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Synthesis of Polylactic Acid from Apple, Pineapple, and Potato Residues

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Abstract. Polylactic acid (PLA), a recyclable and biodegradable polymer, is essential for bioplastic production. Driven by the growing need for sustainable alternatives to petroleum-based plastics and the pressing issue of global food waste, PLA emerges as a promising biodegradable polymer derived from renewable resources such as sugarcane, corn, and biomass. Food waste presents a significant opportunity to produce PLA. While the conversion of food waste into lactic acid (LA), the PLA precursor, has been extensively studied, the subsequent transformation into PLA remains relatively unexplored. This research gap underscores the need for comprehensive investigations to understand the properties, production efficiency, and overall feasibility of producing PLA from food waste. This study aimed to produce PLA from food waste-derived LA. Apple, pineapple, and potato residues, rich in carbohydrates, served as substrates for LA fermentation using *Lactobacillus Casei*. The resulting LA was polymerized into PLA via ring-opening polymerization (ROP) using zinc oxide and tin (II) 2-ethylhexanoate as catalysts. Fourier Transform Infrared Chromatography (FTIR) confirmed the presence of LA in the fermentation broth, with the carbonyl and hydroxyl groups detected and LA appearing at peak 2.45 minutes in High-Performance Liquid Chromatography (HPLC). Apple residue yielded the highest LA percentage (31.36%), followed by pineapple (23.41%) and potato (20.81%). FTIR also indicated PLA formation due to the carbonyl group being slightly higher and the hydroxyl group being slightly lower than LA. Gel Permeation Chromatography (GPC) results showed potato residue produced PLA with a significantly higher molecular weight (12,662) compared to apple (543). Notably, apple residue PLA exhibited desirable monodisperse properties, which are advantageous for food packaging applications. This study demonstrates the potential of transforming food waste into valuable bioplastics, contributing to waste reduction and environmental sustainability.

Keywords: Bacteria, Fermentation, Food Waste, Lactic Acid, Polylactic Acid

INTRODUCTION

Due to their unique biodegradable properties, bioplastics receive significant attention from governments and industries. Conventional plastics, derived from petroleum or natural gas, are widely used in daily life but contribute to environmental challenges. Plastic waste accumulation in landfills and releasing harmful greenhouse gases, such as methane and carbon dioxide, through leaching pose serious environmental

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threats (Chandegara *et al*., 2015). Substituting bioplastics for conventional plastics can mitigate these issues. Among the various biodegradable plastics developed, polylactic acid (PLA) based plastics hold considerable promise.

PLA is a promising biodegradable polyester often termed the "polymer of the 21st century." Its mechanical, chemical, and biological properties rival traditional petrochemical-based polymers like polypropylene, polyethylene, and polystyrene (Nawaz *et al*., 2017). As concerns over fossil fuel depletion intensify, PLA has emerged as a viable alternative to renewable resources. Its suitability for packaging applications, particularly for short-shelf-life products like yogurt, bottled water, and juices, is attributed to its favorable mechanical and physical properties (García Ibarra *et al*., 2016). Lactic acid (LA), the precursor to PLA, can be produced from carbohydrates through fermentation.

Food waste, comprising any edible or inedible food removed from the supply chain, poses a significant environmental and economic challenge. Governments worldwide grapple with managing this issue as massive quantities of food are discarded annually. In Malaysia, the Solid Waste Management and Public Cleansing Corporation (SWCorp) reported approximately 16,688 tonnes of food waste generated daily in 2019, predominantly from households and restaurants (Ramli *et al.*, 2022). Recognizing the potential of food waste, researchers have identified it as a rich source of cellulose, a complex carbohydrate convertible into valuable products like LA (Chua *et al.*, 2019). Fruits such as apples, pineapples, and potatoes, abundant in food waste, are promising feedstocks because they contain a high amount of carbohydrates for LA production. These materials can be sourced from various establishments, including restaurants, universities, kitchens, and biomass facilities.

Ring-opening polymerization (ROP) is the preferred method for producing high molecular-weight PLA (Yang *et al*., 2021). This two-stage process involves converting LA to lactide, followed by ROP to form PLA. ROP offers advantages over direct condensation methods regarding product purity, molecular weight control, and environmental impact due to its solvent-free nature and ability to produce stereo-specific PLA.

The escalating demand for alternatives to petroleum-based polymers, coupled with growing environmental concerns, necessitates the development of sustainable polymers. PLA emerges as a promising candidate due to its biodegradability. However, its practical application is hindered by knowledge gaps concerning its mechanical and chemical properties, particularly when derived from food waste. Moreover, the efficient production of PLA from carbohydrate-rich food waste like fruit waste remains understudied. Therefore, research should be conducted to unlock PLA's full potential and explore novel, environmentally friendly polymers with desirable properties.

This study will evaluate the fermentation of LA from apple, pineapple, and potato residues as food waste, followed by the synthesis of PLA through ROP. The process involves multiple stages (Figure 1). Initially, lactic acid bacteria ferment carbohydrates in the food waste to produce LA. Subsequent purification steps will remove impurities from the LA. The purified LA will then undergo ROP to form PLA. Characterization of both LA and PLA will be conducted using Fourier-Transform Infrared (FTIR), Gel Permeation

Chromatography (GPC), and High-Performance Liquid Chromatography (HPLC) analysis.

MATERIALS AND METHODS

Materials

Materials used in the research included apple residues (Peels of Red Fuji Apple), pineapple residues (Peels of Yellow N36 Pineapples), potato residues (Peels of Russet Potatoes), De Man, Rogosa and Sharpe (MRS) Agar/Broth, α-amylase enzyme (derived from Aspergillus oryzae), distilled water, zinc oxide (ZnO), tin(II) 2-ethylhexanoate ($Sn(Oct)_2$) catalyst, and lactobacillus casei (Orla-Jensen) Hansen and Lessel (ATCC 393) bacterial strain.

Methods

Substrate

Food waste, specifically ripe apple peels, pineapple peels, and potato peels residues, was collected from restaurants surrounding UiTM Shah Alam and used in this study. Macroscopic impurities were manually removed from the food waste. Each food waste sample weighed 500 g before undergoing a 24-hour drying process at 60°C to reduce moisture content and inhibit degradation before fermentation. The desiccated food waste was then milled to a controlled particle size and stored at 4°C in a refrigerator until further use.

Microbial Community (Culture and Inoculum Preparation)

Lactobacillus casei (Orla-Jensen) Hansen and Lessel (ATCC 393) was the selected microbial strains for lactic acid production. The bacterial culture was incubated on De Man–Rogosa–Sharpe (MRS) Agar/Broth at 37°C under aerobic conditions supplemented with 5% CO_2 in a controlled environment incubator for 48 hours to achieve a sufficient population density for inoculation. Lactobacillus strains hold significant commercial value due to their high acid tolerance, yield, productivity, and production of L/D-lactic acid (Abedi and Hashemi, 2020).

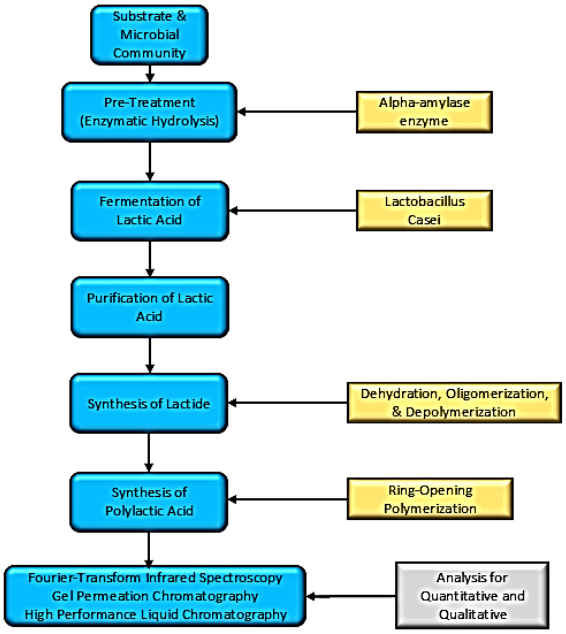


Fig. 1: Flowchart of polylactic acid process

Enzymatic Hydrolysis

Enzymatic hydrolysis was performed by utilizing α-amylase solution derived from *Aspergillus Oryzae* as an enzyme to breakdown complex carbohydrate chains (polysaccharides) into simple sugars (monosaccharides) (Manandhar and Shah, 2020). 100 g of food waste was distributed into each beaker. Subsequently, 0.5 g of α-amylase was diluted in 200 mL of distilled water for each beaker. The substrate and enzyme mixture were stirred at a rotational speed of 150 rpm using a magnetic stirrer for 60 minutes at room temperature on a hotplate stirrer to facilitate the degradation of food waste into simple sugars for subsequent fermentation.

Fermentation of Lactic Acid

Simultaneous Saccharification and

Fermentation (SSF) were employed for the fermentation of food waste. The fermentation process was conducted in Erlenmeyer flasks containing a mixture of food waste and *L. casei* inoculum obtained from MRS Agar/Broth. The samples were cultivated at 37°C with a shaker speed of 1500 rpm for 48 hours in a controlled environment incubator. The pH of each sample was measured and recorded both pre- and post-fermentation process.

Purification of fermentation broth

The fermentation broth underwent purification to recover lactic acid by removing cell biomass and color impurities. Cell biomass was removed from the fermentation broth through centrifugation at 5000 rpm for 30 minutes. The resulting supernatant was filtered using filtration paper to eliminate the remaining biomass precipitate. The resulting lactic acid supernatant was stored at 4°C to minimize degradation.

Synthesis of Lactide

Lactide, the cyclic dimer of lactic acid, was synthesized through a multi-step process involving dehydration, oligomerization, and depolymerization. Dehydration was performed using 100 mL of lactic acid and 0.5 g of zinc oxide as a catalyst in a beaker with a magnetic stirrer and a thermocouple. The mixture was heated to 80°C for 2 hours on a hotplate stirrer to remove water content. Subsequently, oligomerization and depolymerization processes were carried out at 150°C for 3 hours and 170°C for 3 hours, respectively. The crude lactide product was cooled to room temperature, and impurities were removed by filtration using filter paper. The purified lactide was stored at 4°C.

Synthesis of Polylactic Acid

Ring-opening polymerization (ROP) of lactide was used to synthesize PLA. A 40:1 lactide-to-catalyst molar ratio was achieved by adding 0.5 mL of tin(II) 2-ethylhexanoate ($Sn(Oct)_2$) catalyst to 20 mL of melted lactide in a reactor. The mixture was transferred to a reaction vessel with a magnetic stirrer and thermocouple. The ROP was conducted at 200°C for 2 hours with continuous stirring on a hotplate stirrer.

Characterization of Polylactic Acid and Lactic Acid

PLA and lactic acid samples were characterized using three analytical techniques. Fourier-Transform Infrared Spectroscopy (FTIR-Perkin Elmer) was employed to identify the functional groups present in lactic acid ($C_3H_6O_3$) and polylactic acid $(C_3H_4O_2)n$. The measurement was performed at a resolution of 4 cm-1 in the mid-range (4000-400 cm-1). High-Performance Liquid Chromatography (HPLC-Perkin Elmer) analysis was used to determine the presence of lactic acid in the fermentation broth. A Reverse-Phase HPLC system with acetonitrile : water mobile phase (7:3 v/v) was used. The flow rate was adjusted to 1.0 mL/min for 15 min. The temperature of the column was controlled at 25°C. Before HPLC analysis, the lactic acid sample was centrifuged at 14,000 rpm for 10 minutes to remove cell mass and insoluble materials. 10 µl of lactic acid was injected using an autoinjector and detector at 210 nm. Gel permeation chromatography (GPC-Waters) was used to determine the relative molecular weight of polylactic acid. The samples were dissolved in tetrahydrofuran (THF) and analyzed using gel chromatography at room temperature.

RESULTS AND DISCUSSION

This chapter presents the findings of a quantitative and qualitative analysis of lactic acid (LA) and polylactic acid (PLA). High-Performance Liquid Chromatography (HPLC) was used to identify and quantify LA in the samples by comparing peak retention times to a standard. Fourier-Transform Infrared (FTIR) analysis was utilized to characterize the LA and PLA functional groups. Finally, Gel Permeation Chromatography (GPC) determined the relative molecular weight of PLA derived from apple, pineapple, and potato residues.

Peak of Lactic Acid

HPLC analysis is a method for separating, identifying, and quantifying LA and PLA. Preparing 1000 ppm of 90% pure LA with water produced a standard LA peak. As bands emerge from the column, flow transports them to one or more detectors that provide a voltage response proportional to time. The moment at which each peak arises identifies the sample component relative to a standard. The area of the peak represents the amount of LA.

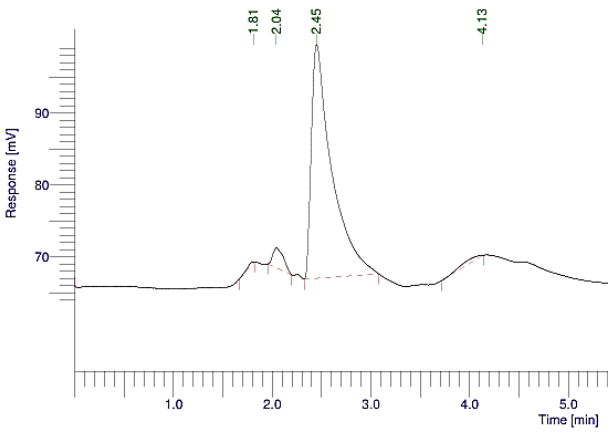


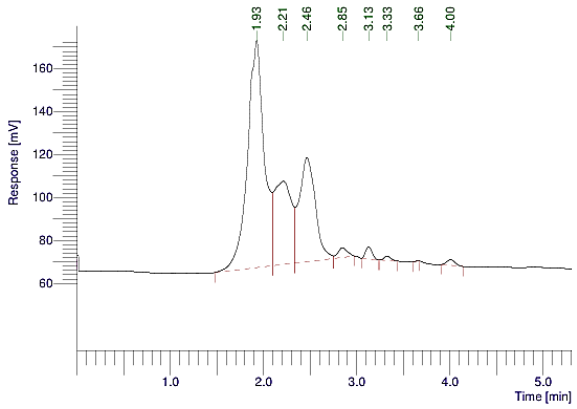
Fig. 2: Peak of standard curve for pure lactic acid at 1000 ppm

Based on Figure 2, the highest peak occurs at minute 2.45, showing pure LA response to the detector where the area under the curve is 468240.83 uV.s, which indicates 93.75% of pure LA under the peak area. The other peaks from the graph represent another component in the solution. 2.45 minutes is determined as the retention time for LA for experiment samples. Furthermore, the retention time of LA can be overlapped or shifted under the same curve at 2.45 minutes.

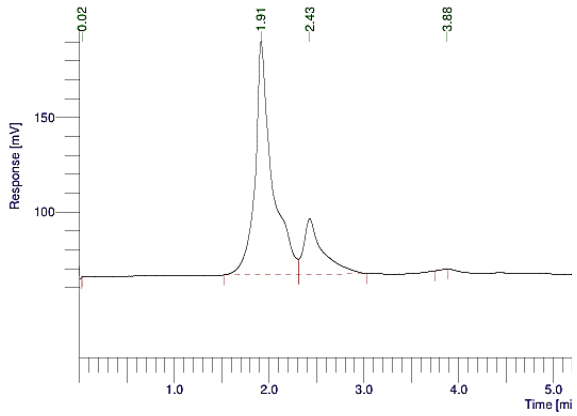
Based on Figure 3, HPLC analysis revealed the presence of LA in the fermentation broths of pineapple, potato, and apple residues. Pineapple residue exhibited an LA peak at 2.464 minutes with an area of 582459.40 uV.s, corresponding to a concentration of 23.41%. Potato residue displayed an LA peak at 2.428 minutes with an area of 404280.13 uV.s, indicating a concentration of 20.81%. Apple residue demonstrated the highest LA content with a peak at 2.323 minutes and an area of 156085.69 uV.s, equating to 31.36%. While slight shifts in peak retention times were observed compared to the standard LA solution, the presence of LA in all three fermentation broths was confirmed. An additional, prominent peak at approximately 1.91-1.93 minutes was observed in all samples, indicating the presence of another component.

According to the HPLC analysis, the results revealed that apple residue yielded the highest LA content, with a peak area of 31.36% at 156085.69 uV.s. Pineapple and potato residues exhibited lower LA percentages. According to the USDA Organic (2023), apples have higher sugar content (10.4g/100g) compared to potatoes (4.2g/100g), and pineapple (9.9g/100g) might contribute to this difference. The study by Ana et al. (2024) and Beatriz et al. (2008)

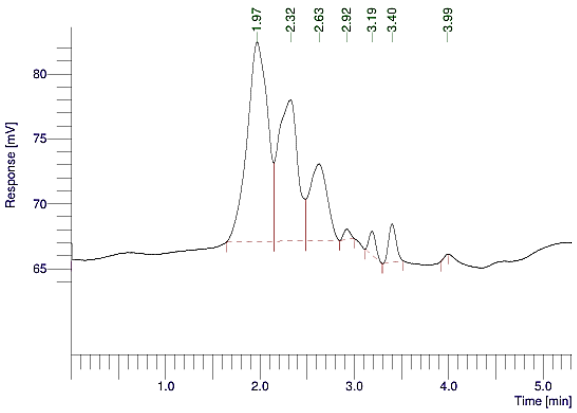
proved that apple pomace can be used in lactic acid production, yielding a concentration of 40.72 and 32.5 g/L, respectively.



a. Pineapple residue



b. Potato residue



c. Apple residue

Fig. 3: Peak of curve for lactic acid from sample

Aside from LA, the other components detected between 1.91 and 1.97 represent by-products or impurities such as acetic, fumaric, propionic, butyric acids, and ethanol, commonly produced during fermentation (Tsapekos et al., 2020). The area percentage for LA was notably lower (less than 35%) compared to the combined area of these other components (over 45%), indicating a higher yield of by-products.

The effectiveness of lactobacilli in producing LA may be influenced by the pH level before fermentation, which should ideally be above 5. Producing high yield of LA, lactobacilli prefer to operate at a pH between 5 and 7 (Wang et al., 2020). Along with using fewer bacteria, the acidic medium inhibited the fermentation process.

Functional Groups of Lactic Acid

FTIR analysis is a method for determining the functional groups of a product to gain a deeper understanding of the fermentation process. Analysis of the FTIR spectrum verified the formation of a product by proving the characteristic bands of the material in the fermentation broth, such as LA. LA comprises functional carboxyl groups, including -CO, which represents the carbonyl (carboxylic) group; -OH, the hydroxyl group; and -CH, the alkane group. These functional groups are commonly present in the fermentation of LA. FTIR demonstrates the presence of these functional groups in the fermentation broth by passing infrared (IR) radiation through a sample, absorbing some of the radiation, and recording the absorbance. Three samples were analyzed using FTIR to determine functional groups in the fermentation broth.

The FTIR analysis of LA from pineapple, potato, and apple residue is shown in Figure 4. LA obtained from all three samples demonstrated a broad and intense peak ranging from 3400 cm^{-1} to 3200 cm^{-1}, representing the -OH stretch and hydroxyl group. Second, a sharp peak representing the

carbonyl (carboxylic group) stretch, -C=O, appeared between 1670 cm^{-1} and 1650 cm^{-1}. The -C-O- stretch was observed at 1130 cm^{-1} to 1040 cm^{-1}. The alkane chain, characterized by the -CH3 bend, was located between 1430 cm^{-1} and 1410 cm^{-1}, with apple residue displaying the highest intensity in this region. Other than the expected LA functional groups, additional components were identified in the fermentation broth. A peak in the region from 700 cm^{-1} to 500 cm^{-1} suggested the presence of a C-Br stretch, indicating a halo compound. Furthermore, a weak peak between 2160 cm^{-1} and 2140 cm^{-1} corresponded to a C≡C stretch.

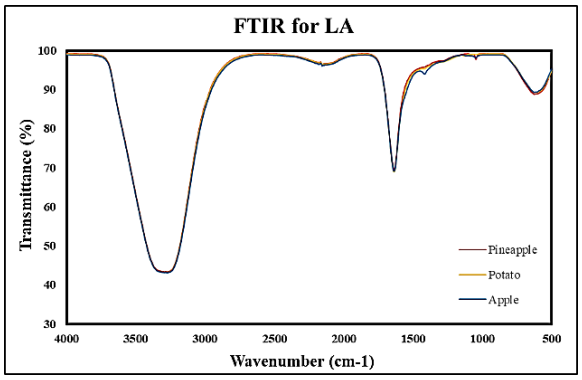


Fig. 4: FTIR spectrum for lactic acid

Table 1. Summary of FTIR for lactic acid

Functional Group	Standard Frequency (cm^{-1})	Lactic Acid (cm^{-1})		
		Pineapple Residue	Potato Residue	Apple Residue
-OH	2400-3400	3274	3273	3272
-C=O	1650-1750	1651	1650	1650
-C-O-	1000-1300	1046	1124	1048
-CH3	1375-1475	1424	1421	1417
-C≡C-	2140-2100	2141	2141	2158

The FTIR analysis of LA from potato, pineapple, and apple residue revealed the production of LA in the fermentation broth. Carboxylic acid (-OH stretch) exhibited a more intense peak than the other functional groups. This result is due to additional organic acids, such as citric and malic acids, commonly found in these substrates (Ma et al., 2018). Furthermore, the observed LA quantity was lower than anticipated, possibly due to the presence of an inhibitor that restricted lactic acid bacteria metabolism. Malic acid, a potential substrate for lactic acid bacteria conversion into L-LA, might also contribute to this discrepancy (Paramithiotis et al., 2022). Other functional compounds or impurities like alkynes are also detected in the FTIR. Alkynes are also less frequent during fermentation than alkanes or alkenes, which alkynes may originate from the substrate or materials.

Functional Groups of Polylactic Acid

The purpose of FTIR analysis for PLA is to confirm the formation of a product by demonstrating the characteristic bands of the material in solutions by the ROP process. As LA, the monomer was polymerized, the hydroxyl group reacted with the acid group to form an ester bond, resulting in PLA. PLA comprises carbonyl (ester) stretch bonds, -C=O, -C-O- stretch bonds, and alkane group, $-CH_3$, differing from its monomer by the absence of the hydroxyl group (-OH) chain. Three samples were analyzed using FTIR to determine functional groups in the solution.

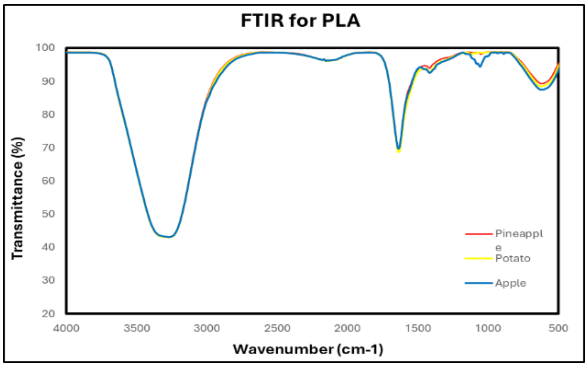


Fig. 5: FTIR spectrum for polylactic acid

The FTIR analysis of PLA from pineapple, potato, and apple residue is shown in Figure 5. PLA obtained from three samples revealed a broad, high-intensity peak ranging from

3350 cm^{-1} to 3200 cm^{-1}, representing the -OH stretch where it is not present in PLA structure. The carbonyl (ester) stretch, -C=O appeared as a sharp peak from 1650 cm^{-1} to 1600 cm^{-1}, and the -C-O- stretch was observed at a weak peak from 1130 cm^{-1} to 1040 cm^{-1}, where apple residue displayed high-intensity. The alkane chain, characterized by the $-CH_3$ bend, was located between 1430 cm^{-1} and 1410 cm^{-1}, with apple residue showing the highest intensity, followed by potato and pineapple residues. In addition to the expected PLA functional groups, other functional groups were identified in the solution. For example, at low wavelengths of the bond, from 700 cm^{-1} to 500 cm^{-1}, it represents the C-Br stretch, a halo compound. Furthermore, the other group occurs at the weak peak between 2160 cm^{-1} and 2140 cm^{-1} and can be identified as C≡C stretch.

Table 2. Summary of FTIR for lactic acid

Functional Group	Standard Frequency (cm^{-1})	Polylactic Acid (cm^{-1})		
		Pineapple Residue	Potato Residue	Apple Residue
-OH	2400-3400	3272	3273	3272
-C=O	1650-1750	1653	1650	1651
-C-O-	1000-1300	1048	1123	1058
-CH3	1375-1475	1417	1415	1415
-C≡C-	2140-2100	2156	2156	2156

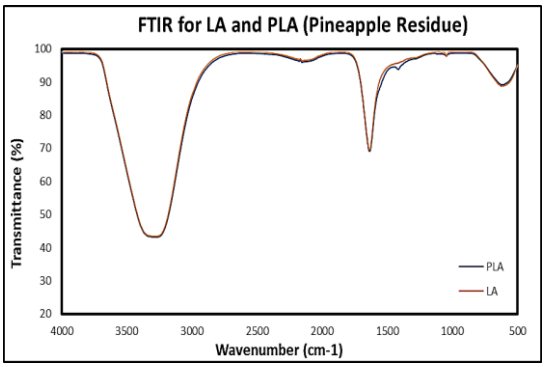
The FTIR analysis of PLA from potato, pineapple, and apple residue revealed the production of PLA in the fermentation broth. Carboxylic acid (-OH stretch) displayed a higher intensity peak than the other functional groups. This result is unexpected as the -OH group is reduced during polymerization to form water (Nyiavuevang et al., 2022). Other functional compounds or impurities like Alkynes are also visible in the FTIR. Alkynes are also less common during the biological process than alkanes or alkenes, which may originate from the substrate or materials of lactic acid fermentation.

Comparison of Functional Groups between Lactic Acid and Polylactic Acid

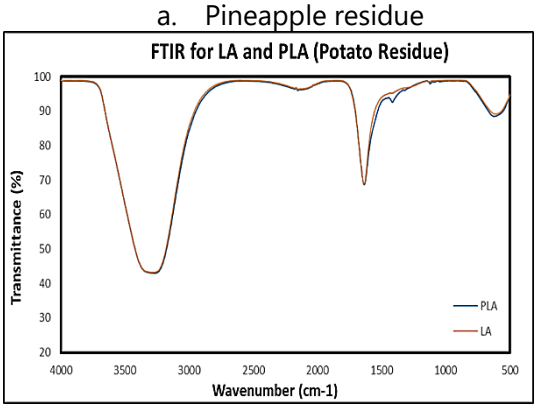
Comparing LA and PLA is essential to understand how the chemical structure of the monomer LA changes into the polymer PLA during ROP. The chemical structure changes from a carboxylic acid compound to an ester compound. Noticeably, there is a difference between chemical structures where PLA does not contain or has fewer hydroxyl groups, such as -OH stretch. Furthermore, the carbonyl stretches, such as -C=O and -C-O-, should show a greater intensity peak for a polymer than a monomer. Besides, the $-CH_3$ bend represents the alkane group; the polymer should show high-intensity peaks compared to the monomer.

Figure 6 presents an FTIR analysis comparing the structural characteristics of LA and PLA derived from pineapple, potato, and apple residues. Across all samples, the intensity of the -OH stretch peak between 3400 cm^{-1} and 3000 cm^{-1} is slightly lower in PLA than in LA. This reduction is attributed to the breakdown of the -OH chain during polymerization as it combines with acid groups to form ester bonds. The carbonyl stretch, -C=O, represented by a sharp peak between 1650 cm^{-1} and 1600 cm^{-1}, exhibits slightly higher intensity in PLA than LA for all samples. The -C-O- stretch, observed between 1130 cm^{-1} and 1040 cm^{-1}, shows slightly higher intensity in PLA for potato and pineapple residues, while it is significantly more intense in PLA derived from apple residue than its LA counterpart. These peak intensity variations indicate the conversion of monomer to polymer, which may reveal the arrangement of molecules along the polymer

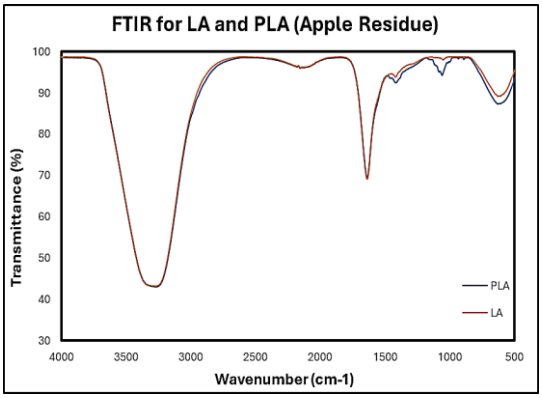
chain. Finally, the -CH_3 bend peak between 1430 cm^{-1} and 1410 cm^{-1} is more intense in PLA than in LA for all samples, further supporting the monomer-to-polymer transition.



a. Pineapple residue



b. Potato residue



c. Apple residue

Fig. 6: FTIR spectrum for polylactic acid

Comparison of LA and PLA from potato, pineapple, and apple residues reveals slight differences in FTIR spectra for all functional groups. These findings indicate that only a small amount of PLA was produced during the ROP. This is attributed to the rigorous purity requirements for converting LA into PLA. Additionally, the -OH stretch shows small differences between LA and PLA, emphasizing removing water by eliminating the -OH chain from the lactide structure before polymerization.

Comparison of Molecular Weight Polylactic Acid using GPC

GPC is used further to verify the presence of PLA in a solution. GPC is an analytical technique for separating dissolved molecules by size based on their elution from a porous gel-filled column. GPC can characterize polymers by identifying various molecular weights such as number average molecular weight (Mn), weight average molecular weight (Mw), and polydispersity index (PDI). Mn indicates the average molecular weight of a polymer chain based on the number of polymer chains present in a sample while, Mw is the average molecular weight of a polymer chain calculated from its weight contribution in a sample. PDI represents the molecular weight distribution in a polymer sample. PDI can be calculated as the ratio of the weight average molecular weight (Mw) to the number average molecular weight (Mn), which indicates polymer homogeneity, with values less than one signifying a monodisperse sample and greater than one representing a polydisperse sample. Table 3 displays the three samples Mn, Mw, and PDI values.

Table 3. Analysis of PLA using GPC

Samples/ Residues	Mn (Daltons)	Mw (Daltons)	PDI $Wm^{-1}k^{-1}$
Pineapples	-	-	-
Potato	6421	12662	1.973
Apple	541	543	1.004
Whey (Ali et al., 2021)	15563	39193	2.518

The value of PLA in pineapple residue is unidentified. Potato residue contains PLA with Mn of 6421 Daltons, Mw of 12662 Daltons, and PDI of 1.97. In contrast, apple residue PLA has Mn of 541 Daltons and Mw of 543 Daltons, with a given ratio for PDI of 1.00. Potato residue displays significantly higher Mn, Mw, and PDI than apple and pineapple residues. Research by Ali (2021) indicated PDI values exceeding 2.0 for whey-derived PLA.

A trend indicating a correlation between low LA purity and high molecular weight PLA. Potatoes, exhibiting lower LA purity than apples, produce PLA with a higher molecular weight. While impurities like water can accelerate initiator decomposition, leading to faster polymerization and decreased molecular weight (Eromosele et al., 1989), purity is generally proportional to polymer molecular weight (Hyon et al., 1997). Nonetheless, the PDI for apple residue is 1, indicating monodisperse properties, implying that the molecular weight of the polymer chains is relatively uniform and more desirable for use in various applications. This study and the comparison with whey-derived PLA demonstrate that a PDI above 2.0 consistently indicates a more polydisperse polymer with a broader molecular weight distribution. This implies the presence of polymer chains with significantly varying lengths. Polymers with lower PDI values, such as those from apple residue, tend to exhibit better mechanical strength and degradation resistance compared to high PDI polymers like those from potato residue (Balla et al., 2021). The polymerization of pineapple residue is unsuccessful, likely due to insufficient operating temperatures. ROP requires elevated temperatures to initiate monomer chain cleavage and subsequent polymer formation.

CONCLUSIONS

This research successfully demonstrated the feasibility of producing lactic acid (LA) from food waste, specifically apple, pineapple, and potato residues, and subsequently converting it into polylactic acid (PLA). FTIR analysis confirmed the presence of LA in the fermentation broth by detecting carbonyl and hydroxyl groups, while HPLC analysis identified an LA peak at 2.45 minutes. However, fermentation also generated significant by-products, likely due to the acidic environment required for growth of lactic acid bacteria. Among the tested residues, apple residue exhibited the highest LA yield, followed by pineapple and potato residues. The subsequent ring-opening polymerization yielded PLA, as evidenced by FTIR spectral changes where the carbonyl group was slightly higher and the hydroxyl group was slightly lower than LA. GPC analysis revealed variations in molecular weight properties among the PLA samples derived from different residues, with apple residue PLA demonstrating a more desirable monodisperse distribution. While this study establishes a foundation for PLA production from food waste, further research is necessary to optimize fermentation conditions, minimize by-product formation, and enhance PLA properties for practical applications.

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