Potential for Biomass Valorization Through Torrefaction in Botswana: A Review

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Abstract

Botswana is a semi-arid country hence encourages the growth and propagation of various vegetation including family Leguminosae (Fabaceae) such as Prosopis mesquite which was initially introduced in Botswana to combat desertification and provide fodder but has however become a problematic specie which hinders biodiversity in areas of propagation and dominate over local flora. Biomass valorization is largely underexplored in Botswana despite the abundant presence of invasive biomass resources and need for sustainable energy solutions. Currently, the feasibility of converting local biomass to biofuels such as prosopis mesquite has not been fully assessed. As such, this study seeks to discuss the potential of biomass valorisation in Botswana through torrefaction using the invasive prosopis mesquite species as feedstock. To evaluate its potential for bioenergy conversion, its thermochemical and chemical properties are characterized by assessing key parameters such as lignocellulosic composition, thermal stability and calorific value so as to determine its overall energy density. Characterization of prosopis mesquite thickets is achieved using analytical techniques such as Fourier Transform Infrared Spectroscopy (FTIR) in which the functional group and chemical bonds related to biomass composition are identified, thermogravimetric analysis (TGA) examines thermal degradation patterns and bomb calorimetric analysis estimates energy content of biomass. This analysis provides insight on prosopis potential as feedstock for biofuel production. By turning an environmental challenge into an energy solution, this research offers a pathway for sustainable biomass valorisation that aligns with global climate goals and Botswana's Vision 2036.

Keywords: Torrefaction, Prosopis mesquite, Biomass Characterization.

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1. Introduction

Botswana confronts several problems in using biomass energy successfully. The absence of innovative biomass processing technology and infrastructure impedes the effective conversion of raw biomass into renewable energy products. Furthermore, a lack of research and regulatory frameworks for biomass energy development has hampered the country's capacity to properly utilize its substantial biomass resources.

Amongst many underutilized biomass material in Botswana is Prosopis mesquite, which exhibits drought resistance or tolerance due to its deep root system. Prosopis mesquite is an invasive tree largely found in the west part of Botswana. Prosopis species were introduced in various areas to solely counterpart desertification and improve quantity and quality of fodder resources in arid regions [1]. It is characterized by deep root system, the roots reach a depth of 20 to 25 m. These roots aid the mesquite to tap water from deep underground resulting in shortage of underground water as the water table reduces [2] and in cases where groundwater availability is insufficient, it absorbs humidity from the air. Current local methods to control the rapid propagation of Prosopis include pruning mature plants which has proven ineffective, as the plant continues to invade and thrive. The long dormancy period of Prosopis seeds, which can remain viable in the soil for up to ten years makes all traditional efforts to reduce its spread inevitable [3]. Moreover, the increasing urgency of climate change and land degradation has driven global interest in sustainable energy solutions. The production of solid biofuel is emerging as a promising avenue to mitigate climate change, produce renewable energy, and curb greenhouse gas emissions. Solid biofuel enhances energy security and reduces reliance on fossil fuels, making it a crucial element in the global transition to sustainable energy systems. In order to use prosopis mesquite as a biomass energy source, its biofuel properties should be enchanced as raw biomass exhibits high moisture content and low energy density [4] and as such hinders its efficiency as a fuel source. To improve these properties torrefaction emerges as a viable solution. Torrefaction is a pre-treatment technique that involves heating biomass in an oxygen-limited environment at temperatures typically ranging from 200°C to 300°C. This technique induces changes in biomass properties such as reduced moisture content, an increased HHV and increased hydrophobicity as observed in [5] report and these changes makes it more suitable for energy application.

1.1 Objective of the study

This research aims to explore the potential of prosopis mesquite as biomass feedstock for torrefaction by evaluating its thermochemical and chemical properties. Various methods of characterization are employed such as Thermogravimetric analysis to evaluate moisture content, fixed carbon, volatile matter and ash content. Use of Fourier Transform infrared spectroscopy to quantify the composition of functional group in biomass, determining the elemental composition (carbon, hydrogen, oxygen, nitrogen, sulfur) as well as quantifying caloric value of raw biomass. All this will be done in order to determine the energy potential of biomass and behavior during torrefaction.

2 Literature Review

Raw biomass of Prosopis mesquite often exhibits low energy density and poor fuel properties [6]. The quality of biomass as feedstock is determined through various thermochemical analysis. Proximate and ultimate analysis are largely used to examine solid biofuels quality. This determination is based on examining the chemical properties of prosopis mesquite based on fixed carbon, ash content, volatile matter and moisture content present in the feedstock. Moisture Content refers to the presence of water in biomass which can drastically affect its energy content, drying requirements, and combustion efficiency. High moisture content can lead to energy losses during combustion.

Figure 1: Prosopis mesquite bushes found in Botswana

In a study conducted by [7] it was established that a low moisture content is desired as high moisture content(MC) poses challenges during torrefact process hence the need for biomass pre-treatment in order of remove excess moisture from feedstock. An average range of 3% to 8% was observed for MC which was significantly lower than the 10- 12% recommended by O Norm M7135. Prosopis raw biomass exhibits high volatile matter content of 62-76% across various studies, a high volatile matter suggests an increased liquid yield which shows potential for condensable and non-condensable vapor generation [8]. [4] indicates that volatile matter composition decreases for formation of biochar, this is due to decomposition of cellulose and lignin. It was also established that low ash content is desired for efficient burning as a high ash content acts as a heat sink and results in reduced combustion efficiency.

In a study conducted by [4] the calorific value of prosopis was found to be 18.2 MJ/kg and [9] obtained 18.33MJ/kg calorific value of the same specie. Calorific value is a significant factor that indicates suitability for energy generation. Theoretically, the calorific value is expected to increase after torrefaction and this is influenced by the loss or release of volatile matter. This is proven by various studies where the calorific value increased to 29.43MJ/kg [4] and [10] indicates a calorific value of 24- 32.8 MJ/kg for temperature range of 300-800℃. The increase in HHV is a key indicator of the energy densification achieved through the process. Studies report that torrefaction significantly increases the energy density of biomass, making it more comparable to coal in terms of HHV. For example, torrefied biomass often shows an increase in HHV from around 15–19 MJ/kg for untreated biomass to 22–25 MJ/kg for torrefied material [11], depending on the feedstock [12].

FTIR is used to identify functional groups in the biomass, it highlights insight on the structural and chemical changes that occur to biomass during torrefaction. The approach is based on the idea that molecular vibrations happen at precise frequencies that correlate to the energy of infrared light. Research on Prosipis Africana, a member of the Prosipis species, was found to contain functional groups such as carboxylic acid, amines, alkanes, alkynes and other functional groups commonly found in plant biomass [11]

The suitability of biomass as feedstock is dependant on the lignocellulosic properties which according to [13] biomass with low lignin and high cellulosic and hemicellulosic content is preferred which most agricultural residue and plants exhibit.The calorific value of biomass before and after torrefaction is used to determine biomass suitability as feedstock.. The literature also discusses how different torrefaction temperatures and residence times affect the calorific value and emphasizes that higher torrefaction severity (longer time or higher temperature) increases energy content, but at the cost of reduced mass yield. Balancing these factors is crucial for process optimization.

Given the abundance and rapid growth as well as problematic nature in various areas of Botswana, Prosopis mesquite has emerged as a potential feedstock for biofuel production. However, its high lignin content can complicate the conversion process. Torrefaction can effectively mitigate these challenges by reducing lignin content, increasing the biomass' energy density, and enhancing its fuel properties. This transformation positions Prosopis mesquite as a viable candidate for sustainable biofuel production.

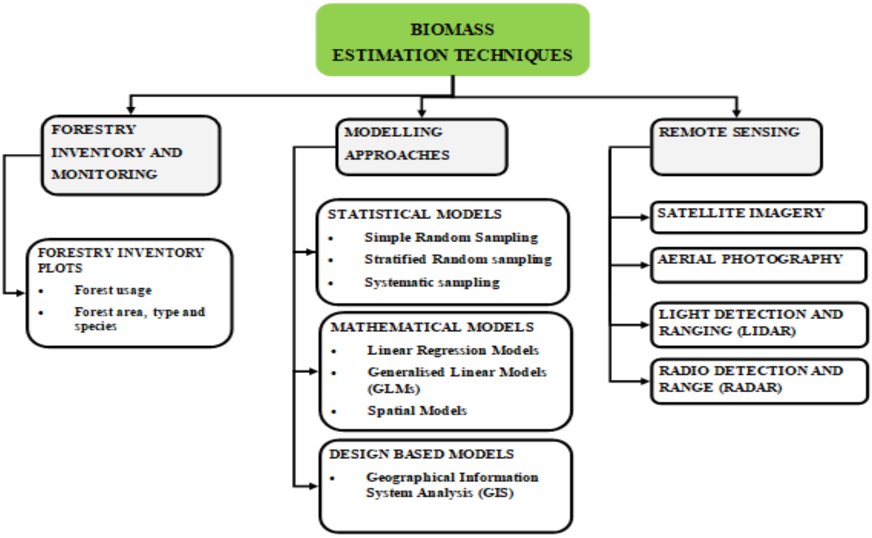

Figure 2: Biomass estimation techniques

3 Conclusion.

The potential for biomass valorization employing the torrefaction process in Botswana is high, with use of prosopis mesquite as the feedstock promising to aid in renewable energy sector in the nation, aligning with the Sustainable Development Goals (SDGs) as well combating the nonsensical nature they posed to the environment and biodiversity in the districts.

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5 Declaration of interest.

I confirm that there was no conflict of interest with any of the authors during this work.

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