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MECHANICAL PERFORMANCE OF SALVADORA PERSICAL (MISWAK) REINFORCED POLYLACTIC ACID MATRIX COMPOSITES FOR THREE DIMENSIONAL PRINTING

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Abstract: This study examines the mechanical performance of polylactic acid (PLA) matrix composites reinforced with *Salvadora Persica (Miswak)*. With the increasing use of environmentally friendly materials, researchers are focusing on the production of biodegradable materials. However, incompatibility between PLA and filler materials used in PLA composites causes mechanical problems during production. This study deals with the production and characterization of PLA composites containing lignocellulosic and inorganic fillers using maleic anhydride grafted polylactic acid (PLA/g/MA) as a matrix. The aim of the research is to examine the mechanical specifications of Miswak powder reinforced PLA composites and to evaluate their suitability for practical applications. PLA was used as the matrix material and PLA/g/MA was used as the compatibilizer. Composites containing Miswak powder at different weight concentrations (5%, 10%, 15% and 20%) were characterized using scanning electron microscopy along with tensile and bending tests. The obtained results showed that different Miswak concentrations affect the mechanical specifications of the composites. Composites at 5% concentration demonstrated excellent interlayer adhesion and high mechanical strength, demonstrating favorable mechanical specifications. The findings show that Miswak powder is a potential filling material to improve the mechanical specifications of PLA composites and provide antimicrobial benefits. The results of this study shed light on the mechanical performance of Miswak reinforced PLA matrix composites, which are promising for 3D printing applications. In addition, it is stated that the materials used, such as natural filling materials, contribute to the development of sustainable and environmentally friendly materials by reducing the environmental impact.

Keywords: Salvadora Persica, Miswak powder, Polylactic acid, PLA composites, Mechanical specifications, 3D printing

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1. Introduction

Polylactic acid (PLA) has gained significant attention as a potential alternative to petroleum-based plastics due to its renewable nature and biodegradability (Rujitanaroj et al., 2015). However, PLA exhibits certain limitations in terms of its mechanical properties, such as low tensile strength and impact resistance (Garlotta, 2001). To overcome these limitations, researchers have focused on the development of PLA composites by incorporating compatible fillers that can enhance its mechanical performance (Avérous, 2008). Among the various fillers investigated, natural fillers have garnered interest due to their abundance, renewability, and potential cost advantages (Zhang and Jiang, 2018). *Salvadora Persica (S. Persica, Miswak*) stands out as a promising natural filler for reinforcing PLA composites (Hassan and Hassan, 2019). Miswak is derived from the Miswak tree and possesses bioactive compounds with antimicrobial, antioxidant, and anti-inflammatory properties. These properties make Miswak an attractive candidate for improving the mechanical specifications of PLA composites while also providing additional benefits (Almas, 2002). Miswak has been traditionally used as a natural oral hygiene tool in many cultures (Dar-Odeh et al., 2019). Several studies have highlighted the oral health benefits of Miswak, including its antimicrobial and plaque-reducing properties (Baeshen et al., 2017; Winarni et al., 2019). Miswak has also been compared to conventional toothbrushes, demonstrating comparable or even superior oral hygiene outcomes (Chauhan et al., 2020). Mechanical (tensile strength, percent elongation, bending strength, impact resistance and compressive strength) and abrasive wear properties of Miswak reinforced polymer composites were examined (Savas, 2018; Khalaf, 2013; Oleiwi et al., 2017). Its mechanical specifications, such as flexibility and toughness, make it suitable for chewing and maintaining oral hygiene (Bramantoro et al., 2018). The incorporation of Miswak into PLA composites holds great potential for various applications, including 3D printing. However, limited research has been conducted to explore the mechanical performance of Miswak reinforced PLA composites specifically for 3D printing applications. Therefore, this study aims to investigate the mechanical specifications of Miswak powder reinforced PLA composites and evaluate their suitability for 3D printing.

Here is a summary of the key points:

Objective: The aim of the research is to investigate the mechanical performance of PLA composites reinforced with Miswak powder and evaluate their suitability for practical applications, particularly in 3D printing.

Background: The increasing demand for environmentally friendly materials has led researchers to explore biodegradable options such as PLA. However, PLA has limitations in terms of mechanical properties, which can be addressed by reinforcing it with compatible fillers.

Miswak as a Reinforcing Filler: Miswak, derived from the Miswak tree, is considered a promising natural filler for strengthening PLA composites. Miswak contains bioactive compounds with antimicrobial properties, making it an attractive candidate for enhancing the mechanical specifications of PLA composites.

Composite Production and Characterization: The study utilizes PLA/g/MA as a matrix and Miswak powder as the reinforcing filler. Composites with different weight concentrations of Miswak (5%, 10%, 15%, and 20%) are produced and characterized using scanning electron microscopy (SEM), as well as tensile and bending tests.

Mechanical Property Effects: The results indicate that the mechanical specifications of the composites are influenced by the concentration of Miswak. Composites with a 5% Miswak concentration exhibit excellent interlayer adhesion and high mechanical strength, demonstrating favorable mechanical properties. However, as the Miswak concentration increases, the mechanical specifications of the composites may be affected differently.

Significance: The findings of this study shed light on the mechanical performance of Miswak reinforced PLA matrix composites, highlighting their potential for 3D printing applications. Additionally, the use of natural fillers like Miswak contributes to the development of sustainable and environmentally friendly materials by reducing their environmental impact. Although Miswak is a candidate material for the production of natural fiber-reinforced polymer matrix composites due to its fiber-like structure, there are very few studies on this subject. There are a limited number of studies on the mechanical properties of Miswak-added polymer matrix composites. In this study, a PLA matrix is reinforced with Miswak powder at different weight concentrations. The mechanical specifications of the composites have been characterized using a variety of tests, including tensile and bending tests. The morphology and interface interactions between Miswak powder and PLA matrix were investigated using SEM. Additionally, thermal properties and compatibility of composites will be analyzed. The findings of this research contribute to the understanding of the mechanical performance of *S. Persica (Miswak)* reinforced PLA composites and their potential for 3D printing applications. Also, the use of Miswak as a natural filler in PLA composites has the potential to lead to the development of sustainable and environmentally friendly materials.

2. Materials and Methods

S. persica has a natural fiber structure and is among the most commonly used medicinal plants for oral hygiene (Sher et al., 2010). *S. persica* is chemically composed of butanediamide, N-benzyl 2-phenylacetamide, benzyl isothiocyanate, salvadorin, alkoids, chlorides, high amounts of fluoride and silica, sulfur, vitamin C, essential oils, small amounts of tannins, saponins, flavonoids and sterols (Darout et al. al., 2000). Sulfur, alkaloids, butanediamide and N-benzyl-2-phenylacetamide in Miswak are agents that provide antimicrobial effect (Dutta and Shaikh, 2012). In the literature, it was stated that *S. persica* extracts showed antimicrobial activity against Staphylococcus aureus, Streptococcus mutans, Lactobacillus acidophilus, E. coli and Pseudomonas aeruginosa. Miswak is being used for different applications due to its low cost and ready availability as well as its antibacterial effect. On the other hand, it is known that Miswak improves mechanical properties due to its fiber-like structure. Miswak sticks were obtained from a Türkiye-based e-commerce platform and stored in hygienic vacuum packaging. These Miswak products were imported by the Kureyshi Essence Company. Miswak sticks have been specially processed and turned into Miswak powder with various physical and chemical properties. The process involved peeling, breaking, drying, grinding and drying the sticks. The obtained Miswak powder was stored in airtight plastic bags. Miswak powder is an ingredient obtained from the Miswak plant. This powder contains ingredients such as cellulose, hemicellulose, and lignin, which contain organic compounds. It also contains functional groups such as phenolic, carboxylic, alcoholic and amine groups. Miswak powder contains various phytochemicals such as sulfur, chloride, fluoride, vitamin C, tannins, silica, alkaloids and essential oils. Also, chemical components include beta-sitosterol, glycosides, pyrrolidine, pyrrole and piperidine. Other properties of Miswak powder such as pH value and conductivity were also determined. Miswak powder has been characterized for use as a filler in PLA composites. Miswak fibers mixed with PLA were mixed using a twin screw extruder and then extruded using a single screw extruder. The resulting Misvak PLA Composite filament was prepared for use in 3D printing. This filament offers a sustainable and environmentally friendly alternative to traditional filaments. The natural antibacterial properties of Miswak powder stand out as additional benefits of the composite material. Miswak/PLA composite filament was used to create tensile test specimens in accordance with ASTM 638

Type IV standards. This composite filament is evaluated as a promising material for various applications by combining the advantages of PLA as well as the natural properties obtained from the Miswak plant. Table 1 shows the mixing ratios of samples containing polylactic acid (PLA), PLA/g/MA (polylactic acid modified with maleic acid), and Miswak fiber (Miswak). The PLA/W0 sample contains only 100% PLA, while the PLA/W5 sample has 94% PLA, 1% PLA/g/MA and 5% Miswak content. Similarly, 88% PLA, 2% PLA/g/MA and 10% Miswak in the PLA/W10 sample, 81% PLA, 4% PLA/g/MA and 15% Miswak in the PLA/W15 sample, and 74% in the PLA/W20 sample. It has PLA, 6% PLA/g/MA and 20% Miswak content. These mixing ratios show the compositions of the composite samples and the percentage of materials they contain. These ratios can affect the properties and performance of the composite material. The schematic illustration of composite filament preparation typically involves several steps (Figure 1).

Table 1. Sample combination rates

Sample name	PLA (wt%)	PLA/g/MA (wt%)	Miswak (wt%)
PLA/W0	100	0	0
PLA/W5	94	1	5
PLA/W10	88	2	10
PLA/W15	81	4	15
PLA/W20	74	6	20

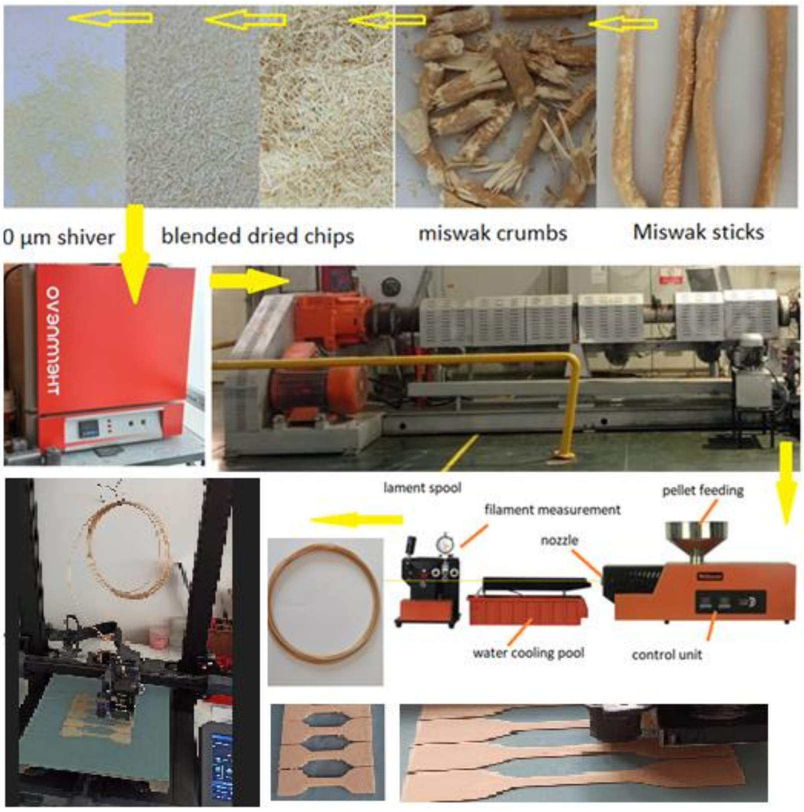

Figure 1. PLA/MF preparation and printing cycle.

Here is a general description of the process:

Selection of Matrix Material: A suitable matrix material is selected, such as PLA or another compatible polymer.

Selection of Reinforcement Material: Reinforcement material is selected, in this case this material can be Miswak powder or any desired filler.

Mixing: Matrix material and reinforcement material are mixed thoroughly. This can be achieved using a twin screw extruder or other mixing techniques to ensure uniform distribution of the filler in the matrix.

Extrusion: The mixed material is fed into a single screw extruder. The extruder melts the composite mix and pushes it through a die of the desired filament diameter, forming a continuous filament.

Cooling and Solidification: The extruded filament is cooled rapidly to solidify the material and maintain its shape. This can be done using cooling baths or air cooling.

Winding: The solidified filament is wound onto a spool or bobbin for storage and later use in 3D printing.

Better Distribution: Smaller particles provide a more homogeneous distribution in the polymer matrix. This homogeneous distribution can improve the overall properties of the material, eg. mechanical properties or thermal properties.

Increased Surface Area: Reducing the particle size increases the overall surface area. This can enable the Miswak to better interact and bond with the polymer, which can affect the overall properties and performance of the material. However, reducing the particle size too much can sometimes lead to undesirable results. For example, agglomeration of nanoscale particles can be a problem. This means that the particles clump together and form large clumps, which can negatively affect the material's properties. The Miswak powders used in this study were sieved at an average size of 10 microns.

3. Results and Discussion

Density values of composite samples containing PLA and Miswak fiber (MF) are given in Table 2. It is observed that there is an increase in the density of PLA-MF composites as the MF content increases. While the density of PLA sample is 1.240 g/cm^3, the density of PLA-MF10 sample containing 10% MF is 1.255 g/cm^3, the density of PLA-MF20 sample containing 20% MF is 1.283 g/cm^3 and the density of PLA-MF30 sample containing 30% MF is 1.308 g/cm^3 has been determined. These results show that Miswak fiber increases the density of composites. Density increase can affect the physical properties of the composite material and can be an important factor in applications.

Table 2. Specifications of PLA-MF composite density

Specimens	Density (g/cm^3)	Density increment, %
PLA	1.240	—
PLA-MF10	1.255	1.21%
PLA-MF20	1.283	2.23%
PLA-MF30	1.308	5.48%

The composition of natural fibers significantly affects the performance of composite materials. Current research shows that MF has a lower cellulose concentration compared to other natural fibers. However, it is stated that it is difficult to obtain pure cellulose because it is closely related to lignin and hemicellulose. MF has the highest hemicellulose content compared to other natural fibers and is characterized by hemicellulosic binding microfibrils that provide structural reinforcement. Lignin, on the other hand, acts as an adhesive between cells in the cell wall, maintaining the flexibility, properties and structure of the fiber.

3.1. Tensile Properties of PLA-MF Composites

The tensile test, commonly referred to as the tension test, is a crucial mechanical evaluation that assesses a material's resistance to forces trying to pull it apart. Initiated with a specific goal, this test establishes the material's reaction to uniaxial forces and fetches data on properties like the ultimate tensile strength, yield strength, Young's modulus, and more. Preparing for the test involves using specimens often shaped like a dog-bone to ensure the highest stress occurs in the gauge section (Figure 2).

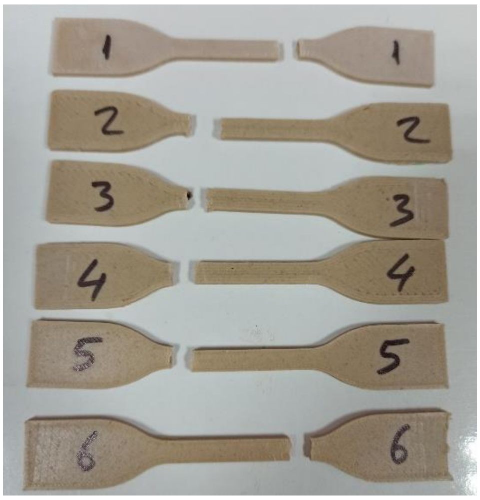

Figure 2. Tensile tested samples.

Anisotropic materials might necessitate specimens cut in varied orientations, such as longitudinal or transverse. The primary equipment used is the universal testing machine (UTM), which has a movable upper grip and a fixed lower one, ensuring the specimen is held firmly. As the test proceeds, the UTM exerts an increasing axial force on the specimen, with its elongation consistently monitored, often through an extensometer, until the sample fractures or reaches a set strain. The outcomes, typically showcased as a stress-strain curve, denote various material properties, including its elasticity, yield point, and UTS, along with its elongation that signifies ductility as a percentage increase from its initial size. The tensile properties of PLA samples with different MF contents are given in Table 3.

Table 3. The percentage of fiber content is detailed

Specimen	σ (MPa)	E (MPa)	ε (%)
PLA/W0	58.48	2985	3.94
PLA/W5	51.36	2940	3.12
PLA/W10	44.24	2895	2.3
PLA/W15	37.12	2850	1.48
PLA/W20	30	2805	0.66

σ= tensile strength, E= young's modulus, ε= elongation at break

As the MF content of the samples increases, the tensile strength (σ) decreases. The PLA/W0 sample (0% MF) has the highest tensile strength, while the PLA/W20 sample (20% MF) has the lowest tensile strength. Similarly, the Young's modulus (E) value also decreases as the MF content increases. Elongation at break (ε) value decreases as the MF content increases. These results show that the addition of MF negatively affects the mechanical specifications of PLA composites (Figure 3).

That is, higher MF content reduces the toughness and flexibility of the samples. These findings suggest that MF content should be considered to evaluate and optimize the effect of composite on performance.

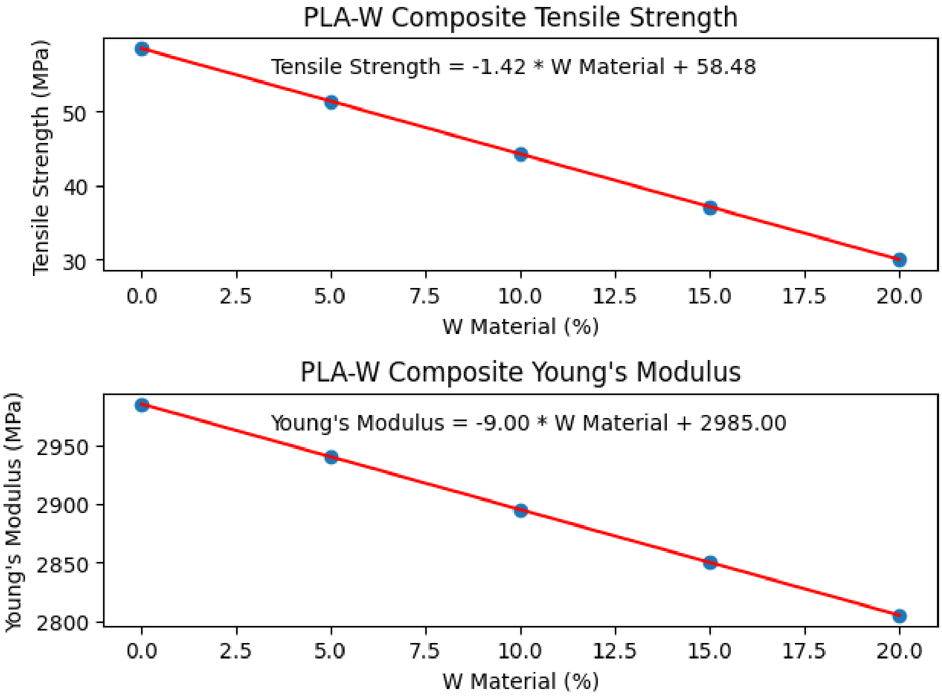

Figure 3. Tensile strength and the Young's modulus of PLA-MF composites.

Miswak fiber contains extractants as well as components such as lignin, hemicellulose and cellulose. MF can be classified as a drought-resistant natural fiber obtained from *S. persica*, a tropical tree species. This fiber has a high hemicellulose content compared to other natural fibers and is characterized by hemicellulosic binder microfibrils that provide structural reinforcement. Lignin plays an important role in maintaining the flexibility, properties and structure of the fiber. MF, when combined with PLA polymer, affects the mechanical and thermal properties of the composite. The results presented in Table 3 show that PLA composites containing MF cause a decrease in tensile strength and E values. As the amount of MF increases, the strength properties of the composite material decrease. The reason for this can be shown as insufficient adhesion of the fibers with the matrix and the resulting voids. However, the addition of MF resulted in an increase in E values compared to polymers. In the design of fiber-reinforced composite materials, a solid connection at the fiber-matrix interface and minimizing gaps are important. In addition, it is seen that the parameters used in the production process of the composite affect the fiber distribution and mechanical properties.

3.2. Flexural Specifications and Shore D Hardness of PLA-MF Composites

The bending properties of composite specimens are given in Table 4. With the increase of MF content in composite samples, flexural strength and flexural E values decrease. PLA/W0 sample has the highest flexural strength and E, while PLA/W20 sample has the lowest values. These results show that the bending performance of the composite decreases as the MF content increases. This may be due to poor adhesion and voids formed at the fiber-matrix interface. Insufficient wetting of the fibers can cause voids to form and reduce the mechanical specifications of the composite. Therefore, it is important to pay attention to factors such as fiber-matrix interaction and filler material distribution in order to improve the bending performance of composites containing MF (Figure 4).

Table 4. Flexural specifications of composite specimens

Specimen	Flexural Strength (MPa)	Flexural Young's Modulus (GPa)
PLA/W0	89.15	3.35
PLA/W5	78.81	3.25
PLA/W10	68.47	3.15
PLA/W15	58.13	3.05
PLA/W20	47.79	2.95

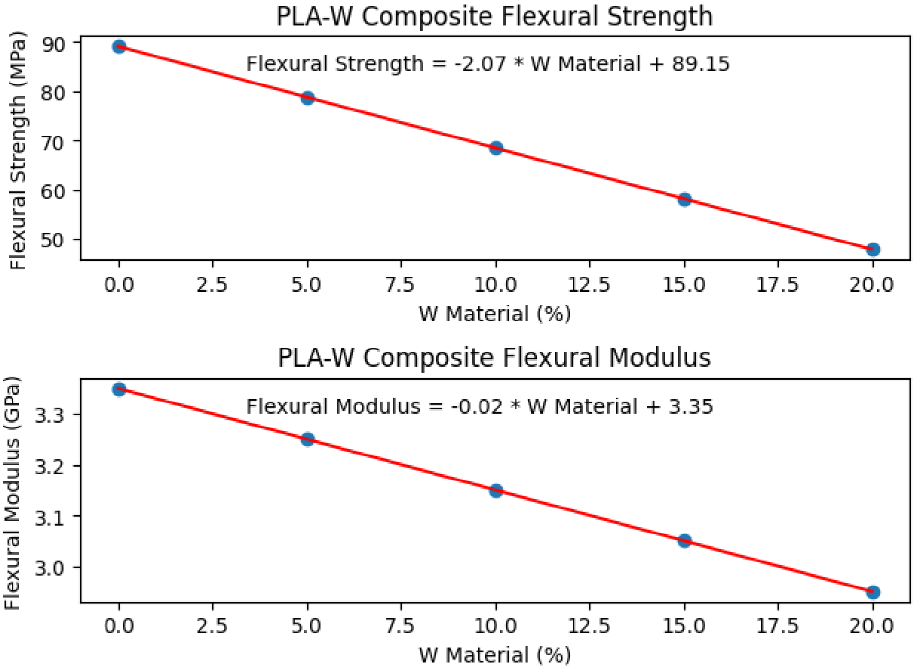

Figure 4. Flexural strength and the flexural modulus of PLA/-MF composites.

Bending properties of composite samples are given in Table 4. With the increase of MF content, flexural strength and flexural E values decrease. PLA/W0 sample has the highest flexural strength and E, while PLA/W20 sample has the lowest values. The results show that insufficient interfacial bonding in composites containing MF increases porosity and causes a decrease in properties. These results are also consistent with SEM findings in previous studies. In addition, changes in the flexural strength and modulus of different natural fiber reinforced PLA composites were observed in other studies in the literature (Diyana et al., 2022; Pérez, 2021). These studies show that attenuation at the fiber-matrix interface can reduce the stiffness of the composite. The Miswak-reinforced PLA composite exhibited a Shore D hardness value of 68.5 HD (Figure 5). This value signifies a comparison with pure PLA noticeable improvement over pure PLA.

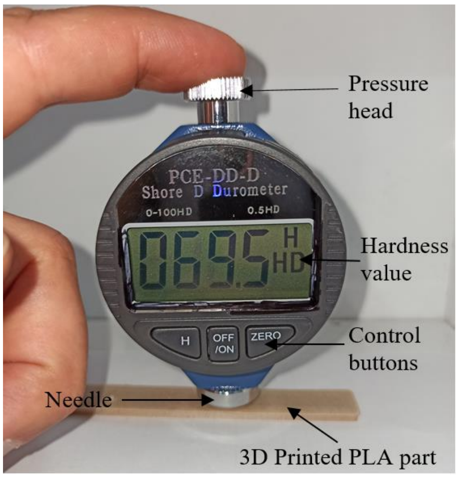

Figure 5. Shore D hardness meausurement of Miswak reinforced PLA composite part.

The increase in hardness can be attributed to the inherent properties of Miswak fibers and their interaction with the PLA matrix. The adhesion between the Miswak fibers and the PLA matrix, as well as the dispersion of fibers within the matrix, play a pivotal role in determining the hardness. The observed Shore D hardness suggests that the Miswak fibers offer a promising avenue for improving the mechanical properties of PLA, especially for applications where enhanced hardness is beneficial.

3.3. Scanning Electron Microscope of PLA-MF Composites

Based on the data in Table 2, 3 and 4, the properties of MF reinforced PLA composites were evaluated. The SEM images shown in Figures 6.a and 6.b show the microstructure of samples with different proportions of MF. In the sample containing 10% MF (Figure 6.a), it was observed that there was no homogeneous bonding between the fibers and the matrix, and voids were formed. Factors such as production and processing conditions, fiber volume ratio, and fiber length can contribute to void formation in polymer composites. In addition, other variables such as matrix material and moisture content may also have an effect on void formation. The presence of MF disrupted the flow of molten resin, resulting in the formation of meso-and micro-voids. The irregularity of the air permeability of the MF caused the formation of more voids and weakened the matrix-fiber connection. These gaps can act as stress concentration points under loading conditions, leading to earlier failure of samples. These results are also consistent with the findings of previous studies (Chauhan et al. 2020; Bramantoro et al., 2018; Rafiqah et al., 2023).

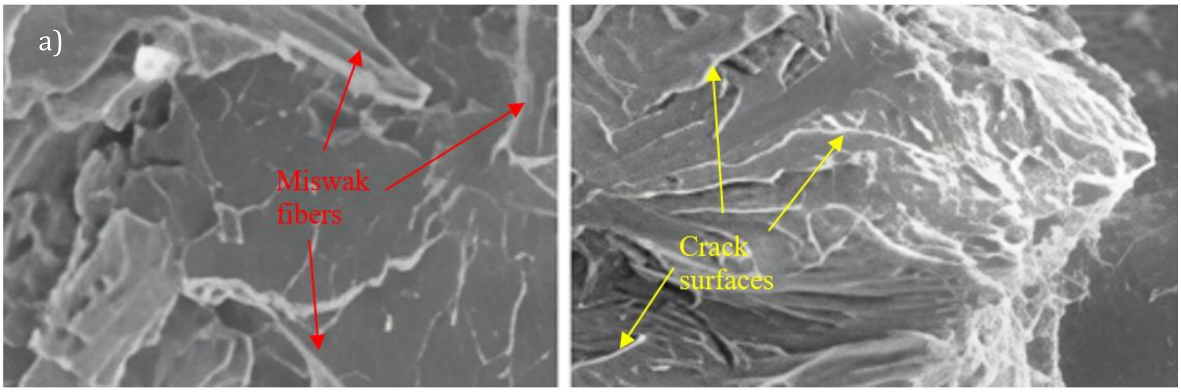

Figure 6. SEM micrograph of stretched surfaces of PLA-MF composites with different loading ratios. (a) shows the stretched surface of the PLA-MF10 10% wt sample at 100 times magnification, while (b) shows the PLA-MF20 stretched surface of the 20% wt sample.

On the other hand, the image in Figure 6.b shows the presence of voids indicating ineffective interfacial bonding between the hydrophilic matrix and the hydrophobic natural fiber. Also, incomplete fiber wetting can be observed due to poor matrix adhesion on the impurity-rich fiber surface. This results in complete separation of the matrix from the fibers under the applied tensile forces. Examination of Figure 6.b reveals that a fiber breakage and fiber drawing scenario can be seen. Microscopic examinations show composite fracture caused by fiber-fiber interactions within the matrix. This observation is in line with previous studies (Nur Diyana et al., 2022; Rafiqah et al., 2023; Savaş, 2019; Chaaben et al., 2022). Based on these analyses, polylactic acid/Miswak fiber (PLA-MF) composites are likely to exhibit low mechanical specifications due to factors such as inappropriate fiber use, weak fiber-matrix interactions, and matrix separation. Nur Diyana et al. (2022) studied the chemical, physical and mechanical specifications of MF to investigate the use of MF as a potential supplement for toothbrush materials (Nur Diyana et al., 2022). Researchers fabricated MF reinforced composites at different weight percentages (0%, 10%, 20%, and 30%) in a PLA matrix and performed various tests. Chemical analyzes revealed a high content of cellulose in MF. This can be considered as a feature that can facilitate the equal transfer of the stress load between the fiber and the matrix. However, it has been observed that the low cellulosic content in MF negatively affects the interfacial bond between fiber and matrix. When the physical properties were examined, it was observed that the density increased as the fiber content increased. This result indicates that MF may be suitable for applications such as toothbrush handles. SEM analysis revealed that voids in composites contribute to the reduction in mechanical properties. Mechanical test results showed that the proposed material performed comparable to commercially used materials. The thermal analysis results showed that the composite material has a similar melting point with pure PLA, which means that both materials have similar processing temperatures. Dynamic mechanical analysis (DMA) results revealed that PLA-MF 30 composite has a higher storage modulus (2062 MPa) and a lower tan δ value (0.6) compared to other PLA-MF composites. These results show the effects of pretreatments and/or adapters. In conclusion, the study of Diyana et al. revealed the potential of using MF as a supplement in toothbrush materials. The chemical and physical properties of MF affect the mechanical specifications of composites. The results show that the proposed composite exhibits similar performance to commercially used materials and may be a viable option for toothbrush materials. The study by Rafiqah et al. (2023) investigates the mechanical and thermal properties of alkali-treated MF and PLA composites. The study addresses the difficulty of the hydrophilic nature of Miswak fiber, which complicates its interaction with the hydrophobic PLA matrix (Rafiqah et al., 2023). The composites were treated with different concentrations of sodium hydroxide (NaOH): 1%, 2% and 3% by weight. The characterization of the composites was carried out using methods such as Fourier Transform Infrared Spectroscopy (FTIR), tensile testing, thermogravimetric analysis (TGA), DMA and SEM. The results show that the alkali treatment did not significantly improve the interfacial bonding, which is supported by the uneven tensile strength data. However, it was observed that the treated fiber surface showed an increase in the tensile strength of PLA composites reinforced with Miswak fiber. Tensile strength increased by 18.01%, 6.48% and 14.50% in composites treated with 1%, 2% and 3% wt NaOH concentrations, respectively. A slight increase in tensile modulus (0.7%) was observed in only 2% wt of processed fiber, whereas at 1% wt and 3% wt NaOH concentrations the modulus decreased by 4.15% and 19.7%. TGA for thermal stability analysis showed that alkali-treated fiber composites showed a slight improvement in thermal stability, especially at elevated temperatures. The DMA results reveal that surface-treated composites show higher storage modulus, especially for PLA reinforced with 2%wt alkali-treated MF. This suggests that alkaline treatment is effective. In summary, the work of Rafiqah et al. highlights the influence on the mechanical and thermal properties of alkali-treated reinforced Miswak fiber and PLA composites. The findings reveal improvements in tensile strength and thermal stability with the treated fiber surface, but indicate that further improvements are needed in interfacial bonding. The study conducted by Savaş (2018) focuses on investigating the structural, mechanical, and tribological properties of Miswak powder reinforced polypropylene (PP) composites (Savaş, 2019). The composites were prepared using a PP matrix and a maleic anhydride-grafted PP (PP/g/MA) copolymer as a coupling agent. Different concentrations of Miswak powder (5, 10, 20, and 30 wt%) were incorporated into the composites. Various characterization techniques were employed to evaluate the properties of the composites. Tensile and flexural tests were performed to assess the mechanical behavior, DMA was conducted to examine the viscoelastic properties, X-ray diffraction was used to analyze the crystalline structure, SEM allowed for microstructural analysis, a goniometer measured the contact angles and surface energy, water uptake tests evaluated the moisture absorption capacity, and a ball-on-disc test assessed the tribological performance of the composites. The results indicate that the addition of Miswak powder at different concentrations positively influenced the properties of the composites. Particularly, composites with lower Miswak concentrations (5% and 10%) exhibited improved mechanical and tribological properties while maintaining good surface integrity. The 5% Miswak reinforcement showed promising performance even under wet conditions, making it suitable for potential applications in medical parts. In summary, the study highlights the potential of Miswak powder reinforced PP composites by demonstrating their enhanced structural, mechanical, and tribological properties. The findings suggest that composites with lower Miswak concentrations can fulfill the requirements for effective adhesion, high surface energy, and desirable mechanical and tribological performance. This research opens up possibilities for utilizing Miswak-reinforced composites in various applications, including medical parts. The study conducted by Rihem Chaaben et al. (2020) focuses on the development of a novel biocomposite for dental materials by incorporating Miswak powders into poly (methyl methacrylate) (PMMA) resin (Chaaben et al., 2022). The use of Miswak has been investigated to improve the bioactive properties of dental restoration materials. Material characterization was performed on both the individual components and the developed biocomposite, which contained 30 wt% of *S. persica*. X-ray diffraction, FTIR, differential scanning calorimetry, and high-performance liquid chromatography techniques were employed to analyze and characterize the materials. The results revealed the presence of organic chemical compounds from Miswak that are responsible for biological activities, as well as mineral chemical compounds that are beneficial for dental applications and oral health. The absence of toxic residual monomers was also confirmed, ensuring the safety of the developed composite. Furthermore, the composite demonstrated antioxidant activities, as evidenced by its total polyphenol flavonoid content. The study also demonstrated the antibacterial activity of both Miswak and the composite material. In summary, this study introduces a novel biocomposite by incorporating Miswak powders into PMMA resin for dental applications. The characterization results confirm the presence of bioactive organic and mineral compounds, the absence of toxic residual monomers, and the antioxidant and antibacterial activities of the composite material.

The present study investigated the mechanical performance of Miswak reinforced PLA matrix composites for 3D printing applications. The incorporation of Miswak powder at different weight concentrations (5%, 10%, 15%, and 20%) was explored, and PLA/g/MA was used as a compatibilizer to improve the compatibility between the filler and matrix. The results obtained from the tensile and flexural testing demonstrated that the addition of Miswak powder positively influenced the mechanical specifications of the PLA composites. Specifically, the composite with 5% Miswak concentration exhibited excellent interlayer adhesion and high mechanical strength. This enhancement can be attributed to several factors. First, Miswak powder contains natural fibers rich in cellulose, which can effectively transfer stress from the matrix to the reinforcement, thereby improving the load-bearing capability of the composite. Additionally, the use of PLA/g/MA as a compatibilizer promoted better adhesion between the Miswak powder and PLA matrix, leading to improved mechanical performance. SEM analysis provided insights into the microstructure of the composites. The images revealed a homogeneous distribution of Miswak powder within the PLA matrix, indicating good dispersion and interfacial bonding. Furthermore, the presence of Miswak powder helped to reduce the formation of voids and microcracks, contributing to enhanced mechanical properties. The findings of this study suggest that Miswak powder has significant potential as a reinforcing material for PLA composites in 3D printing applications. The improved mechanical properties, including increased strength and interlayer adhesion, indicate the suitability of these composites for load-bearing applications. Moreover, the antimicrobial properties associated with Miswak powder provide additional benefits, making these composites suitable for applications requiring antimicrobial characteristics. The utilization of natural fillers like Miswak powder in PLA composites offers a sustainable and eco-friendly alternative to conventional plastic materials. By incorporating Miswak powder, the environmental impact can be reduced while maintaining or even enhancing the performance of the composites. In conclusion, the present study successfully demonstrated the mechanical performance of Miswak reinforced PLA matrix composites for 3D printing applications. The findings indicate that Miswak powder can effectively improve the mechanical specifications of PLA composites, making them suitable for various practical applications.

Miswak powder was incorporated at varying concentrations. A significant finding was that the 5% Miswak concentration yielded excellent mechanical strength and adhesion. SEM images corroborated these findings, showing a homogeneous distribution of Miswak powder in the PLA matrix. This enhancement in properties is due to Miswak's rich cellulose content and the use of a compatibilizer. The composites could have potential applications in areas that require antimicrobial properties, presenting an eco-friendly alternative to conventional plastics. In essence, while Miswak fiber holds promise as a reinforcing material in various composites, challenges persist in terms of achieving consistent and strong interfacial bonding. The current study on 3D printing applications, however, reveals promising mechanical properties, especially at lower Miswak concentrations.

Figure 6's Scanning Electron Microscope (SEM) images shed light on the microstructural complexities of PLA-MF composites, serving as direct visual support for experimental conclusions. Figure 6.a, representing a sample with 10% MF, displays a conspicuous lack of uniform bonding, evident voids, and disrupted matrix continuity due to MF, suggesting potential production issues and the impact of fiber volume ratio. Figure 6.b accentuates the gaps hinting at poor interfacial bonding, possibly due to hydrophilic-hydrophobic disparities, incomplete fiber wetting implying impurity-driven adhesion issues, and discernible fiber breakage indicative of weaker interactions. Additionally, fiber-fiber interactions seem more prominent than fiber-matrix ones. These SEM revelations underscore concerns about PLA-MF composites' mechanical performance, emphasizing the significance of optimal fiber dispersion, adhesion, and bonding. Improved production and processing could lead to enhanced mechanical properties, broadening their application potential.

4. Conclusion

In this study, the mechanical performance of Miswak reinforced polylactic acid (PLA) matrix composites was investigated. The results shed light on the potential use of Miswak powder as a natural filler in PLA composites for 3D printing applications. The following conclusions can be drawn from the study:

i.) Miswak powder, obtained from the Miswak tree, contains lignin, hemicellulose, cellulose, and other organic compounds. It has a high hemicellulose content compared to other natural fibers, which provides structural reinforcement to the composite.

ii.) The addition of Miswak fiber to PLA composites affects their mechanical properties. As the Miswak fiber content increases, there is a decrease in tensile strength, E, flexural strength, and flexural E values of the composites.

iii.) The decrease in mechanical specifications can be attributed to insufficient adhesion between the fibers and the matrix, resulting in the formation of voids. The presence of voids acts as stress concentration points, leading to earlier failure of the composites.

iv.) Despite the decrease in mechanical properties, Miswak powder offers additional antimicrobial benefits to the PLA composites, making them potentially useful for applications requiring antimicrobial properties.

v.) The density of PLA/Miswak composites increases with increasing Miswak fiber content. This density increment can affect the physical properties of the composites.

vi.) The morphology analysis using SEM revealed the presence of voids and ineffective interfacial bonding between the matrix and the Miswak fibers, further confirming the mechanical performance of the composites.

The results highlight the importance of optimizing the fiber-matrix interaction and filler material distribution in order to improve the mechanical specifications of Miswak reinforced PLA composites. The findings of this study contribute to the development of sustainable and environmentally friendly materials by utilizing natural fillers such as Miswak powder. Further research and experimental analysis are required to better understand the effects of Miswak fiber on composite performance and to optimize the manufacturing processes for enhanced mechanical specifications.

Limitation and Future Works

By addressing the following limitations and the suggested future works, researchers can further advance the knowledge and application of Miswak reinforced PLA composites, paving the way for sustainable and high-performance materials in various industries.

Limitations:

Limited research: The research in this specific area is limited, indicating a gap in the existing literature. Further studies are needed to explore other aspects such as the printability, dimensional stability, and surface quality of these composites in the context of 3D printing.

Optimal Miswak concentration: The present study investigates Miswak powder concentrations at different weight percentages. However, the optimal concentration for achieving the best mechanical specifications and other desirable characteristics of the composites is yet to be determined. Further research is required to identify the ideal Miswak concentration that balances mechanical performance, printability, and other relevant factors.

Future works:

Printability assessment: Evaluating the printability of

Miswak reinforced PLA composites is an important aspect for their application in 3D printing. Future research should focus on assessing the printability parameters, such as extrudability, adhesion between layers, and dimensional accuracy, to ensure successful and reliable printing of the composites.

Optimization of processing parameters: Investigating the effect of processing parameters, temperature, nozzle size, and printing speed, on the mechanical specifications and overall performance of Miswak reinforced PLA composites is crucial. Optimizing these parameters can help achieve enhanced mechanical specifications and better compatibility between the Miswak filler and PLA matrix.

Characterization of functional properties: In addition to mechanical properties, future studies should explore the functional properties of Miswak reinforced PLA composites, such as antimicrobial activity and biocompatibility. Understanding these properties will broaden the potential applications of these composites, particularly in the field of dental materials and other biomedical applications.

Long-term durability assessment: Assessing the long-term durability and stability of Miswak reinforced PLA composites is essential to ensure their reliability and suitability for real-world applications. Investigating the effects of environmental factors, aging, and repeated loading on the mechanical performance and structural integrity of these composites will provide valuable insights for their practical use.

Comparative studies: Conducting comparative studies with other reinforcement materials, such as synthetic fibers or nanoparticles, can provide a better understanding of the advantages and limitations of Miswak reinforced PLA composites. Comparative analyses will aid in determining the unique properties and potential niche applications of Miswak-based composites in the realm of 3D printing and beyond.

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	F.K.	A.K.
C	60	40
D	100	
S		100
DCP	70	30
DAI		100
L	50	50
W	70	30
CR	40	60
SR	100	
PM	80	20
F	100	

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

There is no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans. The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to.

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