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# Development and Characterization of Biomass Pellets Using Yard Waste †

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**Abstract:** In Pakistan, energy production from nuclear, hydro, and gas sources is about 99%, and only 1% is produced from renewable energy resources. Biomass is an emerging renewable resource for Pakistan obtained by converting loose biomass into pellets of high density. In this regard, biomass is receiving more and more attention day by day due to its abundant availability. Due to improper management of biomass in terms of transportation, handling, storing, and lack of awareness, its use for energy production is very low. The environmental and health effects of dumping and incineration techniques are becoming more dangerous for developing countries and rural communities day by day. The densification technique is a currently emerging technology for developing countries. Pellet development using yard waste is a new concept that can meet energy demands in addition to reducing environmental pollution and sources of waste management. For this purpose, the biomass of yard waste was shredded and then dried under sunlight or open drying to reduce the moisture content in the biomass material to less than 16% before being carbonized. Five samples with different moisture content levels were made and pellets were prepared from them. The results achieved by the characterization of pellets show that yard waste pellets at 5% moisture content had the highest calorific value of about 17.76 MJ/kg. Flue gas analysis was carried out and emissions from all were determined at all five moisture contents.

**Keywords:** Pakistan; energy production; renewable energy; biomass; densification technique; pellets; flue gas analysis



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## 1. Introduction

Pakistan has seen a sharp rise in urbanization and population expansion, which has raised energy consumption [1]. For its energy needs, the nation mostly depends on fossil fuels, especially oil and natural gas [2]. Power Generation and Shortages: Pakistan is having trouble producing enough electricity to meet the country's expanding demand, which is causing regular power outages [3]. Potential for Renewable Energy: Although renewable energy sources, such as wind and solar power, have a lot of promise, their percentage in the energy mix is still quite small [4]. Infrastructure Restraints: The energy sector's inefficiencies are a result of both inadequate infrastructure and transmission losses [5]. Circular Debt and Financial Viability: The energy industry has long struggled with circular debt, which compromises the ability to generate and distribute electricity profitably [6]. The establishment of a stable and investor-friendly energy sector has been hampered by inconsistent policies and regulatory obstacles [7]. The use of fossil fuels has an impact on the environment since it increases air pollution and contributes to climate change [8]. Energy-related disputes and other regional geopolitical variables might affect the security and dependability of energy supplies [9]. To maximize energy utilization, better energy efficiency policies and conservation techniques are required [10].

In the year 2019, world energy consumption increased to 13.8 billion tons of fuel, corresponding to up to 567 Exajoules, along with 1.7% of the decadal average growth rate per year [11]. Renewable energy is becoming increasingly essential due to increasing energy demands posing environmental concerns and depleting fossil fuel reserves. The Paris Agreement 2015, the first global climate agreement, aims to limit temperature increase to under 2 degrees, indicating potential momentum in the renewable energy market [12]. The UN's sustainable growth goals emphasize the importance of energy, with Goal 7 and Goal 13 focusing on clean and affordable energy and climate action, respectively. These goals emphasize the need for new and renewable resources to transform the world, ensuring sustainable progress without compromising future generations' ability to meet their own needs [13]. It is anticipated that renewables will play an important role in the future energy demand of the world. Furthermore, renewable energy resources are clean, sustainable, and non-depleting.

The report of REN21's 2017 shows that 19.3% of global energy consumption is renewable, with solar, hydropower, biomass, geothermal, and wind being the most significant sources. Biomass energy, accounting for 9% of primary energy supply, accounts for 55.4% of traditional use in developing countries. Yard waste is considered a carbon-neutral fuel due to its lack of net carbon dioxide emissions compared to fossil fuels. It can be used as a primary source of power and heat, reducing acidic gas and CO2 emissions [14]. The use of yard waste and agricultural residues as fuel will reduce emissions caused by open burning and landfill disposal, respectively, and therefore will be a source of revenue for all stakeholders. In this consequence, biomass yard waste has the maximum potential to be used as a sustainable and renewable source for energy production.

The production of thermal energy using yard biomass waste focuses on compacted fuel to overcome its disadvantages like irregular shape, high moisture content, and low bulk density, which make it difficult and expensive to transport, handle, and store [15]. Burning biomass yard waste material in the form of pellets for power generation deals with the drawbacks of old-style use of biomass yard waste such as low heating efficiency [16]. Biomass waste pellets could be used as fuel directly for heating boilers, residential heating stoves, and large power plants [17]. Some properties of biomass material can affect the quality of the pellets, such as moisture content, particle size, and operating conditions like applied pressure, die temperature, die geometry, holding time, and chemical composition [18]. Yard waste and forest waste are the main kinds of biomass feedstock that can be used as fuel after densification [19]. Biomass materials of various types have been utilized or mixed with other waste like sewage sludge and municipal waste. Modern techniques and technologies enable the conversion of biomass into liquid, solid, and gaseous forms, making it a clean and efficient resource [20].

Biomass conversion involves two routes: biochemical and thermochemical. Biochemical conversion involves enzymes and bacteria converting lignocellulosic biomass into biofuel. Thermochemical conversion uses heat and oxygen to convert biomass into energy and other forms. Thermochemical conversion has advantages over biochemical conversion, such as consumption of the entire biomass material, faster kinetics, and more flexibility in feedstock [21]. The thermochemical conversion of biomass involves direct combustion, pyrolysis, and gasification. Direct firewood combustion is the primary energy source for 2.5 billion people worldwide, primarily used in developing nations for heating and cooking in rural areas. India's industries primarily utilize modern renewable energy resources, mostly from biomass sources like rice husks, wheat straw, bagasse, and cotton stalks, to meet around 10% of their energy demand [22]. Wood chips are popular in developed nations due to automated heating processes for biopower and bioheat generation. European countries like England, the Netherlands, Belgium, Germany, and Denmark are the top consumers of renewable energy from biomass waste pellets [23]. China, Germany, the Netherlands, and the U.K. use wood pellets for bioenergy production to cope with their energy demand [24]. India is increasingly considering biopower as a renewable energy source, alongside wind, solar, and hydro. One example is power production from rice husks in rural Bihar, which uses a husk power system to electrify these areas [25].

The need to improve the feedstock base and use varied feedstocks presents new challenges for pellet manufacturers. They face difficulties in developing pellets from diverse feedstocks with different characteristics and morphologies. To optimize palletization, efforts are made to produce high-quality pellets using non-woody biomass like leaves, grasses, wheat straw, corn stover, poplar, switchgrass, barley straw, rice straw, hay, reed canary, lodgepole pine, and yard waste [26]. The production and utilization of fuel pellets from yard waste are not fully explored globally, particularly in developing countries. Further research is needed to increase biomass utilization potential and contribute to a sustainable and renewable bioenergy network. The next chapter will discuss the development of non-woody biomass pellets from yard waste, characterizing them at different moisture contents, testing their durability, emissions, and other aspects of production.

The objective of the study was biomass waste management by making pellets of biomass waste with the help of a pelletizer. To characterize biomass pellet products and to measure their calorific value, burning rate, durability, ash content, and flue gases per unit volume.

## 2. Materials and Methods

This study was concerned with the development of pellets by using yard waste material and its characterization, including proximate and ultimate analysis. This study was conducted in the Engineering Workshop of the Faculty of Agricultural Engineering on the University of Agriculture's main campus, which has lots of potential for yard waste. The study was conducted in three steps:

Step 1: Yard waste collection.
Step 2: Palletization process.
Step 3: Analysis of pellets.

### *2.1. Yard Waste Collection*

The quantification of the yard waste produced at the Engineering Workshop of the Faculty of Agricultural Engineering at the University of Agriculture, Faisalabad was measured and analyzed daily to determine how much waste was being collected daily. To estimate the quantity of yard waste, the estate management office was visited to identify the facts and figures regarding the collection of yard waste from the university. The large number of leaves and stems produced by pruning and natural activities like wind and decaying were collected from the trees along the sides of the roads. The waste produced during pruning activities like trimmed grass is also a main source produced in grassy ground.

### *2.2. Palletization Process*

#### 2.2.1. Shredding of Collected Waste

The waste collected from Agronomy Farms at the University of Agriculture; Faisalabad was shredded to reduce its size according to the requirements of a pelletizer machine. The process involved a shredder machine placed near the biogas plant. The goal was to reduce the particle size of yard waste to the required range for the pellet formation machine. After shredding, the material was passed through sieves with mesh sizes of 6 to 9 mm. The remaining material with particles of 6 to 9 mm size was collected for further processing and sampling. This process is crucial to produce pellets.

#### 2.2.2. Moisture Content

The quantity of water absorbed by any material is called the moisture content of that material. Moisture content generally varied from surrounding to surrounding conditions and material to material. In yard waste, 15 to 20% moisture content is normally present but may differ according to climatic conditions. The moisture content measurement of the waste material used for the palletization process is necessary for the quality of pellets. The moisture content should be retained up to an optimum level to produce good-quality pellets.

2.2.3. Sample Preparation

The biomass after shredding was then dried up to the moisture content levels of 5%, 8%, 11% 14%, and 17%. Each sample constituted 10 kg of biomass waste. The yard waste was collected randomly. A sample of the yard waste contained grass, fresh and dry leaves, stems, and pruned branches of trees and shrubs.

2.2.4. Palletization

After achieving the required level of moisture, the waste material was then put on the belt conveyor of the pelletizer machine locally made by a Ph.D. student at the University of Agriculture Faisalabad placed near the biogas plant at Agronomy Farms on the University of Agriculture main campus. The belt conveyor conveyed the material into the jaw of the pelletizer machine, where the compaction of the yard waste took place, and after compaction, the refined form of pellets came out of the machine. Then, the pellets were collected, stored, and handled.

*2.3. Analysis of Pellets*

2.3.1. Volatile Matter Determination

Volatile matter pellets formed using yard waste were determined using a muffle furnace locally made by a Ph.D. student at the University of Agriculture Faisalabad. The apparatus used in this experiment was present at the environmental engineering lab at the University of Agriculture, Faisalabad. A muffle furnace 1400 was used in this experiment to determine volatile matter.

2.3.2. Ash Content Determination

Ash content produced due to the burning of the pellets was determined using a muffle furnace available at the Engineering Lab Faculty of Agricultural Engineering and Technology. The same model 1400 muffle furnace was used in the determination of volatile matter.

2.3.3. Fixed Carbon Determination

Fixed carbons refer to the mineral matter that is present without moisture, ash, and VM. The fixed carbon was calculated after the analysis of MC%, ash content, and volatile matter. The following relation was used to determine the fixed carbon percentage %.

$$\text{Fixed carbon } \% = 100 - (\text{MC}\% + \text{Ash } \% + \text{Volatile matter}\%)$$

2.3.4. Calorific Value Determination

The calorific value is the amount of heat required to raise the temperature of one gram of water by one degree. The calorific value of yard pellets was calculated using a bomb calorimeter. Calorific value is only dependent on the material composition and independent of the particle size compaction pressure. To find the calorific value, an oxygen bomb cloud was used which was presented at the Engineering Workshop of the Faculty of Agricultural Engineering and Technology.

Calculated calorific value.

Higher heating values can be calculated using a formula consisting of volatile matter, fixed carbon, and ash content. The formula is:

$$\text{CV} = 0.3536 \text{ FC} + 0.1559 \text{ VM} + 0.0078 \text{ Ash}$$

#### 2.3.5. Calculation of Carbon Contents

Every biomass material contains carbon contents in it. Formation of carbon dioxide takes place when the carbon emitted from the biomass burning reacts with atmospheric oxygen. Fixed carbon, MC%, and volatile matter were determined first and then the required percentage was given by the following relation:

$$C\ (\%) = 0.97\ C + 0.7\ (VM - 0.1A) - M(0.6 - 0.01M)$$

#### 2.3.6. Calculation for Hydrogen Content Measurement

The following relation was used to calculate hydrogen percentage:

$$H\ (\%) = 0.036C + 0.086(VM - 0.1A) - 0.0035M\hat{}2(1 - 0.02M)$$

#### 2.3.7. Determination of Nitrogen

Nitrogen is the main source in the composition of plants. Plants absorb nutrients from the soil and in this way, the nitrogen is absorbed by the plants from the roots. Artificially applied nitrogen in fertilizer is also a source of nitrogen uptake for plants. Yard biomass has a huge quantity of nitrogen due to fertilizer application and high growth rate. Nitrogen contents in yard waste pellets were calculated by using the relation:

$$N\ (\%) = 2.1 - 0.02VM$$

#### 2.3.8. Flue Gases Determination

The composition of percentages of flue gases can be measured by using a gas analyzer apparatus. During the process of burning pellets, an amount of flue gas is emitted from the pellet. So, the composition of flue gases exhausted from yard waste biomass pellets was measured by a digital gas analyzer in the Environmental Engineering Lab.

#### 2.3.9. Determination of Yard Waste Pellet Durability

Durability refers to a pellet's ability to withstand wear and tear during handling and storage. The composition of a material is a key factor in determining its durability. However, it can vary depending on the material, surrounding conditions, and handling procedures. A free-fall method was used to test durability, dropping pellets from a height of 1.8 m and analyzing them through a sieve. The material under the sieve and on it was then weighed.

The durability of biomass pellets can be calculated using the following relation:

$$D = Wi - Wf/Wi \times 100$$

where Wi = Initial wt. in grams, Wf = final wt. in grams.

#### 2.3.10. Bulk Density

Bulk density is the mass per unit volume of any material. Bulk density was measured by taking general measurements of pellets. The mass, length, and diameters were measured using instruments like a Vernier caliper for diameter measurement, measuring tape for length measurement, and digital balance for determination of mass. Bulk density was determined using the following relation:

$$\rho = m/v$$

## 3. Results and Discussions

The estate department at the University of Agriculture, Faisalabad (UAF) reports that three to four trolleys of yard waste are collected daily in winter and seven to eight trolleys in summer due to higher growth rates in summer and autumn. Seasonal variations also impact yard waste production, with summer experiencing more wind and stormy weather, and autumn being the start of leaves falling. The study reveals great potential for the production and availability of yard waste at the main campus. It is estimated that 130 kg/hr of yard waste material can be converted into pellets, depending on the pelletizer machine's accuracy and procedures.

### *3.1. Effect of Moisture Content on Volatile Matter*

This study reveals that as the moisture content of yard waste biomass pellets increases, the volatile matter decreases. The highest volatile matter was found at 8% moisture content, while the lowest was produced at 15% moisture content. The trends of volatile matter and moisture content can be observed in Figure 1.

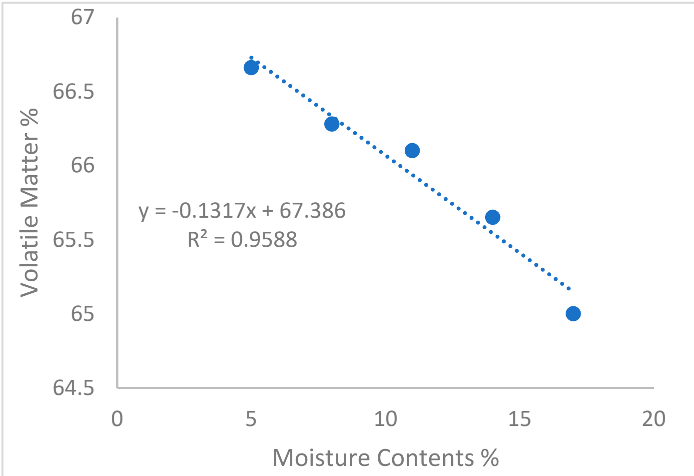


**Figure 1.** Effect of moisture content on volatile matter.

### *3.2. Effect of Moisture Content on Ash Contents*

This study found that moisture content in biomass pellets from yard waste significantly impacts ash contents, which can vary between different biomasses. The maximum ash content percentage was found to be at 5% moisture content, indicating that as moisture content in the pellets increased, so did the ash contents after burning, as shown in Figure 2.

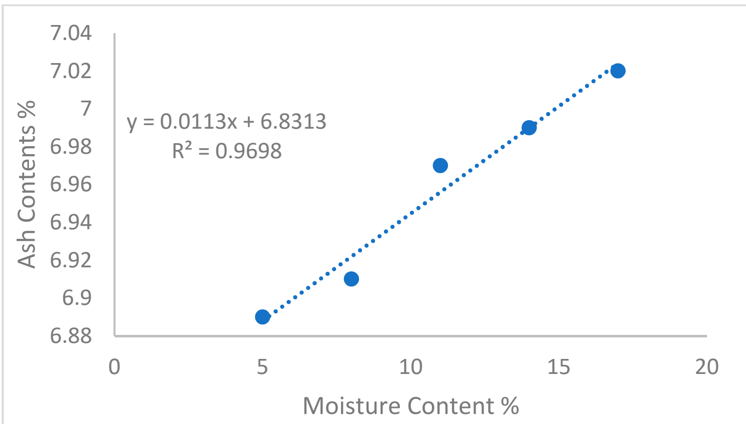


**Figure 2.** Effect of moisture contents on ash.

### *3.3. Effect of Moisture Content on Fixed Carbon*

Fixed carbon, the combustible material in fuel, decreases with increased moisture content. The highest fixed carbon percentage in yard waste biomass pellets was found at 6% moisture content, while the lowest was at 15%. Experiments showed that increasing moisture content in biomass pellets led to a decrease in fixed carbon percentage. The maximum fixed carbon value was 16.19% at 6% moisture content, while the minimum was 10.13% at 15% moisture content as shown in Figure 3.

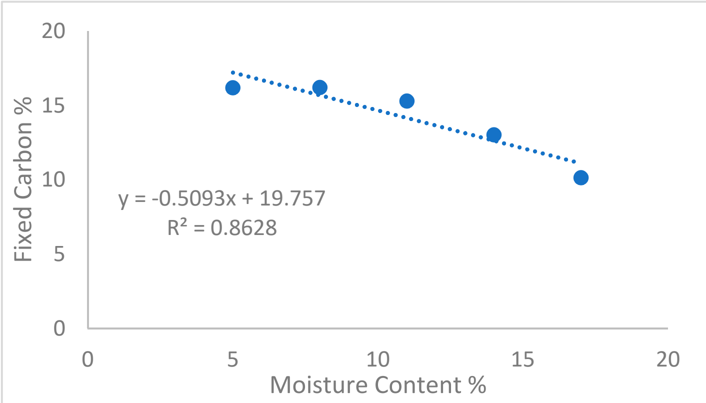


**Figure 3.** Effect of moisture content on fixed carbon.

### 3.4. Effect of Moisture Content on Calorific Value

The calorific values of all pellets were higher at 6% moisture content, decreasing as moisture content increased. Yard waste had the highest value of 17.76 MJ/Kg at 6% moisture. Higher values were found at 5% moisture content, while significantly lower values were found at 17% moisture content. The maximum calorific value was 17.7 MJ/Kg at 5% moisture content, and the minimum was 16.86 MJ/Kg at 17% moisture content, as shown in Figure 4.

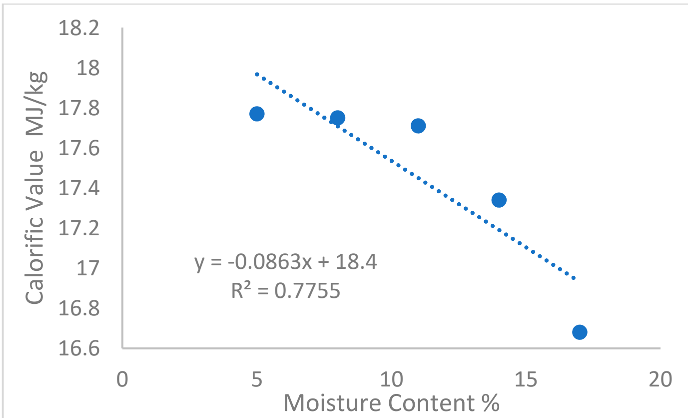


**Figure 4.** Effect of moisture content on measured calorific value.

### 3.5. Effect of Moisture Content on Density

The highest density of yard waste pellets was noted at 5% moisture content with a density of 993 Kg/m$^3$, while the density was 943 kg/m$^3$ at 17% moisture content of raw biomass. The density of pellets decreased with increasing moisture content, as shown in Figure 5.

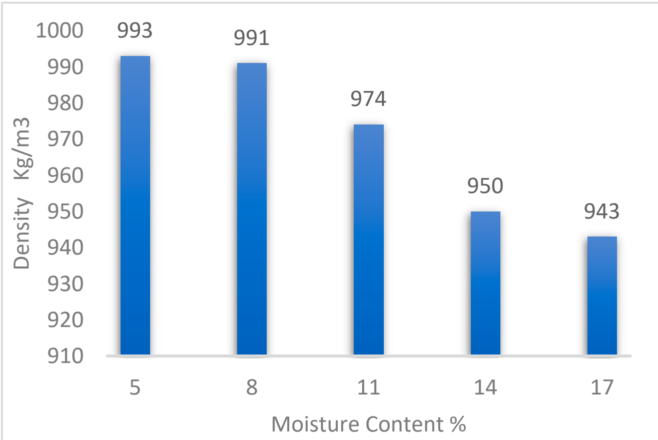


**Figure 5.** Effect of moisture content on density.

### 3.6. Effect of Moisture Content on Durability

Durability is an important factor in biomass pellets. It was seen that durability increased as moisture content increased. It was shown in the experiments that minimum durability was found at the moisture content level of 5%, while higher durability was found at the moisture content level of 17%. This can be seen from the graph in Figure 6, showing the trend of the durability decreasing with increasing moisture content.

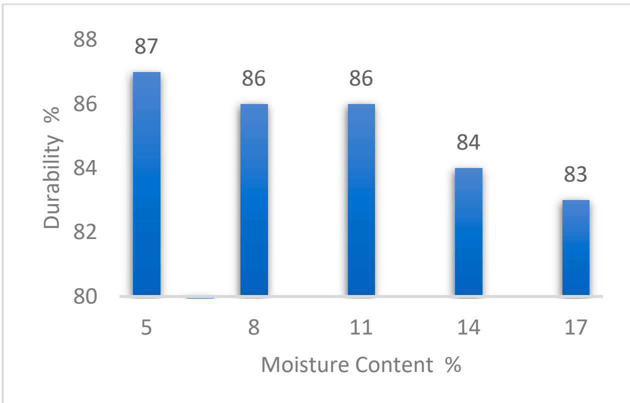


**Figure 6.** Effect of moisture content on durability.

### 3.7. Ultimate Analysis

This study analyzed the carbon, hydrogen, and nitrogen contents in yard waste biomass pellets. Nitrogen is present in agricultural fields due to fertilizers, and carbon emissions are lower than petroleum products. Moisture content affects carbon emissions, possibly due to strongcarbon–hydrogen bonding in leaves and twigs. Nitrogen content is higher at lower moisture content levels and lower at higher moisture content levels. Overall, the analysis highlights the potential benefits of using yard waste for biomass pellets.

#### 3.7.1. Contents of Carbon

Carbon contents present in yard waste pellets are shown below. The bar chart in Figure 7 describes the carbon contents in yard waste pellets at different levels of moisture content. It can be seen that at 5% moisture content, the carbon contents are minimal, while at 17%, the maximum carbon content can be seen. So, with an increase in moisture content carbon content also increases.

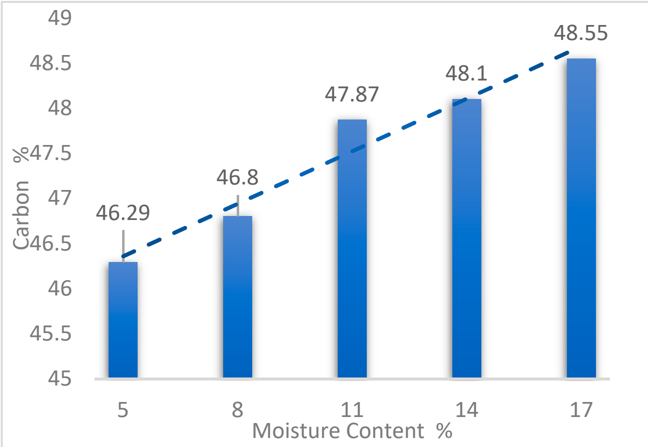


**Figure 7.** Level of carbon contents emissions at different moisture contents.

### 3.7.2. Hydrogen Contents

This study found that hydrogen content in biomass materials increases with moisture content, with a minimum of 5% and a maximum at 17%. The hydrogen content varies significantly with moisture content, with a linear trend at different levels. High hydrogen emission levels may be due to strong hydrogen and carbon bonding in the biomass materials, as evidenced by the 5% moisture content and 6.02% hydrogen content at 17% moisture content, as shown in Figure 8.

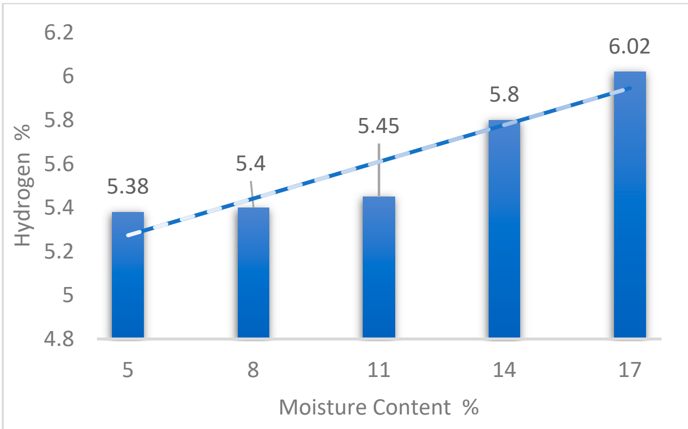


**Figure 8.** Hydrogen contents emissions at different levels of moisture content.

### 3.7.3. Nitrogen Contents

This study found that nitrogen content in yard waste increases with moisture content, while its minimum decreases at 17%. This indicates that moisture plays a crucial role in producing hydrogen from yard waste during burning. Nitrogen content values varied significantly with moisture content, with 1.02% at 5% and 0.89% at 17%. The nitrogen content trended linearly at different moisture content levels, as shown in Figure 9.

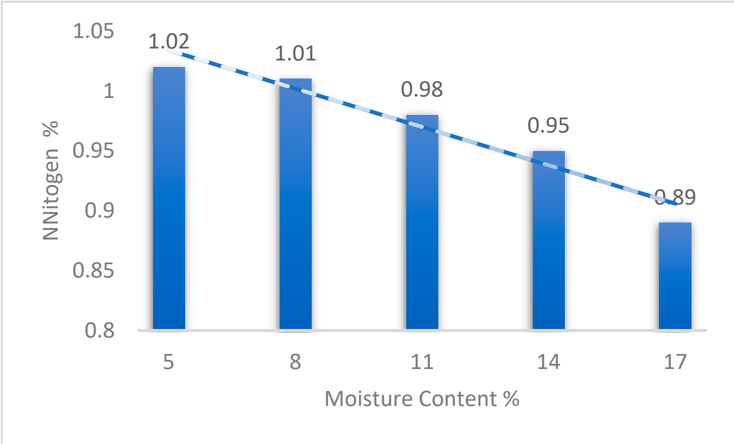


**Figure 9.** Nitrogen content emissions at different levels of moisture content.

### 3.8. Exhaust Gas Analysis

The analysis of yard waste pellets revealed an increase in carbon dioxide production due to an increase in moisture content levels from 5 to 17%. This increase in carbon dioxide emissions is harmful to the environment as it contributes to the carbon cycle already present in plants. However, there was little change in carbon monoxide emissions. As moisture content increased, so did the emission levels of carbon monoxide. The increase in exhaust gases, including $CO_2$ and CO, also increased the temperature of flue gases, as these gases are emitted at high levels, increasing flue gas temperature. These emission analyses were conducted at room temperature, assuming no external interference.

#### 3.8.1. Emissions of Carbon Dioxide

The study reveals that burning yard waste pellets produces carbon dioxide as a flue gas. The emissions were minimal at 8% moisture content, while they reached the maximum at 17%. The emission rate from yard waste pellets at a 17% moisture level was 6.555%. The graph shows a linear trend, indicating that higher carbon dioxide emissions are harmful to the environment and pollute it daily. The increasing amount of carbon dioxide emissions is a significant environmental concern, as shown in Figure 10.

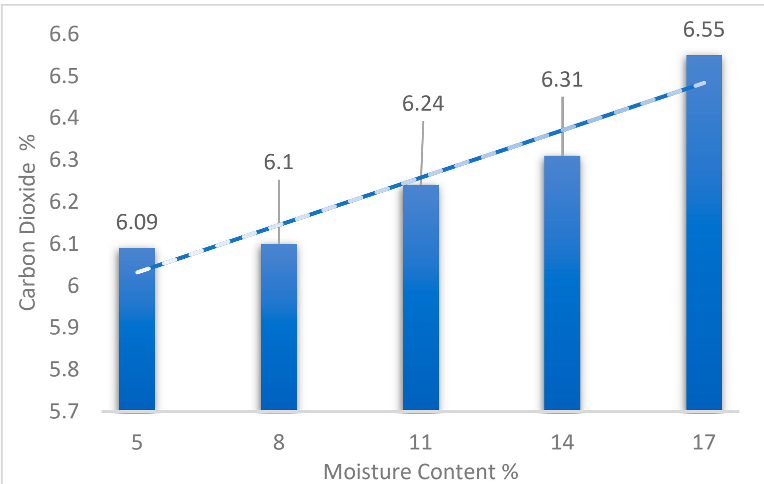


**Figure 10.** Emissions of $CO_2$ from yard waste pellets at different MC levels.

#### 3.8.2. Emissions of Carbon Monoxide

Carbon monoxide is emitted as a flue gas when burning biomass pellets made from yard waste. The emission was minimal at 5% moisture content, while it reached the maximum at 17% moisture content. The emission of carbon monoxide from yard waste pellets at 5% moisture content was 172 mg/m$^3$, while at 17% moisture content, it was 177 mg/m$^3$. A linear trend can be observed in the graph, with the minimum CO emission at 5% moisture content and the maximum at 17% moisture content. The emission of carbon monoxide from yard waste pellets is significant, as shown in Figure 11.

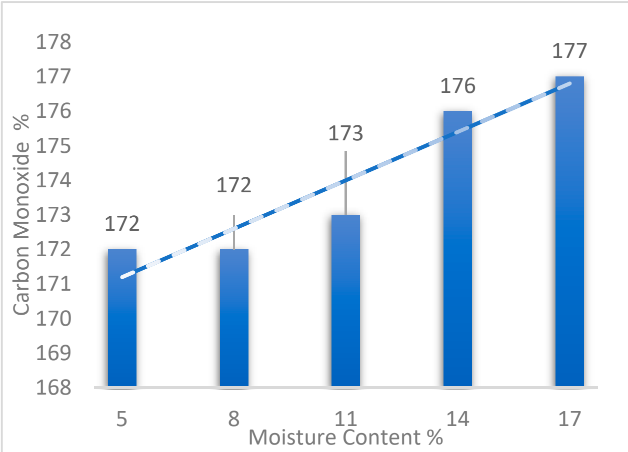


**Figure 11.** Emissions of CO from yard waste pellets at different MC levels.

### 3.8.3. Emission of Nitrogen Oxide

Nitrogen oxide is emitted as a flue gas when burning biomass pellets made from yard waste. The emission levels varied, with minimum emissions at 8% moisture content and maximum emissions at 11% moisture content. The emission of nitrogen oxide from yard waste pellets varied at different moisture content levels, with the maximum emission at 14% moisture content being 162 mg/m$^3$. The emission of nitrogen oxide was highest at 17% moisture content, with a maximum emission of 141 mg/m$^3$. The emission variation was evident at 11% moisture content. Overall, the emission of nitrogen oxide from yard waste pellets is a significant concern for environmental health, as shown in Figure 12.

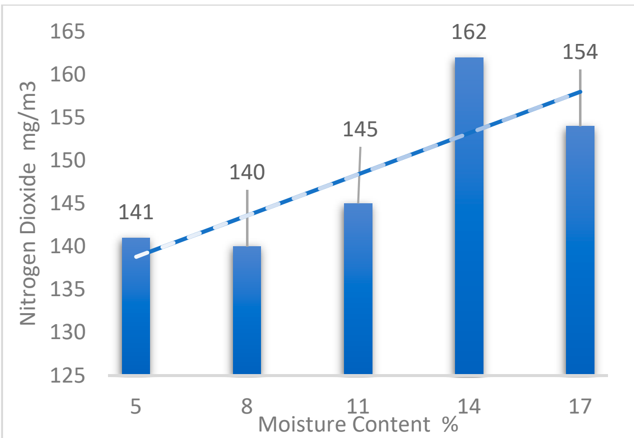


**Figure 12.** Emissions of NOx from yard waste at different MC levels.

## 4. Conclusions

This research concluded that the technique of palletization using yard waste is cheap, reliable, and environmentally friendly. To obtain the maximum calorific value, durability, and density of pellets, the palletization of biomass should be performed in the moisture content range between 5% and 11%. The minimum ash contents were obtained with 5% moisture content, so when the moisture content level was kept under 5% to 11, the calorific value was high, ash contents were low, emissions were reduced, and durability was high.

This study highlights the importance of transitioning to sustainable energy sources, particularly biomass, to address Pakistan's energy crisis. It also suggests that modern technology like densification can help mitigate the negative health and environmental impacts of traditional waste disposal methods.

**Author Contributions:** Conceptualization, U.Z.; Introduction, R.M.S. and A.R.; Materials and Methods, A.S. and U.Z.; Results and Discussions, M.S. and U.Z.; Conclusions, U.Z., R.M.S. and M.S.; Writing—Original Draft Preparation, M.D.M.; Writing—Original Draft Preparation and Writing—Review and Editing, M.S. All authors have read and agreed to the published version of the manuscript.

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