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Suitability of Cassava Starch and Waste Paper Binders for Biomass Pellet: A Review Study

Erokare, E.T.,[1*] Umunna, M. F.,[1] Efe J. I.,[2] Nyorere O.,[1] Iweka S. C.,[3] Okoh, P.C.,[4] Ikoko, O.,[5] Ekwemuka, J.U.[6]

[1]Department of Agricultural and Bio-system Engineering, Southern Delta University, Ozoro
[2]Department of Mechanical Engineering, Igbenadion University, Okada
[3]Department of Mechanical Engineering, Southern Delta University, Ozoro
[4]Department of Civil and Water Resources Engineering, Southern Delta University, Ozoro
[5]Department of Agricultural and Bioenvironmental Engineering, Delta State Polytechnic, Ogwashi Uku
[6]Department of Computer Engineering, Southern Delta University, Ozoro

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ABSTRACT

Biomass is biodegradable organic matter originating from plants, animals, and microorganisms that is not derived from fossil sources. It can serve as a direct solid fuel for purposes such as cooking or be converted through various methods, including pyrolysis, gasification, and direct combustion, into biofuels and electricity, as well as for generating heat, steam, and mechanical or shaft power. The aim and objective of this research work is to review the suitability of cassava starch and waste paper as binders for biomass pellet production. From the literatures reviewed, handling, storing, processing, or transporting pellets may lead to the release of fines. The use of binders, which firmly hold the pellets together when introduced, has helped to alleviate these significant disadvantages over time. Particle sizes, compaction pressure, and the kind and type of binders used all significantly affect pellet quality. As a result, Cassava starch, a complex carbohydrate composed of numerous glucose units linked through glycosidic bonds, is a potential binder for pellet production. This review indicates that biomass is abundant and suitable for use as an energy source worldwide. The energy value and mechanical strength of biomass materials, including palm waste, rice husk, wood chips, sawdust, coconut shells, and other similar materials, are increased by pelletizing or briquetting them. In conclusion from the review, cassava starch and waste paper, when used as binders for biomass, demonstrated greater compressive strength and net heating value, which makes them more suitable for biomass palletization.

1. Introduction

Biomass is defined as non-fossil, biodegradable organic matter derived from biological sources such as plants, animals, and microorganisms. It represents the fourth-largest energy resource globally following coal, petroleum, and natural gas and is projected to contribute substantially to the

Corresponding Author: *Email address* erokaretega.e@gmail.com **(Erokare, E. T)**
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njetsefoe@gmail.com; njetsefoe@yahoo.com;

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global energy mix due to its renewability, carbon neutrality potential, and versatility in energy conversion technologies, and energy mix [1, 2]. Biomass materials encompass a wide range of substances, including products, by-products, residues, and wastes generated from forestry and agricultural activities, biodegradable, non-fossil components found in industrial and municipal waste streams. Common examples include trees, grasses, crops, agricultural residues, wood and wood-based waste, bagasse, discarded paper, municipal solid waste, food processing residues, aquatic plants and algae, and animal waste [3].

Biomass is a naturally occurring resource that, with proper management, can be harvested sustainably, making it a renewable energy source. It can be used directly as a solid fuel for cooking or converted through methods like pyrolysis, gasification, and combustion to generate biofuels, electricity, steam, heat for industrial processes, and mechanical energy. There are several clear drawbacks to using raw agricultural waste as fuel feedstock, such as the inability to regulate the biomass's rate of combustion, the supply of mechanized feed, the low heat density, the challenges of handling and transporting the stock, and the need for a lot of storage space. According to [3], the majority of these challenges stem from the low bulk density of agricultural waste. However, these obstacles can be overcome by compacting the waste into pellets, thereby enhancing its suitability as a fuel source.

However, from observations, handling, storing, processing, or transporting pellets may lead to the release of fines. The use of binders, which firmly hold the pellets together when introduced, has helped to alleviate these significant disadvantages over time. Particle sizes, compaction pressure, and the kind and type of binders used all significantly affect pellet quality. As a result, this paper reviews the suitability of cassava starch and waste paper as binders for biomass pellet production.

2.0 Palletization and Handling Properties of Biomass

2.1 Pelleting of Biomass

Cooking with wood fuel poses several health risks, particularly for individuals who are fully exposed to the smoke. These risks are especially pronounced in rural areas and other settings lacking proper ventilation. Studies have also revealed that the smoke released during the burning of biomass contains a lot of contaminants that, in varying quantities, are quite dangerous to people (4). Both children and adults are at higher risk for common ailments when exposed to biomass smoke. Smoke exposure has been linked to a higher risk of acute lower respiratory infections such as pneumonia in children [5, 6].

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To avoid these issues as well as those related to environmental contamination, these biomass materials can be compressed into denser products (such as briquettes or pellets), which will turn them into superior biofuel products. The thermo-mechanical process of palletization aims to raise the bulk density and particle size of solid materials [7]. Although a wide range of biomass types, including forest residues, agricultural and agro-industrial wastes, shells and hulls, cereal crops and straw, municipal solid waste, sewage sludge, and animal waste, are used in the fuel pelletization industry, softwood and hardwood woody biomass remain the most commonly utilized feedstocks (8).

Bio-pellets are utilized both in residential settings and in power generation facilities. Currently, their primary large-scale application is co-firing in coal-fired power plants. Since pellets can be easily pulverized into fine particles using existing coal grinding systems and directly injected for combustion, they are well-suited for integration with coal. This method provides a straightforward and cost-effective approach to lowering carbon dioxide (CO_2) emissions from coal-based power generation.

According to(9), global pellet production saw a substantial increase between 2013 and 2018, rising from under 30 megatons to over 50 megatons. Producing high-quality pellets is vital for various applications, and assessing their quality is a key factor in ensuring the sustainable and effective use of biofuels [10].

Recent studies have extensively reviewed the different types of briquetting and pelleting machines employed in the production of biomass briquettes and pellets (11). While biomass pellets (Figure 2.1b) are generally smaller than briquettes, they are also products of the densification process. These pellets are usually cylindrical, with diameters ranging from 3 to 27 mm and lengths between 3 and 31 mm [12]. Cylindrical briquettes, on the other hand, typically range from 18 to 55 mm in diameter and 10 to 100 mm in length [13,14 ,15]. However, it is important to note that no universally accepted standards clearly distinguish the dimensions of pellets from those of briquettes [16].

Fig. 2.1: (a-b) Depicts biomass briquettes and pelleted samples. Source: [13]

[17] noted that biomass pelleting plants are capable of producing pellets and briquettes in various shapes, such as square, hexagonal, and cylindrical. However, cylindrical pellets are the most commonly produced. The diameter of

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these pellets typically ranges from 3 mm to 8 mm, and can sometimes exceed this size, though they do not usually exceed 30 mm [18].

Pellets are one method of waste management. Pelleting can be utilized as a fuel source or as a shield against various environmental issues, depending on the substance of interest. Pellets of coal and agricultural waste, including rice husk and sawdust, can be used as cooking fuel [19].

Sawdust, one of the biomasses noted by [20], has a wet basis (WB) moisture content of 40% to 55%. Thus, when used to make pellets, it is dried to a moisture content of 10% to 15% (WB) [21]. The most popular method uses combustion gases in rotary drum dryers, which recover the energy in the moist gases by passing them through flue gas condensers. Such dryers and boilers are only utilized in large-scale industrial facilities due to their significant investment requirements. In these factories, drying is the second-largest expense after raw materials, accounting for around 25% of overall production costs [22,23].Pellet production was evaluated across four different operational scales: a large-scale facility with an annual output of 80,000 tonnes, a medium-scale plant producing 8,000 tonnes per year, a small-scale plant with a capacity of 800 tonnes annually, and a micro-scale plant generating 80 tonnes per year [22,24,20].

[17] highlighted that countries rich in forestry biomass have prioritized the development of biomass pelleting as a fuel source. In Sweden, for instance, densified biomass pellets contribute 46.7% to national energy use, within a 30% renewable energy mix. Across the European Union, biomass pellets are widely used and commonly found in supermarkets. Many EU countries have established technical standards, and the industry has reached a mature stage of commercialization. Similar trends are likely to emerge in regions like Asia-Pacific and Africa [25].

The physical properties of bio pellets are primarily determined by two factors: durability and density. Densified biofuels' mechanical durability indicates their ability to retain their integrity during handling and transportation; durability here refers to the biofuels' behavior regarding mechanical wear, which causes dust or fine particles to be produced during the transport and storage processes. The presence of dust and fine particles in biomass pellets can lead to several issues, including health hazards for users, operational problems like boiler feed blockages, and heightened risks of fire or explosion during handling, storage, and transport. Pellet quality is affected by factors such as moisture content, lignin concentration, feedstock particle size, and the conditions under which pelletization occurs. Enhancing the mechanical durability of bio pellets

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often involves the use of binders; however, this must be done carefully to avoid adverse environmental impacts and increased greenhouse gas emissions [26, 27].

According to published research, a variety of binders, including proteins, vegetable oils, sugary and starchy binders, and lignin, have been used for this purpose. Among the natural binder components of biomass, lignin serves to strengthen the material's mechanical durability. Syringyl and guaiacyl units, which make up the majority of the lignin in softwood species, are chemically distinct from those in hardwood lignin [27].

2.2 Handling Characteristics of Biomass Pellets

The assessment of pellet quality is a multifaceted process that involves evaluating various parameters, including diameter, length, bulk density, moisture content, ash content, volatile matter, fixed carbon, higher heating value, and thermal behavior. Effective handling practices play a pivotal role in the storage, transportation, and management of biomass pellets. The primary factors influencing these characteristics are the shape, density, and type of raw material utilized.

2.2.1 Factors Influencing Pellet Quality

Pellet density and durability are significantly influenced by several factors, including the physical and chemical properties of the feedstock, temperature, and pressure applied during pelletization, as noted by [28]. The type of pellet press employed also has a profound impact on pellet quality, with mechanical piston presses generally producing pellets with higher density compared to hydraulic piston presses, according to (17). However, increasing pellet density may be counterproductive, as it could negatively impact combustion performance.

The bulk density of commercial-grade pellets typically ranges from 550 to 700 kg/m³, depending on their size, although theoretical densities can reach up to 1200 kg/m³. The air-filled voids between pellets during storage lower their energy density, making them susceptible to handling and transportation challenges. The toughness against mechanical action, or brittleness, will vary depending on the source of material and production method.

2.2.2 Pellet Handling and Storage

Inspections at production facilities have shown that while hydraulic piston presses have encountered reliability challenges, mechanical piston presses have demonstrated satisfactory reliability. The type of pellet press utilized is another variable that affects the outcome, with hydraulic presses designed for small-scale production producing

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softer, more sensitive pellets. The pellets made with mechanical piston presses are more vulnerable to extraneous objects like screws or nails.

The resistance of pellets to humidity is a crucial component of their handling qualities, with pellets being prone to degradation in humid environments due to the water-soluble nature of their natural binding agents, as noted [29, 17]. This highlights the importance of proper storage and handling practices to maintain pellet quality.

2.3 Biomass Pellet Production

Biomass pellets are a popular renewable material for energy generation and transmission in both domestic and industrial settings due to their high energy content, compressive strength, durability, affordability, and accessibility, as reported by [30, 31, 32]. However, the performance of pellets depends on the kind of binder and the components utilized in the manufacturing process.

2.3.1 Binders for Pellet Production

The selection of binders is a critical aspect of pellet production, with a wide range of materials having been used to improve pellet quality, including starch, biosolids, microalgae, and lignosulfonates, as noted by [33, 34, 35]. The choice of binder and its quantity significantly impact pellet quality, with binders having higher cellulosic content potentially resulting in lower durability and energy content. The incorporation of binders has significantly mitigated the earlier disadvantages associated with pellet production, including the release of fines during handling, storage, processing, or transportation of pellets. Key factors influencing pellet quality include particle size, compaction pressure, and the type and characteristics of the binder used.

2.3.2 Advantages of Biomass Pelletization

The densification of biomass into fuel pellets with greater density than the original materials has garnered significant attention due to its numerous advantages, including ease of storage and transportation, consistent pellet or briquette shape and size, simplified feeding into industrial systems, enhanced thermal conversion efficiency, and a compact form suitable for handling and use, as reported by [31, 2, 36,32, 37]

2.3.3 Cassava Starch as a Binder

Cassava starch, a complex carbohydrate composed of numerous glucose units linked through glycosidic bonds, is a potential binder for pellet production. Cassava is a major source of starch, thriving in tropical regions with optimal climatic conditions for its cultivation. The starch content of

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njetsefoe@gmail.com; njetsefoe@yahoo.com;

cassava roots ranges from 12 to 33%, with sweet and bitter varieties predominantly grown due to their starch content. The composition of a cassava root consists of approximately 70% water, 24% starch, 2% fiber, 1% protein, and about 3% other components, including minerals. Starch granules in cassava vary in shape and size, with pure starch appearing as a fine, white, odorless powder that is insoluble in both.

3.0 Conclusion

The literature research indicates that biomass is abundant and suitable for use as an energy source worldwide. Numerous research studies have shown that the energy value and mechanical strength of biomass materials, such as sawdust, wood chips, rice husk, coconut shell, and palm wastes, can be enhanced through pelletizing or briquetting processes. The review affords the use of cassava starch and waste paper, when used as binders for biomass, demonstrates greater compressive strength and net heating value, andis more suitable for biomass palletization. Furthermore, the use of cassava starch and waste paper as binders for biomass pellets aligns with SDG 12 (responsible consumption and production) by fostering better resource management and enhancing waste disposal practices through prevention, reduction, recycling, and reuse.

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njetsefoe@gmail.com; njetsefoe@yahoo.com;

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njetsefoe@gmail.com; njetsefoe@yahoo.com;

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