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Research Article

Characterization, performance evaluation and optimization of wheat straw – bagasse blended fuel pellets

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Abstract. This study was carried out to assess the fuel pellets produced from wheat straw and sugarcane bagasse. The wheat straw and bagasse were blended into four ratios including; 10:90, 30:70, 70:30 and 90:10 (wheat straw: bagasse) and developed into fuel pellets. The fuel pellets were characterized to determine the moisture content, volatile matter, fixed carbon, ash content, calorific value, bulk density and mechanical durability. The ignition time, burning rate and specific fuel consumption of the wheat straw – bagasse blended fuel pellets were studied at varying blend ratios (10:90, 30:70, 70:30 and 90:10), moisture contents (9.1%, 10.6%, 12.6% and 14.7%) and raw material particle sizes (2 mm, 4 mm, 6 mm and 10 mm). Results indicated that the wheat straw: bagasse blend ratios containing more proportion of bagasse (30:70 and 10:90) recorded a shorter ignition time, higher burning rate and lower specific fuel consumption. Larger raw material particle sizes exhibited shorter ignition time, higher burning rate and specific fuel consumption. Moreso, the fuel pellets with low moisture contents also recorded shorter ignition time, higher burning rate and lower specific fuel consumption. It was concluded that fuel pellets with high quantity of bagasse, large particle sizes and low moisture content demonstrated favorable combustion characteristics. Response surface methodology was used in the optimization so as to determine the optimum combination of blending ratio, moisture content and raw material particle size that would result in the lowest ignition time, highest burning rate and lowest specific fuel consumption. Results indicated that an optimum combination of a wheat straw: bagasse blend ratio of 10:90, moisture content of 14.70% and a particle size of 10.00 mm resulted in the lowest ignition time, highest burning rate and lowest specific fuel consumption.

Keywords: wheat straw, sugarcane bagasse, ignition time, burning rate, specific fuel consumption

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1. Introduction

Access to reliable energy is essential for everyday life (Khandker *et al.* 2012). Fossil fuel for energy supply across the world has become unsustainable (Okafor *et al.* 2022). According to Shafiee & Topal (2009), a new formula known as the Klass model has been used to determine the depletion times for gas, coal and oil, and coal will be the only fossil fuel available up to 2112. Aside from danger of depletion, Adeleke *et al.* (2020) discussed the report from the inter-governmental panel of climate change which stated that fossil fuels release high levels of carbon dioxide and there has been a 57.5% rise in carbon dioxide emissions since 1990. Uzoejinwa *et al.* (2018) in their study noted that biomass sources of energy are the most potential, plentiful and highly subsidized alternative sources of renewable energy to supplement the inadequate supply of fossil fuel as well as lessen the effect of global warming. Rimantho *et al.* (2023) indicated that Kenya embarked on low-carbon development (LCD) as decreed by UNFCCC (United Nations Framework Convention on Climate Change) to mitigate climate change as a national development strategy. Biomass has the potential to be utilized in the production of biofuels to improve energy security for the future without endangering food security (Saleem 2022).

Biomass can be obtained from agricultural residues such as wheat straw, bagasse, rice husks, macadamia nuts and aquatic plants such as macroalgae. Macroalgae is divided into brown algae, red algae and green algae which can be used to produce biochar through a process known as pyrolysis (Chen *et al.* 2022). Kenya is an agricultural country in East Africa with a wide range of agricultural products (Ochieng *et al.* 2016). There is a lot of agricultural waste from sugarcane and wheat after harvesting and processing, and this waste can be converted to biomass energy (Dasappa 2011).

Kenya has an annual production of approximately 1.6 million tons of sugarcane bagasse (Kabeyi 2021). Wheat is the second most essential cereal after maize. Njuguna *et al.* (2016) reported that the annual wheat production in Kenya is about 442,000 MT. Ruiz *et al.* (2012) stated that from every 1.3kg of wheat grain production, approximately 1kg of wheat straw is produced. In the developing nations, energy from biomass material is mainly used for heating and cooking. It is also used in industries to produce heat energy especially in the boilers. According to Okoko *et al.* (2017), the utilization of biomass energy has a large potential in improving local access to energy in form of electricity, heat and liquid fuels. Takase *et al.* (2021) stated that a transition into biomass sources of energy would reduce the dependence on imports and improve energy security in Kenya.The major source of energy in most parts of Kenya is charcoal made from wood fuel (Njiru & Letema 2018). About

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82% of the urban population and 34% of rural households depend on charcoal (Jung & Huxham 2018). The cutting of trees has serious consequences for the conservation and management of forest resources (Shoddo 2022). Consequently, deforestation would lead to climate change (Suramaythangkoor & Gheewala 2008). Efforts over the recent years have boosted the need to adopt the use of biomass fuel pellets (Duguma *et al.* 2020). Mawusi *et al.* (2023) reported that biomass fuel pellets have become an important part of the energy sector and their use is evolving at a faster rate. Fuel pellets made from wheat straw and sugarcane bagasse pelletization can be an alternative source of renewable energy. Fuel pellets are usually smokeless hence reducing indoor air pollution-related diseases, and they burn for longer duration of time. They also have a great potential to meet energy demands in both urban and rural settings. The utilization of fuel pellets has many advantages over wood fuel and charcoal such as cleanliness, high heating value, smaller space required for storage and convenient to use (Theerarattananoon *et al.* 2011; Hadiyanto *et al* 2023). Past research has shown that parameters such as moisture, blending ratio and particle size have an effect on the quality of a biomass fuel (Zeng *et al.* 2018). However, research to determine on the properties of a combination of wheat straw and bagasse in Kenya has not been adequately carried out. Lack of such information would lead to under-utilization of wheat straw and bagasse as a potential source of biomass energy. Therefore, there is a need to study the properties of wheat straw – bagasse blended fuel pellets in order to determine the quality of fuel.

The aim of this study is to characterize the wheat straw – bagasse blended fuel pellets according to the calorific value, bulk density, mechanical durability, moisture content, volatile matter, fixed carbon and ash content; and to investigate the effects of blending ratio, moisture content and raw material particle size on the ignition time, burning rate and specific fuel consumption. Ignition time is the amount of time taken (in seconds) to ignite. Burning rate is defined as the rate at which a given mass of fuel is combusted in air. Specific fuel consumption is defined as the ratio of the mass of fuel consumed (in grams) to the quantity of boiling water (in litre).

2.0 Materials and Method

2.1 Preparation and characterization of the fuel pellets

Sugarcane bagasse and wheat straw were collected from agricultural farms around Nakuru County in Kenya. The feedstocks were milled using a hammer mill (Model HM-05). A diesel flat die pellet mill (Model 300BD) was used for pelletization. It consists of an electric motor, transmission box, main shaft, flat die, pressing rollers and feeding hopper. Through a feeding hopper, the raw biomass material was poured into a pelletizing chamber in which it was squeezed through the pressing rollers and a flat die. It then flowed out via the die holes thus forming the fuel pellets.

The proximate analysis of the produced pellets was performed to determine the fuel pellets' moisture content, volatile matter, ash content and fixed carbon. This was achieved based on the American Society of Testing and Materials (ASTM) standard as indicated by Ikelle *et al.* (2020). Calorific value, bulk density and mechanical durability were also determined.

2.1.1 Moisture content

2 g of crushed pellet was weighed and put into a crucible. The crucible was then put in an oven at a constant temperature of 107 °C, weighing every 1 hour until there was no change in mass as per ASTM D4442. The crucible was then removed from the oven and immediately covered. It was cooled in a desiccator and the weight of the pellet sample was determined again at room temperature. This experiment was repeated three times. The moisture content was then calculated using equation 1.

$$MC\ (\%) = (W_i - W_f)/W_i \times 100\% \quad (1)$$

where, MC – moisture content, W_i is the initial weight of the sample, W_f is the final weight of the sample after cooling to room temperature.

2.1.2 Volatile matter

After the determination of moisture content, the dried sample (as per ASTM D3175 standards) was placed in a nitrogen flask. It was then heated in the furnace at a temperature of 350 °C for 10 minutes. The crucible was then taken out of the furnace and cooled to room temperature in the desiccator. This experiment was repeated three times.

The volatile matter was then calculated using equation 2.

$$\text{Volatile matter}\ (\%) = ((V_i - V_f) / V) \times 100\% \quad (2)$$

where,V_i - the initial weight of the sample , V_f - the final weight of the sample after cooling (After being heated to 107 °C till there was no change in mass), V – the final weight of the sample after cooling (After being heated to 350 °C for 10 minutes)

2.1.3 Ash content

The sample residue after determining the volatile matter was put in a crucible, placed inside a furnace and heated for 3 hours to a temperature of 550 °C (ASTM E1755). The crucible was taken out of the furnace and cooled in the desiccators. The final weight of the sample was recorded. This experiment was repeated three times.
The ash content was then calculated using equation 3.

$$\text{Percentage Ash content} = (A_i / A_f) \times 100\% \quad (3)$$

where, A_i – the initial weight of the sample , A_f - the final weight of the sample after cooling (after being heated to 550 °C for 3 hours)

2.1.4 Fixed carbon

The fixed carbon was obtained by subtracting the percentages of the moisture content, ash content and volatile matter from the original mass of the fuel pellet sample. This experiment was repeated three times.
The fixed carbon was then calculated using the equation 4.

$$\text{Percentage fixed carbon} = 100\% - (\%\ MC + \%\ VM + \%\ A) \quad (4)$$

where,MC – moisture content, VM – volatile matter, A – ash content

2.1.5 Calorific value of the fuel pellet samples

The e2K Oxygen bomb calorimeter manufactured from South Africa was used to determine the Net calorific value. 0.5 g of the sample was weighed into a crucible. The crucible was placed into the bomb vessel, and the bomb vessel was then filled with 30 bars of pure oxygen. The bomb vessel was placed into the calorimeter, and the lid closed to avoid interference by environmental factors to the bomb vessel. The sample was ignited once the temperature within the bomb vessel stabilized. The calorimeter took about 4 minutes to determine the calorific value of the fuel sample in (MJ/kg). The net Calorific Value of the sample was read directly from the Oxygen bomb calorimeter. Then the bomb vessel was removed and cooled so that it could be reused again. This experiment was repeated three times.

2.1.6 Bulk density

0.5 kg of fuel pellets was weighed using a digital weighing scale and the volume obtained using a graduated measuring cylinder. This experiment was repeated three times. The bulk density was then calculated using equation 5.

Bulk density = mass of biomass sample (kg) / volume of cylinder (m^3) (5)
(Liu & Lennartz 2019)

2.1.7 Mechanical durability

50 g of fuel pellets sample was weighed on a digital weighing scale and loaded in a tumbling mill rotating at 50 rpm for a duration of 10 minutes. The sample was then sieved through a 2 mm sieving mesh, and the pellets were weighed afterwards. The durability index (DI) was calculated by obtaining the ratio of the mass of the pellets before tumbling to the mass of pellets after tumbling. This experiment was repeated three times. The mechanical durability was then calculated using the equation 6.

Percentage Durability Index = (m_i / m_f) × 100 (6)

where, m_i – mass of pellets before tumbling, m_f – mass of pellets after tumbling

2.2 Sensitivity analysis

A sensitivity analysis was performed to investigate the impact of varying raw material particle size, blending ratio and moisture content on the ignition time, burning rate and specific fuel consumption of the wheat-bagasse pellets.

2.2.1 Particle size

The wheat straw and bagasse were milled separately using a hammer mill with varying sieve size openings of 2 mm, 4 mm, 6 mm and 10 mm. These particle sizes were guided by Bergstrom et al. (2008). The moisture content and wheat straw to bagasse blending ratio were kept constant at 10.6% and 70:30 by mass. A molasses binder was added at a ratio of 1:3 (molasses: feedstock) by mass and then pelletized. The ignition time, burning rate and specific fuel consumption of the fuel pellets were then investigated at the various particle sizes. This experiment was repeated three times.

2.2.2 Blend ratio

The wheat straw and bagasse were milled separately using a hammer mill with a sieve size opening of 6 mm. The moisture content was also kept constant at 10.6%. The crushed wheat straw and bagasse was blended to the following four ratios 10:90, 30:70, 70:30 and 90:10 by mass. A molasses binder was added at a ratio of 1:3 (molasses: feedstock) by mass in each batch and pelletized. The ignition time, burning rate and specific fuel consumption of the fuel pellets were then investigated at the various blending ratios. This experiment was repeated three times.

2.2.3 Moisture content

The wheat straw and bagasse were milled separately using a hammer mill with sieve size openings of 6 mm. It was then blended in a ratio of 70:30 by mass. The blended mixture was then divided into four batches and sundried. The moisture contents were guided by Onukak et al. (2017) who investigated the performance of a biomass fuel with moisture contents ranging between 8-12%. Batch one was sundried for 4 days and obtained a moisture content of 9.1%. Batch two was sundried for 3 days and obtained a moisture content of 10.6%. Batch three was sundried for 2 days and obtained a moisture content of 12.6%. Batch four was sundried for 1 day and obtained a moisture content of 14.7%. A molasses binder was added to each batch at a ratio of 1:3 (molasses: feedstock) by mass and then pelletized. The ignition time, burning rate and specific fuel consumption of the fuel pellets were then investigated at the various blending ratios. This experiment was repeated three times.

2.3 Optimization by Response Surface Methodology

This is a technique used in a situation whereby several variables have an effect on the response of the system (Ahmad *et al.* 2024). The procedure is as follows:

a) Choose independent variables (blend ratio, moisture content and particle size).
b) Choose response variables (ignition time, burning rate and specific fuel consumption).
c) Create an experimental design.
d) Regression analysis.
e) Development of the response function (Quadratic polynomial).
f) Create contour plots of response surface.
g) Search for optimum operating conditions.

3. Results and Discussion

3.1 Properties of wheat straw – bagasse fuel pellets

3.1.1 Proximate analysis

Figure 1 illustrates the proximate analysis of the fuel pellets at various values of blending ratios. The results showed that the volatile matter and ash content increased with an increase in the wheat straw content, and decreased with an increase in the bagasse content while fixed carbon registered an opposite trend.

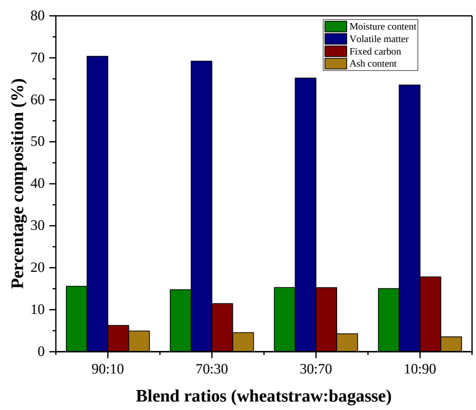

Fig. 1. Effects of blend ratio on the moisture content, volatile matter, fixed carbon and ash content

The moisture content varied between a maximum of 15.5% for the wheat straw: bagasse ratio of 90:10 and a minimum of 14.7% for the wheat straw: bagasse ratio of 70:30. According to Onukak *et al.* (2017), the tolerance level of moisture content for biomass fuel is 8-12%. This would produce biomass fuel of high calorific value due to the good porosity which facilitates the circulation of air within the fuel for combustion. Werther *et al.* (2000) stated that a high moisture content affects the particle heating process, thus increasing the time for heating and drying, hence delaying the release of volatiles which affects the combustion process. Therefore, a drying process was necessary to improve the quality of the fuel pellets by reducing the moisture content to within the tolerance level for a biomass fuel.

The volatile matter content varied between a minimum of 63.5% for a wheat straw: bagasse ratio of 10:90 and a maximum of 70.3% for a wheat straw: bagasse ratio of 90:10. Werther *et al.* (2000) stated that most biomass materials have a high volatile matter that is quick to ignite and burns rapidly. However, according to Kongprasert *et al.* (2019), biomass fuel with a very high volatility produces a lot of smoke . Therefore, fuel pellets with lower volatility have more desirable fuel characteristics.

The ash content varied between a minimum of 3.5% for a wheat straw: bagasse ratio of 10:90 and a maximum of 4.9% for a wheat straw: bagasse ratio of 90:10. According to Cuiping *et al.* (2004), most biomass fuels are characterized by very low levels of ash content. Kongprasert *et al.* (2019) reported that having a low ash content is characterized by having a high heating value or calorific value. In this work, the wheat straw: bagasse ratio of 10:90 has a greater potential to be used as a renewable source of energy due to its low levels of ash content.

The wheat straw: bagasse ratio of 10:90 had the highest fixed carbon of 17.8%, and the wheat straw: bagasse ratio of 90:10 had the lowest fixed carbon of 6.2%. A high level of fixed carbon in a biomass fuel means that the fuel pellets are of better quality. The level of fixed carbon in the fuel pellets is the main generator of heat in the process of combustion (Onochie *et al.* 2017).

The above obtained results were compared to single source biomass (wheat straw and bagasse) as follows. Jahromi *et al.* (2020) conducted a study to determine the chemical properties of sugarcane bagasse. The results included; 1.42% ash content, 16.39% fixed carbon, 69.99% volatile matter and 1.14% moisture content. In addition, Singh *et al.* (2020) utilized wheat straw for biomass gasification and investigated its' chemical properties. The results included; 8.38% moisture content, 74.02% volatile matter, 9.49% ash content and 8.11% fixed carbon. From the above studies, wheat straw has a high ash content and a low fixed carbon. Therefore, blending it with bagasse is necessary to improve the chemical composition of the fuel.

3.1.2 Calorific value, bulk density and mechanical durability

Table 1 shows the impact of blend ratio on the fuel pellets' calorific value, bulk density and mechanical durability. The results showed that the calorific value, bulk density and mechanical durability increased with an increase in the bagasse content, and decreased with an increase in the wheat straw content.

The highest calorific value of 16.686 MJ/kg was observed at a wheat straw: bagasse blend ratio of 10:90. The blend ratio 90:10 recorded the lowest calorific value of 14.167 MJ/kg. The decrease in calorific value with increasing wheat straw content is attributed to the higher increase in the levels of ash content hence leading to the lower calorific values. Kongprasert *et al.* (2019) reported that the calorific value is affected by the level of

Table 1
Test results for calorific value, bulk density and mechanical durability

Blend Ratios Wheat straw: Bagasse	Calorific value (MJ/kg)	Bulk density (kg/m^3)	Mechanical durability (%)
90:10	14.167	496.9307	97.8062
70:30	14.926	530.9317	98.9808
30:70	16.375	660.5180	99.8964
10:90	16.686	728.0622	99.9992

ash content. A low ash content increases the calorific value of biomass material. Also, high fixed carbon in biomass material increases the calorific value. Fuel pellets with a high calorific value are considered to be of high quality.

The highest value of bulk density of 728.0622 kg/m^3 was observed at a wheat straw: bagasse blend ratio of 10:90 while the lowest bulk density of 496.9307 kg/m^3 was attained at the ratio of 90:10. The bulk density influences the combustion efficiency and the durability of the fuel pellets. A high density enables the fuel pellets to be easily handled and transported (Karkania *et al.* 2012). Pelletization also improves the bulk density of the material (García *et al.* 2019). The bulk density of bagasse biomass material ranges from 280 kg/m^3 to 320 kg/m^3. Pelletization enhances the bulk density of the biomass material (T. & Olorunnisola 2014). A high bulk density denotes a high calorific value.

The highest value of mechanical durability was observed at a wheat straw: bagasse blend ratio of 10:90 to be 99.9992%. The lowest value of mechanical durability was observed at a ratio 90:10 which is 97.8092%. The mechanical durability of the fuel pellets for all the blending ratios falls within the standard pellet quality of 95-100% (Saeed *et al* 2021).

3.2 Effect of selected parameters on the performance of the fuel pellets

3.2.1. Particle size

The effect of varying particle size at a constant moisture content and blending ratio on the ignition time, burning rate and specific fuel consumption of the wheat-bagasse fuel pellets is shown in Fig. 2. Ignition time was observed to reduce with increasing particle size while burning rate and fuel consumption recorded an opposite trend.

From Fig. 2 the highest ignition time of 83 seconds was observed at 2 mm particle size. A 10 mm particle size registered

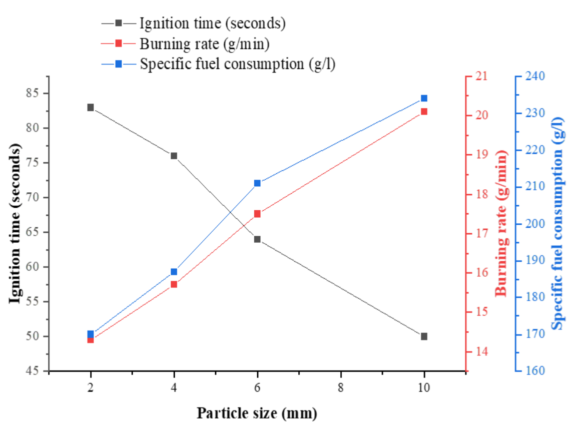

Fig. 2. Effect of varying particle size on the ignition time, burning rate and specific fuel consumption

the lowest ignition time of 50 seconds. The shortest ignition time recorded of 50 seconds at 10 mm particle could be due to the high porosity in between the particles which enhances easy flow of oxygen to support combustion. Larger particles have more pronounced air spaces to increase flow of air in between the fuel pellets which supports faster combustion (Davies 2013). A higher burning rate of 20.1 g/min was observed at 10 mm particle size while a 2 mm particle size registered a lower burning rate of 14.3 g/min. The values of the specific fuel consumption also increased from 170 g/l at a particle size of 2 mm to 234 g/l at a particle size 0f 10 mm. This could be attributed to the porous nature of the fuel pellets with large particle sizes. Anggraeni *et al.* (2021) stated that large particle sizes exhibit a low compressed density hence contributing to the highly porous nature of the biomass fuel. This causes easy circulation of air to support combustion and positively affects the burning process.

3.2.2. Blend ratio

The effect of varying blend ratio at a constant particle size and moisture content on the ignition time, burning rate and specific fuel consumption of the wheat-bagasse fuel pellets is shown in Fig. 3. Ignition time and specific fuel consumption was observed to reduce with increasing proportion of bagasse while burning rate recorded an opposite trend.

From Fig. 3, the highest ignition time of 89 seconds was observed at a wheat straw: bagasse blend ratio of 90:10. A blend ratio of 10:90 registered the lowest ignition time of 35 seconds. The highest ignition time recorded of 89 seconds at a wheat straw: bagasse blend ratio of 90:10 could be due to the presence of high volatile matter in the blends containing more wheat straw. According to Onukak *et al.* (2017), the presence of high volatile matter increases the ignition time because more time is taken to burn off the volatiles before combustion.

A higher burning rate of 16.6 g/min was observed at a wheat straw: bagasse blend ratio of 10:90 while a blend ratio of 90:10 registered a lower burning rate of 10.6 g/min. The values of specific fuel consumption ranged from 138 g/l at a wheat straw: bagasse blend ratio of 10:90 to 176 g/l at a blend ratio of 90:10. This could be due to the high ash content in the blends with more wheat straw. A high ash content decreases the burning rate of a biomass fuel and consequently, increases the specific fuel consumption of a biomass fuel. Onukak *et al.* (2017) indicated that the ash clogs the burning medium thus hindering the flow of air needed for combustion.

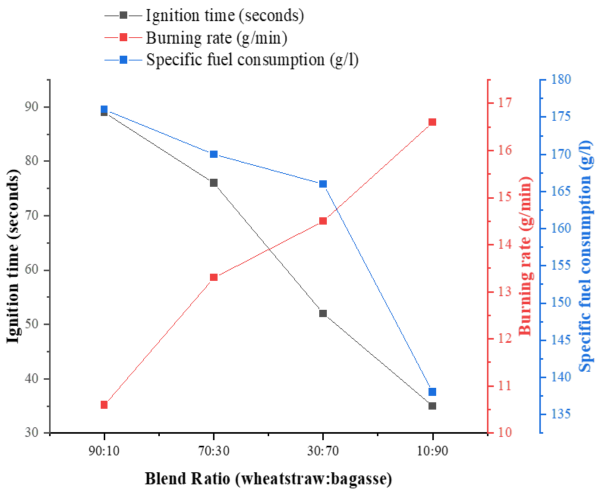

Fig. 3. Effect of varying blending ratio on the ignition time, burning rate and specific fuel consumption

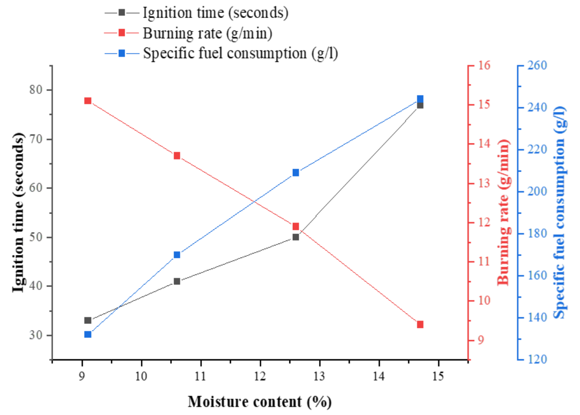

Fig. 4. Effect of varying moisture content on the ignition time, burning rate and specific fuel consumption.

3.2.3. Moisture content

The effect of varying moisture content at a constant particle size and blend ratio on the ignition time, burning rate and specific fuel consumption of the wheat-bagasse fuel pellets is shown in Fig. 4. Ignition time and specific fuel consumption was observed to increase with an increase in the moisture content while burning rate recorded an opposite trend.

From Fig. 4, the highest ignition time of 87 seconds was observed for the sample with MC of 14.7%. The sample with MC of 9.1% recorded the lowest ignition time of 33 seconds. This shows increase in ignition time as the moisture content of the fuel pellet increased. The burning characteristics of a biomass fuel are greatly affected by the level of moisture content. A high moisture content causes difficulty in ignition (Tamilvanan 2013). A higher burning rate of 15.1 g/min was observed for the sample with MC of 9.1% while the sample with MC of 14.7% registered a lower burning rate of 9.4 g/min. The specific fuel consumption varied from 132 g/l for the sample with MC of 9.1% to 244 g/l for the sample with MC of 14.7%. This observation might be due to the fact that during combustion, the moisture within the biomass absorbs the heat produced from the burning fuel to form vapor due to the latent heat of vaporization (Tamilvanan 2013). This slows down the burning process for the samples with high moisture content. According to Onukak *et al.* (2017), the tolerance level of moisture content of a biomass fuel ranges between 8-12%. Moisture content above this tolerance level will slow down the burning characteristics. From the results, it was clear that a high moisture content had a negative impact on the combustion of the fuel pellets.

3.3 Optimization by Response Surface Methodology (RSM)

Fig. 5 (a) – (d) shows the combined effect of moisture content and particle size at various values of blend ratio on the ignition time. The shortest ignition time was observed at the region of high particle size and blend ratios containing more bagasse. The moisture content did not have a significant effect on the ignition time.

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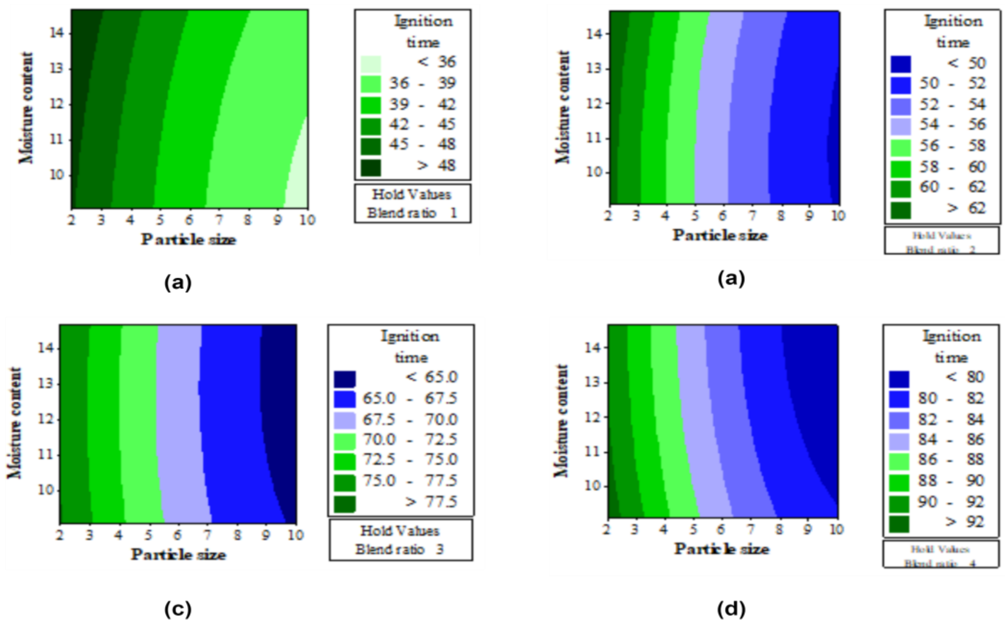

Fig. 5. Contour plots of Ignition time vs Moisture content, Particle size and Blend ratio

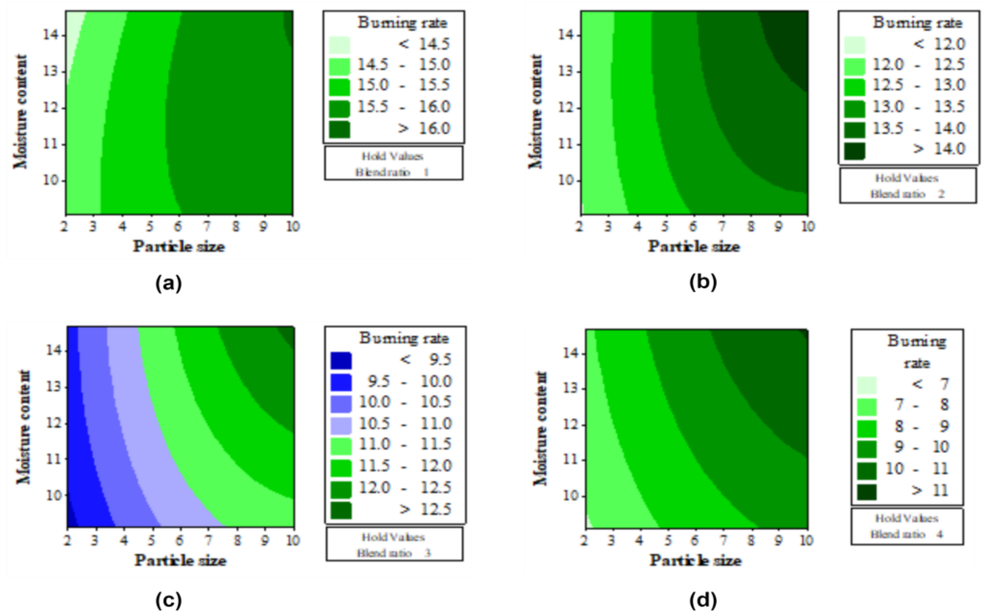

Fig. 6. Contour plots of Burning rate vs Moisture content, Particle size and Blend ratio

Fig. 6 (a) – (d) demonstrates the interaction effects of moisture content and particle size at different blend ratios on the burning rate. It was observed that the burning rate was maximized at a high particle size. An increase in the particle size leads to a high burning rate. This trend is in agreement with Anggraeni *et al.* (2021) stated that the porous nature of large particle size leads to an increase in the burning rate because there is easy circulation of air to support combustion. Blend ratios containing more bagasse exhibited a higher burning rate. In earlier tests, blend ratios containing more bagasse recorded a low ash content. A low ash content enhances the burning rate of a biomass fuel (Onukak *et al.* 2017). A moisture content tending to 14.7% depicted a higher burning rate. According to Stelte *et al.* (2012), the optimum moisture content for pelletization of various grasses varies between 10-15%.

Fig. 7 (a) – (d) demonstrates the combined effects of moisture content and particle size at different blend ratio on the specific fuel consumption. A low specific fuel consumption was observed at a smaller particle size. This could be attributed to the limited flow of air within the fuel pellets due to the small air spaces leading to a slow burning and low specific fuel consumption (Anggraeni *et al.* 2021). There was no significant effect of moisture content on the specific fuel consumption. An increase in the proportion of bagasse in the blend ratios led to a decrease in the specific fuel consumption. As observed earlier, blends containing more bagasse exhibited a low ash content. A low ash content will enhance efficient combustion because the

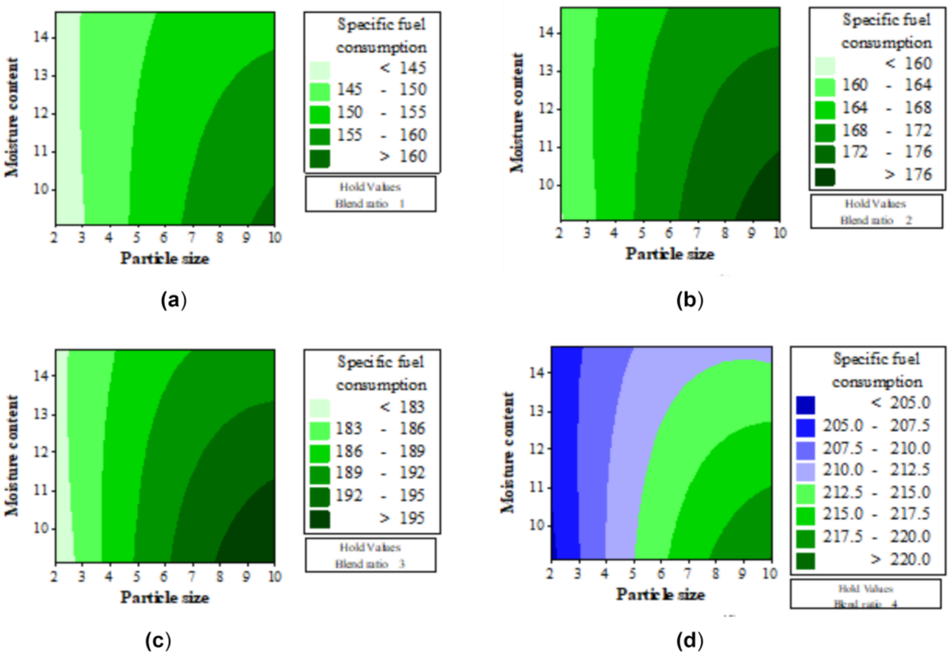

Fig. 7. Contour Plots of Specific fuel consumption vs Moisture content, Particle size and Blend ratio

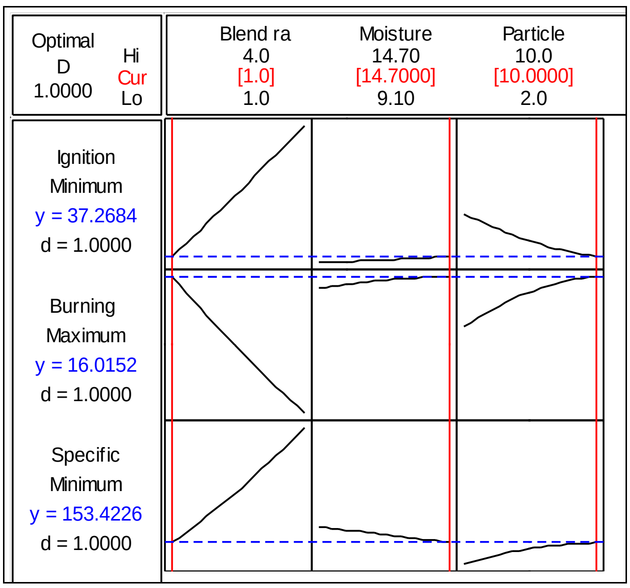

Fig. 8. Optimization Response

burning medium is not clogged with ash (Onukak *et al.* 2017). This will lower the specific fuel consumption.

Fig. 8. illustrates RSM optimization for blend ratio, moisture content, particle size to obtain a low ignition time, high burning rate and low specific fuel consumption. The results indicated that an optimum combination of a wheat straw: bagasse blend ratio of 10:90, moisture content of 14.70% and a particle size of 10.00 mm resulted in the lowest ignition time of 37.2684 seconds, highest burning rate of 16.0152 g/min and lowest specific fuel consumption of 153.4226 g/l.

4. Conclusion

This study sought to produce, characterize and evaluate the performance of wheat straw – bagasse blended fuel pellets with respect to the combustion properties. The largest particle size of 10 mm recorded the shortest ignition time of 50 seconds, highest burning rate of 20.1 g/min and the highest specific fuel consumption of 234 g/l. Fuel pellets with larger particle sizes ignited and burnt faster as compared to the fuel pellets of smaller particles sizes. The highest moisture content at 14.7% resulted in the highest ignition time of 77 seconds, lowest burning rate of 9.4 g/min and highest specific fuel consumption of 244 g/l. This revealed that fuel pellets with a low moisture content demonstrate better fuel characteristics as compared to fuel pellets with a high moisture content. The blends containing more bagasse (30:70, 10:90) demonstrated a short ignition time, high burning rate and low specific fuel consumption as compared to the blends containing more wheat straw (90:10, 70:30). This could be explained by the level of ash content. The blends containing more bagasse exhibited a low ash content which is favorable for combustion hence the fuel pellets ignite and burn faster with a low specific fuel consumption. The graphical result of Response surface methodology indicated that the optimum combination of a wheat straw: bagasse blend ratio of 10:90, moisture content of 14.70% and a particle size of 10.00 mm would achieve the lowest ignition time, highest burning rate and lowest specific fuel consumption.

This work has not only developed blended fuel pellets but also optimized the parameters to obtain fuel pellets with favorable burning characteristics. Therefore, the production of fuel pellets from wheat straw and sugarcane bagasse should be advocated because it will greatly curb deforestation. Instead of cutting trees for fuel wood, the fuel pellets would be produced from agricultural waste and used as a high-quality fuel. This will also create employment opportunities in the pellet manufacturing industry hence leading to economic growth within the community.

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