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EXPERIMENTAL INVESTIGATION ON UTILIZATION OF AGRICULTURAL CROP RESIDUE AND PLASTIC MULCHING WASTE FOR PELLET PRODUCTION

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Abstract- The rising demand for renewable energy sources and the need for effective waste management have driven research into alternative bioenergy solutions. This study investigates the production and characterization of energy-dense pellets made from agricultural crop residues (wheat straw, rice husk, maize straw, mustard stalk, and lemongrass) blended with plastic mulching waste. Pellets were prepared in varying biomass-to-plastic waste ratios (85:15, 90:10, and 95:5) and analyzed for physicochemical properties such as proximate analysis, calorific value, bulk density, and stability. Results indicated that the addition of plastic waste enhanced the calorific value and mechanical durability of the pellets. Among the biomass types, lemongrass and mustard stalk demonstrated superior performance due to their low ash content, high fixed carbon, and stability. The findings highlight the potential of integrating plastic waste with agricultural residues to produce high-quality pellets for sustainable energy applications.
Keywords: Renewable Energy Sources, biomass, agricultural residues.

1. INTRODUCTION

The global energy sector is facing unprecedented challenges due to the depletion of fossil fuel reserves, rising greenhouse gas emissions, and increasing energy demands [1–3]. These emphasize the urgent need for transitioning to sustainable and clean renewable energy solutions [4–6]. Biomass, a renewable resource derived from agricultural residues, offers a promising alternative for energy generation [6–8]. However, raw biomass suffers from limitations such as low calorific value, high moisture content, and poor mechanical properties, which hinder its large-scale utilization as a fuel [9–11].

On the other hand, plastic mulching waste, a widely used material in modern agriculture, poses severe environmental issues due to its non-biodegradable nature [12]. Integrating plastic waste with agricultural residues for pellet production presents a dual advantage of effective waste management and improved pellet performance [13–15]. Pellets, owing to their uniform size, high energy density, and ease of transportation, are increasingly recognized as a versatile biofuel [16,17].

This study aims to evaluate the potential of agricultural crop residues combined with plastic mulching waste to produce high-quality pellets. The investigation focuses on understanding the impact of different biomass-to-plastic ratios on the physicochemical properties of the pellets, including proximate analysis, calorific value, bulk density, and stability. The research provides insights into the optimization of biomass-plastic mixtures for sustainable energy applications.

2. MATERIALS AND METHODS

2.1 Selection of Raw Materials

The biomass used in this study included wheat straw, rice husks, maize straw, mustard stalk, and lemongrass, all of which were sourced locally from agricultural fields. These residues were selected for their abundance and potential as bioenergy feedstocks. Plastic mulching waste, primarily low-density polyethylene (LDPE), was collected from agricultural fields, cleaned, and shredded into small pieces to facilitate uniform mixing with the biomass.

2.2 Pellet Preparation

The preparation of pellets was carried out using a flat-die pellet mill. Biomass residues were dried to reduce moisture content and shredded into smaller pieces to ensure homogeneity. The materials were mixed with shredded plastic waste in three ratios: 85% biomass + 15% plastic, 90% biomass + 10% plastic, and 95% biomass + 5% plastic. The mixtures were conditioned by adding water to achieve an optimal moisture content of 10–12%. The conditioned mixtures were fed into the pelletizing machine, where they were subjected to high pressure and elevated temperatures (120–140°C) to form cylindrical pellets with a consistent size of 20 mm in length and 6 mm in diameter. The addition of plastic waste aimed to enhance the binding properties, calorific value, and mechanical durability of the pellets. The prepared pellets were collected, cooled, and stored in dry conditions for subsequent analysis.

2.3 Physicochemical Characterization

2.3.1 Proximate Analysis

The moisture content, volatile matter, ash content, and fixed carbon of the pellets were determined using standard procedures [18,19]. Dried pellet samples were analyzed using a muffle furnace for volatile matter and ash content measurements, while fixed carbon was calculated by subtracting the other components.

2.3.2 Calorific Value

The higher heating value (HHV) of the pellets was measured using an automatic digital bomb calorimeter [12]. Approximately 1 g of powdered pellet sample was burned in an oxygen-rich environment at 25 atmospheric pressure, and the calorific value was directly recorded.

2.3.3 Bulk Density

The bulk density of the pellets was determined by filling a cylindrical container with the pellets, leveling the surface, and measuring the weight-to-volume ratio [20].

2.3.4 Stability

Pellet stability was assessed by measuring the pellet length immediately after production, after one week, and after two weeks of storage. A Vernier caliper was used for precise length measurements, and stability was expressed as the percentage reduction in length over time.

3. RESULTS AND DISCUSSION

3.1 Proximate Analysis

The proximate analysis revealed significant variations in the physicochemical properties of the pellets based on the biomass type and plastic content. As shown in Table 3.1, lemongrass pellets with 85% biomass and 15% plastic exhibited the lowest ash content (6.8%) and the highest fixed carbon (14%), indicating superior combustion properties. Conversely, rice husk pellets had the highest ash content (15%), which could hinder their energy efficiency.

Table-3.1 Proximate Analysis of Pellets

Biomass Type	Moisture Content (%)	Volatile Matter (%)	Ash Content (%)	Fixed Carbon (%)
Wheat Straw	8.5	70.2	8.3	13.0
Rice Husk	9.0	65.0	15.0	11.0
Maize Straw	8.0	72.0	7.5	12.5
Mustard Stalk	9.5	68.5	8.0	14.0
Lemongrass	8.2	71.0	6.8	14.0

3.2 Calorific Value

The addition of plastic waste significantly enhanced the calorific value of the pellets. Table 3.2 shows that lemongrass pellets with 15% plastic waste achieved the highest calorific value (17.87 MJ/kg), followed by mustard stalk and wheat straw pellets. This improvement can be attributed to the higher energy content of plastic compared to biomass.

Table-3.2 Calorific Value of Pellets (MJ/kg)

Biomass Type	85% Biomass + 15% Plastic	90% Biomass + 10% Plastic	95% Biomass + 5% Plastic
Wheat Straw	17.39	16.53	15.82
Rice Husk	16.95	16.11	15.39
Maize Straw	17.27	16.43	15.70
Mustard Stalk	17.59	16.34	15.90
Lemongrass	17.87	17.16	16.24

3.3 Bulk Density

Bulk density is a critical parameter for evaluating the storage, transportation, and energy efficiency of pellets. Higher bulk density ensures that more energy can be stored and transported per unit volume, reducing logistical costs. The results, presented in Table 3.3, indicate that the bulk density of the pellets increased with a higher proportion of plastic waste. This can be attributed to the improved binding properties of the plastic, which enhanced the compactness of the pellets during the pelletization process. Among the tested biomass types, lemongrass pellets exhibited the highest bulk density (820 kg/m³) at 85% biomass and 15% plastic. Mustard stalk pellets also showed a comparable bulk density of 790 kg/m³, making them suitable for energy storage and transportation. In contrast, rice husk pellets had the lowest bulk density (720 kg/m³), likely due to their coarse texture and high ash content.

Table-3.3 Bulk Density of Pellets (kg/m³)

Biomass Type	85% Biomass + 15% Plastic	90% Biomass + 10% Plastic	95% Biomass + 5% Plastic
Wheat Straw	800	780	750
Rice Husk	720	700	680
Maize Straw	770	750	730
Mustard Stalk	790	770	750
Lemongrass	820	800	770

The trend demonstrates the significant role of plastic content in improving bulk density. Lemongrass, with its inherent high volatile matter and low ash content, achieved the best compactness, making it ideal for bioenergy applications.

3.4 Stability

Stability is an essential property for evaluating the mechanical durability of pellets during storage and handling. Length reduction over time was measured to assess the resistance of pellets to deformation. The results, summarized in Table 3.4, show that pellets with higher plastic content (15%) exhibited minimal length reduction, indicating superior mechanical stability. Lemongrass and mustard stalk pellets demonstrated the least reduction (0–0.5%) after two weeks, maintaining their structural integrity under ambient conditions. In contrast, rice husk pellets showed the highest length reduction (up to 2%) at lower plastic content, reflecting weaker binding properties.

Table-3.4 Stability of Pellets

Biomass Type	Initial Length (mm)	Length After 1 Week (mm)	Length After 2 Weeks (mm)	Length Reduction (%)
Wheat Straw	20.0	19.9	19.9	0.5
Rice Husk	20.0	19.8	19.6	2.0
Maize Straw	20.0	19.9	19.8	1.0
Mustard Stalk	20.0	20.0	20.0	0.0
Lemongrass	20.0	20.0	20.0	0.0

The data confirm that higher plastic content contributes to better durability. The stability of lemongrass and mustard stalk pellets can be attributed to their intrinsic structural properties and enhanced binding with plastic waste. These results highlight the suitability of such pellets for long-term storage and transportation.

CONCLUSION

This study highlights the viability of integrating agricultural crop residues with plastic mulching waste to produce energy-efficient and durable bioenergy pellets. The results demonstrated that the optimized blend of 85% biomass and 15% plastic significantly improved key pellet properties. Lemongrass pellets exhibited the best performance, with the lowest ash content (6.8%) and highest fixed carbon (14%), indicating superior combustion properties. The addition of plastic waste notably enhanced the calorific value, with lemongrass pellets achieving the highest value of 17.87 MJ/kg. The highest bulk density (820 kg/m³) was also recorded for lemongrass pellets, ensuring cost-effective storage and transport. Furthermore, pellets with 15% plastic content showed exceptional mechanical stability and durability, with minimal length reduction over two weeks, making them highly suitable for energy applications. These findings emphasize the potential of this innovative approach in addressing waste management challenges while advancing bioenergy solutions.

PRACTICAL IMPLICATIONS

The results highlight the feasibility of integrating plastic mulching waste with agricultural residues for producing high-quality pellets. This approach not only enhances the energy potential of biomass but also provides a sustainable solution for managing agricultural and plastic waste. The findings suggest that lemongrass and mustard stalk are the most promising biomass types for pellet production due to their superior physicochemical properties.

FUTURE SCOPE

While the study demonstrated promising results, further research is required to optimize the biomass-to-plastic ratio for maximizing energy efficiency and minimizing emissions during combustion. Additionally, life cycle analysis and emissions testing should be conducted to assess the environmental impacts of using plastic waste in bioenergy production.

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