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Impact of Starch-Based Bioplastic Film Reinforced with Alkaline Treated Lemongrass Fiber and Lemongrass Essential Oil on the Barrier and Mechanical Properties

Saiful Bahri Mohd Diah[1], Sharifah Hanis Yasmin Sayid Abdullah[1,2*], Yew Been Seok[1], Ireana Yusra Abdul Fatah[1], Nor Iza A. Rahman[3], Fadli Hafizulhaq[4,5], Nur Nazira Alias[1]

[1] Faculty of Innovative Design and Technology, University Sultan Zainal Abidin, Kampus Gong Badak, 21300 Kuala Nerus, Terengganu, Malaysia
[2] Biomaterials and Nanomaterials Research Group, Smart Technology Research Cluster, University Sultan Zainal Abidin, Kampus Gong Badak, 21300 Kuala Nerus, Terengganu, Malaysia
[3] Faculty of Medicine, University Sultan Zainal Abidin, Kampus Kota, 20400 Kuala Terengganu, Terengganu, Malaysia
[4] Department of Agricultural and Biosystem Engineering, Universitas Andalas, Padang, Indonesia
[5] Research Collaboration Center for Nanocelulose between BRIN and Universitas Andalas, Padang, Indonesia

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ABSTRACT

Bioplastics offer a promising alternative to synthetic plastics in food packaging due to their biodegradability and non-toxicity. However, their limited mechanical properties and water sensitivity hinder widespread adoption. In this study, starch-based composite bioplastic films were prepared using a solution casting method, incorporating alkaline-treated lemongrass fiber (2-10 wt%) and lemongrass essential oil (1-3%) as reinforcement materials. Fiber characterization revealed structural, thermal, and morphological improvements as result of alkaline treatment. The reinforced bioplastic films exhibited enhanced mechanical properties, reaching up to 2.5MPa, attributed to improved fiber integration with the starch matrix. Additionally, the incorporation of lemongrass essential oil significantly improved barrier properties, reducing water uptake to 30% and water permeability to 6.7615×10^{-11} g/s.m.Pa. The findings demonstrate the suitability of starch-based bioplastic reinforced with LF and LEO for food packaging applications.

1. Introduction

Food industry is the highest industry consuming plastic as it is widely being used as packaging application [1]. In response to the environmental concerns associated with synthetic plastics, there is growing interest in developing biodegradable and sustainable alternatives for food packaging. Biodegradable packaging materials, such as biopolymers or bioplastics offer the potential to reduce the harmful impact of synthetic plastics on the environment. These materials are designed to break down naturally, reducing waste accumulation and pollution. Overall, while synthetic plastics have advantages in terms of versatility, durability, cost-effectiveness, and convenience, their negative

* *Corresponding author.*
E-mail address: shyasmin@unisza.edu.my

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environmental impact and potential health concerns have led to the exploration of alternative, more sustainable options for food packaging [2,3].

Starch is a commonly used matrix to produce bioplastics, which are biodegradable and eco-friendly alternatives to traditional plastics. It comes from renewable and abundant resources, biodegradable, and do not contribute to plastic pollution [4]. It has been used in various application including food packaging, pharmaceuticals, and agriculture. However, there are also limitations that retard its wide application. Starch-based bioplastic films are known to have poor mechanical properties, which limits their application in various industries, including packaging [5,6]. By reinforcing these films with alkaline-treated lemongrass fiber, it is aim to improve their mechanical strength and durability [7,8].

Another critical aspect of starch-based bioplastic films is their high water sensitivity, which compromises their performance, especially in humid environments or food packaging applications [9]. Incorporating lemongrass essential oil, with its hydrophobic properties, into the bioplastic matrix offers a potential solution to reduce water uptake and enhance water resistance, thereby improving the overall stability of the film [10]. Apart from that, numerous researchers reported that reinforcement of essential oils into starch-based packaging can increase their stability and retain their flavour and functional properties especially in food packaging application [11,12]. Its inherent antimicrobial, antioxidant, and insect repellent properties offer promise for extending shelf life, enhancing product protection, and promoting consumer appeal [13,14].

This study investigates the impact of incorporating alkali-treated lemongrass fibers (LF) and lemongrass essential oil (LEO) into potato starch bioplastics at three different loadings. The effect of the reinforcement on chemical composition, surface morphology, thermal degradation and tensile properties were explored by Fourier transform-infrared (FT-IR) spectroscopy, field-emission scanning electron microscopy (FESEM), thermogravimetric analysis (TGA), and universal testing machine (UTM) respectively.

2. Methodology

2.1 Material

Lemongrass biomass was purchased from local farmer around Kuala Nerus, Terengganu, Malaysia. Lab-grade potato starch, Glycerol 85%, Acetic acid (glacial) 100% was purchased from Sigma-Aldrich (M) Sdn Bhd. Lab-grade 99 percent Lemongrass essential oil. Sodium Hydroxide (NaOH).

2.2 Fiber Preparation

The lemongrass was cut into small 2-3 cm pieces, which were then rinsed with flowing water to remove impurities from the lemongrass fibre. After cleaning, the lemongrass fiber was dried in a dry oven at 60 ^{o}C for 4 hours. The LF was subsequently divided into two groups: raw lemongrass fiber and NaOH-treated lemongrass fibre. After drying in a dry oven for 4 hours, the fiber was blended and sieved to 250µm for the raw fiber group. Meanwhile, a part of the fiber was soaked for 15 minutes in a 5% NaOH solution to improve the surface of the fiber. It was then rinsed with flowing water to neutralize the pH of the fibre. Once the fiber reached a neutral pH, it was dried in a dry oven before being blended and sieved to 250µm [15]. The process was illustrated in Figure 1.

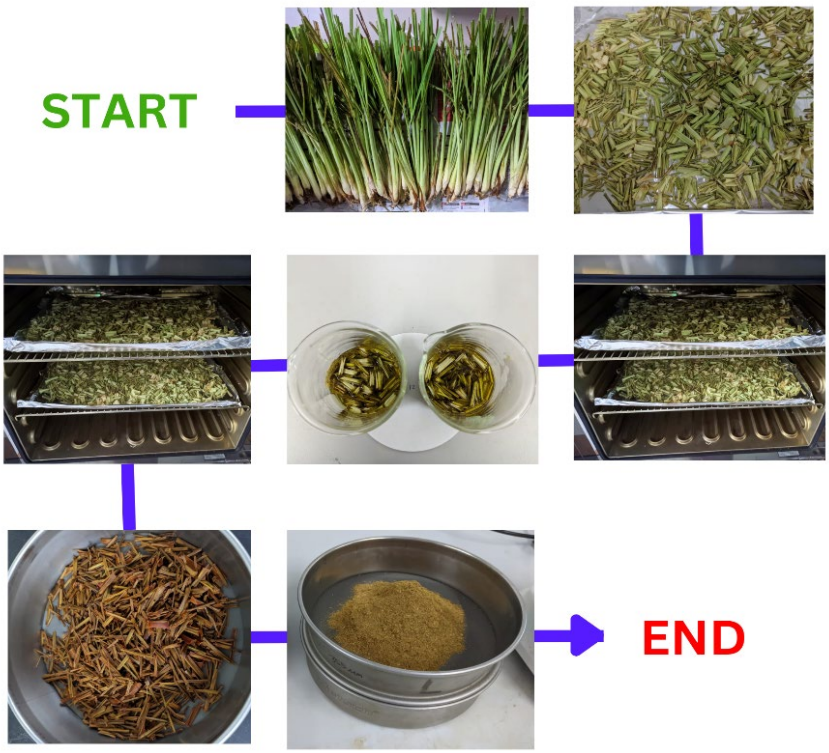

Fig. 1. Lemongrass fiber preparation

2.3 Thermoplastic Starch (TPS) Preparation

A bioplastic film was produced by dissolving 10 grams of laboratory-grade potato starch, 5 ml of glycerol, and 2 ml of acetic acid in 185 ml of water. As stated in Table 1, different weight percentages (w/v) of LF and LEO were added to the solutions. The solution was then cooked for 15 minutes on a hot plate at 85 °C while being continuously stirred with a glass rod. The heating stopped when the solution started to become viscous. Promptly after mixing, the mixture was evenly spread onto a glass petri dish measuring 12 cm in diameter. It was then subjected to a temperature of 36 °C within a drying oven for a duration of 72 hours, facilitating the drying process of the mixture. After completion, the resultant bioplastic material was allowed to cool down to room temperature before being carefully removed. Figure 2 illustrate the process of thermoplastic starch preparation for this study based on method by Hamin *et al.,* [15]

Table 1
Formulation of LF and LEO used in thermoplastic starch composite

Sample	Lemongrass fibre, wt%	Lemongrass essential oil, v%
Virgin TPS (control)	0	0
2LF_1LEO	2	1
2LF_2LEO	2	2
2LF_3LEO	2	3
6LF_1LEO	6	1
6LF_2LEO	6	2
6LF_3LEO	6	3
10LF_1LEO	10	1
10LF_2LEO	10	2
10LF_3LEO	10	3

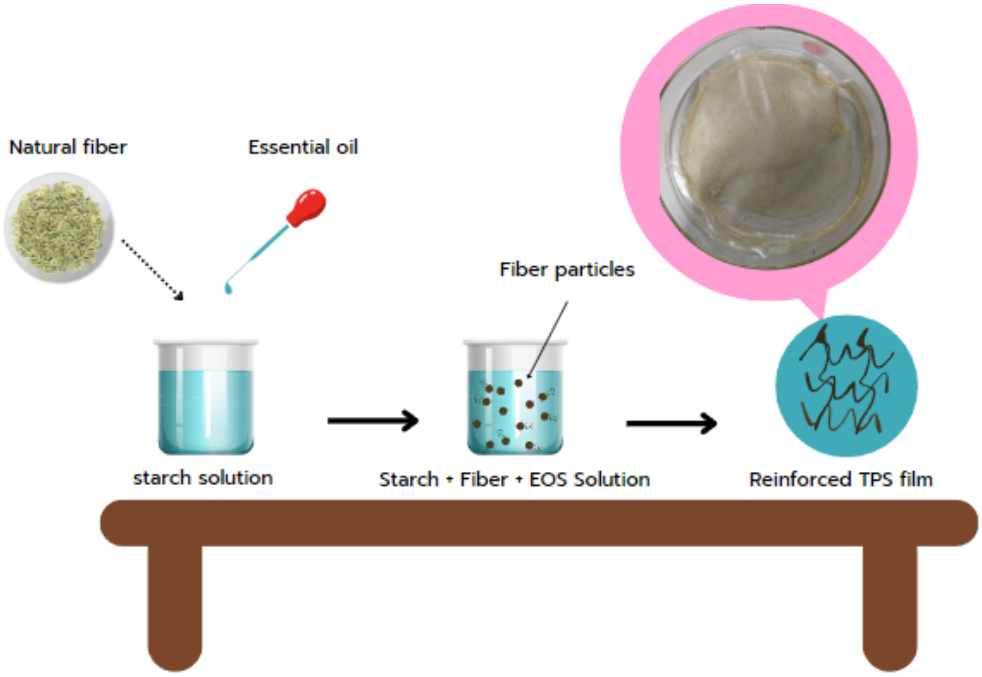

Fig. 2. Schematic diagram of thermoplastic starch preparation

2.4 Fiber Characterization
2.4.1 Moisture and ash analysis

The Sartorius Moisture Analyzer was used to study moisture content, whereas the ash content was determined by the TAPPI T-211 om-02 (2002) procedure and calculated by the Eq. (1) below. The ash content was expressed as a percentage of oven dry weight of the material [16].

$$Ash, \% = \frac{A \times 100}{B} \quad (1)$$

where A is the weight of ash, g and B is the weight of test specimen, g moisture-free

2.4.2 Morphology analysis

The field emission scanning electron microscopy (FE-SEM) coupled with energy dispersive x-ray (EDX) analysis (Thermo Fisher Scientific, Quattro ESEM, United States) was employed to investigate the surface morphology, fracture structure, and elemental composition of both treated and untreated fibres. To prepare the samples, they were gently pressed onto carbon tape and affixed to an FE-SEM stub. To prevent the build-up of electrostatic charges during imaging, a thin platinum coating (30 nm thickness) was applied using the GSEM Ion Sputter Coater G20. An image at 500× magnification was captured at an electron energy of 10 keV using the Everhart–Thornley detector (ETD) [17].

2.4.3 Thermogravimetric analysis (TGA)

A NETZSCH Simultaneous Thermal Analysis (STA, 2500 Regulus, Germany) instrument was used to perform thermogravimetric analysis to study fiber thermal degradation. The temperature ranged from 25 °C to 600 °C, with a heating rate of 10 °C/min. The analysis was conducted under a protective

nitrogen gas atmosphere at a flow rate of 40 mL/min to prevent oxidative fiber degradation. Weight loss of the fibres was recorded based on temperature variation.

2.4.4 Fourier Transform Infrared (FTIR) analysis

Functional group analysis of both treated and untreated lemongrass fibers was conducted through FTIR analysis. The spectra were captured using the Attenuated Total Reflectance (ATR) sampling technique with the Perkin Elmer Spectrum Two FT-IR Spectrometer (from the United States) across the frequency range of 400 to 4000 cm^{-1}.

2.5 Thermoplastic Starch (TPS) Characterization

2.5.1 Barrier analysis

The water absorption measurement was determined based on ASTM standard method D570. A compact fragment of the specimen was trimmed to dimensions of 1 cm × 2 cm. The initial weight of the sample was documented. Subsequently, the sample will be submerged in a beaker encompassing 60 mL of water at room temperature for a duration of 24 hours. After withdrawal from the water and careful drying, the ultimate weight was recorded. The amount of water uptake can be calculated by using the Eq. (2) below [18].

$$WA = \left(\frac{W_0 - W}{W_0}\right) x100 \quad (2)$$

where W_0 is the initial weight of the film sample, and W is the final weight of the film sample.

The assessment of water vapor permeability was conducted following a methodology outlined by Cazon *et al.,* [19], which was slightly adapted to suit the requirements of this study. A wide-mouthed cup with a diameter of 28.27 mm was utilized, and filled with 50 mL of distilled water, ensuring that a headspace of less than 50 mm is maintained between the water's surface and the exposed area of the film. The film sample was positioned between two gaskets, guaranteeing proper placement without any cracks or wrinkles, effectively covering the entire mouth of the cup. This assembled cup was then be introduced into a desiccator containing silica gel, and it was kept at room temperature for a duration of 2 days. The initial weight of the cup was recorded before been placed into the desiccator, and the weight loss of the cup was recorded to the nearest $1x10^{-4}$ g. Water vapour permeability (WVP) are calculated according to the Eq. (3) below.

$$WVP = \frac{\Delta m \cdot L}{A \cdot \Delta t \cdot P} \quad (3)$$

where Δ_m/Δ_t (g/s) is the flux measured as a weight loss of the cell per unit of time and calculated as the slope of the weight loss of the cup, to the nearest 0.0001g, versus time; $A(m^2)$ is the actual exposed area determined by the mouth cup diameter; and P (Pa) is the vapor pressure differential calculated as 4245 Pa at room temperature.

2.5.2 Mechanical analysis

Tensile test was conducted to evaluate the effects of adding fillers such as raw and treated lemongrass fibre, along with lemongrass essential oil, on the properties of the films. The test was

carried out using a universal tensile testing machine (Shimadzu, AGX-500N, Japan). All samples were tested following the ASTM D882-18 standard, with slight modifications for the purpose of this study. The films were prepared in strips measuring 3.00 cm in width and 8.00 cm in length, with a thickness of 0.040 ± 0.003 cm, measured by (IP65-MX, MITUTOYO) Coolant Proof Digital Micrometer. The films were secured to the grip machine with 5 cm between the grips, leaving an exposed area of 3.00 x 5.00 cm. The crosshead speed of the machine was set at 5.00 cm/min until the film broke during testing.

3. Results

3.1 Fiber Characterization

3.1.1 Proximate analysis

Table 2 displays the results of the proximate analysis performed on lemongrass fibres. Upon alkaline treatment, moisture and ash content was found to significantly reduced to 4.24 and 5.49%. The alkaline treatment effectively eliminates wax, hemicellulose, and lignin that are present in the Fiber properties [20]. The loss of these components will significantly reduce the overall moisture content. Simultaneously, the removal of non-cellulosic components will also contribute to a lower ash content due to the removal of mineral and organic components [21]. Alkaline treatment significantly improved the cellulose content to 74.14% as reported by Bekele *et al.,* due to elimination of non-cellulosic component thus promoting the accessibility of cellulose. The decreased in lignin content contributes to enhanced fiber durability and resistance, rendering the fibres more resilient and less prone to fracturing [22].

Table 2
Proximate analysis of untreated and treated lemongrass fiber

Sample	Untreated lemongrass fibre	Treated lemongrass fibre
Moisture %	7.36	4.24
Ash %	10.93	5.49
Cellulose %	39.50[a]	71.70[a]
Hemicellulose %	22.60[a]	9.52[a]
Lignin %	28.50[a]	13.83[a]

[a] Data extracted from Bekele *et al.,* [21]

3.1.2 Morphology analysis

Figure 3 provides a visual representation of the alterations in surface morphology between the untreated and treated fibres. Notably, differences in smoothness and roughness are evident between the two types of fibres. As demonstrated in Figure 3(a), the untreated fiber shows a smooth surface attributed to the presence of a wax layer comprising pectin, lignin, waxes, and other contaminants. This wax layer results in inadequate bonding between the fiber and the matrix, leading to suboptimal surface wetting (Figure 3(a)). Conversely, Figure 3(b) presents a rougher and more rugged surface for the treated fiber in comparison to the untreated one. The chemical treatment with alkaline substances serves to eliminate non-cellulosic components such as lignin from the natural fibres. Through processes of defibrillation and washing, the amorphous chemical constituents are removed, resulting in a textured fiber surface free from surface impurities and featuring numerous surface depressions [23]. Moreover, the fabrication of the composite contributes to an enhanced mechanical bond between the lemongrass fibres and the composite material.

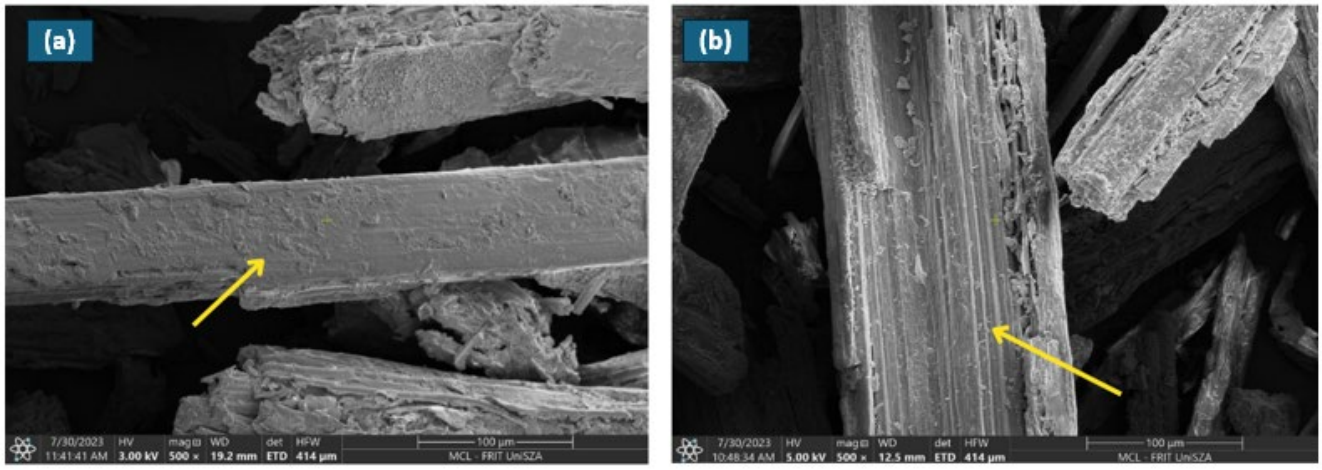

Fig. 3. Scanning electron microscopy of (a) x500 untreated and (b) x500 treated lemongrass fiber

The elemental analysis for untreated and treated lemongrass fibres conducted by EDX analysis is presented in Table 3. The primary elemental constituents shared among all fiber series were oxygen and carbon. These elements predominantly constitute the cellulose, hemicellulose, and other non-cellulosic polymer structures within the fibres. A noteworthy observation is the reduction in carbon content within NaOH-treated lemongrass fibres in comparison to their untreated counterparts. This phenomenon strongly suggests that the alkaline treatment was successful in dissolving the lignin phase, which is rich in carbon. Consequently, this process led to a decrease in the carbon content due to the elimination of amorphous, lignin, and hemicellulose components from the lemongrass fibres. Figure 4 shows the EDX analysis spectrum of untreated sugarcane bagasse revealed minor traces of minerals like copper, zinc, and aluminium. On the other hand, the EDX analysis of NaOH-treated fibres exhibited a reduction in copper and zinc components, alongside the presence of a titanium element at a level of 0.2%. Following the EDX analysis, Fourier Transform Infrared (FTIR) spectroscopy was utilized to establish a clear connection between the structural modifications on the lemongrass fiber surface both before and after the NaOH treatment. This spectral analysis effectively confirmed the successful removal of non-cellulosic amorphous constituents from the fibres.

Table 3
Elemental composition of untreated and treated lemongrass fibre

	Composition, wt%	
Sample	Untreated lemongrass fibre	Treated lemongrass fibre
Oxygen (O)	74.9	79.6
Carbon (C)	24.5	19.1
Copper (Cu)	0.6	0.3
Titanium (Ti)	-	0.2
Zinc (Zn)	0.6	0.1
Aluminium (Al)	0.2	-
Vanadium (V)	-	-

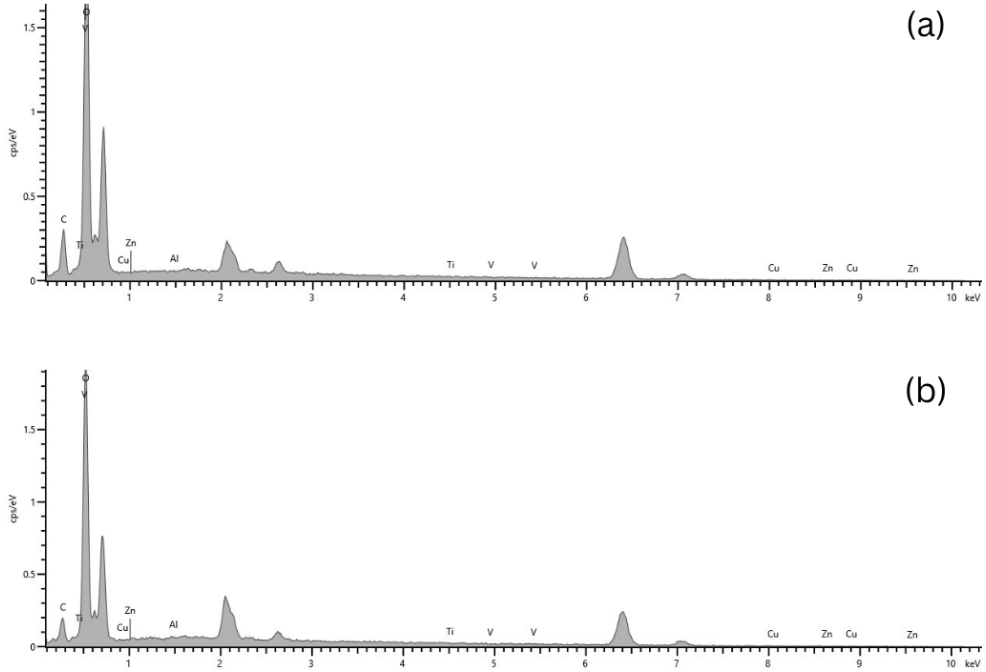

Fig. 4. EDX spectrum of (a) untreated and (b) NaOH treated lemongrass fiber

3.1.3 Fourier Transform Infrared (FTIR) spectroscopy analysis

Figure 5 displays the FTIR spectra of untreated and treated lemongrass fiber accessed from 400–4000 cm^{-1}. Table 4 contains a summary of every vibration peak presented in both samples. Both untreated and treated fiber displayed a similar spectrum, with cellulose, hemicellulose, and lignin predominating. After NaOH treatment, the peak intensity was altered and diminished. In untreated lemongrass fibre, the broad absorption bands at 3311 cm^{-1} are related to the hydroxyl (OH) functional group (Table 4). The alkaline treatment breaks down the lignin and, consequently, leads to fewer OH bond disruptions in the NaOH-treated lemongrass fibre. This effect is evident from the considerable reduction in the intensity of the OH group in the lemongrass fiber post the alkaline treatment. In both untreated and treated lemongrass fibres, the peaks observed at 2918 cm^{-1} and 2917 cm^{-1} are attributed to C-H anti-stretching, while the peak at 2847.36 cm^{-1} is associated with C-H stretching in the methyl and methylene groups, respectively. These findings are in line with previous studies by Ikhuoria *et al.,* [24]. The stretching vibrations of N-H bending (amine), and O-H bending are responsible for the bands at 1626.51 cm^{-1} and 1370.75 cm^{-1} in untreated lemongrass fibre, respectively [7,21]. In the NaOH-treated lemongrass fibres the stretching peaks at this absorption band were gone. This result is consistent with earlier research that discovered the alkaline treatment was successful in eliminating lignin and hemicelluloses done by Parre *et al.,* [25]. According to Nascimento *et al.,* [26] C-O stretching in cellulose, hemicellulose, and lignin is what caused the bands at 1033.14 cm^{-1} and 1029.39 cm^{-1} for untreated and treated lemongrass fibre, respectively.

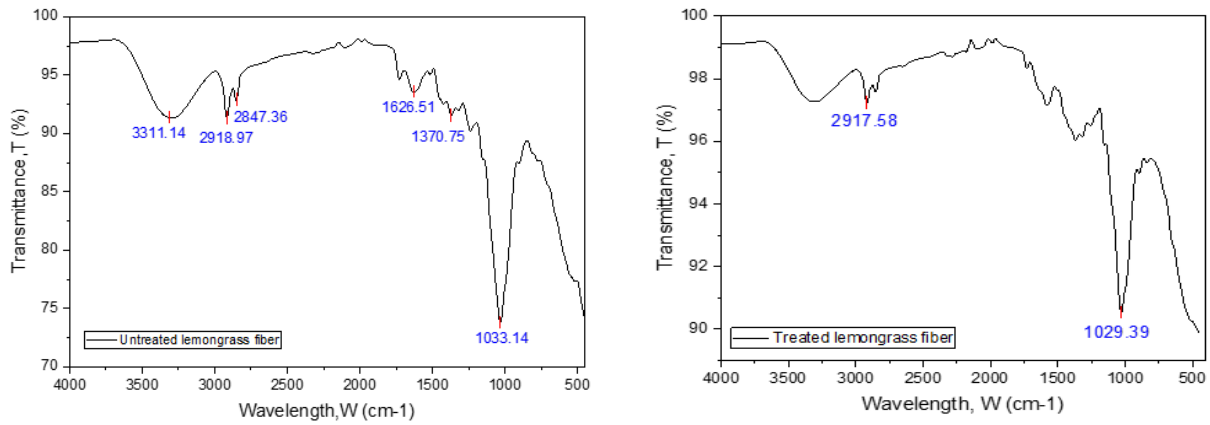

Fig. 5. FTIR spectrum of untreated and treated lemongrass fiber

Table 4
FTIR Spectral bands of untreated and treated lemongrass fibre

Frequency, cm^{-1}		
Untreated lemongrass fibre	Treated lemongrass fibre	Functional groups
3311.14	-	O-H stretching
2918.97	2917.58	C-H anti-stretching
2847.36	-	C-H stretching
1626.51	-	N-H bending
1370.75	-	O-H bending
1033.14	1029.39	C-O Stretching

3.1.4 Thermogravimetric Analysis (TGA)

The TGA curves of the untreated and treated lemongrass fiber are shown in Figure 6. It is evident from the plot that thermal decomposition of untreated and treated lemongrass fiber took place in three stages. The first stage of thermal reduction is due to weight loss upon eradication moisture and other waxy materials that can be observed between 50 and 160 °C. The second stage started between 170 and 350 °C due to broken down of hemicellulose and cellulose components. The corresponding weight loss was found to be higher in untreated (57.75%) compared to treated (32.84%) lemongrass fiber due to lower lignocellulosic components in treated lemongrass fibre [27]. It demonstrates that fiber made of treated lemongrass has superior thermal stability at lower temperatures [28,29]. Degradation of alpha-cellulose is linked to the final stage of weight loss between 380 and 550 °C. In the third decomposition stage, which takes place at a higher temperature, the treated lemongrass fiber started to decompose earlier and with less weight loss (11.63%) than the untreated lemongrass fiber did with (15.87%). In conclusion, the surface modification of the lemongrass fiber by NaOH treatment resulted in improved thermal stability thus promoting it as a best natural filler for thermoplastic starch reinforcement.

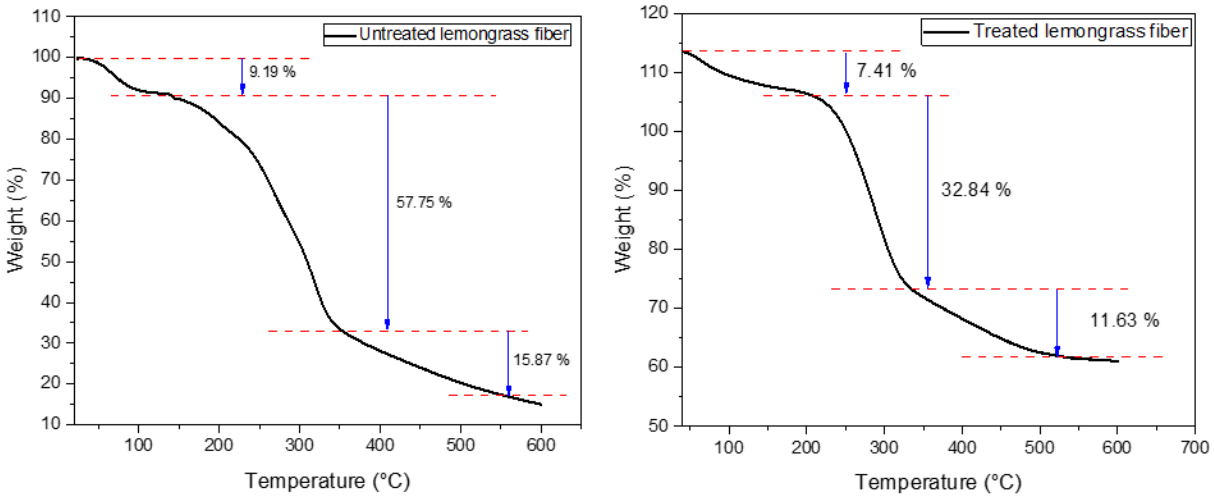

Fig. 6. TGA spectrum of untreated and treated lemongrass fiber

3.2 Thermoplastic Starch (TPS) Characterization

3.2.1 Barrier analysis

Table 5 represent the barrier properties of thermoplastic film as indicated by percentage of water absorption and water vapour permeability. It was noticed that virgin TPS absorbed the most water uptake (48.22 %) due to the hydrophilic behaviour which facilitates its water absorption tendency (14.5653 x 10^{-11} g/s.m.Pa) and caused the virgin TPS to swell when it is immersed in water or exposed to moisture. Reinforcement using LF and LEO significantly affect the barrier properties of TPS. It was found that higher loading of LF lead to increment in water absorption capacity as evident in sample 2LF_1LEO (37.22%), 6LF_1LEO (38.21%) and 10LF_1LEO (47.40%), respectively. This results can be attributed to the hydrophilic nature of cellulose, which is the main components of LF that incorporated in the TPS. On the other hand, highest water vapour permeability was found in 2LF_1LEO (10.8852x10^{-11} g/s.m.Pa) as compared to 6LF_1LEO (8.1647x10^{-11} g/s.m.Pa) and 10LF_1LEO (10.8020x10^{-11} g/s.m.Pa), respectively. At higher fiber loading, the excess fibers may lead to agglomeration or poor dispersion within the matrix, resulting in irregularities and pathways for water vapor to penetrate the film.

The incorporation of LEO in the TPS showed decrement in both water absorption and water vapour permeability at higher loading of LEO regardless of fiber loading (Table 5). It can be observed that at 2wt% LF, the water absorption capacity significantly reduced from 37.22% to 34.26% at 1v% LEO and 3v% LEO, respectively. This might be due to the hydrophobic behaviour of lemongrass essential oil thereby reducing the affinity of the film for water vapour molecules through the TPS film [29]. These findings are correlated with previous research conducted by several other researchers [30-33] and support the notion that the inclusion of oils enhances the hydrophobic nature of polymer-based films, ultimately leading to a decrease in their water vapor permeability.

Table 5
Barrier properties of reinforced thermoplastic film

Sample	Thickness, mm	Water absorption, %	Water vapour permeability, (g/s.m.Pa)
Virgin TPS (control)	0.4226	48.22 ±0.53	14.5653×10^{-11}
2%LF_1%LEO	0.4426	37.22 ±0.34	10.8852×10^{-11}
2%LF_2%LEO	0.4355	37.19 ±0.54	10.0805×10^{-11}
2%LF_3%LEO	0.4346	34.26 ±0.74	9.4310×10^{-11}
6%LF_1%LEO	0.4576	38.21 ±0.77	8.1647×10^{-11}
6%LF_2%LEO	0.4408	35.09 ±0.37	7.0147×10^{-11}
6%LF_3%LEO	0.4523	30.15 ±0.28	6.7615×10^{-11}
10%LF_1%LEO	0.4766	47.40 ±0.34	10.8020×10^{-11}
10%LF_2%LEO	0.4680	40.32 ±0.18	10.1557×10^{-11}
10%LF_3%LEO	0.4766	39.22 ±0.30	9.9014×10^{-11}

3.2.2 Mechanical analysis

Figure 7 illustrates the tensile strength and elongation at break of the composite films at different loading of LF and LEO. In general, the incorporation of LF and LEO significantly enhances the tensile strength of the composite film as compared to the virgin thermoplastic material. Focusing on samples with the same LEO percentage but different LF percentages 2%LF_1%LEO and 6%LF_1%LEO shows the general trend of increasing tensile strength with higher LF percentages 2.3658 MPa and 2.5314 MPa respectively. This trend suggests that LF plays a crucial role in enhancing the mechanical properties of the thermoplastic film. However, beyond a certain LF percentage, the rate of increase in tensile strength may diminish, as evidenced by potential plateauing effects observed in some compositions with the fiber loading reached 10%, due to excesses percentage of lemongrass fiber may decrease its interaction with the polymer matrix, reducing the strength of the composite film. This finding is consistent with finding reported in the literature by Bekele *et al.,* [21], who observed a similar trend regarding the maximum percentage of lemongrass fiber as a filler in plastic films. Nevertheless, the result obtained from the 6%LF_3%LEO exhibit the optimum composition as it reached the highest tensile strength 2.7544 MPa compared to others composition. On the other hand, elongation at break gradually increases with higher concentrations due to the emulsion's role in aiding polymeric chain sliding during stretching, as suggested by Sun *et al.,* [33].

Table 6
Mechanical properties of reinforced thermoplastic film

Sample	Thickness mm	Tensile Strength MPa	Elongation at Break %
Virgin TPS (control)	0.4226	1.6469 ± 0.02	55.12
2%LF_1%LEO	0.4426	2.3658 ± 0.05	50.31
2%LF_2%LEO	0.4355	2.3578 ± 0.11	51.29
2%LF_3%LEO	0.4346	2.2541 ± 0.01	56.42
6%LF_1%LEO	0.4576	2.5314 ± 0.02	49.31
6%LF_2%LEO	0.4408	2.6208 ± 0.10	57.41
6%LF_3%LEO	0.4523	2.7544 ± 0.02	65.23
10%LF_1%LEO	0.4766	2.4611 ± 0.02	54.03
10%LF_2%LEO	0.468	2.2254 ± 0.01	52.53
10%LF_3%LEO	0.4766	2.0824 ± 0.02	56.94

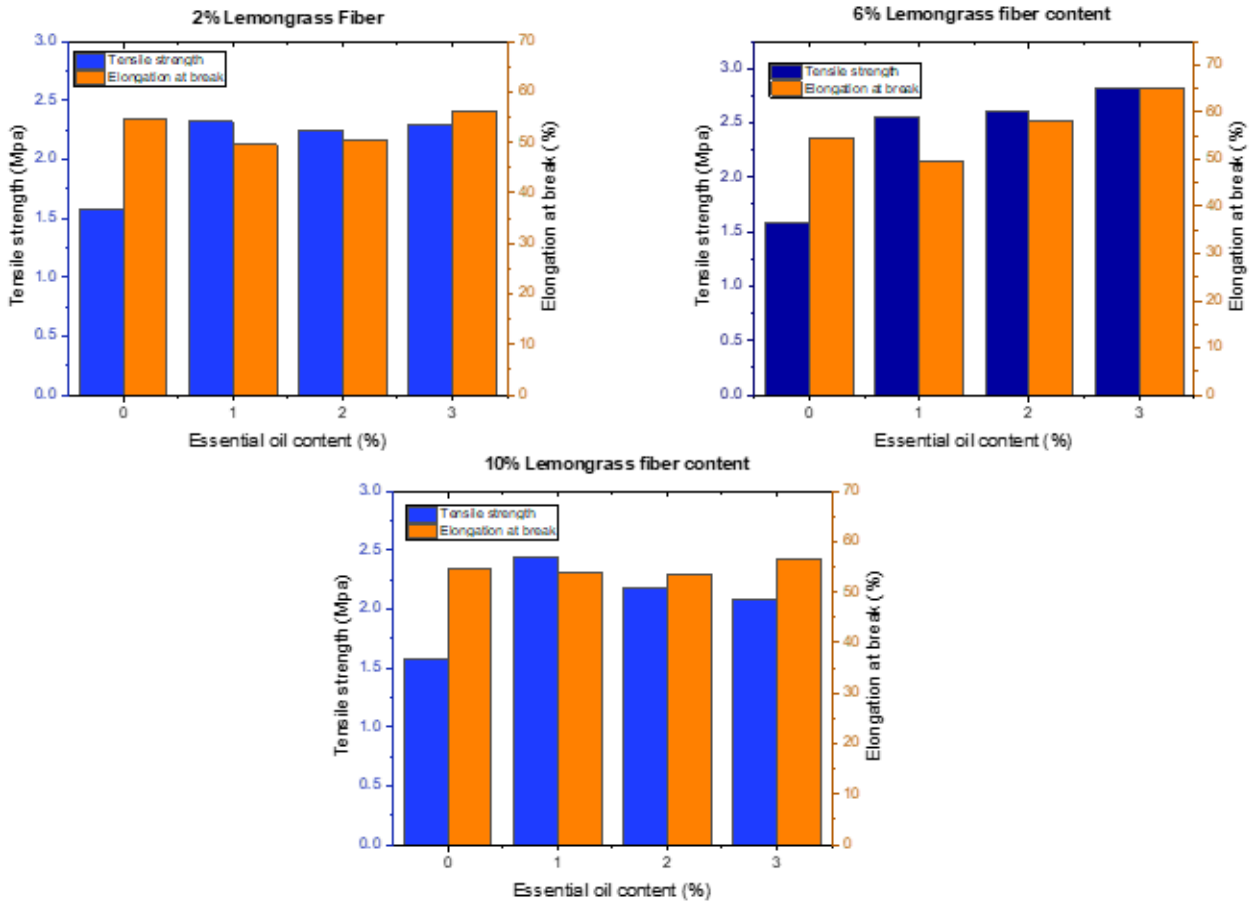

Fig. 7. Tensile strength and elongation at break of reinforced thermoplastic film

4. Limitation and Future Research

This study has evaluated the capacity of composite bioplastic, reinforced with lemongrass biomass and infused with lemongrass essential oil. However, it only discussed in terms of mechanical and barrier properties of the produced composite bioplastic. While biodegradability is an advantage for sustainability, it may limit the material's shelf life and suitability especially for food packaging applications which require long-term food preservation. Future research should focus on innovative material engineering techniques that aim to extend the shelf life of biodegradable materials while maintaining their eco-friendly characteristics. Exploring novel biocompatible additives or coatings and investigating advanced packaging technologies could pave the way for sustainable materials that meet both environmental and functional demands, thus enabling a more sustainable future for food preservation and packaging.

5. Conclusions

This study has successfully evaluated the effect of reinforcement TPS with of NaOH-treated LF and LEO on the barrier and mechanical properties. From this study, several conclusions were drawn including:

i. The proximate analysis results showed that NaOH-treated LF reduced the non-cellulosic components such as non-cellulose constituents such as hemicellulose, lignin, and surface impurities.

ii. FTIR analysis confirms the removal of the non-cellulosic components as a result of alkaline treatment through the reduction and diminishing functional groups of hemicellulose and lignin from the major peaks.
iii. Morphology evaluation using SEM analysis unveiled that the surface morphology of the NaOH-treated fibres displayed increased roughness compared to the untreated fibres.
iv. TGA peaks reveals better thermal stability in NaOH-treated LF due to the removal of non-cellulose constituents in the treatment stage.
v. The TPS reinforced with LF and LEO showed improvement in barrier properties due to presence of hydrophobic essential oil which in turn helps to reduce the moisture absorption and permeability of the film.
vi. The tensile test reveals improvement in tensile strength and elongation at break in all reinforced TPS samples. The highest tensile strength and elongation at break were exhibited at 6 wt% LF and 3% LEO, respectively.

As a conclusion, the reinforcement of NaOH treated LF and LEO has improved the properties of the TPS, thus widening the potential of this material as an alternative for synthetic food packaging.

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