Development of Antioxidant Packaging Film Using Indian Gooseberry Extract, Tamarind Extract, and Polyvinyl Alcohol

Md Ushama Shafoyat[1], Adiba Tasnim[2], Fasiha Tanzeem Taiba[3], Maisha Farzana[4], S M Al Amin[5], Khandoker Mahmood Shahriar[6]

[1,2,3,4,6] *Department of Biomedical Engineering, Military Institute of Science and Technology, Dhaka, Bangladesh*

[5] *Department of Fisheries and Marine Bioscience, Gopalganj Science and Technology University, Gopalganj 8100, Bangladesh*

***Abstract*—Active material-based food packaging has lately gained prominence over conventional material-based packaging. In order to generate novel active composite films for packaging applications, tamarind seed (T) and Indian gooseberry (G) extracts were added to a polyvinyl Alcohol (PVA) matrix, applying a solvent-casting process. The morphological, thermal, and antioxidant activities of PVA-tamarind seed-Indian gooseberry composite films were investigated to see if the presence of tamarind seed and gooseberry extracts affected the film's properties. The effect of T and G concentration on the films' antioxidant capacity, water resistance, and opacity was investigated. Additionally, characteristics such as morphological features, thermal behavior, and tensile strength have been addressed in detail. The experimental findings demonstrated that PVA/TG films developed with an evenly greenish and brownish hue, high transparency, and potent antioxidant properties. According to the results of moisture content and water vapor permeability, the PVA film with TG demonstrated somewhat higher water resistance, especially at a low TG level (10 wt%). The tensile strength of the PVA can be compounded by up to 10% by weight of BT without noticeably degrading. Due to the chemical interactions between PVA and TG and the formation of charm at high temperatures, the PVA/TG films demonstrated better thermal degradation behavior than PVA alone. Food items that are prone to oxidation by microbial attack may be preserved using films made with higher antioxidant activity. According to the results, there is a lot of opportunity for this product to be evaluated for products that have additional value for incorporation into functional packaging.**

***Index Terms*—Active Packaging, Biodegradable Polymer, Antioxidant, Antibacterial, Packaging material, Tamarind Sid powder, Indian gooseberry**

I. INTRODUCTION

The widespread consumption of conventional packaging produced from fossil fuels is resulting in significant environmental issues. Despite not being recyclable or biodegradable, this packaging is widely used in many different applications. To replace packaging materials derived from petroleum, there is a growing need for environmentally friendly packaging created from bio-based resources. Demand for green packaging made from bio-based resources continues to increase to replace petroleum-based packaging materials [1], [2]. The most prevalent innovation in packaging now is the creation of active packaging with antimicrobial, anti-UV, and antioxidant qualities. This is especially useful for food and biomedical applications, as it effectively prevents manufactured goods from degrading during storage, display, and transportation procedures [3], [4]. PVA is a linear synthetic polymer designed to be water soluble, non-toxic, biocompatible, and biodegradable. Due to its excellent film-forming capabilities and suitable mechanical and thermal properties, PVA is an excellent alternative for creating sustainable active packaging materials [1], [2], [5]. It has been widely reported recently that PVA can be used to make PVA-based films with antibacterial and/or antioxidant qualities by combining it with natural active ingredients such as lignin [[6], [7], [7],[8] 10], essential oils [9], [10], tomato by-product extract [7], [10], and chitosan [4], [11], [12].

The seeds of tamarind [13] exhibit strong antibacterial activity against a variety of harmful microorganisms. Research has demonstrated that tamarind seed extracts

efficiently suppress the growth of both Gram-negative bacteria, such as Aeromonas hydrophila and Pseudomonas aeruginosa, and Gram-positive bacteria, such as Staphylococcus aureus and Bacillus cereus. The bioactive components found in the seeds, which include flavonoids, tannins, and unsaturated fatty acids, have contributed to the antibacterial properties [14]. These chemical compounds are thought to cause the demise of bacteria by degrading their cell walls and membranes. It has been found, for example, that methanolic extracts of tamarind seeds prevent Pseudomonas aeruginosa, a frequent pathogen linked to nosocomial infections, from forming biofilms [15], [16]. In addition, tamarind seed polysaccharides have demonstrated antibacterial action against Escherichia coli, indicating their potential as natural preservatives or pharmaceutical agents [17]. The efficacy of these extracts varies depending on the solvent used for extraction, with methanol and ethanol extracts often exhibiting higher antibacterial activity compared to aqueous extracts [18]. The Indian gooseberry, frequently referred to as amla (Phyllanthus emblica L.), has remarkable antibacterial activity against a variety of pathogenic microbes. Extractions from amla fruits and leaves have been shown to be effective against Gram-negative bacteria like Escherichia coli and Klebsiella pneumoniae as well as Gram-positive bacteria like Staphylococcus aureus and Bacillus subtilis. [19]. Ellagic acid, quercetin, and gallic acid are among the bioactive components found in amla that are principally responsible for the antibacterial activity. These compounds have been shown to enhance the efficacy of conventional antibiotics such as ampicillin [20]. These compounds appear to trigger bacterial cell death by dissolving the cell walls of the bacterium and blocking vital enzymes. Amla seed methanolic extracts have also shown inhibitory effects on bacteria that are resistant to many drugs, including those that produce extended-spectrum β-lactamase (ESBL) [21]. The extraction solvent affects the effectiveness that these extracts are; methanol-based extracts often have stronger antibacterial activity than aqueous extracts [22]. Utilizing natural active ingredients reduces the danger of potential toxicity by migration when compared to synthetic active agents, particularly in the fields of food packaging and biomedical applications.

This work developed a PVA-based packaging film with antioxidant capability using different amounts of extracts from Indian gooseberries and tamarind seeds [23], [24], [25], [26], [27], [28], [29], [30], [31]. Using a solvent casting method, PVA-Tamarind seed and/or Indian gooseberry films were created. Thickness, opacity, moisture content, water solubility, water vapour permeability, antioxidant activity, tensile test, thermal stability, and infrared spectroscopy were all thoroughly specified as pertinent and significant packaging characteristics. Additionally, the resultant films' mechanical, morphological, thermal, and chemical structures were determined.

II. MATERIALS AND METHODS

2.1. Materials

PVA, tamarind seed powder, Indian gooseberry powder, and ethanol were purchased from the Science Lab, Midford, Puran Dhaka, Bangladesh. PVA has a hydrolysis degree of 98% and a degree of polymerization around 1750 ± 50. 1,1-diphenyl-2-picrylhydrazyl (DPPH, 96%) was bought from Science Lab, Midford, Puran Dhaka. All other materials were analytical reagents and used with purification (96%).

2.2. Extraction

The antibacterial properties required for our active package were extracted using tamarind seed powder and Indian gooseberry powder. A combination of 5 gm of tamarind seed powder and Indian gooseberry powder with 100 ml of 75% ethanol solution, respectively, was prepared. The solution was transferred to an airtight conical flask, where it was magnetically stirred at 40 C under 450 rpm for 2 hours. It was cooled overnight for 12 hours in a UV chamber. A 42 Whatman filter paper was used to separate the extracts from their sediments.

2.3. Film Preparation

A 5% PVA solution was prepared at a constant temperature (25°C) under magnetic stirring for 20 min to ensure complete dissolution. PVA was mixed with Tamarind seed extract and Gooseberry extract, respectively, at weight ratios of 95:5 and 90:10, combined at 90:5:5, and magnetically stirred for 20 min at constant temperature until complete dissolution. Immediately, 20 mL of each film-forming solution was cast onto a self-made glass plate (15.24 cm × 10.16 cm) and air-dried at room temperature.

After 72 hours of incubation, the films were peeled off for further use. The resulting films were termed PU (control), PVA, PT5, PT10, PG5, PG10, and PT5G5 based on the Polythene (PU), PVA (P), Tamarind seed (T), and Gooseberry extract (G) content.

2.4. Film Characterizations

2.4.1. Thickness

The thickness of each film was determined using a screw gauge (Total brand) with a resolution of 0.001 mm. The thickness of each specimen was measured at 3 random positions, and the average thickness was calculated [32].

2.4.2. Opacity Characteristics

The opacity of films was determined by measuring the absorbance at a wavelength of 600 nm using a T80+ UV/VIS spectrophotometer (pg instruments ltd, UK) according to the method of Wen et al. [35]. Each specimen was cut into a rectangular strip with dimensions of 4 cm × 1 cm and placed in a spectrophotometer cell [33]. Each sample was measured 3 times. The opacity was evaluated using Eq. (1)

Opacity = Abs/x … …….(1)

Where A is the absorption of film at 600 nm, and x is the thickness of the film.

2.4.3. Moisture Content

Specimen sections of 1 cm × 1 cm were prepared for the moisture content test. All samples were pre-weighed (M0) and dried in an oven at 105°C to a constant weight (M1). The film was kept at room temperature for 72 hr. While conducting the test, the room temperature was 27°C, and the Humidity was 46 % [33]. The moisture content (MC) of the films was calculated using Eq. (2). Three replicates were performed for each measurement.

$$\text{MC}\ (\%) = \frac{(M0-M1)x100}{M0} \text{…….(2)}$$

2.4.4. Water Solubility

Each film was cut into 1 cm × 1 cm sections and weighed (M0). The specimens were placed in distilled water at room temperature for 24 h. Then, the films were removed and dried to a constant weight at 105°C (M1) [33]. At least three replicates were performed for each measurement. The water solubility (WS) was calculated based on Eq. (3):

$$\text{WS}\ (\%) = \frac{(M0-M1)x100}{M0} \text{…….(3)}$$

2.4.5. Water Vapor Permeability

The water vapor permeability (WVP) was determined after the method described by Peng et al. [34] and Wen et al. [35] with the same modifications. The films were cut into round pieces with 30 mm diameter and sealed into test tubes (inner diameter: 15 mm, height: 125 mm) filled with 3 g granular anhydrous calcium chloride. Then, the covered test tubes were placed in a desiccator containing 1 L of distilled water, providing RH gradients of 100%. An open test tube with only calcium chloride was placed with the test sample as the reference sample. The test tube was weighed every 12 hours for 3 consecutive days. Three test was performed for each sample.

2.4.6. Antimicrobial Activity

The antifungal efficacy of polymer samples was evaluated to determine their potential as antimicrobial materials in packaging applications [36]. The antifungal activity was assessed against common fungal strains such as Aspergillus niger and Candida albicans using agar diffusion and/or zone of inhibition methods.

2.4.7. Releasing Tamarind extract and Indian gooseberry extract content

Each sample (1 cm x 1 cm) was soaked in 30 mL distilled water under magnetic stirring for 30 min (at room temperature 27°C and humidity of 46%). The absorbance of the obtained solution was measured at 275 nm using a T80+ UV/VIS spectrophotometer (pg instruments ltd, UK). Three repetitions were tested for each sample. The average of absorbances at 275 nm (ABS, λ = 275 nm) was calculated. Three repetitions were tested for each sample.

2.4.8. Tensile Test

The specimens for tensile testing were cut into rectangles of 50 mm in length and 10 mm in width. The tensile test was performed at room temperature (27 ° C) and a relative humidity of 46% on a Zwick Roell universal testing machine (model 5569, Germany), operated according to ASTM D638-14 and ISO 527-2 standards which provide guidelines for determining the tensile properties of plastics, ensuring global recognition and acceptance of the testing

framework (ASTM International, 2014; International Organization for Standardization, 2012). The crosshead speed was set at 50 mm/min. Three repetitions were tested for each sample.

2.4.9. Thermal Stability

The thermal behavior of the films was performed in 2 parts. In the first part, the tested samples (2cm x 2cm) were boiled using a water bath from 30 to 100°C with a constant heating rate of 10°C /min. In the second part, the tested samples (2cm x 2cm) were heated using an oven from 30 to 100°C with a constant heating rate of 10°C /min. Each sample was tested 3 time and average value and standard deviation found.

2.4.10. Infrared Spectroscopy

All films were characterized using a Spectrum Two FT-IR Spectrometer (PerkinElmer) in an attenuated total reflection mode in the range from 4000 to 500 cm^{-1}.

III. RESULTS AND DISCUSSION

3.1. Thickness

Table 1: Comparison of thickness between the reference sample and experimental sample.

Ser	Sample	Thickness (mm) AVG	Rmk
1.	PU (reference)	0.05 ± 0.01	
2.	PVA	0.08 ± 0.01	
3.	PT5	0.07 ± 0.01	
4.	PG5	0.06 ± 0.01	
5.	PT10	0.06 ± 0.02	
6.	PG10	0.07 ± 0.01	
7.	PT5G5	0.07 ± 0.015	

From the table 1, we can see that the experimental sample thickness is slightly higher than the reference sample. However, this small thickness change cannot affect the results of different laboratory tests.

3.2. Opacity Characteristics

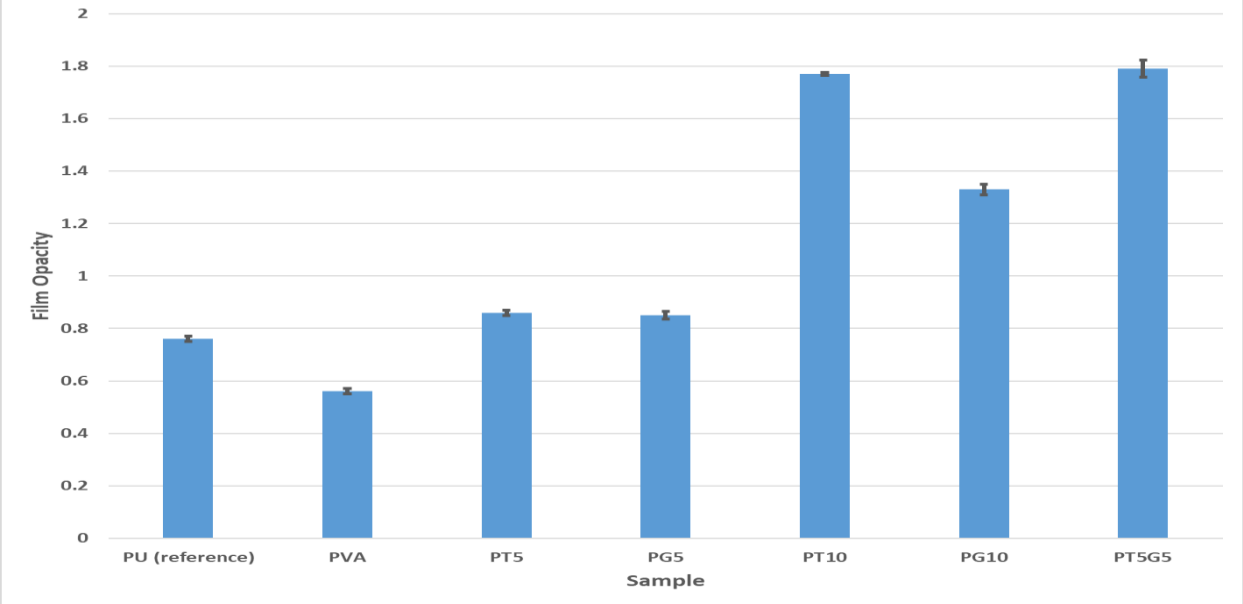

Figure 1: shows the opacity of films at a wavelength of 600 nm using a T80+ UV/VIS spectrophotometer (pg instruments ltd, UK), according to 2.4.2.

The figure 1 shows that the opacity of the experimental sample increases slightly with the increasing concentration of the extract. The PU (reference) sample showed opacity of 0.76, which is higher than PVA film but lower than the other 5 samples. A higher opacity value for polythene generally indicates that the material is less transparent and scatters more light (PT5G5 and PT10), resulting in an opaque appearance. Conversely, a lower opacity value suggests higher transparency (PVA, PT5, PG5), allowing more light to pass through. While transparency in food packaging can be desirable for showcasing freshness and quality, a higher opacity value (meaning the material is less transparent) is

generally considered better for protecting food and extending its shelf life. Opaque packaging blocks light, which can degrade food products like fats, oils, and certain vitamins. From our test results, it is clear that for lower transparency, PT5G5 or PT10 can be used, and for higher transparency, PG5 can be used.

3.3. Moisture Content

The moisture content behavior of the antioxidant packaging films was systematically investigated through a controlled and standardized procedure, specifically employing a moisture content test. This test aimed to assess the films' response to moisture absorption, a critical parameter for evaluating their potential applications in real-world scenarios. The test was conducted on 2.4.3. And the result is found using Equation (2).

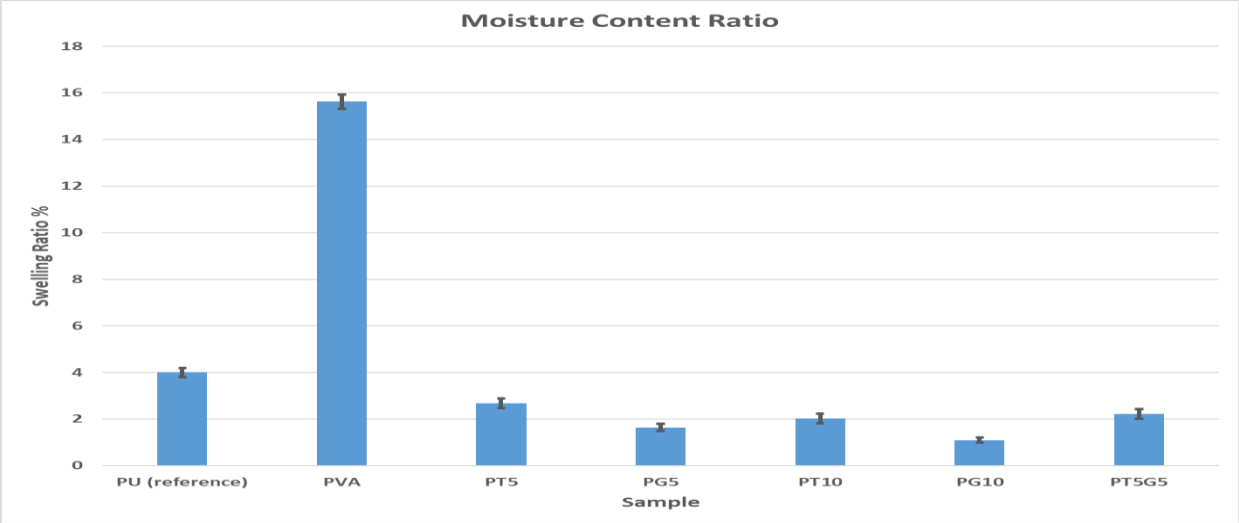

Figure 2: Moisture content test results of 7 sample

From figure 2 PU reference sample absorbed moisture content is 4%. PVA film exhibited substantial Moisture content, with a ratio of approximately 15.625%, indicating its notable moisture absorption capacity. Films containing botanical extracts, especially PG5 Film, displayed significant Moisture content, 1.639%, and PG10 film displayed 1.098% Moisture content, suggesting that higher concentrations of extracts contributed to increased hydrophilic properties. The film PT5G5 exhibited a moderate Moisture content ratio of 2.22%, indicating a balanced response to moisture absorption. The PG10 Film displayed the lowest Moisture content, 1.098%. The ability of packaging films to absorb moisture is a critical factor in preserving the quality and shelf life of food products. Excessive moisture within the packaging can lead to issues such as microbial growth, loss of product integrity, and compromised freshness. On the other hand, an optimal level of moisture absorption can prevent condensation, inhibit microbial proliferation, and maintain the food product's texture and taste. Understanding the swelling behavior of antioxidant packaging films, especially those incorporating botanical extracts, allows for the customization of packaging solutions based on specific food preservation requirements. So the PG10 film is the best choice for the food packaging it absorbed less moisture than the other 5 samples.

3.4. Water Solubility

The swelling behavior of the antioxidant packaging films was systematically investigated through a controlled and standardized procedure, specifically employing a swelling test. This test aimed to assess the films' response to moisture absorption, a critical parameter for evaluating their potential applications in real-world scenarios. The test was conducted on 2.4.4. shown in Figure 3, 4, and the result is found using Equation (3).

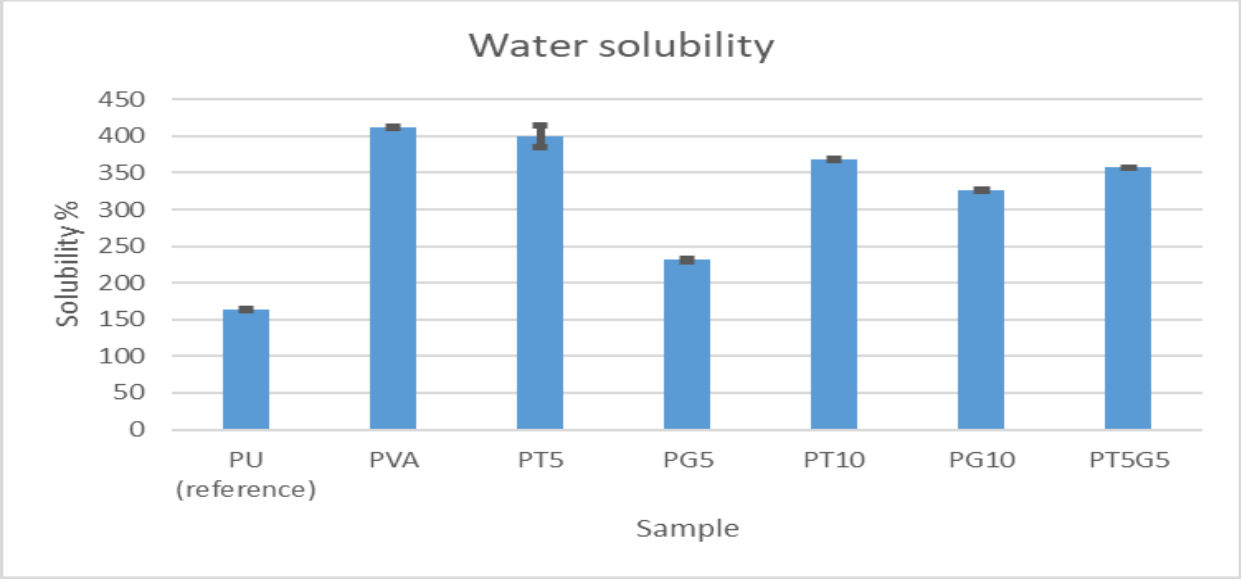

Figure 3: Water solubility test results of different samples

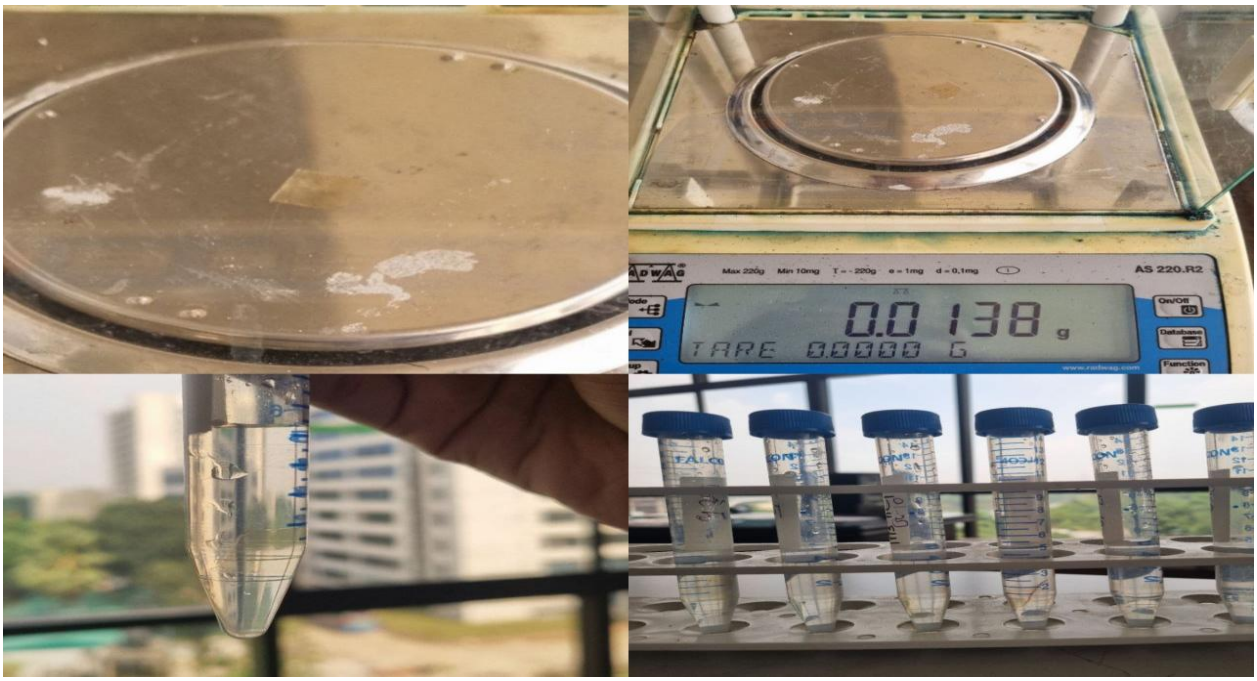

Figure 4: measured weights of samples before and after swelling

The PU reference film exhibited very low swelling, with a ratio of approximately 164%; the PVA film exhibited substantial swelling, with a ratio of approximately 412%, indicating its notable water absorption capacity. Films containing botanical extracts, especially PT5 Film, displayed significant swelling, 399%, and PT10 Film displayed 368% swelling, suggesting that higher concentrations of extracts contributed to increased hydrophilic properties. The film PT5G5 exhibited a moderate swelling ratio of 357%, indicating a balanced response to water absorption. The PG5 Film displayed good swelling, 231%, which will be near the PU reference sample value, and a possible candidate for PU alternative.

3.5. Water Vapor Permeability

The evaluation of water vapor permeability in the antioxidant packaging films involved a meticulous testing process to assess their barrier properties. The

test was conducted according to 2.4.5. Procedure. The films were sealed securely to eliminate any potential leaks that might compromise the accuracy of the test.

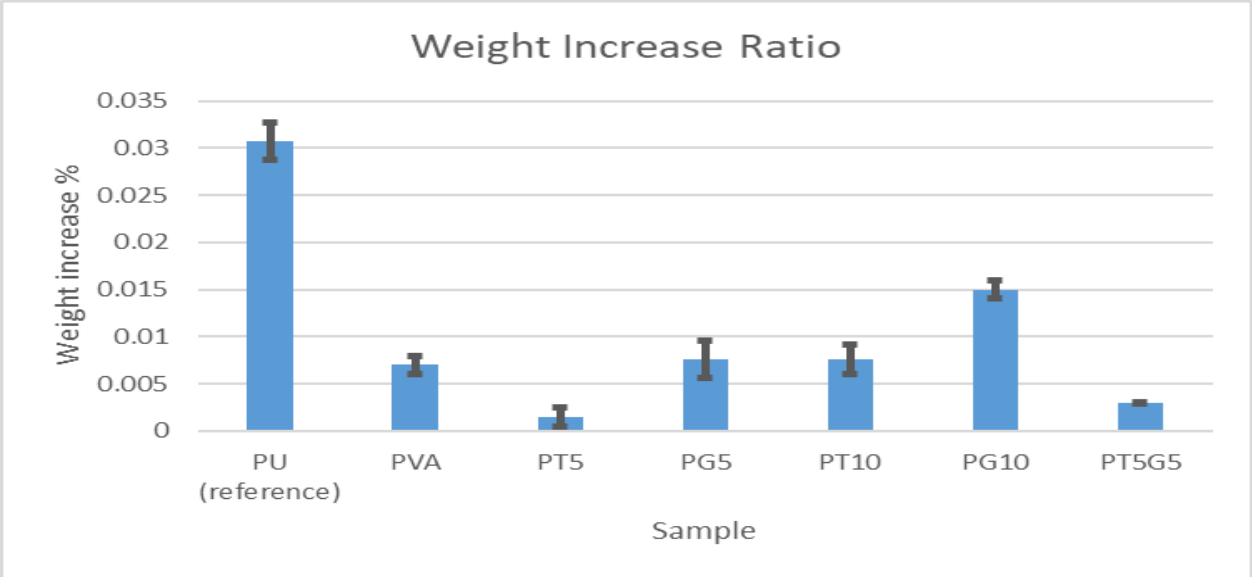

Figure 5: Water vapor permeability of 6 sample.

From figure 5 throughout the test duration, the reference and covered test tubes were closely monitored. We investigate that the reference sample weight increased slightly after 72 hr.; it increased by 0.307%, but other sample weight changes are very small. Remarkably, none of the films exhibited any penetration, as evidenced by the WVP data of 3 days. This observation underscored the robust barrier properties of the films against water vapor, suggesting their efficacy in preventing undesired humidity ingress. These findings hold significance, particularly in food packaging applications, where maintaining optimal moisture levels is critical for preserving the quality and shelf life of products. The water vapor permeability test, conducted under conditions resembling real-world scenarios, provides valuable insights into the films' barrier performance, contributing to their suitability for practical applications.

3.6. Antimicrobial Activity

The antifungal efficacy of the samples was evaluated against common fungal strains such as Candida albicans using the zone of inhibition method. The test was conducted according to 2.4.6. Procedure. The tested samples are PU, PVA, PT5, PG5, PT10, PG10, and PT5G5 (figure 6). PU served as a reference, as it is a widely used baseline synthetic polymer with relatively low antifungal activity. It showed no inhibition zones, likely due to the lack of inherent antimicrobial properties in conventional PU formulations. The results suggest that unmodified PU does not effectively resist fungal colonization.

Pure PVA exhibited slightly higher antifungal activity compared to PU. Its hydrophilic nature may help retain moisture that can influence diffusion of any additives, but it lacks bioactive components. It shows no inhibition zones.

Incorporation of 5% turmeric extract into the PVA matrix significantly enhanced antifungal activity. Curcumin, the primary bioactive compound in turmeric, is known for its antifungal and anti-inflammatory properties. The sample displayed small inhibition zones, particularly against Candida albicans, suggesting curcumin's effectiveness in disrupting fungal membranes.

The addition of 5% gooseberry extract showed antifungal performance. Gooseberry is rich in polyphenols and ascorbic acid, contributing to fungal cells' oxidative stress. We found a small inhibition zone here.

Doubling the turmeric concentration to 10% resulted in a marked increase in antifungal activity. Larger inhibition zones were observed against C. albicans,

confirming a dose-dependent effect of turmeric. The increased curcumin content likely intensified membrane disruption and protein denaturation in fungal cells.

Similarly, the 10% gooseberry-loaded PVA sample showed enhanced antifungal potential over its 5% counterpart. The stronger inhibition is attributed to a higher concentration of bioactive phytochemicals, particularly tannins and vitamin C that interfere with fungal growth mechanisms.

The combination of 5% turmeric and 5% gooseberry in the PVA matrix yielded the most promising antifungal activity among all tested formulations. The synergistic interaction between curcumin and gooseberry polyphenols appeared to amplify the antifungal effects, resulting in the largest inhibition zones. This combination exhibited broad-spectrum activity and may be suitable for applications requiring enhanced antifungal protection.

The study demonstrates that the antifungal activity of PVA can be significantly enhanced through the incorporation of natural plant extracts. The combination of turmeric and gooseberry (5% each) was the most effective, indicating a potential synergistic effect. These findings suggest that bioactive PVA composites could serve as eco-friendly alternatives for antifungal coatings, biomedical films, or packaging materials.

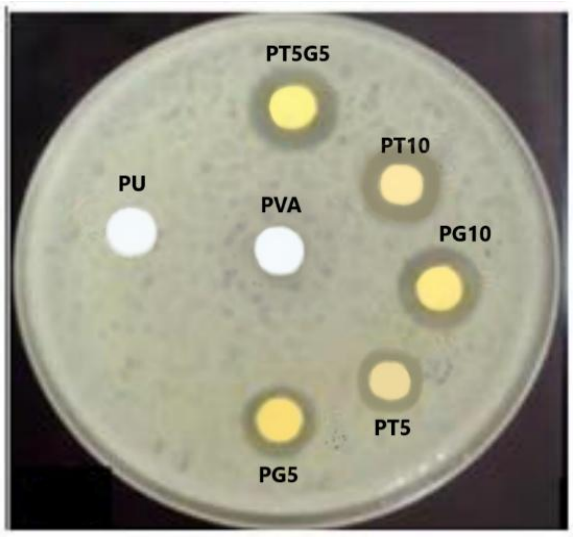

Figure 6: Antifungal test result of 7 samples shown here.

The antifungal performance of packaging films was investigated using bread samples. Bread samples were wrapped in each polymer film and stored under ambient conditions favorable to fungal growth. Fungal activity was assessed visually and microbiologically over a storage period of 7 to 14 days (Figure 7), with focus on common spoilage fungi such as Aspergillus spp., Penicillium spp., and Rhizopus spp. The effectiveness of each film was evaluated based on the extent of fungal growth and, appearance of spoilage. PU-wrapped bread (figure 7a) showed significant fungal growth within 4–5 days. PU lacks inherent antifungal properties and allows limited gas exchange, leading to moisture retention and fungal colonization. PVA Film (figure 7b) Slightly improved antifungal resistance compared to PU, but fungal colonies were visible by day 6–7. PVA has better film-forming and moisture-regulating properties, but lacks bioactive compounds to suppress fungi. PT5 (figure 7c) Notable reduction in fungal growth, with only mild surface spotting after 10 days. Turmeric (curcumin) imparts antifungal activity by disrupting fungal membranes and inhibiting spore germination. PG5 (figure 7d) Moderate fungal suppression observed, slightly less effective than turmeric. Gooseberry contains polyphenols and antioxidants (e.g., vitamin C), which help limit fungal proliferation. PT10 (figure 7e) significantly enhanced antifungal performance, with no visible spoilage up to 12 days. Higher curcumin content offers strong antifungal action; ideal for longer shelf-life packaging. PG10 (figure 7f) Improved performance over 5% version, though slightly less potent than 10% turmeric. Increased concentration of phenolic compounds and acidity from gooseberry extract contributes to fungal growth inhibition. PT5G5 (figure 7g) Best overall antifungal performance among all samples. No visible fungal growth for up to 14 days. Synergistic effect of curcumin and gooseberry phytochemicals provided broad-spectrum antifungal protection, likely due to combined mechanisms of oxidative stress induction, membrane disruption, and pH modulation. The study demonstrates that PVA films enriched with natural antifungal agents such as turmeric and gooseberry extracts can greatly enhance the shelf-life and fungal resistance of brade samples. The combination of turmeric 5% + gooseberry 5% emerged as the most effective formulation, offering a natural, biodegradable, and functional packaging solution with potential applications in food preservation and herbal product storage.

Fungal Growth

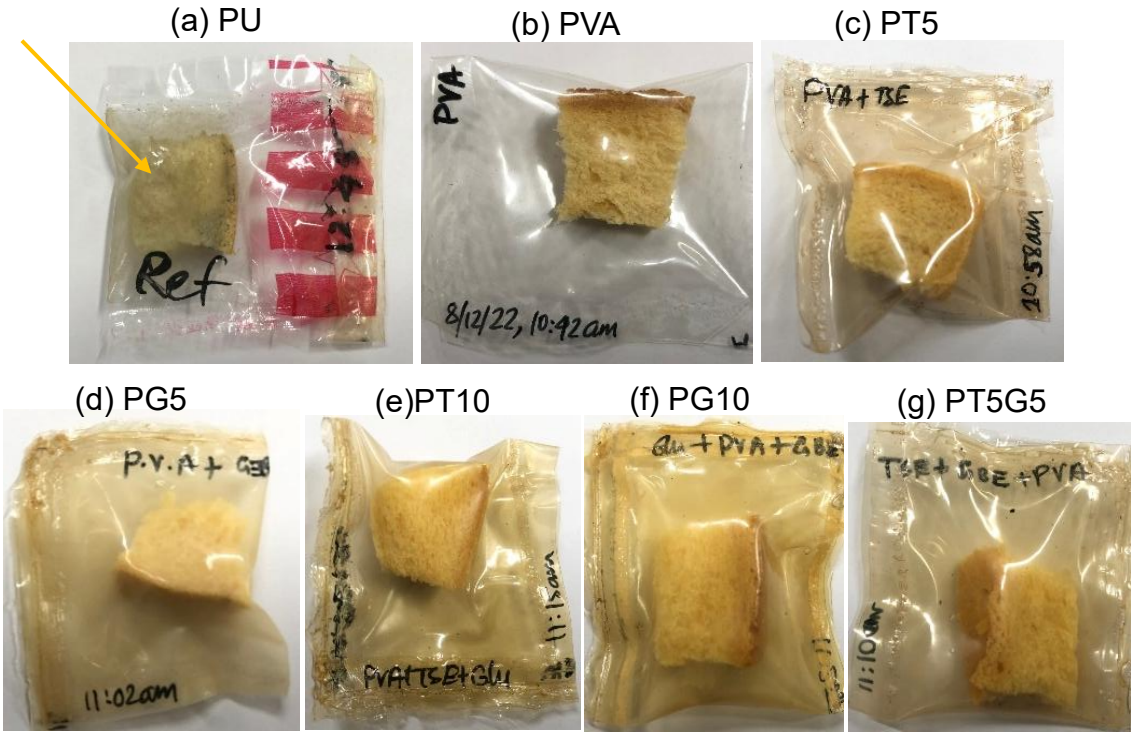

Figure 7: Food packaging result of 7 samples shows fungal growth and antimicrobial property.

3.7. Releasing Tamarind extract and Indian gooseberry extract content

The releasing tannin of the Six sample (PVA, PT5, PG5, PT10, PG10, PT5G5) was measured according to the 2.4.7 procedure.

Table 2: release tannin data

Ser	Sample	Absorbance
1.	PVA	0.005 ± 0.001
2.	PT5	0.009 ± 0.001
3.	PG5	0.006 ± 0.0015
4.	PT10	0.017 ± 0.01
5.	PG10	0.011 ± 0.01
6.	PT5G5	0.009 ± 0.001

where we are evaluating tannin release at 275 nm from six PVA-based film (PVA, PT5, PG5, PT10, PG10, PT5G5) samples using a UV-Vis spectrometer, the outcomes can be interpreted based on tannin content, interaction with PVA, and extract concentration. PVA sample shows very minimal absorbance at 275 nm which was 0.005. the main reasone behind that pure PVA does not contain tannins or UV-absorbing phytochemicals. PT5 shows moderate absorbance which was 0.009. Reasoned behind that is turmeric is rich in curcuminoids, which absorb strongly around 420 nm, not 275 nm. It has minimal tannin content, so absorbance at 275 nm would be relatively low or background level. Any absorbance is likely due to overlapping minor phenolic content or interference. PG5 film showed Moderate absorbance at 275 nm which was 0.006. the main reason is Amla (Indian gooseberry) is rich in hydrolysable tannins (e.g., emblicanin, chebulagic acid) and ascorbic acid, both of which absorb near 265–280 nm. Clear evidence of tannin release. The amount released will depend on how extract is dispersed and how it interacts with PVA. PT10 film showes high absorbance at 275 nm which was 0.017. The reason behind it was tamarind pulp has high polyphenol and tannin content (especially water-soluble), and we've used double the concentration compared to the other single-extract samples. This sample may show the highest tannin release, provided the extract is well-incorporated and not entrapped by PVA. PG10 shows higher absorbance than the PG5 sample which was 0.011. Main reasone behind it was greater extract loading should correlate with greater tannin content release,

assuming uniform dispersion and consistent diffusion. Strong tannin release profile, potentially close to or exceeding tamarind depending on extract quality. PT5G5 showed moderate to high absorbance at 275 nm. Reason is gooseberry provides tannins; turmeric contributes little at 275 nm. Any change in release behavior could result from interactions between the extracts or with the PVA matrix. If turmeric extract interferes with gooseberry diffusion or creates aggregation, the release might be lower than gooseberry-only sample. Alternatively, it could be similar or enhanced due to synergistic interactions.

3.8. Tensile Test

The tensile properties of the antioxidant packaging films were systematically evaluated through a rigorous tensile testing procedure conducted using a Universal Testing Machine (UTM). Adherence to standardized protocols ensured the precision, reliability, and comparability of the obtained results. The test was conducted according to 2.4.8. Procedure.

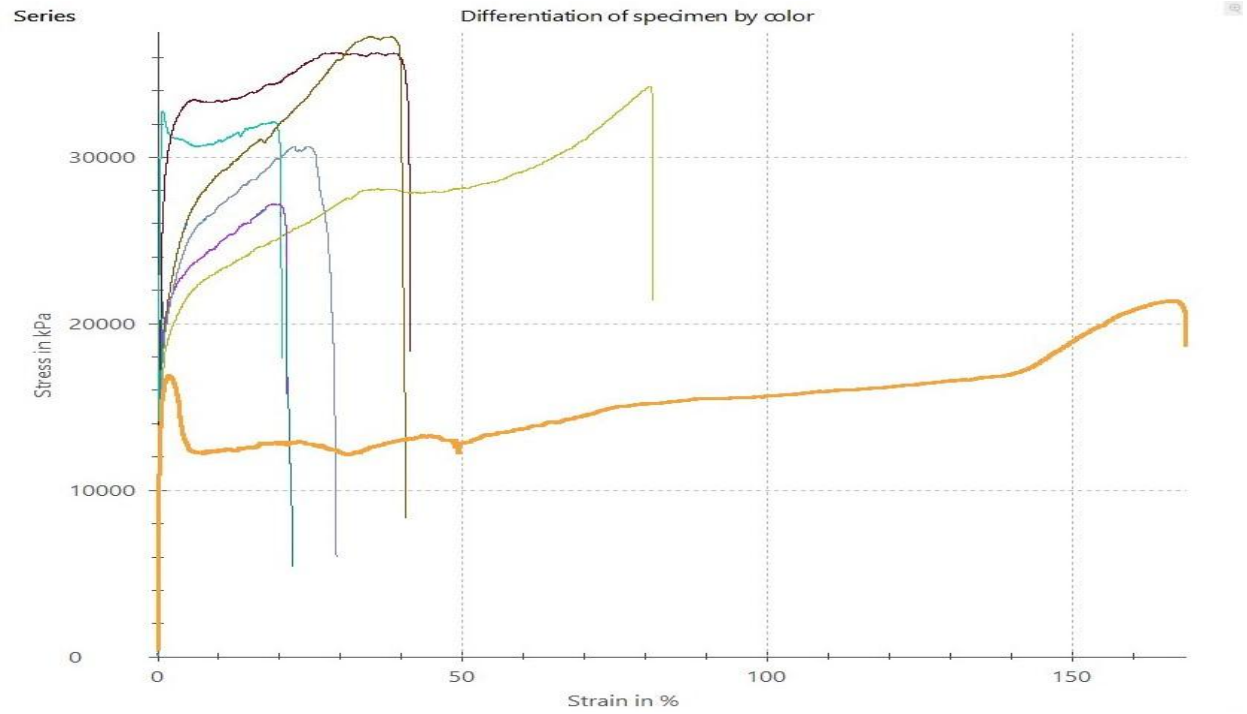

Figure 8: Tensile test curve of the tested samples

The elastic modulus from Figure 8 reflects the stiffness of the material. The reference sample (PU) elastic modules were 3530, and only the PVA elastic modules were 5690. Films containing Gooseberry extracts, PG5, and PG10 both exhibited higher elastic modules, 3440 MPa and 4060 MPa. Films containing PT5 and PT10 both exhibited elastic moduli of 8080 MPa and 4150 MPa. The film contains PT5G5 exhibits an elastic modulus of 3980. Compared to other films, PT5 of turmeric extract indicated greater resistance to deformation (8080 MPa).

The strength at maximum load demonstrates the material's ability to withstand stress. The PG10 film demonstrated the highest strength (37.3 MPa), surpassing the reference (PU) and other films.

Elongation at break measures the film's extensibility before rupture. Films containing PG5 extracts (81%) exhibited higher elongation at break values, suggesting greater elasticity than other films.

These results underscore the influence of extract concentrations on the mechanical properties of the films. Notably, the combination of Tamarind and Gooseberry (PG5T5) produced a film with intermediate mechanical characteristics, indicating a potential synergistic effect. The PU film served as a benchmark, providing a reference for comparison. This analysis provides valuable insights into the

mechanical performance of the antioxidant packaging films, guiding further optimization and refinement efforts in the pursuit of a robust and functional packaging solution.

3.9. Thermal Stability

For the first portion of the test, the film samples exhibited notable resilience to prolonged exposure to high temperatures. Observations post-drying indicated minimal structural changes, maintaining their initial flexibility and color, suggesting a robust resistance to thermal stress shown in Figure 9. For the second portion, the film samples demonstrated commendable resistance to direct exposure to elevated temperatures. Minimal alterations were noted, emphasizing the films' robust nature under more immediate thermal stress conditions shown in Figure 9. A comprehensive analysis and comparison of results from both portions of the test revealed nuanced insights into the films' responses to varied thermal stress scenarios. Any observed changes or damage were considered, providing a holistic understanding of the films' thermal stability.

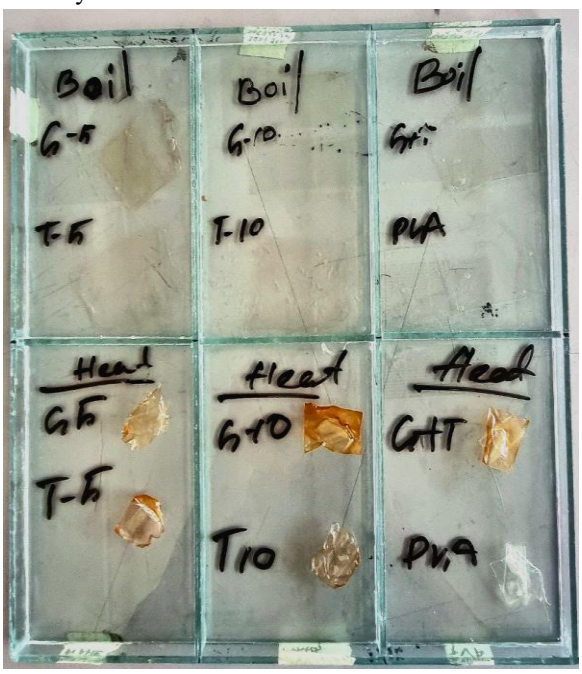

Figure 9: Thermal stability test results.

3.10. Infrared Spectroscopy

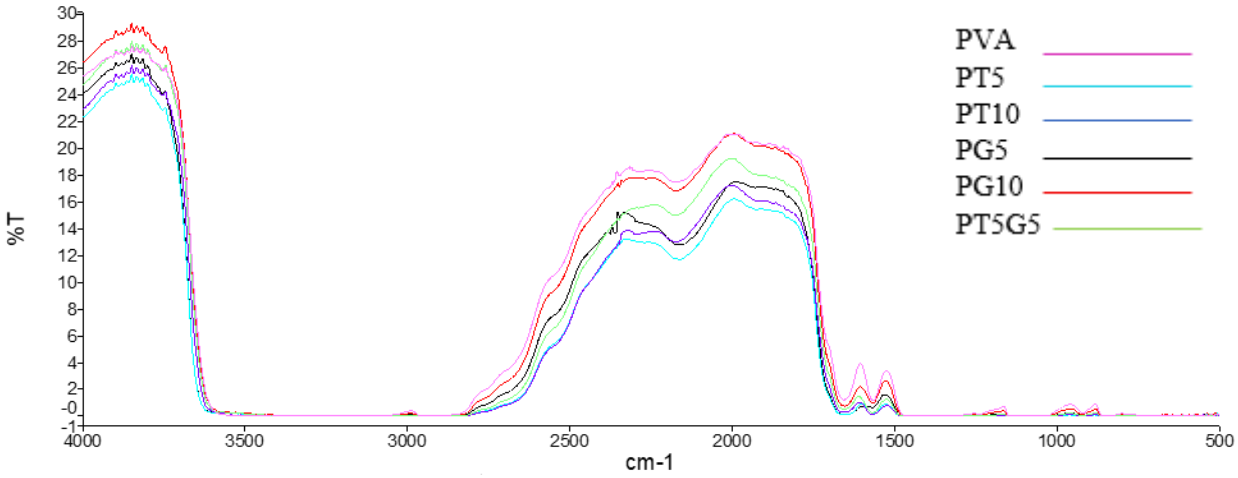

Figure 10: FTIR result of the 6 experimental samples

FTIR result, shown in Figure 10, indicates that the developed film has similar characteristics to the control PVA film, and adding tamarin and gooseberry did not affect the film's chemical bond.

IV. CONCLUSION

The development of antioxidant packaging films incorporating Tamarind Extract, Indian Gooseberry Extract, and Polyvinyl Alcohol represents a significant stride toward sustainable and efficient packaging solutions. The project successfully achieved the formulation of films with commendable tensile strength, antioxidant properties, and thermal stability, laying a foundation for their potential application in the dynamic field of sustainable food packaging. The findings contribute valuable insights into the material science of these films, showcasing their promise in

preserving both the structural integrity of packaging and the freshness of food products. However, as with any scientific endeavor, certain limitations and opportunities for further exploration exist. Time constraints tempered the depth of antioxidant property assessment, and future studies could delve into a more comprehensive evaluation. The exclusive focus on film samples, rather than complete packaging packets, provides a basis for practical applicability but invites further scrutiny in real-world scenarios. Mechanical testing, while indicative of film strength, opens doors for more extensive investigations into diverse mechanical properties. The study's constraints in extract concentrations and polymer choice offer insights for optimization strategies in subsequent research. The absence of a long-term stability assessment and direct testing with real food products hints at potential avenues for extended exploration. Considering these aspects, the research project not only contributes to the current understanding of antioxidant packaging films but also delineates pathways for future advancements and refinements. This holistic perspective positions the project as a steppingstone in the ongoing journey toward sustainable and effective packaging solutions, ensuring a resilient and impactful trajectory in the broader landscape of materials science and environmental sustainability.

V. ACKNOWLEDGMENTS

We praise the Creator for His mercy in allowing us to complete this project. We are very appreciative of the support provided by the Department of Biomedical Engineering and other departments of the Military Institute of Science and Technology.

REFERENCE

[1] M. Aslam, M. A. Kalyar, and Z. A. Raza, "Polyvinyl alcohol: A review of research status and use of polyvinyl alcohol based nanocomposites," *Polym. Eng. Sci.*, vol. 58, no. 12, pp. 2119–2132, 2018, doi: 10.1002/pen.24855.

[2] N. B. Halima, "Poly(vinyl alcohol): review of its promising applications and insights into biodegradation," *RSC Adv.*, vol. 6, no. 46, pp. 39823–39832, Apr. 2016, doi: 10.1039/C6RA05742J.

[3] P. Cazón, M. Vázquez, and G. Velazquez, "Cellulose-glycerol-polyvinyl alcohol composite films for food packaging: Evaluation of water adsorption, mechanical properties, light-barrier properties and transparency," *Carbohydr. Polym.*, vol. 195, pp. 432–443, Sep. 2018, doi: 10.1016/j.carbpol.2018.04.120.

[4] H. Haghighi *et al.*, "Development of antimicrobial films based on chitosan-polyvinyl alcohol blend enriched with ethyl lauroyl arginate (LAE) for food packaging applications," *Food Hydrocoll.*, vol. 100, p. 105419, Mar. 2020, doi: 10.1016/j.foodhyd.2019.105419.

[5] M. E. Hoque, M. U. Shafoyat, and F. Tabassun, "Polymers, Their Composites, Blends, and Nanocomposites for the Fabrication of Prosthetics," in *Applications of Biopolymers in Science, Biotechnology, and Engineering*, John Wiley & Sons, Ltd, 2024, pp. 361–389. doi: 10.1002/9781119783473.ch15.

[6] M. E. Hoque and M. U. Shafoyat, "6 - Self-healing polymer nanocomposite films and coatings," in *Polymer Nanocomposite Films and Coatings*, M. Pandey, K. Deshmukh, and C. M. Hussain, Eds., in Woodhead Publishing Series in Composites Science and Engineering. , Woodhead Publishing, 2024, pp. 181–217. doi: 10.1016/B978-0-443-19139-8.00010-3.

[7] K. F. El-Nemr, Mohamed ,Hamdi R., Ali ,Magdy A., Fathy ,Rasha M., and A. S. and Dhmees, "Polyvinyl alcohol/gelatin irradiated blends filled by lignin as green filler for antimicrobial packaging materials," *Int. J. Environ. Anal. Chem.*, vol. 100, no. 14, pp. 1578–1602, Nov. 2020, doi: 10.1080/03067319.2019.1657108.

[8] W. Yang *et al.*, "Antioxidant and antibacterial lignin nanoparticles in polyvinyl alcohol/chitosan films for active packaging," *Ind. Crops Prod.*, vol. 94, pp. 800–811, Dec. 2016, doi: 10.1016/j.indcrop.2016.09.061.

[9] F. Debiagi, R. K. T. Kobayashi, G. Nakazato, L. A. Panagio, and S. Mali, "Biodegradable active packaging based on cassava bagasse, polyvinyl alcohol and essential oils," *Ind. Crops Prod.*, vol. 52, pp. 664–670, Jan. 2014, doi: 10.1016/j.indcrop.2013.11.032.

[10] K. Szabo *et al.*, "Active Packaging—Poly(Vinyl Alcohol) Films Enriched with Tomato By-Products Extract," *Coatings*, vol. 10, no. 2, Art. no. 2, Feb. 2020, doi: 10.3390/coatings10020141.

[11] M. P. Balasubramaniam *et al.*, "Synthesis of chitosan-ferulic acid conjugated poly(vinyl alcohol) polymer film for an improved wound healing," *Mater. Today Commun.*, vol. 25, p. 101510, Dec. 2020, doi: 10.1016/j.mtcomm.2020.101510.

[12] Y. Peng, Y. Wu, and Y. Li, "Development of tea extracts and chitosan composite films for active packaging materials," *Int. J. Biol. Macromol.*, vol. 59, pp. 282–289, Aug. 2013, doi: 10.1016/j.ijbiomac.2013.04.019.

[13] E. Caluwé, K. Halamová, and P. Van Damme, "Tamarindus indica L. – A review of traditional uses, phytochemistry and pharmacology," *Afr. Focus*, vol. 23, Feb. 2010, doi: 10.21825/af.v23i1.5039.

[14] H. Y. Lam, S. A. Hassan, N. Ismail, N. M. Noor, and W. R. W. Makhtar, "Medicinal Properties of Tamarind Seeds: A Mini Review," *J. Biochem. Microbiol. Biotechnol.*, vol. 12, no. 2, Art. no. 2, Dec. 2024, doi: 10.54987/jobimb.v12i2.1012.

[15] M. E. Hoque and M. U. Shafoyat, "Biopolymers and Their Composites for Biotechnological Applications," in *Applications of Biopolymers in Science, Biotechnology, and Engineering*, John Wiley & Sons, Ltd, 2024, pp. 189–217. doi: 10.1002/9781119783473.ch8.

[16] H. Y. Lam, S. A. Hassan, N. Ismail, N. M. Noor, and W. R. W. Makhtar, "Medicinal Properties of Tamarind Seeds: A Mini Review," *J. Biochem. Microbiol. Biotechnol.*, vol. 12, no. 2, Art. no. 2, Dec. 2024, doi: 10.54987/jobimb.v12i2.1012.

[17] L. Ren *et al.*, "Physicochemical, Rheological, Structural, Antioxidant, and Antimicrobial Properties of Polysaccharides Extracted from Tamarind Seeds," *J. Food Qual.*, vol. 2022, no. 1, p. 9788248, 2022, doi: 10.1155/2022/9788248.

[18] E. Bonin *et al.*, "Study of chemical constituents, antioxidants and antimicrobial activities of Tamarindus indica L. seed," *J. Food Sci.*, vol. 88, no. 11, pp. 4639–4652, 2023, doi: 10.1111/1750-3841.16739.

[19] M. A. A. Orabi *et al.*, "Nutritional, Antioxidant, Antimicrobial, and Anticholinesterase Properties of Phyllanthus emblica: A Study Supported by Spectroscopic and Computational Investigations," *Metabolites*, vol. 13, no. 9, Art. no. 9, Sep. 2023, doi: 10.3390/metabo13091013.

[20] R. Saini, V. Kumar, C. N. Patel, A. Sourirajan, and K. Dev, "Synergistic antibacterial activity of Phyllanthus emblica fruits and its phytocompounds with ampicillin: a computational and experimental study," *Naunyn. Schmiedebergs Arch. Pharmacol.*, vol. 397, no. 2, pp. 857–871, Feb. 2024, doi: 10.1007/s00210-023-02624-0.

[21] V. Sarojamma, E. Siddhartha, and R. Vadde, "Antibacterial Effect of Indian Gooseberry (Phyllanthus emblica L.) Extract Against ESBL Producing Multi-Drug Resistant Bacteria," *J. Biomed. Res. Environ. Sci.*, vol. 5, no. 2, pp. 227–232, Feb. 2024, doi: 10.37871/jbres1886.

[22] E. J. B. Jose, J. S. Azariah, M. Radhakrishnan, K. Rajagopal, M. Sundaramoorthy, and N. P. Pillai, "Comparative Study on the Phyllanthus Acidus and Phyllanthus Embilca and their Antimicrobial Activity," *Int. J. Pharm. Phytopharm. Res.*, vol. 12, no. 1–2022, Art. no. 1–2022, 2022, doi: 10.51847/9CSOk0twSN.

[23] P. Terzioğlu and Y. Sıcak, "Citrus Limon L. Peel Powder Incorporated Polyvinyl Alcohol/Corn Starch Antioxidant Active Films," *J. Inst. Sci. Technol.*, vol. 11, no. 2, Art. no. 2, Jun. 2021, doi: 10.21597/jist.825560.

[24] H. Yehia, "Methanolic Extract of Neem Leaf (Azadirachta indica) and its Antibacterial Activity Against Foodborne and Contaminated Bacteria on Sodium Dodecyl Sulfate-Polyacrylamide Gel Electrophoresis," 2016. Accessed: May 06, 2025. [Online]. Available: https://www.semanticscholar.org/paper/Methanolic-Extract-of-Neem-Leaf-(-Azadirachta-)-and-Yehia/8aa7bd1dda8cb9498cb10300a586e44a7a841153

[25] K. Harjai, A. Bala, R. K. Gupta, and R. Sharma, "Leaf extract of Azadirachta indica (neem): a potential antibiofilm agent for Pseudomonas aeruginosa," *Pathog. Dis.*, vol. 69, no. 1, pp. 62–65, Oct. 2013, doi: 10.1111/2049-632X.12050.

[26] J. Liao *et al.*, "Development of Antioxidant Packaging Film Based on Chinese Bayberry Tannin Extract and Polyvinyl Alcohol," *J. Renew.*

Mater., vol. 10, no. 1, pp. 19–31, 2021, doi: 10.32604/jrm.2021.016152.

[27] B.-E. Teleky *et al.*, "Development of Pectin and Poly(vinyl alcohol)-Based Active Packaging Enriched with Itaconic Acid and Apple Pomace-Derived Antioxidants," *Antioxidants*, vol. 11, no. 9, Art. no. 9, Sep. 2022, doi: 10.3390/antiox11091729.

[28] N. Li *et al.*, "Development of pH-Indicative and Antimicrobial Films Based on Polyvinyl Alcohol/Starch Incorporated with Ethyl Lauroyl Arginate and Mulberry Anthocyanin for Active Packaging," *Coatings*, vol. 12, no. 10, Art. no. 10, Oct. 2022, doi: 10.3390/coatings12101392.

[29] A. A. Kudom, BenA. Mensah, and M. A. Botchey, "Aqueous neem extract versus neem powder on Culex quinquefasciatus: Implications for control in anthropogenic habitats," *J. Insect Sci.*, vol. 11, no. 1, p. 142, Jan. 2011, doi: 10.1673/031.011.14201.

[30] U. S. Uthaya Kumar *et al.*, "Extracted Compounds from Neem Leaves as Antimicrobial Agent on the Physico-Chemical Properties of Seaweed-Based Biopolymer Films," *Polymers*, vol. 12, no. 5, Art. no. 5, May 2020, doi: 10.3390/polym12051119.

[31] N. Hashim, S. Abdullah, L. S. Hassan, S. R. Ghazali, and R. Jalil, "A study of neem leaves: Identification of method and solvent in extraction," *Mater. Today Proc.*, vol. 42, pp. 217–221, Jan. 2021, doi: 10.1016/j.matpr.2020.11.726.

[32] P. Terzioğlu and Y. Sıcak, "Citrus Limon L. Peel Powder Incorporated Polyvinyl Alcohol/Corn Starch Antioxidant Active Films," *J. Inst. Sci. Technol.*, vol. 11, no. 2, Art. no. 2, Jun. 2021, doi: 10.21597/jist.825560.

[33] J. Liao *et al.*, "Development of Antioxidant Packaging Film Based on Chinese Bayberry Tannin Extract and Polyvinyl Alcohol," *J. Renew. Mater.*, vol. 10, no. 1, pp. 19–31, 2021, doi: 10.32604/jrm.2021.016152.

[34] Y. Peng, Y. Wu, and Y. Li, "Development of tea extracts and chitosan composite films for active packaging materials," *Int. J. Biol. Macromol.*, vol. 59, pp. 282–289, Aug. 2013, doi: 10.1016/j.ijbiomac.2013.04.019.

[35] H. Wen, Y.-I. Hsu, T.-A. Asoh, and H. Uyama, "Antioxidant activity and physical properties of pH-sensitive biocomposite using poly(vinyl alcohol) incorporated with green tea extract," *Polym. Degrad. Stab.*, vol. 178, p. 109215, Aug. 2020, doi: 10.1016/j.polymdegradstab.2020.109215.

[36] G. Biliuta *et al.*, "Development and Characterization of Polymeric Films Loaded with Terbinafine for Fungal Infection Treatment," *Polymers*, vol. 17, no. 8, Art. no. 8, Jan. 2025, doi: 10.3390/polym17081004.