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RESEARCH ARTICLE
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Morphology and Tensile Properties of Biocomposite based Polyvinyl Alcohol and Cassava Starch Reinforced by Lemon Peel Fiber

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ABSTRACT

This study investigated the tensile properties, fracture morphology, and biodegradability of Polyvinyl Alcohol (PVA) and cassava starch biocomposites reinforced with lemon peel fibers. The biocomposites were prepared using the solution casting method with variations of lemon peel fiber fillers of 1, 2, 3, and 4%. Adding lemon peel fibers significantly increased the tensile strength as this addition increased the fiber content. Notably, the highest tensile strength observed was 14.82 MPa for the PVA/cassava starch biocomposite containing 3% lemon peel fibers. This result surpassed the tensile strength of the pure PVA and the PVA/cassava starch composites. This indicates that the lemon peel fibers effectively reinforce the matrix, resulting in stronger interfacial bonds and a more compact composite structure. In contrast, the elongation at break values decreased with higher concentrations of starch and fibers, indicating that adding fibers made the material stiffer and less flexible. In addition, this study assessed the biodegradation rate of the biocomposites, and found that the biocomposite with the highest lemon peel fiber content (4%) exhibited the most rapid biodegradation, with a degradation rate of 80.47% after 15 days of burial. This suggests that the presence of lemon peel fibers improves the mechanical properties of the biocomposites and increases their environmental friendliness. These findings suggest that PVA/cassava starch biocomposites reinforced with lemon peel fiber show significant potential as a sustainable alternative to conventional synthetic plastics, offering a balance of strength, flexibility, and environmental degradability.

Keywords: Polyvinyl Alcohol (PVA), Lemon Peel Fiber, Cassava starch, Biocomposite, Tensile properties.

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INTRODUCTION

Over the past twenty years, biocomposites have gained attention as viable alternatives to traditional composite materials because of their environmental benefits and availability (Asrofi et al., 2017; Al Amin et al., 2023). Applications of biocomposites have reached several sectors, such as household use, automotive parts such as brake linings and dashboards, and food packaging (Haris et al., 2024; Asrofi et al., 2025a; Asrofi et al., 2025c). Biocomposites are solid materials made by combining two or more substances, each maintaining its distinct properties (Wahono et al., 2018; Asyraf et al., 2022a). The most widely produced biocomposites use matrices extracted from nature, such as Polyvinyl Alcohol (PVA), Polylactic Acid (PLA), Chitosan, and starch from nature (Mayilswamy & Kandasubramanian., 2022; Asrofi et al., 2025b; Pradiza et al., 2025). Among the matrices that have good biocompatibility and biodegradability is Polyvinyl Alcohol (PVA) (Liu et al., 2022).

Polyvinyl Alcohol (PVA) is a type of polymer used as a matrix for biocomposites and has the potential too for bioplastic production due to its biodegradability and water solubility (Cano et al., 2015; Domene-López et al., 2018;

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Abdullah & Dong 2019). Apart from that, Polyvinyl Alcohol (PVA) also has other properties such as film-forming ability, high resistance to oil and solvents, and gas barrier properties (Mathew et al., 2019). Because it has biodegradability and dissolves in water, this type of polymer has been widely studied (Shalumon et al., 2011). However, Polyvinyl Alcohol (PVA) has weaknesses because the purchase price is relatively expensive, and the time to decompose in the environment is a bit long (Delavari & Stiharu, 2022). Therefore, it is essential to find 'greener' alternative materials that are affordable and derived from renewable sources (Asyraf et al., 2022b). In addition, another disadvantage possessed by Polyvinyl Alcohol (PVA) is that the absorption of moisture is quite high because the OH groups found have a large number (Abral et al., 2020; Asrofi et al., 2025b). To correct these weaknesses, mixing Polyvinyl Alcohol (PVA) with natural starch is a solution to minimize production costs (Asrofi et al., 2019). Currently, the most commercially important starch sources for bioplastics materials are corn, rice, cassava, potatoes, and peas (Abral et al., 2019b). Research on incorporating Polyvinyl Alcohol (PVA) matrices with starch has been carried out (Asrofi et al., 2019). Adding starch into Polyvinyl Alcohol (PVA) causes a decrease in mechanical properties. This phenomenon occurs due to poor interfacial bond between Polyvinyl Alcohol (PVA) and the starch, such as bengkuang starch. In addition, starch is hydrophilic. Hence, adding starch to Polyvinyl Alcohol (PVA) can reduce the mechanical properties of its film. To overcome this, adding natural fiber or clay particles is a solution (Abdullah et al., 2017; El Bourakadi et al., 2019). A potential natural fiber due to its cellulose content is the lemon peel. Lemon fruit (citrus limon) consumed produces waste in peels that are very unfortunate if not utilized (Benny et al., 2023). However, it will have good results if the role of lemon peel fibers is maximized through chemical treatments such as alkalization (Pradiza et al., 2025). Lemon peel has a composition of 21.2% by weight of cellulose, 1.6% by weight of hemicellulose, 0.4% by weight of lignin and 5.1% by weight of protein, 31% by weight of pectin (Zhang et al., 2020).

Previously, Polyvinyl Alcohol (PVA) was investigated by adding the natural fiber from durian peel waste (Mahardika et al., 2021). The study showed an increase in tensile strength at the addition of 6% durian peel fiber up to 154%. Another study reported an increased tensile strength when the PVA matrix was added with natural fiber from mango seed waste (Asrofi et al., 2023). Adding 1g mango seed waste into the Polyvinyl Alcohol (PVA) matrix increases the tensile strength up to 170%. These results confirm that the Polyvinyl Alcohol (PVA) Matrix combined with several natural fiber wastes can bond well, increasing tensile strength. However, to reduce production costs, Polyvinyl Alcohol (PVA) can be combined with cassava starch (Asrofi et al., 2019).

Previous studies on Polyvinyl Alcohol (PVA) matrix-based biocomposites combining cassava starch and cellulose fibers found that the presence of sonicated starch gel on Polyvinyl Alcohol (PVA) reduced the heat and moisture resistance and reduced the transparency of the mixed film (Abral et al., 2019a). Upon the addition of fibers, the heat resistance and moisture resistance of the sonicated biocomposites increase due to the stronger hydrogen bonding between the fibers and the matrix. The tensile strength of the sonicated biocomposite containing 10 g of fiber increased by 215% compared to the sonicated mixture. Another study reported mixing Polyvinyl Alcohol (PVA) and starch with date palm leaf fiber reinforcement (Ray et al., 2021). Adding date palm leaf fibers to the Polyvinyl Alcohol (PVA) and starch matrix increases the tensile strength up to 160%. In addition, other mechanical properties such as flexural strength and impact strength also increase. This is due to the evenly dispersed addition of fiber into the Polyvinyl Alcohol (PVA) and starch matrix, resulting in good bonding. Furthermore, from the literature, it is known that using cellulose from natural fibers as reinforcement in biocomposites is a way to improve environmentally friendly products (Rangappa et al., 2020; Mahardika et al., 2021).

Based on the discussion above, this research examines polyvinyl alcohol with cassava starch used as a matrix combined with lemon peel (citrus limon) fibers. Because of its cellulose content, lemon peel fiber has the potential as a filler for Polyvinyl Alcohol (PVA) and cassava starch biocomposites. Previous research has rarely investigated the use of lemon peel as a filler in biocomposites. This raises the opportunity to utilize waste from nature as reinforcement in biocomposites. This research aims to study the tensile properties of PVA/cassava starch mixed with lemon peel fibers as biocomposite fibers. The results of this biocomposite research are expected to represent the discovery of environmentally friendly biocomposites that can replace synthetic plastic packaging on the market.

MATERIALS & METHODS

Materials

Polyvinyl Alcohol (PVA) as a matrix obtained from Chang Chun Petrochemical Co., LTD. with a solubility of 87.58%. The Laboratory of Material Testing, Department of Mechanical Engineering, University of Jember, Jember, Indonesia, supplied Cassava Starch. The lemon Peel (Citrus Limon) fibers were obtained from a local herbal factory in Mojokerto, Indonesia. Other chemicals, such as Sodium Hydroxide (NaOH), were obtained from the regional chemical market, UD. Aneka Kimia, located at Jember, Indonesia.

Preparation of Lemon Peel Fiber

The fibers were dried to constant weight in an oven at 90℃ for 12 hours, and were alkalized for 24 hours using 1% NaOH. The fibers were dried to a constant weight, ground in a blender, and sifted using an iron sieve (149-177μm) until powder formed.

Preparation of Biocomposite Film

Biocomposite with lemon peel as fiber was made using the solution casting method. Polyvinyl Alcohol (PVA) and cassava starch mixed with a ratio of 80:20 wt% dissolved in water with a stirrer and heated to 90℃ within 60min to form gelatin. Lemon peel fiber was added to the mixture and stirred for 40min. Then, it was cast on a glass mould and dried in an oven at 40℃ for 24 hours. Finally, the dried film was cut according to ASTM D882-18 following previous research (Asrofi et al., 2020). Table 1 shows the composition of biocomposites.

Table 1: Composition of Lemon Peel-reinforced PVA/Cassava Starch biocomposite

Sample Code	Composition		
	Polyvinyl Alcohol (wt%)	Cassava Starch (wt%)	Lemon Peel (wt%)
PVA	100	0	0
PVAS	80	20	0
PVAS/1LP	80	20	1
PVAS/2LP	80	20	2
PVAS/3LP	80	20	3
PVAS/4LP	80	20	4

Tensile Strength

Tensile testing was carried out to determine the mechanical properties of the PVA/cassava starch biocomposite with lemon peel as fiber. The results obtained were tensile strength and elongation at break. The test equipment used was the Universal Tensile Machine Shimadzu AGS-X with a capacity of 5 kN. The withdrawal speed used was 80 mm/s. Sample size was according to ASTM- D882-18 standard.

Scanning Electron Microscope (SEM)

A Scanning Electron Microscope (FESEM Thermo Scientific Quattro S with 1500x magnification and 3 kV voltage) was used to observe the fracture morphology of the PVA/Cassava starch filled with lemon peel biocomposite after tensile testing.

Soil Burial Degradation Test

Biodegradation was carried out to determine the rate of decomposition of the PVA/cassava starch biocomposite filled with lemon peel. This test uses ASTM D6003-96 like previous research for biodegradability of plastic biocomposites (Lee et al., 2025). Before the calculation, samples were buried in humus soil for 0, 5, 10, and 15 days. The soil specifications used contained 25% nitrogen, 7% phosphorus, 9% potassium, 3.7% iron, 55.3% other nutrients and a soil pH of 6 as in previous studies (Asrofi et al., 2024).

RESULTS & DISCUSSION

Tensile Strength

Tensile strength and elongation are used to determine the mechanical properties of the PVA/Cassava starch biocomposite and its fibers. Tensile strength values of all samples tested are reported in Fig. 1.

Fig. 1 shows the decreasing tensile strength of PVA when starch was added. This phenomenon occurs due to poor interfacial bonding between PVA and starch (Asrofi et al., 2019). The large number of free OH bonds causes poor compatibility between PVA and starch (Abral et al., 2019a). This was confirmed by a similar study, where cassava starch in PVA decreased tensile strength (Asrofi et al., 2024). This result is supported by the poor compatibility between PVA and starch, reflecting the weak intermolecular hydrogen bonding between the two polymers (Wei et al., 2024).

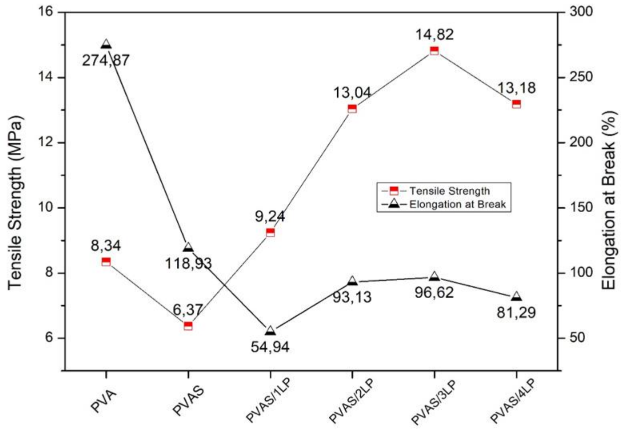

Fig. 1: Tensile Properties of Tested Biocomposites.

Meanwhile, the tensile strength of the biocomposite increases with the increase in the percentage of lemon peel fiber. In this study, PVA/cassava starch with 3% lemon peel fibers had the highest tensile strength value of 14.82 MPa. The fibers are well dispersed in the matrix because the number of hydrogens in the polymer bonds increases, making the polymer chains less mobile (Feng et al., 2023). This phenomenon occurs due to good adhesion at the interface of the matrix and fibers (Fahma et al., 2017). Other studies supporting these results found increased tensile strength in PVA biocomposites due to good bonding when natural fibers were added (Ray et al., 2021). The morphological observation of the fracture using SEM, as shown in Fig. 3C, demonstrates good bonding between PVA and reinforcement. Another phenomenon was shown when 4% lemon peel was added, where the tensile strength decreased to 13.18 MPa. The decrease in tensile strength occurs as the fibers increase. The addition of this high fibers cannot be adsorbed homogeneously into the film matrix (Abral et al., 2019a). This decrease at the highest fiber addition was also found in previous studies (Ray et al., 2021). This is due to the agglomeration of fibers, which is confirmed by the SEM results shown in Fig. 3D.

The addition of starch and fiber to PVA reduced the elongation value. Pure PVA has a high elongation value of 274.87%. The high elongation value of PVA was also found in previous research (Mittal et al., 2020). However, the elongation value of PVA decreased after adding cassava starch and lemon peel. The elongation value continues to decrease with increasing fluctuations in the ratio of lignin to PVA because the low ductility of the lignin solution means that the addition of various solutions does not show a good increase in elongation strength (Korbag & Saleh., 2016). This result is supported by previous research, where the elongation value decreased after adding fillers (Ali et al., 2022).

Fracture Surface Morphology Pure PVA and PVA/Cassava Starch

Fig. 2 shows the fracture surface morphology of the sample without fiber additions. Fig. 2A is neat PVA. The surface of neat PVA is very smooth because there is no fiber, so the PVA dissolves entirely with water and produces a soft surface (Ejara et al., 2021). The smooth

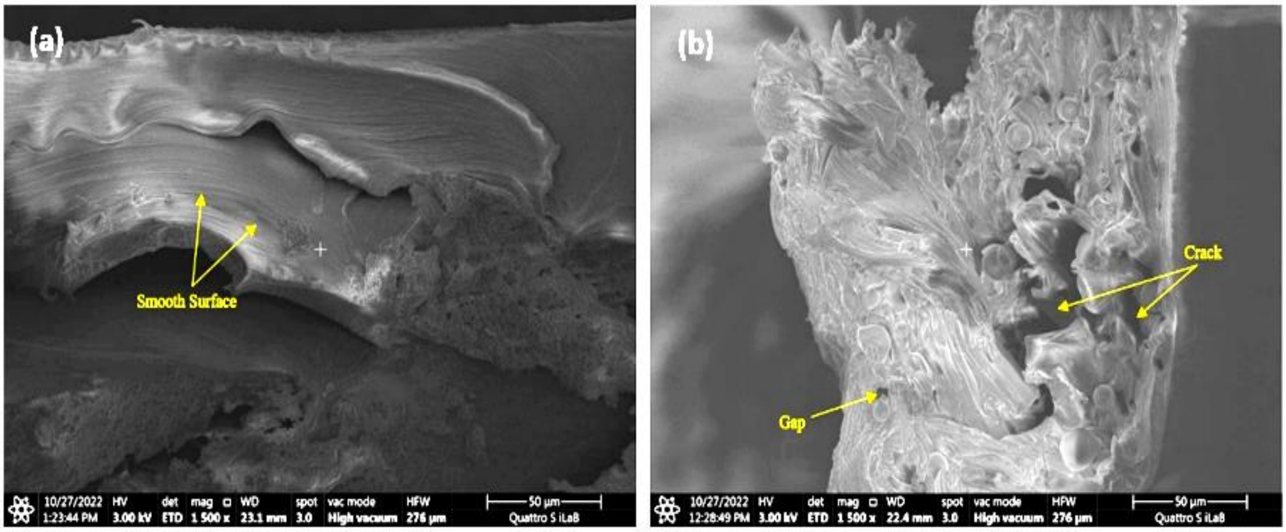

Fig. 2: Fracture Surface Morphology of neat PVA and PVA/Starch: a) PVA, b) PVAS.

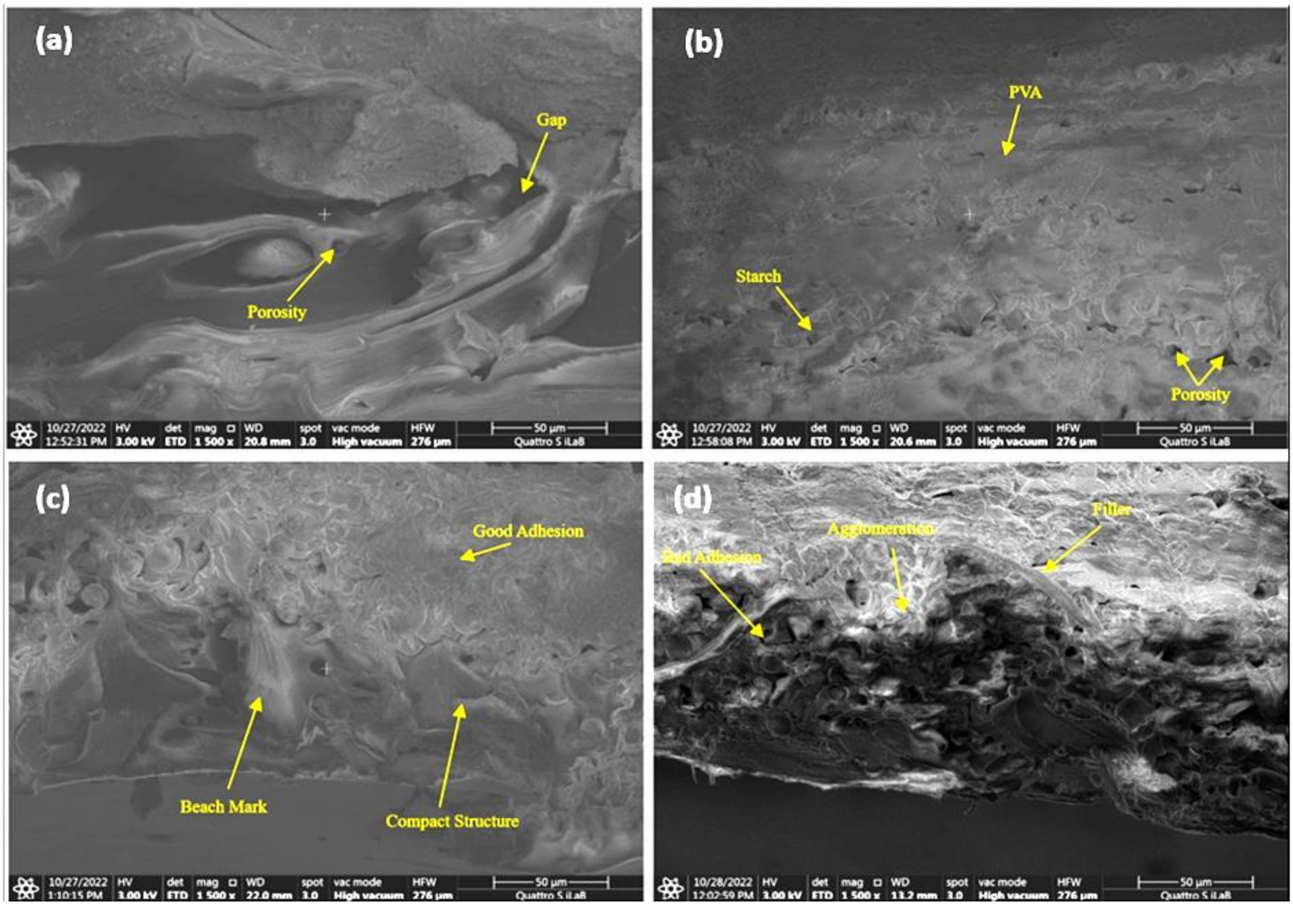

Fig. 3: Fracture Surface Morphology of PVA/Starch biocomposite with lemon peel fiber additions by SEM image: a) PVAS/1LP, b) PVAS/2LP, c) PVAS/3LP, and d) PVAS/4LP.

morphology of pure PVA was also found in previous studies, which indicates the homogeneity of a suitable PVA matrix (Asrofi et al., 2024). Similar results were also found in another study that obtained a fine PVA structure (Kansiz et al., 2024). Cracks and gaps were found after adding cassava starch, as shown in Fig. 2B, where poor compatibility between PVA and starch caused this phenomenon to occur (Abral et al., 2019a). Poor compatibility between PVA and starch is the cause of the decrease in tensile strength (Patil et al., 2021).

Fracture Surface Morphology of Biocomposite

The fracture surface morphology of the biocomposite is displayed in Fig. 3. The addition of 1% and 2% lemon peel in PVA/Cassava starch-based biocomposite is shown in Fig. 3A and 3B, respectively. The results show that the surface of the sample has gaps, porosity, or space in the biocomposite sample. This was because the fibers were not uniform and not evenly distributed and there was an inhomogeneous bond between the matrix and the fiber, which reduced the tensile strength (Syafri et al., 2019). This was also found in previous studies, where gaps and porosity did not maximize the tensile strength (Asrofi et al., 2023). Meanwhile, good adhesion was shown by the addition of 3% lemon peel fiber. As shown in Fig. 3C, there was good adhesion due to the compact structure obtained from the good dispersion of the fibers without buildup, thereby increasing the tensile strength (Asrofi et al., 2018). Fig. 3D shows a biocomposite with the addition of 4% fiber, and agglomeration events were found in this morphological observation. Agglomeration is a phenomenon where particles accumulate, which causes the force distribution between the matrix and the fiber to be imperfect, causing a decrease in the tensile strength value (Rahim Labbafzadeh & Vakili, 2022). Imperfect mixing can cause agglomeration, poor adhesion, and the inability to treat the sample further when it is casted into the biocomposite mold (Korbag & Saleh, 2016).

Biodegradation Rate

Fig. 4. shows the results of biodegradation testing of PVA/Cassava starch biocomposite with lemon peel fiber as filler. It can be seen that the rate of weight loss increases with increasing content of filler peel lemons. The highest biodegradation was found in the addition of 4% lemon peel filler, which was 80.47% (Table 2). The results were similar to the previous study, where the composition with the highest amount of filler had the best biodegradation rate (Korbag & Saleh, 2016). Other studies also confirm that a higher percentage of filler or fiber in the PVA and starch mixture will result in better biodegradability (Mohammed et al., 2023).

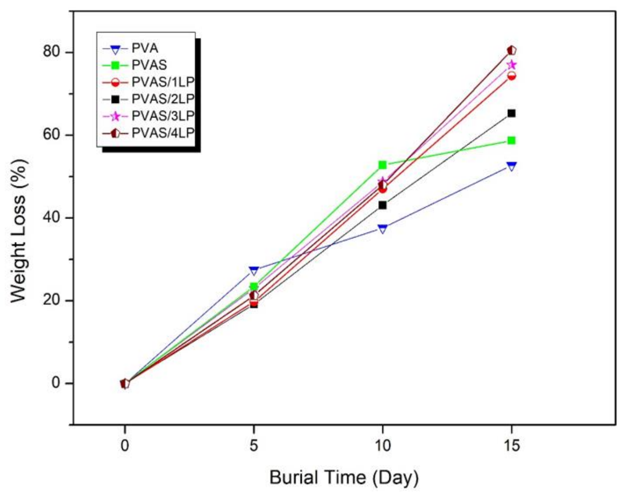

Fig. 4: Biodegradation rate of PVA/Cassava Starch reinforced by lemon peel fiber.

Factors that affect the increase in biodegradation could be due to the influence of temperature experienced during biodegradation and the reaction of natural fibers with soil microorganisms (Alexy et al., 2003). High content of fillers increases its susceptibility to mycobacterial attacks (Pandit & Kumar 2021). When exposed to aqueous environments, these microorganisms, including fungi and bacteria, affect the composite film (Ibrahim et al., 2019). The hydrophilic nature of PVA can absorb water in the soil, thereby increasing mass shrinkage after burial (Thong et al., 2016). The role of chemically treated natural fibers can accelerate the biodegradation process (Chai et al., 2012). These results indicate that polyvinyl alcohol can be mixed with cassava starch and lemon peel filler to increase its biodegradation ability.

Table 2: Biodegradation rate (%) based on percentage weight loss of PVA/Cassava starch reinforced with lemon peel fiber

Sample Code	Burial Time (Days)			
	0	5	10	15
PVA	0	27.47	37.60	52.73
PVAS	0	23.45	52.79	58.69
PVAS/1LP	0	19.16	43.11	65.29
PVAS/2LP	0	19.77	47.05	74.33
PVAS/3LP	0	22.98	48.74	77.00
PVAS/4LP	0	21.26	48.00	80.47

Conclusion

Biocomposites from PVA/Cassava starch-reinforced Lemon Peel fibers have been carried out using the solution casting method. The study results showed that adding lemon peel fibers increased the tensile strength of the PVA/cassava starch biocomposite film. Lemon peel fibers increased the compatibility between the matrix and fibers, as evidenced by the fracture surface morphology with SEM. This phenomenon improves the tensile strength of the biocomposite and is higher than that of a neat PVA film. Moreover, the rate of biodegradation increased when lemon peel was added. This suggests that lemon peel fibers can be an alternative to improve some of the properties required for packaging materials. This research needs to be continued, especially in terms of characterization for thermal stability.

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Data Availability: Data will be available at the request.

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