



Characterization of Raw and Alkali-Treated Typha Grass Fiber for Sustainable Composite Applications

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ABSTRACT

Extensive research has been conducted on the material characterization of various natural fibers, including hemp, flax, sisal, kenaf, coir, and jute, as well as their composites with polymer matrices. The inherent hydrophilicity of natural fibers can lead to inadequate interfacial bonding with hydrophobic matrices. Chemical modification of fiber surfaces, particularly alkalization; alkali treatment, has been employed to address the limitations associated with natural fibers. This research paper presents characterization of unexplored raw and NaOH-treated typha grass fiber (TGF) extracted from typha grass for sustainable composite applications. A comprehensive characterization was conducted using density measurements, water absorption tests, FTIR spectroscopy, and single fiber tensile tests. The treatment resulted in increased density, improved tensile strength and enhanced toughness, but reduced ductility, as evidenced by decreased Young's modulus and percent elongation at break. FTIR analysis showed the effective removal of hemicellulose, lignin, and wax from the fiber surface. Based on the characterization results, Typha grass fibers (TGFs) appear to be a viable candidate for reinforcement in green composites, offering potential for sustainable material applications.

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INTRODUCTION

The pursuit of sustainable materials has led researchers to investigate natural fibers as a substitute for synthetic fibers, leveraging their inherent benefits, including low density, environmental sustainability, and high mechanical performance (Bhudolia et al., 2018; Ramnath et al., 2014; Sahu and Gupta, 2018a; Ramesh et al., 2013; Sahu and Gupta, 2018b). The abundance, affordability, and non-toxic nature of natural fibers further enhance their appeal for use in eco-friendly products (Sahu and Gupta, 2018a; Ramesh et al., 2013; Sahu and Gupta, 2018b; Ali et al., 2018; Noorunnisa Khanam et al., 2010; Sahu and Gupta, 2017). The mechanical properties and water absorption behavior of natural fibers are largely determined by their chemical composition, particularly the proportions of cellulose, hemicellulose, lignin, pectin, and wax. Cellulose is primarily responsible for fiber strength and

stiffness, while hemicellulose plays a key role in governing water absorption capacity and thermal degradation property (Stamboulis et al., 2001).

Lignin contributes to fiber degradation under UV light and provides rigidity to the cell wall, while pectin acts as an inter-fiber bonding agent and waxy substances offer protective functions (Stamboulis et al., 2001; Pejic et al., 2008). However, the presence of pectin and wax can hinder fiber-matrix adhesion in composite materials (Aly et al., 2012). Cellulose, the primary constituent, exists in two forms (Cellulose I and II), with Cellulose II being stronger and more thermodynamically stable (Frącz et al., 2021). Alkali treatment, particularly with sodium hydroxide, can facilitate the transformation of Cellulose I to Cellulose II, leading to enhanced fiber properties (Van de Weyenberg et al., 2006).

Typha grass (*typha domingensis*) has been a significant concern for local farmers and

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manufacturing industries, causing substantial economic losses and disruptions due to its invasive nature. Its presence can impede movement and transportation, reduce crop yields, affect livestock production, and ultimately lead to decreased agricultural output and increased poverty. In response to these challenges, this study seeks to explore the potential of Typha grass fibers (TGF) extracted from typha domingensis as a sustainable reinforcement material for green composites, through characterization of both raw and treated fibers.

MATERIALS AND METHODS

Materials, fiber extraction and surface treatment

Typha grass leaves were sourced from Kura Town, Kano State, Nigeria. The leaves were cleaned with water to remove impurities and then subjected to a one-week soaking period in water under sunlight. Fibers were extracted from the leaves using a biological method (Ramesh et al., 2014). A portion of the extracted fibers underwent alkaline treatment with a 5% (w/v) NaOH solution for 90 minutes. Figure 1 below depicted the typha grass, extracted fiber treatment and the resulting choppy short fibers.

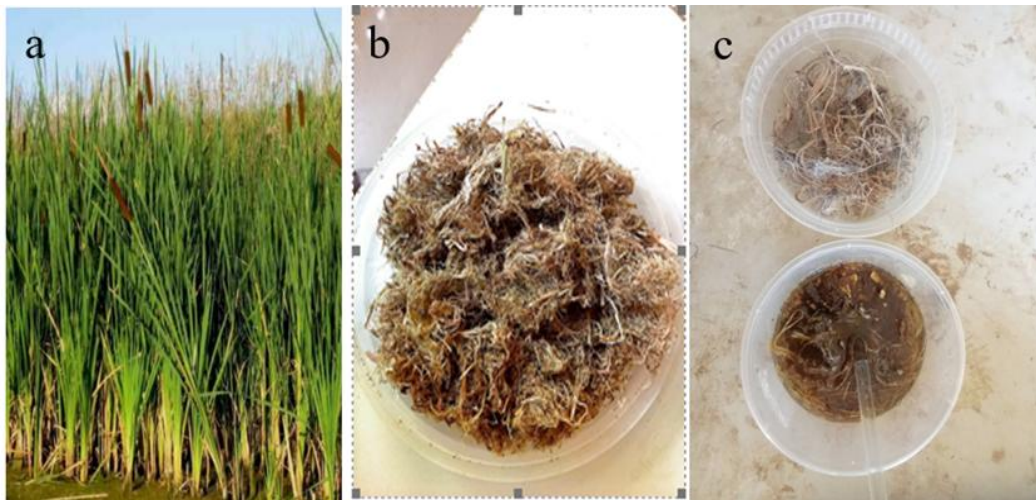


Figure 1: a) A Stand of Typha Grass Plant (Snapped at Kura, Kano State) b) Extracted choppy raw fiber c) Treated fiber with a 5% (w/v) NaOH

Determination of Density

The density of the TGF was determined using a pycnometer with distilled water as the immersion liquid. The fiber density was calculated using the following equation:

$$\rho_{\text{fiber}} = \left(\frac{m_2 - m_1}{(m_3 - m_1)(m_4 - m_2)} \right) \rho_w \dots \dots (1)$$

where m_1 , m_2 , m_3 , and m_4 are the masses of the empty pycnometer, pycnometer with fiber, pycnometer with distilled water, and pycnometer with both fiber and distilled water, respectively. ρ represents the density of distilled water. This method has been previously used in literature for similar measurements (Dawit et al., 2020; Hindi et al., 2025).

Determination of water absorption

Water absorption was determined following ASTM D570. Samples were dried to a constant weight and then immersed in distilled water at 23°C for 24 hours. After removal, excess

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water was wiped off, and the samples were weighed. This process was repeated until no further weight gain was observed. The percentage water absorption ($\%W_a$) was calculated using the following equation:

$$\%W_a = \left((W_f - W_{in}) / W_{in} \right) \times 100\%$$

where W_f is the final weight of the sample after immersion, and W_{in} is the initial weight of the sample before immersion.

Fourier transform-infrared (FTIR) spectroscopy analysis

FTIR analysis was conducted on the raw/treated TGF using a Shimadzu spectrometer, operating in transmittance mode within the spectral range of 400-4000 cm^{-1} . This technique allowed for the determination of the fiber's functional group composition.

Single fiber tensile test (SFTT)

The tensile properties of raw and treated TGFs were evaluated using a UTM, in accordance with ASTM D3379. The tests were conducted at a gauge length of 50 mm and a crosshead speed of 8 mm/min, with 20 samples tested (Hindi et al., 2025). The stress-strain curves for a subset of 4 representative samples are included in this paper.

RESULTS AND DISCUSSION

Density

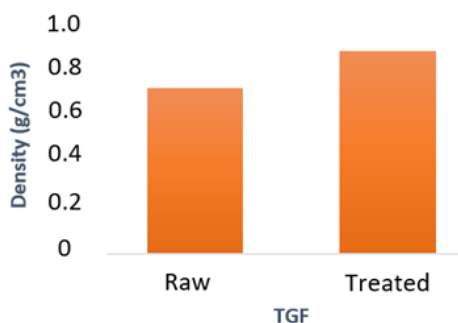


Figure 1: Density of Raw and Treated TGF

The volumetric density of the raw TGF was calculated to be 0.7 g/cm^3 , which increased to 0.85 g/cm^3 after NaOH treatment. As shown in Figure 1, the treatment resulted in a notable increase in density, likely due to the enhanced mass per unit volume of the fiber. This suggests that the NaOH treatment effectively modified the fiber's structure, leading to a more compact and dense material (Hindi et al., 2025).

Water absorption

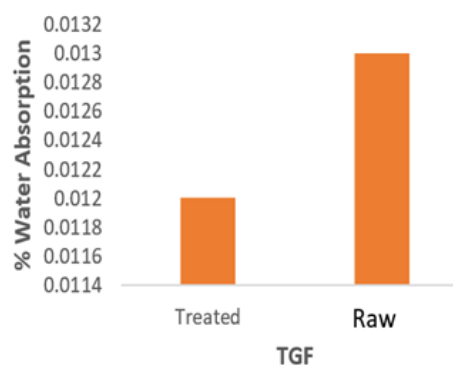


Figure 2: Water absorption of Raw and Treated TGF

The water absorption behavior of raw and 5% NaOH-treated Typha grass fibers (TGFs) is presented in Figure 2. The results show that the alkali-treated TGFs exhibited a 9% reduction in water absorption compared to the raw fibers. This decrease can be attributed to the removal of amorphous components (hemicelluloses, lignin, and other impurities) and improved surface characteristics after alkalization (Pokhriyal et al., 2024), leading to reduced water uptake. Similar findings were reported by Lazić et al. (2018), who observed that alkali treatment reduced hemicellulose content in flax fibers, thereby affecting their moisture absorption properties.

The tensile properties of Typha grass fibers were influenced by their chemical composition and structure, with alkali treatment leading to enhanced tensile strength and flexibility. The stress-strain curves for raw and NaOH-treated fibers are presented in Figures 4 and 5, respectively. The tensile strength of the raw fibers was comparable to other natural fibers, such as jute, sisal, and hemp. After alkali treatment, the tensile strength and toughness of the fibers increased, while the Young's modulus decreased. This improvement in tensile strength can be attributed to the removal of hemicellulose, lignin, and other impurities, resulting in well-ordered cellulose chains. The decrease in Young's modulus, on the other hand, suggests an increase in fiber flexibility, as evident from the increased percentage elongation at break. These findings indicate that alkali treatment produces a stronger and more flexible fiber.

CONCLUSIONS

This study demonstrates the potential of Typha grass fibers as a sustainable reinforcement material for composite applications. The NaOH treatment improved fiber properties, including increased density, enhanced water absorption resistance, and improved tensile strength and toughness. The treatment also reduced Young's modulus, indicating increased ductility. These findings suggest that Typha grass fibers can be a viable alternative to synthetic reinforcements. While further research is needed to optimize surface treatments, develop hybrid composites, and evaluate long-term durability, this study provides a foundation for the development of sustainable composite materials with potential eco-friendly engineering applications.

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