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1.1. INTRODUCTION

The rise in population over the years has led to increase in consumption of food. Therefore, food production and storage are the most crucial tasks. Food packaging has become crucial for preventing contamination, interaction with harmful UV radiations, exposure to air and moisture content and spoilage during the storage and transportation of food items. The primary goal of packaging is to prevent food from spoiling and to preserve its quality for a longer period of time. According to research from the Centres for Disease Control and Prevention, every year over 70 million individuals suffer from food-related illnesses. A range of materials are utilized as packaging materials for food preservation and safety[1]. The packaging of food items using polymer-based materials are being widely used due to its excellent thermal and mechanical properties and light-weight nature. But, a major drawback of using these polymeric materials in packaging of food items is its nature of non-degradability which is harmful to the environment and human health. Due to lack of environmental awareness, synthetic polymers are used extensively in the food packaging industry. Thus, attempts are now being made to synthesize packaging films using bio-based biodegradable polymers as they are considered to be the perfect substitute for non-degradable materials [2].

The use of biodegradable polymers for packaging is an effective way of reducing the amount of plastic waste[3]. They are renewable, eco-friendly, non-toxic, flexible, cost effective, abundant and have a low carbon-footprint. The films based on these, for example, starch, cellulose, zein, collagen, polylactic acid (PLA), polybutylene adipate terephthalate (PBAT) are currently used in food packaging industries [4].

Biopolymers, also known as natural or bio-based polymers, are macromolecular substances that are produced by living things. These polymeric materials can be produced from biological substances like sugars, amino acids, oils, or natural fats, or they can occur naturally and be isolated from bacteria, fungi, plants, and animals. Not all biodegradable polymers are biopolymers, and not all biopolymers are biodegradable polymers. The bio-based polymers may be either biodegradable or nonbiodegradable. Biodegradable bio-based polymers include polylactic acid, while biodegradable polymers derived from fossil fuels include polyglycolic acid. As a sustainable alternative to conventional synthetic polymers, biopolymers are regarded as fourth-generation packaging materials. They have a great chance of taking the place of artificial polymers because these are naturally biodegradable and thus, they are advantageous to be used in packaging applications.

Polylactic acid (PLA) is one such thermoplastic biopolymer of monomeric unit of lactic acid, which is obtained from sugarcane, corn starch or tapioca. PLA possess mechanical strength, transparent rigidity, high stiffness and has excellent barrier properties which makes it perfect for making films for food packaging. PLA has better water vapor barrier properties barrier properties. Apart from these properties, PLA has low temperature, heat seal ability, clarity and stiffness that made PLA suitable material for including in production of biodegradable polymer films. But not all PLA samples are suitable for making packaging films. PLA samples with high amorphous regions and low molecular weight cannot be used in packaging as they possess low thermal stability and degrade on faster rates. Highly crystalline PLA sample are also not used as they are relatively brittle and show poor heat resistance [5]. PLA is brittle, shows low thermal stability, low flexibility, low toughness and ductility and has low oxygen barrier in comparison to other polymers and hence, this limits its application [6]. Thus, plasticizer such as polyethylene glycol (PEG) are nowadays incorporated in PLA-based film to increase flexibility. PEG is synthesized by the polymerization of the monomeric unit ethylene glycol. It is non-toxic. It is widely used in food packaging as it is an excellent plasticizer [7]. However, reported PLA-PEG films lack barrier properties. Thus, nowadays, to increase barrier properties, material such as polybutylene adipate terephthalate (PBAT) is used.

Polybutylene adipate terephthalate (PBAT) is another biopolymer obtained from the condensation reaction of butanediol, adipic acid and terephthalic acid. PBAT have high oxygen and water barrier properties. It also possesses good mechanical strength and biodegradable properties like PLA. It is highly flexible, which makes it a very good material for making films for food packaging [4].

Hence, the objective of this work is to synthesize a film composed of PLA/PBAT/PEG to improve the properties of the PLA/PEG film to address the worldwide issue of using non-biodegradable materials for food packaging. The film was optimized by varying PBAT content. The film was characterized by using ATIR-FTIR, TGA, SEM and DSC techniques. Parameters like light transmission, gloss, haze, tensile strength, elongation, water permeability, oxygen permeability were studied, and further, their application was seen in the packaging of Litchi fruit.

1.2. LITERATURE SURVEY

Table 1.1 Reported Literature on PLA, PBAT and PEG-based films

Film	**Method of Synthesis**	**Packaging Application**	**Key Findings**	**Ref**
PBAT/ PLA/ Grape Seed Extract	Blown film extrusion method	Strawberries and Broccoli	Good Radical scavenging capacity, and anti-oxidant properties	[8]
PLA/ PEG/ ADR/ Grape seed extract	Solvent casting	Straw mushroom	Gas-selective packaging and antimicrobial activity	[9]
PLA/ PBAT/ Zinc doped Titanium dioxide	Solvent casting	Banana	Improved anatase polymorph	[10]
PBAT/ Organophilic \Clay nanocomposite	Solvent-free high energy ball milling	Banana	Strong water barrier ability	[11]
Zinc oxide nanoparticles/ PLA	Solvent casting	Grapes	Antimicrobial activity of biofilm against E. coli and S. aureus bacteria	[12]
PLA/ Poly(propylene carbonate)/ Curcumin	Melt extrusion followed by compression molding	Shrimps	Macroscopical color changes with a tunable intensity response for NH3 vapor, which is useful for on-site detection of anti-oxidant activity	[13]

Peppermint oil/ PLA	Solvent casting	Chicken breast meat	Antimicrobial activity against both Gram-positive and Gram-negative bacteria and Peppermint oil's capability to hinder microorganisms' growth	[14]
Poly(butylene succinate)/ PBAT	Blown film extrusion	Mango	Perforation improved the oxygen and carbon dioxide transmission rate	[15]

CHAPTER 2

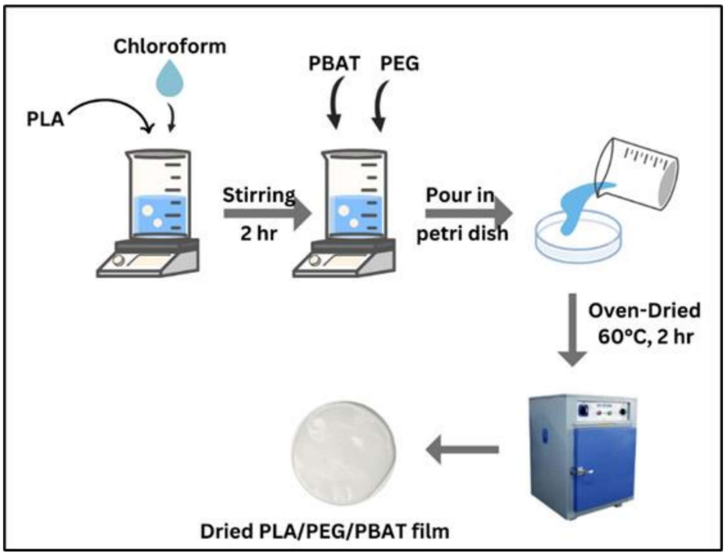
MATERIAL AND SYNTHESIS

2.1 Materials

12 Polylactic acid (PLA-3052D, Nature Works, USA), polybutylene adipate-co-terephthalate (PBAT, Ecoflex, UK) and polyethylene glycol (PEG, Mn=6000 g/mol, Sisco Research Laboratories, Mumbai, India) were utilized as obtained. For the preparation of the solutions, chloroform (MW=119.38 g/mol, Merck, Germany) was used.

2.2 Synthesis of PLA/PBAT/PEG Film

46 The films based on PLA, PEG and PBAT were synthesized by varying the amount of PBAT as represented in Table 2.1. The reaction procedure was carried out by dissolving required amount of PLA in 20 ml of chloroform while being magnetically stirred continuously for 2 hours. Following this, a specific amount of PEG and PBAT were added to the solution and magnetically stirred for an additional hour as shown in Fig. 2.1. The mixture was poured into a petri dish and oven-dried for 2 hours in an oven at 60 ^{0}C. The oven-dried films were then peeled off and used for further analysis [20, 21].



50 **Fig. 2.1** Synthesis of PLA/PEG/PBAT film

Table 2.1. Composition of reagents utilized for the synthesis of the PLA-based films

Sample code	**PLA (g)**	**PBAT (g)**	**PEG (g)**
S-1	0.6	0	0.2
S-2	0.6	0.5	0.2
S-3	0.6	1.0	0.2
S-4	0.6	1.5	0.2
S-5	0.6	2.0	0.2

CHAPTER 3

CHARACTERIZATION TECHNIQUE

3.1. Differential Scanning Calorimetry (DSC)

Differential calorimetry is used for measuring the heat in or out of a sample relative to a reference. Differential Scanning Calorimetry is the technique in which the difference in the amount of heat necessary for the increase in temperature of a sample and reference is measured as a function of temperature. A curve of heat flow versus temperature is obtained on performing DSC experiment known as DSC thermograms.

Principle: DSC measures whether there is less or more heat flow of a sample when it undergoes a physical transformation relative to the reference material as a function of temperature. For example, in exothermic processes, such as crystallization the heat required to increase the sample temperature is less.

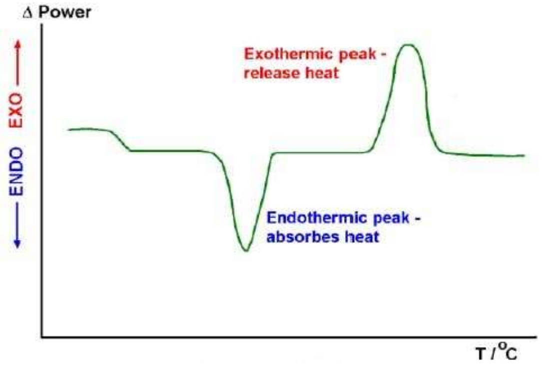


Fig. 3.1 DSC curve demonstrating endothermic and exothermic peak

Instrumentation: The basic instrumental requirements of a power compensation DSC are: heating units, platinum resistance thermometers, sample and reference holders and power/recorder.

1. Heating unit: In power compensation DSC, two distinct heating units are utilized. These heating units can swiftly heat, cool, and equilibrate because of their small size. A large temperature-controlled heating sink contains the heating units.

2. Sample and Reference holders

3. Platinum resistance thermometers: The temperature of the materials is continuously monitored in the sample and reference holders using platinum resistance thermometers.

4. The apparatus records the power differential needed to maintain the reference and sample at the same temperature as specified by the preset settings. Power compensated DSC reacts more quickly but is less sensitive than heat flux DSC [16].

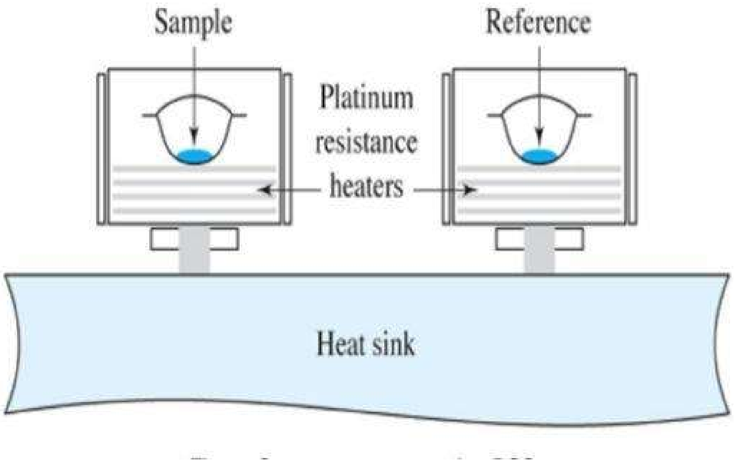


Fig. 3.2 Schematic Representation of power compensation DSC

3.2. Thermogravimetric Analysis (TGA)

Thermogravimetry is the technique in which the change in weight of a substance is recorded as a function of temperature or time. In this technique, the thermal behavior of a substance is recorded and the loss of weight on heating plotted against temperature is called thermal spectra or thermograms.

Principle: TGA studies the changes in the weight of the sample when the sample is heated at a controlled temperature and atmospheric conditions**.** The weight loss indicates volatilization or decomposition of components in a sample.

24 **Instrumentation:** The basic instrumental requirements in TGA are thermal balance, heating device like furnace, sample container, programmer and detector.

1. Thermo Balance: The thermo balance is a balance which is capable of continuously recording of weight change of sample on increasing linear rate of heating.

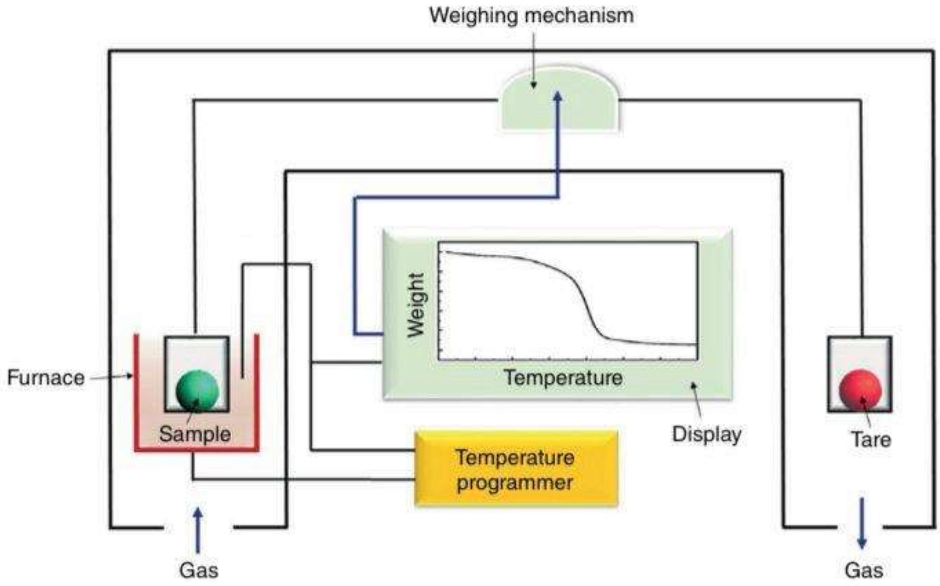


Fig. 3.3 Instrumentation of TGA

26 3.3. Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (SEM) is an experimental technique used for the analysis of surface morphology at spatial resolution and magnification. SEM works on the following principle:

Principle of SEM:

Sample is subjected to high-energy electron beam in SEM and depending on the thickness of the specimen, the high-energy electrons interact with the atoms in a molecule. SEM involves thicker specimens, in which the electrons cannot be transmitted unabsorbed by the sample and the particles emerging from the surface of the sample are used to provide morphological and structural information.

It also reveals crucial details about crystalline nature, topography and chemical composition.

Instrumentation:

SEM components: electromagnetic lenses, specimen chamber, detectors, electron gun and computer system for image processing.

1. Electron gun: It is a source to generate electrons of high energy ranging from kilo electron volt to tens of kiloelectron volts.

2. Electromagnetic lenses: They scan and focus electron beams across the sample with high precision.

3. Chamber for the sample/specimen

4. Detector: It collects the different type of signals that are emitted by sample.

5. Computer system: It processes the collected signals to develop high resolution images of sample's surface [17, 18].

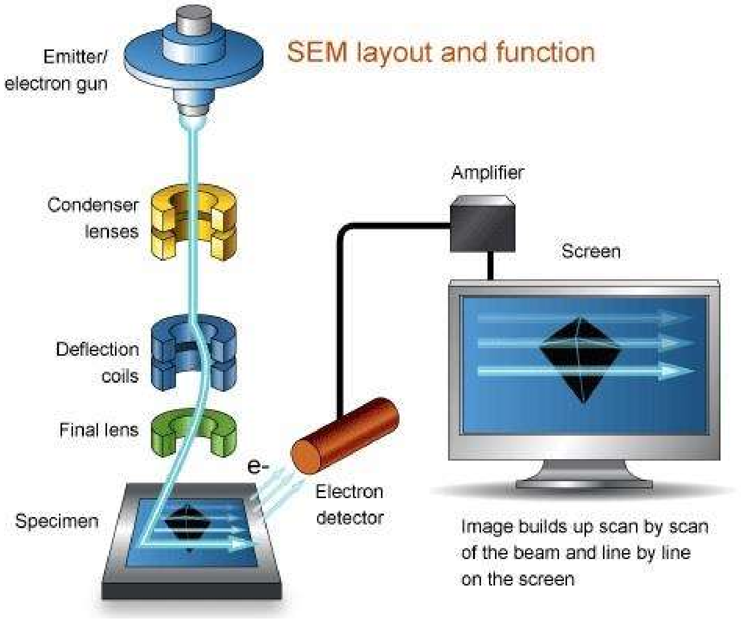


Fig. 3.4 Schematic diagram of SEM

23

3.4. Attenuated Total Reflection-Fourier Transform Infrared Spectroscopy (ATR-FTIR)

Fourier-transform infrared spectroscopy, also known as vibrational spectroscopy, helps to identify functional groups by measuring how materials absorb infrared light as a function of wavelength or frequency. FTIR works on the following principle:

Principle:

The method is based on the idea that molecules become infrared-active due to change in their dipole moment caused by molecular vibrations.

Three regions make up the infrared spectrum:

15

- far-IR (400–10 cm^{-1}),
- mid-IR (4,000–400 cm^{-1}),
- near-IR (14,000–4,000 cm^{-1})

39 In this spectroscopy, IR radiation is passed through the sample and intensity of transmitted light is measured in wavenumber. The plot of transmission against wavenumber yields the infrared spectrum.

19 There are two types of molecular vibrations that is: -

a. Stretching vibrations

- Symmetric
- Asymmetric

b. Bending vibrations

- Rocking
- Scissoring
- Wagging
- Twisting

Instrumentation:

FTIR spectrometer is made up of various components, an IR source, a sample compartment, an interferometer, detector and a computer.

1 1. The Source: A glowing black-body source emits infrared energy. The amount of energy that is presented to the sample (and, eventually, to the detector) is controlled by the aperture through which this beam passes.

2. The Interferometer: The "spectral encoding" occurs when the beam enters the interferometer.

2 3. The Sample: Depending on the kind of analysis being carried out, the beam either passes through or bounces off the sample's surface after entering the sample compartment. Here, particular energy frequencies that are particular to the sample are absorbed.

4. The Detector: For the last measurement, the beam finally reaches the detector.

28 1 5. The computer: The Fourier transformation is performed on the computer after the measured signal has been digitalized and sent there. The user is then shown the final infrared spectrum for interpretation and any additional manipulation [19].

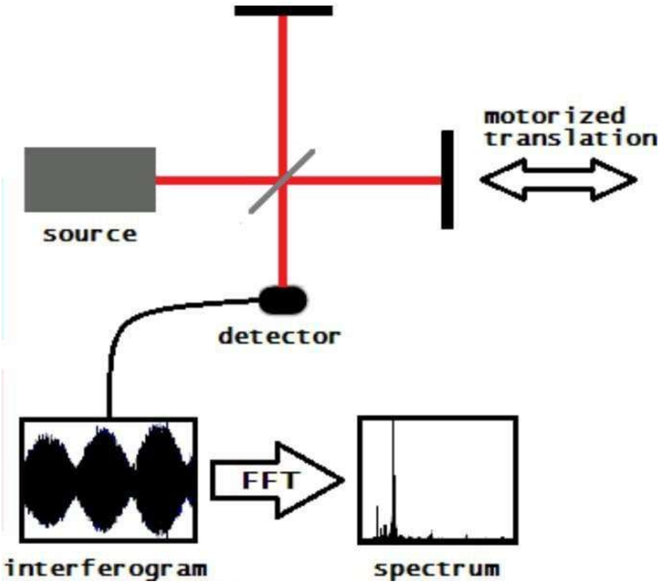


Fig. 3.5 Schematic diagram of FTIR spectrometer

CHAPTER 4

EXPERIMENTAL SECTIONS

57

4.1. Thickness Measurement

The film thickness measurement was conducted using Mitutoyo 7301A Japan Micrometer in accordance of ASTM D638 standards with a sample size of (150 × 25 mm). The average thickness value was determined in Micrometers (um) after five readings were obtained.

4.2. Mechanical Properties

60 The synthesized PLA/PEG/PBAT films were tested for tensile strength and elongation using a Universal Testing Machine (International Equipment) with a 225 Kg load limit. The films were cut into a 150 x 25 mm rectangle in accordance with ASTM D638 guidelines and the load was applied at a crosshead speed of 500 mm/min. The tensile strength was given as Kg/cm^2 and the elongation at break in %. 18

13

4.3. Optical Properties

The optical properties of the food packaging films are important for maintaining the food quality as they affect interaction of harmful UV radiation with the packaging material. 36 The absorbance of the film was measured using a UV spectrophotometer (Model: Cary 300 UV-Vis) at λ, 200-400 nm. The film (20 x 10 mm) was placed inside the spectrophotometer and the % transmittance was determined.

44

4.4. Water Vapor Transmission Rate

The testing of water vapour transmission rate (WTVR) was done adhering to the standards of ASTM F 1249 at 23 °C temperature and 50% relative humidity and 5 cm^2 film area. 11 The Water vapor transmission rate of the films was measured using a 7101 - Systech Illinios model furnished with a P_2O_5 sensor.The formula used for the calculation of water vapour coefficient is given below.

$$\text{Water vapour permeability coefficient} = WVTR \times d \tag{4.1}$$

Where, WVTR is water vapor transmission rate and d denote the thickness of the film in mm.

4.5. Oxygen Transmission Rate

OTR is defined as that quantity of oxygen which passes through the film's thickness at a given point of time. The testing of Oxygen Transmission Rate (OTR) was done using an OTR analyser (8101e OxySense®) adhering to the standards of ASTM D 3985 at 23 °C temperature and 50% relative humidity and with a film area of 5 cm^2.

The oxygen permeability coefficient was calculated by multiplying the oxygen permeability rate by film's average thickness and dividing it by the pressure difference of oxygen across the sides of the film.

$$\text{Oxygen permeability coefficient} = \frac{OTR \times d}{\Delta P} \tag{4.2}$$

Where, OTR is oxygen transmission rate, Δp is the pressure difference (bar) and d is the thickness of the film (mm).

4.6. Packaging Application

Food packaging test was done to evaluate the shelf life of the fruit. Fresh litchis were purchased from a nearby market and those with good appearance and no mechanical damage were chosen. It was then packed in polyethylene film, PLA/PEG film and the synthesized PLA/PBAT/PEG film and was stored at room temperature. The measurements of weight and observation of color change was done at a specific time interval.

4.7. Biodegradation Studies

To evaluate the biodegradability of a polymer, mainly three methods are used: laboratory tests, simulation tests, and field test. However, field testing is the easiest and most practical way for calculating film biodegradation time. Thus, the biodegradation test of the synthesized

8 PLA/PBAT/PEG Film carried out by soil burial test for the time period of 3 months. The film was weighed and buried at a depth of 10 cm inside the moist soil. The film was taken out of the soil at the intervals of 15 days. After weighting the film was again buried inside the soil for further degradation. 7

35 The percentage of degradation was determined using the following equation:

$$\text{Degradation } \% = \frac{A_i - A_f}{A_i} \times 100 \tag{4.3}$$

Where, A_i is the weight of the synthesized PLA/PBAT/PEG film before burial and A_f is the weight after burial.

CHAPTER 5

RESULT AND DISCUSSION

5.1. DSC

DSC analysis was performed for PLA/PEG and PLA/PEG/PBAT films to investigate their thermal behaviour as illustrated in Fig. 5.1. The melting point of PLA/PEG film is observed at 148.93 °C and on addition of PBAT it is found to be at 170.35 °C. The glass transition temperature (T_g) for the PLA/PEG film is found at 58.4 °C and for the PLA/PEG/PBAT film T_g was recorded at 55.2 °C. The decrease of 3.2 °C in T_g is attributed on the widening of molecular chains in the film on addition of PBAT [22].

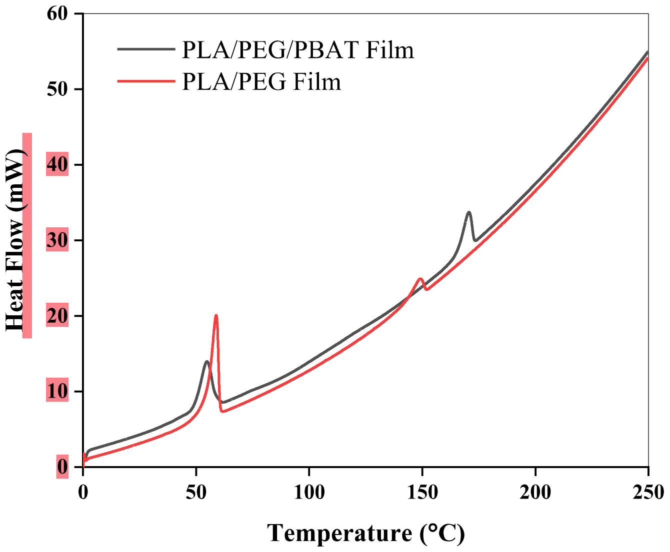


Fig. 5.1 DSC curves of PLA/PEG film and PLA/PEG/PBAT film

5.2. TGA

TGA thermographs of PLA/PEG and PLA/PEG/PBAT film are shown in Fig. 5.2. It was observed that the PLA/PEG film degraded in two steps. The first degradation showed a weight loss of 4.87% from 30-211°C attributed to the decomposition of PEG. The second degradation was observed around 211-366 °C with a weight loss of 83.12% due to the decomposition of PLA chains. However, it is observed that the PLA/PEG/PBAT film degraded in three steps.

The first degradation showed a weight loss of 4.37% from 30-241°C attributed to the degradation of PEG. The second degradation was observed from 241-321 °C with a weight loss of 26.65% due to the decomposition of PLA. The third degradation was observed from 321-442 °C with a weight loss of 56.72% attributed to the decomposition of PBAT.Thus, it revealed that on increasing the amount of PBAT the thermal stability of the synthesized film [23–25].

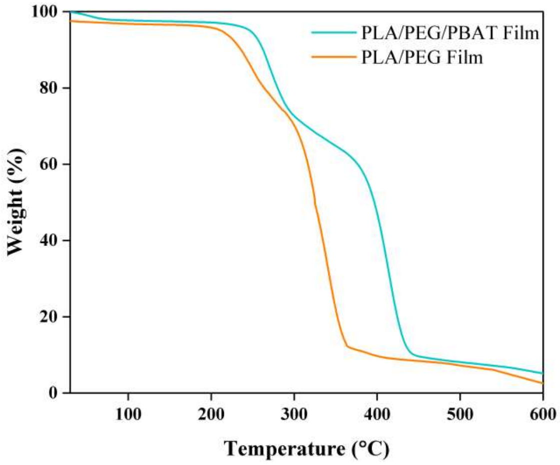
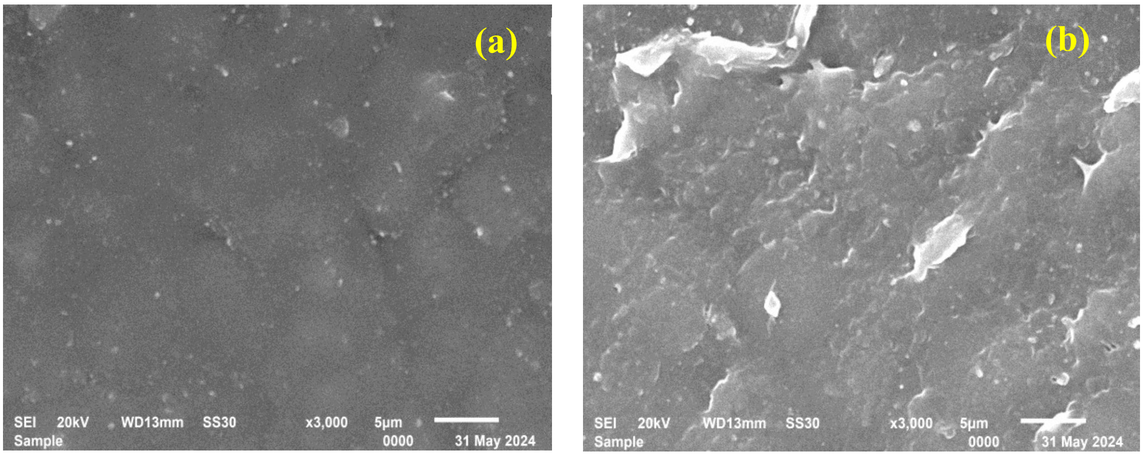


Fig. 5.2 TGA graphs of PLA/PEG film and PLA/PEG/PBAT film

5.3. SEM

SEM images of PLA/PEG and PLA/PEG/PBAT film are displayed in Fig. 5.3. The PLA/PEG film showed a smooth and flat surface with no cracks. However, the SEM micrograph of the PLA/PEG/PBAT film displayed a rougher and wavy surface suggesting that the film undergoes plastic deformation. This reveals that on addition of PBAT, there is an increase in the toughness of the film [25].



48 **Fig 5.3** SEM images of (a) PLA/PEG and (b) PLA/PEG/PBAT film

5.4 ATR-FTIR Spectroscopy

ATR-FTIR spectra of PLA/PEG/PBAT film and PLA/PEG are depicted in Fig. 5.4. In both PLA/PEG and PLA/PEG/PBAT film, peaks at 1080 cm^{-1}, 1173 cm^{-1} and 1092 cm^{-1}, 1179 cm^{-1} respectively contributes to stretching vibrations of C−O group[24]. The peaks observed at 2994 cm^{-1}, 2942 cm^{-1} in PLA/PEG film and 2944 cm^{-1}, 2880 cm^{-1} PLA/PEG/PBAT film are a result of C−H asymmetric and symmetric stretch. The peaks observed at 1752 cm^{-1} and 1739 cm^{-1} correspond to the C=O stretch in PLA/PEG and PLA/PEG/PBAT films respectively. In the ATR-FTIR spectrum of PLA/PEG/PBAT, the intensity of peaks at 2994 cm^{-1} and 2880 cm^{-1} increases as because on addition of PBAT, the number of CH_2 group increases [26].

Furthermore, in the FTIR spectrum of PLA/PEG film the peak corresponding to OH groups is observed at 3605 cm^{-1} and on addition of PBAT the peak is shifted to a lower wavenumber recorded at 3595 cm^{-1}[27] . The slight shift observed in wavenumber concluded that a physical interaction (hydrogen bonding) occurs in the PLA/PEG/PBAT film.

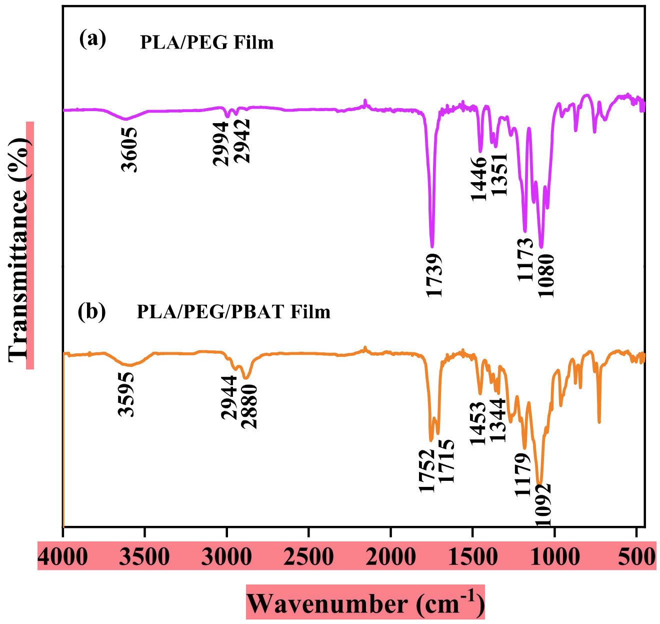


Fig 5.4 ATR-FTIR of (a) PLA/PEG film and (b) PLA/PEG/PBAT film

5.5. Thickness Measurement

It was observed that the thickness of PLA/PBAT/PEG films was decreased from 80.20 to 65.30µm as the PBAT content increases shown in Fig. 5.5. This variation is attributed to the increase in hydrogen bonding and interfacial adhesion between PLA, PBAT, PEG leading to a denser structure and hence results in thinner film [21].

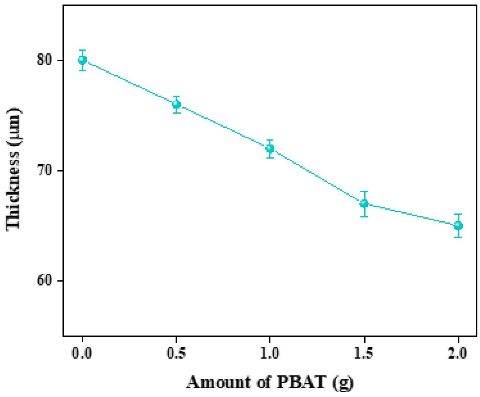


Fig. 5.5 Variation in thickness with increase in PBAT content in synthesized films

5.6. Mechanical Properties

The tensile strength and elongation at break of synthesized PLA/PEG/PBAT films are shown in Fig. 5.6. It is observed that as the PBAT content increases, the PLA/PEG/PBAT film displays higher elongation at break. This arises because PBAT is a random block polymer with a lesser degree of crystallization and also, the flexibility and hardness of the PLA/PEG/PBAT film are enhanced with the increasing PBAT content. Moreover, as demonstrated in the Fig. 5.6, the PLA/PEG/PBAT film displayed a rise in tensile strength with the increase in PBAT amount. This is attributable to the presence of aromatic terephthalate rings inside PBAT, as well as an enhanced tangling between PBAT, PLA, and PEG polymeric chains. Hence, the mechanical characteristics of the synthesized PLA/PEG/PBAT film were enhanced[28].

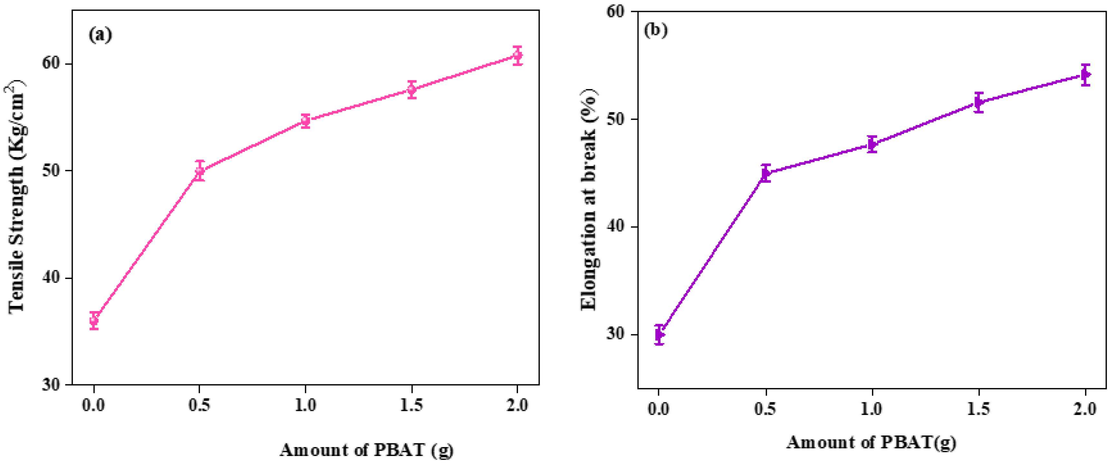


Fig. 5.6 Influence of PBAT on (a) tensile strength and (b) elongation of PLA/PEG/PBAT films

5.7. Optical Properties

The film having high transmittance of light affects the food quality and increases the chances of spoilage. Therefore, the film with low transmittance of light is preferred. The light transmittance curve of the PLA/PEG film and PLA/PEG/PBAT based films is shown in the Fig. 5.7. As the concentration of PBAT increases, it is observed that the transmittance % of UV light of the film decreases. The result is attributed to the light absorbing functional groups in PBAT. On the other hand, the PLA/PEG film without PBAT showed highest transmittance at 46% in the UV region. The ability of food packaging films to shield against UV radiations is considered an important factor. The food quality is adversely affected by UV radiations as it initiates photo-oxidation and photodegradation reactions. [29, 30].

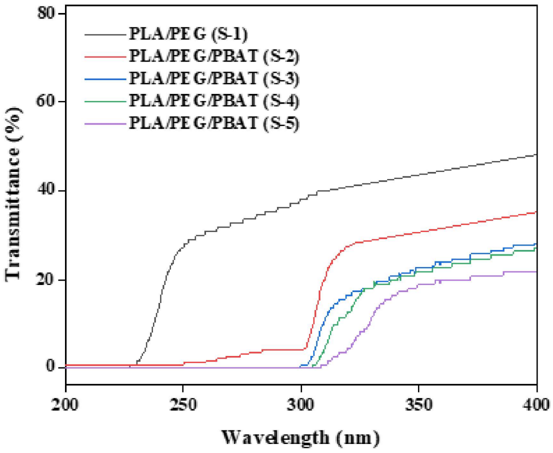


Fig. 5.7 Light Transmittance curve of films with different PBAT concentrations

5.8. Water Vapor Transmission Rate (WVTR)

A small amount of moisture content present during food storage can lead to spoilage of food; water vapor transmission rate is considered as important factor for the application of polymer films in food packaging. Thus, polymers with low water vapor transmission rates are preferred. The water vapor transmission coefficient of PLA/PEG/PBAT film is depicted in the Fig. 5.8. The water vapor permeability coefficient of synthesized PLA/PBAT/PEG film decreases as the PBAT content increases. This decrement is observed due to the hydrophobic groups (CH_2) and terephthalate ring present in PBAT and rise in chain entanglements. It can be concluded that no reaction takes place between PBAT and water which leads to a lower value of water vapor permeability coefficient [21].

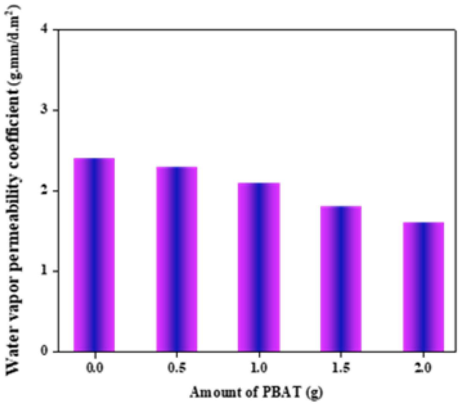


Fig. 5.8 Water Vapor permeability coefficient graph for PLA/PEG/PBAT films

5.9. Oxygen Transmission Rate (OTR)

It is observed that on increasing the amount of PBAT in the synthesized PLA/PEG/PBAT the oxygen permeability coefficient shows a decrease in its value proportionately a shown in Fig. 5.9. The decrease in value is attributed to the interfacial adhesion between the PLA/PEG and PBAT phase resulting in difficulty for diffusion of O_2 molecules to diffuse in and out, creating a tortuous pathway[31]. Thus, a decrease in oxygen permeability coefficient is observed for the synthesized PLA/PEG/PBAT films.

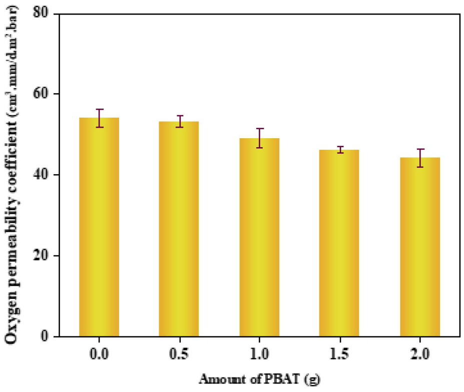


Fig. 5.9 Oxygen permeability coefficient graph for PLA/PEG/PBAT films

5.10. Packaging Application

To examine the packaging application of synthesized PLA/PEG and PLA/PEG/PBAT films for fresh food packaging, the litchis were packed in PE, PLA/PEG and PLA/PEG/PBAT films and were sealed and stored at room temperature. Fig.5.10. depicts the storage of litchi in these three films for 20 days and Table 5.1 demonstrates the changes observed in weight and color of the fruit when kept in (a) PE, (b) PLA/PEG, and (c) PLA/PEG/PBAT films. As observed, the lowest mass loss rate was observed when litchi was packed in PE film attributed to the dense structure of the film [32] and a whitish-green colour was seen concluding the deterioration in the quality of the fruit. Litchi when packed in synthesized PLA/PEG film showed a whiteish brown colour because of fungal contamination whereas when packed with PLA/PEG/PBAT film showcased freshness for at least 20 days and thus, demonstrated prolonging shelf life of the fruit.

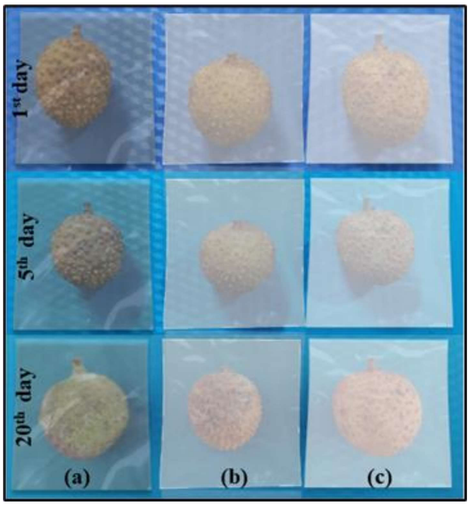


Fig. 5.10 Litchi Preservation performance of (a) Polyethylene film, (b) PLA/PEG film and (c) PLA/PEG/PBAT film

Table 5.1 Physical changes in litchi covered with (a) PE film, (b) PLA/PEG film and (c) PLA/PEG/PBAT film

Sample name	Weight (g)			Colour		
	Day 1	Day 5	Day 20	Day 1	Day 5	Day 20
Polyethylene	9.50	9.25	9.41	Brown	Whitish brown	Whitish -green
PLA/PEG Film (S-1)	8.95	9.16	9.39	Brown	Brown	Whitish brown
PLA/PEG/PBAT Film (S-5)	7.9	8.6	9.31	Brown	Brown	Brown

5.11. Biodegradation Studies

The degradation curve for synthesized PLA/PBAT/PEG film (S-5) is depicted in the Fig.5.11. The maximum degradation of the film was noted at 23.1 ± 0.34% over the time period of 90 days. The degradation is the result of the cleavage of Hydrogen bonds among PBAT, PEG and PLA and the intrinsic biodegradable nature of PLA, PBAT and PEG polymers [33].

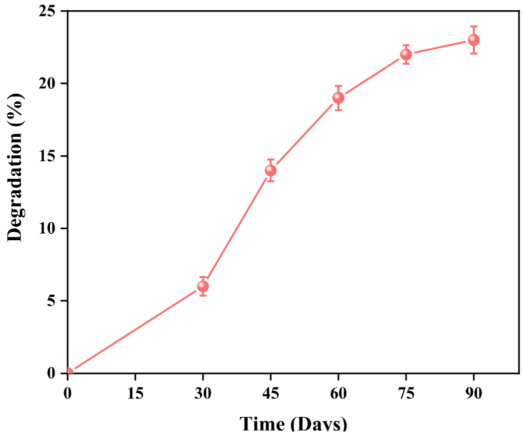


Fig. 5.11 Degradation curve of PLA/PEG/PBAT film

CHAPTER 6

CONCLUSION, FUTURE SCOPE & SOCIAL IMPACT

6.1. Conclusion

This work reveals the successful development of biodegradable PLA/PEG/PBAT film using the solvent casting method. Synthesis of PLA/PEG/PBAT film and PLA/PEG film was confirmed by the FTIR, DSC, TGA and SEM techniques. The tensile strength and elongation at break increase with the rise in PBAT content in the film. Furthermore, the incorporation of PBAT resulted a decrease in oxygen and water vapor permeability. The synthesized PLA/PEG/PBAT films shows a decrease in UV light transmittance (%) with an increase in the concentration of PBAT. Additionally, the thermal stability of the film was found to improve with the addition of PBAT to the film. The packaging test revealed that synthesized PLA/PEG/PBAT film can retain the freshness of litchi for about 20 days. Thus, the study supports the utilization of PLA/PEG/PBAT film for the food packaging application.

6.2. Future Scope

In future, the incorporation of natural compounds such as essential oil, cinnamaldehyde, tea polyphenols, grape seed extract, etc, into PLA/PEG/PBAT films can be carried out to impart antimicrobial properties to synthesized film. The natural antimicrobial agents inhibit the growth of pathogens such as Escherichia coli and Staphylococcus aureus, thereby contributing to the extension of food shelf life. The nanoparticles can be incorporated into the film as they can improve tensile strength, thermal stability, gas, and moisture barrier properties of the film. Additionally, the ratios of PLA and PEG can also be varied, as it may affect the biodegradability and mechanical properties of the films.

6.3. Social Impact

Traditional plastic packaging contributes significantly to environmental pollution, especially in marine ecosystems. Biodegradable films like PLA/PBAT/PEG can decompose under appropriate conditions, potentially reducing the accumulation of persistent plastic waste. The utilisation of biodegradable packaging materials supports several sustainable development goals, including reducing waste and resource consumption, lowering carbon emissions and protecting oceans and aquatic life from plastic pollution, in that it promotes sustainable consumption and reduces the environmental footprint.