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Revolutionizing Biofuel: A Novel Approach to Sustainable Briquette and Pellet Production

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Abstract: This study introduces a novel approach to producing high-efficiency briquettes and pellets using a combination of agricultural residues such as coconut husk, arecanut shell, and sawdust along with tamarind kernel powder (TKP) as a natural binding agent. The aim is to create sustainable biofuels that serve as eco-friendly alternatives to fossil fuels, addressing both environmental and energy security challenges. Prototypes were developed and tested for bulk density, calorific value, moisture content, and ash content. The results indicate that the pellets achieved a superior bulk density of 860 kg/m³ and a calorific value of 16,703 kJ/kg, surpassing many existing biofuel options. Additionally, the briquettes exhibited low ash content (4.1%) and competitive moisture levels (9.1% for pellets), making them efficient in combustion. This research highlights the potential of using inexpensive and abundant agricultural waste, enhanced with TKP, to produce biofuels that are both energy-efficient and environmentally sustainable. With localized production in resource-abundant regions, this approach can contribute to enhancing national energy security and reducing dependence on fossil fuels.

Keywords: Biofuels, Briquettes, Pellets, Renewable energy, Energy security

Energy security has become an increasingly critical issue in the context of global economic stability and development and growing global demand for energy, driven by population growth, urbanization, and industrial expansion, has intensified concerns about the sustainability of traditional energy systems, particularly those reliant on fossil fuels.

Fossil fuels, such as coal, oil, and natural gas, have been the dominant sources of energy worldwide, meeting approximately 80 percentage of global energy needs (Kpalo et al 2020). However, their rapid depletion and associated environmental pollution have become pressing global concerns. The gradual depletion of fossil fuel reserves has created significant challenges for energy security. Moreover, the environmental ramifications of fossil fuel extraction and consumption including greenhouse gas emissions and climate change are of growing concern. The need to transition to more sustainable and cleaner forms of energy is becoming ever more urgent.

In this scenario, biofuels have emerged as a viable solution for addressing both the sustainability of energy supplies and environmental concerns. Biofuels are renewable energy sources derived from biological materials, including agricultural residues, forestry waste, and other biomass resources. By harnessing these materials, biofuels offer the potential to reduce dependency on finite fossil fuels while promoting a more sustainable energy future. Biomass and biofuels are emerging industries, driven by a growing demand for sustainable fuel alternatives (Obi et al 2013). Among the various forms of biofuels, solid biofuels-specifically briquettes and pellets-stand out as efficient and versatile alternatives. Briquettes and pellets are produced by compressing biomass into compact, energy-dense forms that can be easily transported, stored, and used for a range of applications, from residential heating to industrial energy production. Their utilization helps mitigate waste from agricultural and forestry processes while providing a renewable and low-carbon energy source.

Briquetting leverages a natural process, utilizing a natural binder found in all biomass. Lignin, a solid component of biomass, transforms into a liquid under high pressure and heat, binding waste materials together to create high-density biofuel. A briquette is a block of combustible material used as fuel for starting and maintaining fires (Surajo and Mustapha 2017). The relevance of briquettes and pellets in modern energy systems is particularly notable in regions that rely heavily on traditional biomass for cooking and heating. Additionally, the localized production of briquettes and pellets can contribute to rural economic development, creating jobs and fostering energy independence.

Biomass briquettes and pellets have emerged as some of the most efficient energy sources. Variety of waste materials have been employed to produce these fuels. Municipal solid waste has been used to replicate biomass briquettes for on-site energy production (Romallosa and Kraft 2017). Sawdust, date palm trunks, and various crop residues have been used to create biomass briquettes without requiring a binding agent (Garrido et al 2017).

Biofuels like briquettes and pellets play a crucial role in addressing climate change due to their carbon-neutral nature. The carbon released during combustion is balanced by the carbon absorbed by plants, creating a closed cycle, unlike fossil fuels that release long-stored carbon. As fossil fuel reserves deplete, biofuels are emerging as essential renewable alternatives in global energy strategies (World Economic Forum 2023).

This study develops high-efficiency briquettes and pellets using agricultural waste and tamarind kernel powder (TKP) as a natural binder. The prototypes are designed to deliver improved calorific value and energy efficiency while supporting sustainable energy production, waste reduction, and energy security in the region. Tamarind kernel powder (TKP) is a polysaccharide extracted from the endosperm of tamarind seeds (*Tamarindus indica Linn*). This TKP-based gum is a valuable thickening and stabilizing agent with diverse applications. TKP is widely available and economically viable. It is used as an additive, preservative, gelling agent, solidifying agent, binding agent, and stabilizer (Bhavini et al 2018). The combination of these raw materials is expected to result in briquettes and pellets with a higher calorific value compared to those currently available in the market. To create both briquettes and pellets, separate machinery was utilized for each process. The collected raw materials were transported to specialized briquette and pellet production facilities located in the Kolar district of Karnataka, where prototypes were successfully produced for testing and analysis. The objectives of this study are to develop high-efficiency briquettes and pellets using agricultural waste and TKP to enhance calorific value and promote sustainable energy production and support regional energy security.

MATERIAL AND METHODS

Study location and resources: This study focused on the production of briquettes and pellets from agricultural wastes, specifically coconut husk, arecanut shell, and sawdust, mixed in equal proportions. To produce the prototype for testing, 3 kilograms of each raw materials were utilized. The raw materials were sourced from the Davangere (14.0° N to 14.6° N and 75.9° E to 76.4° E) and Tiptur (13.0° N to 13.3° N and 76.5° E to 76.8° E) regions of Karnataka, known for their high production of these agricultural by-products. In addition to these materials, tamarind kernel powder was incorporated as a natural binding agent to enhance both the binding capacity and density of the final products.

Methodology

Briquettes and pellets production: The following methods were employed to produce briquettes and pellets:

Drying: The raw material must be dried to a suitable moisture content before processing. The ideal moisture content varies depending on the type of raw material and the equipment used. Generally, agricultural waste and wood require a moisture content of 8-12%, while mechanical piston presses can handle up to 15% moisture, and hydraulic systems can handle up to 15-30%.

Pulverization: The raw material must be reduced to a suitable particle size before it enters the densification process. The particle size should not exceed 25% of the diameter of the final product for most densification equipment.

Pre-conditioning: To make the raw material softer and easier to work with, superheated steam is often added between the pulverization and densification stages. This conditioning process improves the binding properties of the material and helps prevent the briquettes from falling apart. For pelletizing, a small amount of water and TKP (about 10% and 8% of the raw material weight) is added to the mixture.

Compression of raw materials: The study used a hydraulic press process, which involves compacting the biomass in both the vertical and horizontal directions. The standard briquette weight is 4-6 kg, with dimensions of 450 mm x 160 mm x 80 mm. The power required for briquetting is 37 kW for 1800 kg/h. Pelletizing is a similar process but uses smaller dies to produce cylindrical briquettes between 5-10 mm in diameter and 50 mm in length. The pelletizer has a number of dies arranged as holes bored on a thick steel disk or ring, and the material is forced into the dies by means of two or three rollers. Pellets have good mechanical strength and combustion characteristics.

Cooling: To prevent briquettes from breaking apart, piston press systems often have a cooling track where the material can slowly cool down before being cut to the desired length.

Storing and Transporting: After cooling, the briquettes and pellets are typically stored before combustion. Storage can take place outdoors under a roof, indoors, in containers, or other methods.

Production of TKP: The following are the steps to produce TKP (Bhavini et al 2018)

Cleaning: The kernels are first cleaned to remove dirt and debris with vibrating cleaner machine is used to separate and discard small and large particles.

Roasting: The shell coating of the kernel is firmly attached and needs to be softened. Roasting is an important process that helps to separate the shell from the endosperm and also reduces the water content in the TKP.

Separation: Once the shell is softened, it can be removed from the kernel. The shell is more brittle than the kernel, making separation easier. This step is essential as the shell is not suitable for use in various applications.

Grinding: The separated kernels are then ground in ball mills to produce a fine, smooth powder.

Screening: The ground powder is screened through screens of less than 50 microns to ensure a uniform particle size. This is important to prevent clogging during application and ensure even spreading of the thickener.

Testing and analysis: For testing and analysis, the study conducted various proximate analyses to evaluate the quality and performance of the briquettes and pellets. This included the determination of moisture content, bulk density testing, and calorific value assessment (Bhujbal et al 2023). These tests were carried out in a systematic and scientific manner to obtain accurate and reliable results that would validate the efficiency and suitability of the produced briquettes and pellets for practical applications.

Moisture content: The moisture content of the briquettes was measured using the ASAE Standard S358.2 for forage. Two-grams of samples was oven dried for 24 hours at 105 ± 2°C until their mass remained constant. These tests were conducted at the Seed Testing Laboratory of the University of Agricultural Sciences, Bangalore.

Density test: The test is performed in accordance with the guidelines specified by ISO 18847:2016**,** which provides the standard procedures for determining the bulk density of solid biofuels. The bulk density testing was conducted at the laboratory of the National Centre for Biological Studies, Bangalore.

Calorific value: A bomb calorimeter was used to measure the calorific value of the ground material. The calorimeter consists of a bomb, a metal container, and a thermally insulated jacket. A temperature transducer inside the unit records temperature changes during fuel combustion with cooling system. The gross calorific value was determined experimentally by combusting 2 grams of sample under specific conditions in a bomb calorimeter according to the ASTM D2015-96 standard. The test was conducted at the Bioenergy Research and Quality Assurance Laboratory of the University of Agricultural Sciences, Bangalore.

RESULTS AND DISCUSSION

The proximate analysis results for the biomass residues and coal reveal significant insights into the efficiency and potential of the developed prototypes.

Bulk density performance: The bulk density measurements indicate that the pellets exhibit the highest density at 860 kg/m³, which signifies a high degree of compaction. This enhanced density is attributed to the pelletizing process and the incorporation of tamarind kernel powder (TKP) as a binding agent, demonstrating that the prototype briquettes and pellets are more compact compared to both the biomass residues and coal. Among the biomass residues, the ASC prototype, composed of arecanut shell, sawdust, and coconut husk, also shows a higher bulk density of 302 kg/m³ compared to the GSB formulation, which has a density of 282 kg/m³. This suggests that the ASC mixture benefits from improved compaction and binding properties, potentially due to the optimal combination of its constituent materials. Ideal briquettes possess low moisture content, high density, and high calorific value (Arewa et al 2016).

Moisture content: The ideal moisture content for briquetting depends on the specific feedstock. However, recommend general range of moisture content is 8-12% (FAO 1996). The moisture content of the prototypes reveals that the pellets have the lowest moisture content at 9.1%, which is advantageous for combustion efficiency, as lower moisture content generally results in higher energy output and better performance. In comparison, the ASC prototype has a moisture content of 12.1%, which is slightly higher than the GSB residue's moisture content of 10.7%. ASC's moisture content is somewhat higher, but remains within an

Table 2. Ash content of various biomass

Biomass	Ash content (%)
Saw dust	1.3
Arecanut shell	5.1
Coir pith	6.0
Groundnut shell	6.0
Eucalyptus biomass	6.2*
Coal	25.0-45.0**

Source: FAO -Field Document No.46 1996
*Muhdi et al (2019). **PIB -Ministry of Coal report (2018)

Table 1. Proximate analysis of biomass samples

Parameters	Units	Biomass samples			
		GSB	ASC	Pellets	Coal
Bulk density	kg/m^3	282	302	860	492
Moisture content	%	10.7	12.1	9.1	7.9
Gross calorific value	kJ/kg	10536	13587	16703	28874
Ash content*	%	4.5	4.1	4.1	35

GSB: Groundnut shell, Saw dust and Biomass; ASC: Arecanut shell, Saw dust and Coconut husk are the various combination of raw materials used for making the briquettes; *Authors calculations, based on the average values in Table 2.

acceptable range for biomass fuels. Both prototypes have higher moisture content compared to coal, which has a moisture content of 7.9%. Despite this, the improved compaction and calorific value of the prototypes may mitigate the impact of their slightly higher moisture content.

Calorific value: The highest energy content at 28,874 kJ/kg, were observed in coal reflecting its high energy density. However, given the environmental concerns associated with coal, the focus shifts to the biomass-based prototypes. Among the prototypes, the pellets demonstrate the highest calorific value of 16,703 kJ/kg, indicating that the innovative use of agricultural residues and TKP results in a fuel with substantial energy content. This makes the pellets a competitive alternative in terms of energy output. The calorific value of the briquette is reported between 13000-16000 kJ/kg (Gill et al 2018). The ASC prototype also exhibits a significant calorific value of 13,587 kJ/kg, which is notably higher than that of the GSB residue, which has a calorific value of 10,536 kJ/kg. Although neither prototype matches coal's calorific value, their use of inexpensive agricultural residues and TKP presents a viable and sustainable alternative.

Ash content and combustion efficiency: Ash content refers to the non-combustible residue left after the material has been burned, and lower ash content is generally desirable as it indicates a cleaner, more efficient fuel with fewer emissions and waste. A low ash content is preferable in biomass, as levels exceeding 4% can lead to slagging (Kaliyan and Morey 2009). The ideal ash content of biomass briquettes is in range of 0.91 to 5.44% (Arulkumar et al 2019).

Both the ASC and pellet prototypes have relatively low ash content (4.1%). This suggests that these prototypes produce minimal residue during combustion. The low ash content also indicates that a larger proportion of the biomass material is converted into energy during combustion, enhancing the overall efficiency of these fuels. The GSB biomass residue also exhibits a slightly higher ash content at 4.5%, which, while marginally higher than the ASC and pellet samples, still represents a low ash output. This makes GSB a fairly efficient fuel, although the ASC and pellet prototypes demonstrate slight advantages in terms of cleaner combustion. In stark contrast, coal has an ash content of 30%, which is significantly higher than any of the biomass samples. This high ash content reflects one of the major drawbacks of coal as a fuel source, as it leads to higher emissions, more waste, and greater environmental harm. The ash generated from coal combustion also contributes to pollution and requires more frequent maintenance in industrial systems, adding to its overall environmental footprint. The substantially lower ash content of the ASC and pellet prototypes highlights their superiority over coal in terms of environmental impact and combustion cleanliness. These results further underscore the value of using agricultural residues as an alternative fuel source, offering a more sustainable and efficient option with far fewer negative environmental consequences. Overall, the ASC and pellets prototypes display promising characteristics in terms of bulk density, ash content and calorific value, highlighting their potential as effective alternatives to traditional fossil fuels. The research underscores the innovative approach of utilizing agricultural waste and TKP to enhance the efficiency and sustainability of biomass fuels.

Environmental sustainability and energy security: In addition to the proximate analysis results, the regional assessment of crop residues in Karnataka reveals a substantial opportunity for local briquette and pellet production. The state's diverse agricultural wastes offer a robust foundation for producing sustainable and efficient biofuels.

The widespread availability of agricultural by-products across Karnataka highlights the feasibility of utilizing these resources for biofuel production. The cost analysis of briquettes and pellets reveals a significant economic advantage over coal. Briquettes are priced at approximately ₹8-12 per kg, and pellets at ₹18-21 per kg, while coal ranges between ₹30-40 per kg. This cost difference highlights the affordability of biomass fuels, making them a competitive alternative to coal. Furthermore, the raw materials used for the prototypes-agricultural residues like arecanut husk, coconut husk, and sawdust are not only locally sourced but also sustainable, reducing dependence on non-renewable resources. By utilizing these inexpensive, widely available raw materials, biomass fuels offer both cost-effectiveness and environmental benefits. The presence of several start-ups in the state dedicated to this field further emphasizes the potential for innovation and local engagement. Combining various agricultural residues, with sawdust emerging as a crucial component, can enhance the quality and efficiency of the biofuels produced. Effective promotion and support for indigenous biofuel production can significantly impact the country's energy security (Patil 2020). By leveraging local resources and fostering a robust biofuel industry, Karnataka can contribute to a more sustainable energy future and reduce dependence on fossil fuels.

CONCLUSION

This study evaluated the efficiency of biomass-based prototypes such as ASC (Arecanut Husk, Sawdust, and Coconut Husk) and pellets developed from agricultural residues in comparison to traditional coal. The prototypes exhibited superior performance in terms of compaction,

Table 3. Region-wise potential crop residues for briquettes and pellets production in Karnataka

Region	Districts	Potential crop residue for briquettes and pellets	Approximate calorific value (~kcal/kg)
North Karnataka (15.0° N to 17.9° N and 74.1° E to 77.5° E)	Bagalkote, Ballari, Vijayanagara, Belagavi, Bidar, Gadaga, Koppala, Kalaburagi, Raichuru, Vijayapura, Yadgiri	Groundnut Shell, Paddy husk, Maize cobs and stalk, Chilli, Red gram and Cotton stalks and residues, Sugarcane Bagasse, Mesquite twigs	3100-4500
East Karnataka (12.9° N to 13.9° N and 77.4° E to 78.4° E)	Kolara, Chikkaballapura	Coconut husk, Eucalyptus, Acacia, Chilli stalk, Mesquite twigs	3500-4500
West Karnataka (14.0° N to 16.0° N and 74.3° E to 76.8° E)	Uttara Kannada, Dharwada, Belagavi, Haveri	Paddy husk, Eucalyptus, Acacia, Sugarcane Bagasse, Red gram stalk, Maize cobs and stalk, Chilli stalk	3200-4200
South Karnataka (12.0° N to 14.5° N and 76.5° E to 77.5° E)	Bengaluru Rural, Bengaluru Urban, Ramanagara, Tumakuru, Mandya, Mysuru, Chamarajanagara	Sugarcane Bagasse, Arecanut husk, Coconut husk, Paddy husk, Tamarind husk	3400-4500
Malnad Region (13.0° N to 15.5° N and 75.5° E to 76.8° E)	Chikkamagaluru, Kodagu, Hassan, Shivamogga	Bamboo, Eucalyptus, Acacia, Coffee husk, Coconut husk, Arecanut husk, Paddy husk, Maize cobs and stalk	3500-4400
Central Karnataka (14.0° N to 15.5° N and 75.5° E to 76.5° E)	Davanagere, Chitradurga	Arecanut husk, Maize cobs and stalk, Coconut husk, Paddy husk, Mesquite twigs	3500-4200
Coastal Karnataka (12.5° N to 14.0° N and 74.5° E to 75.5° E)	Udupi, Dakshina Kannada	Coconut husk, Paddy husk, Arecanut husk	3500-4400

combustion efficiency, and environmental impact. The use of tamarind kernel powder (TKP) as a binding agent contributed to improved density and structural integrity. The prototypes also showed competitive moisture content, supporting efficient combustion, and demonstrated significant advantages in terms of cleaner combustion with lower ash content compared to coal. These findings underscore the potential of these biofuels as sustainable alternatives to fossil fuels. Furthermore, the abundant availability of agricultural residues in Karnataka highlights the feasibility of local biofuel production, contributing to energy security and environmental sustainability.

REFERENCES

Arewa ME, Daniel IC and Kuye A 2016. Characterization and comparison of rice husk Briquettes with Cassava peels and cassava starch as binders. *Biofuels* **7**(6): 671-675.

Arulkumar R, Kanagasabapathy H and Neethi MI 2019. Combination of agricultural waste and saw dust into biomass material for Briqutte. *Indian Journal of Ecology* **46**(1): 188-191.

Arya B, Akshay B, Ayush P, Abhishek G, Rajendra C and Shubham M 2023. Biomass briquette as source of energy. *International Research Journal of Modernization in Engineering Technology and Science* **5**(4): 2901-2906.

Bhavini IS, Farida PM 2018. Benefits of Tamarind Kernel Powder: A natural polymer. *International Journal of Advanced Research* **6**(3): 54-57.

Dhanraj AP 2020. Mainstreaming biofuels in India: Analysing weaknesses and opportunities for the sustainability of biofuel and its future policy making. *Indian Journal of Ecology* **47**(2): 543-548.

Food and Agriculture Organization of The United Nations 2024. [https://www.fao.org/4/ad579e/ad579e00.pdf] Accessed on: September 20, 2024.

Garrido MA, Conesa JA and Garcia MD 2017. Characterization and production of fuel briquettes made from biomass and plastic wastes. *Energies* **10**(7): 850-860.

Gill N, Dogra R and Dogra B 2018. Influence of moisture content, particle size, and binder ratio on quality and economics of rice straw briquettes. *Bioenergy Research* **11**(1): 54-68.

Kaliyan N and Vance MR 2009. Factors affecting strength and durability of densified biomass products. *Biomass and Bioenergy* **33**(3): 337-359.

Kpalo SY, Zainuddin MF, Abd ML and Roslan AM 2020. Production and characterization of hybrid briquettes from corncobs and oil palm trunk bark under a low-pressure densification technique. *Sustainability* **12**(6): 2468.

Muhdi AS, Hanafiah DS, Zaitunah A and Nababan FWB 2019. Analysis of biomass and carbon potential on eucalyptus stand in industrial plantation forest, North Sumatra, Indonesia. **In:** IOP Conf. Series: Earth and Environmental Science, Proceedings of *The 8th International Symposium for Sustainable Humanosphere*, October 18-19, 2018, Medan, Indonesia.

Obi FO, Busayo SA and Aneke NN 2014. Biomass briquetting and rural development in Nigeria. *International Journal of Sciences, Environmental and Technology* **3**(3): 1043-1052.

Press Information Bureau of India. [https://pib.gov.in/PressReleasePage.aspx?PRID=1515278] Accessed on: September 19, 2024.

Romallosa ARD 2017. Quality analyses of biomass briquettes produced using a Jack-Driven briquetting machine. *International Journal of Applied Science and Technology* **7**(1): 8-16.

Surajo N and Mustapha A 2017. Construction of a moulder and production of biomass briquette from bagasse for use as a fuel. *International Journal of Scientific Research Engineering and Technology* **6**(9): 1006-1012.

World Economic Forum. [https://www.weforum.org/agenda/2023/12/biomass-waste-sustainable-fuels-carbon-climate-change/] Accessed on: September 20, 2024.

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