt/starch and JSk/starch films were examined to determine the best loading of weight ratio to act as the reference film that will be used for the next procedure. Formulation of jackfruit straw and skin powder to starch ratios was selected at a ratio of 6:4. It was found that various starch loadings had a significant effect on the mechanical and physical properties of JSt/starch and JSk/starch film. JSt/starch film shows that the higher the starch content, the higher the TS value. In contrast with JSk/starch where decreasing starch content does not give effect on the TS value due to cellulose content in jackfruit skin itself which increases the TS as JSk loading increased.

Additionally, loading of plasticizer gave significant effect on mechanical properties of both films JSt/starch and JSk/starch. Both JSt/starch and JSk/starch films show a low TS value but high EaB values than non-plasticized films. This is because the addition of plasticizer which increases the film flexibility. Color for plasticized film shows similar results for both JSt/starch and JSk/starch due to the natural color of jackfruit. For the controlled film for antimicrobial test, both JSt/starch and JSk/starch (6:4) of 25% plasticized loading has been used.

The controlled films were used for the next film procedures where the film properties were studied with the addition of plasticizer. The plasticizer, sorbitol was added at 15%, 25% and 40% to the films. Hence, the addition of plasticizer had influenced the mechanical and physical properties. The thickness of JSt/starch and JSk/starch films at various plasticizer contents changes significantly. The film without plasticizer load shows a higher thickness value than the films plasticized. This is due to plasticizer reduces the viscosity of film solution before casting causing the solution to be evenly spread on the casting plate.

FTIR analysis has been done for starch film, native JSt film and JSt/starch film (4:6). It is found that the -OH(adsorbed water) group peak, which shifts to 1587 cm^{-1} with a broader band than native starch film indicate the presence of new hydrogen bonding in the JSt/starch film. The JSt / starch and native JSt film at 1741 cm^{-1} showed a new and prominent peak, indicating the stretching vibration of -C=O attributes to the carbonyl group.

Thymol of 3% loading was incorporated into the controlled films and were tested against microorganisms for the zone of inhibition area. Clear zone of inhibition were observed on JSk/starch indicating that thymol as antimicrobial agent can be released from films.

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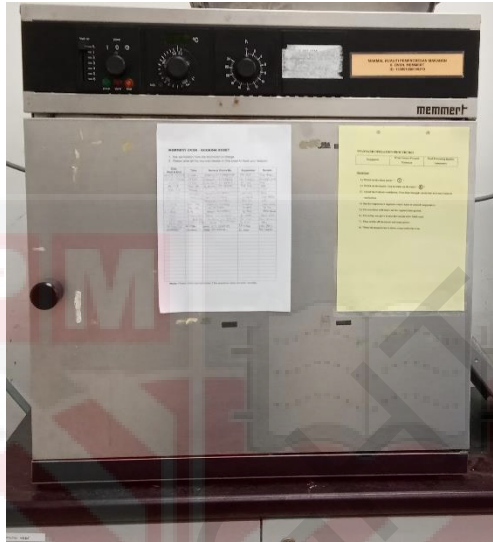
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APPENDICES A: EQUIPMENT

Equipment used in the preparation of jackfruit waste powder:



Oven General Purpose Memmert



Sieve Shaker Retsch – AS200

Equipment used for jackfruit waste film solution:



Stirring Hotplate (Favorit)



Ultrasonic Processor QSONICA Sonicator Model: Q500



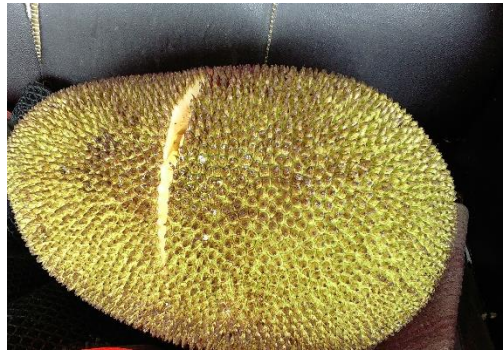
Centrifuge (Universal 320)

Equipment used for mechanical testing:



Screw Side Action Grips (Instron)

Raw Material:



Jackfruit



Jackfruit straw in oven tray for drying process



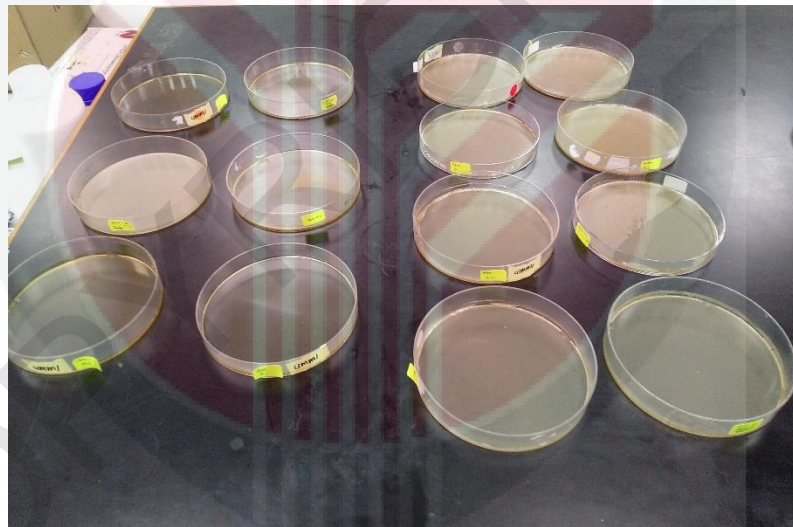
Jackfruit waste powder



**Jackfruit skin and starch
film solution**



**Jackfruit straw and starch
film solution**



**JSt/starch and JSk/starch
films**

APPENDICES B: DATA ANALYSIS

A-1: Film Thickness for various weight ratio of JSt/starch

Sample	Thickness of film (mm) (JSt:starch)	
	5:5	6:4
1	0.119	0.13
2	0.124	0.177
3	0.153	-
4	0.123	-
5	0.13	0.15
Mean	0.1298	0.152333
Variance	0.000184	0.000556
Standard Deviation	0.013554	0.023587

A-2: Film Thickness for various weight ratio of JSk/starch

Sample	Thickness of film (mm) (JSk:starch)	
	6:4	7:3
1	-	0.098
2	0.13	0.087
3	0.107	0.089
4	-	0.105
5	0.104	0.109
Mean	0.11367	0.0976
Variance	0.0002023	0.0000928
Standard Deviation	0.014224	0.009633

A-3: Film Thickness for different plasticizer loading of JSt/starch (6:4)

Sample	Thickness of film (mm) (Plasticizer loading %)			
	0%	15%	25%	40%
1	0.23	0.11	0.08	0.11
2	0.19	0.09	0.13	0.12
3	-	0.12	0.13	0.13
4	0.16	0.11	0.13	0.13
5	-	0.12	0.07	0.14
Mean	0.19333	0.11	0.108	0.126
Variance	0.001233	0.00015	0.00092	0.00013
Standard Deviation	0.035119	0.012247	0.030332	0.011402

A-4: Film Thickness for different plasticizer loading of JSk/starch (6:4)

Sample	Thickness of film (mm) (Plasticizer loading %)			
	0%	15%	25%	40%
1	0.04	0.08	0.14	-
2	0.06	0.06	0.07	0.09
3	0.06	0.04	0.07	0.09
4	0.08	0.06	0.11	0.09
5	0.07	0.07	0.08	0.1
Mean	0.062	0.062	0.094	0.0925
Variance	0.00022	0.00022	0.00093	0.000025
Standard Deviation	0.014832397	0.014832397	0.030495901	0.005

A-5: Mechanical Properties of JSt/starch (6:4) with different plasticizer loading

Sample	Tensile strength (MPa) (Plasticizer loading %)			
	0%	15%	25%	40%
1	-	0.27	0.33	-
2	1.37	0.22	0.36	0.19
3	2.4	0.22	0.39	0.2
4	1.77	-	0.38	-
5	1.94	0.17	0.36	0.12
Mean	1.87	0.22	0.36	0.17
Variance	0.18193	0.0016667	0.00053	0.0019
Standard Deviation	0.42654	0.040825	0.023022	0.043589

Sample	Elongation at Break (%) (Plasticizer loading %)			
	0%	15%	25%	40%
1	26.75	133.83	31.83	-
2	28.45	66.28	35.83	27.2
3	21.75	97.57	27.25	38.8
4	25.25	-	28.37	-
5	-	32.7	27.52	40.45
Mean	25.55	82.60	30.16	35.48
Variance	8.12667	1868.3220	13.3949	52.1408
Standard Deviation	2.8507	43.2241	3.6599	7.22086

A-6: Mechanical Properties of JSk/starch (6:4) with different plasticizer loading

Sample	Tensile strength (MPa) (Plasticizer loading %)			
	0%	15%	25%	40%
1	6.25	2.6	2.27	1.38
2	5.96	-	2.65	1.45
3	6.74	3.89	2.52	1.45
4	-	4.02	-	1.37
5	4.79	3.89	2.66	1.32
Mean	5.94	3.60	2.53	1.39
Variance	0.6863	0.4482	0.032967	0.00313
Standard Deviation	0.82843	0.66948	0.18157	0.055946

Sample	Elongation at Break (%) (Plasticizer loading %)			
	0%	15%	25%	40%
1	-	34.2	34.63	20.02
2	1.57	-	35.6	21.53
3	1.45	38.7	28.78	21.33
4	1.51	38.34	31	22.53
5	1.73	36.05	31.96	25.06
Mean	1.57	36.82	32.39	22.09
Variance	0.0145	4.434025	7.61768	3.54763
Standard Deviation	0.12042	2.1057	2.76001	1.88352