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Effect of feed rate and screw pressing speed to the performance of a charcoal block pressing machine

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Abstract

This study aimed to examine the effects of feed rate and screw pressing speed on the performance of a cassava-stump charcoal block pressing machine as well as to design and develop a prototype. The machine consists of several components, including a mixing tank, screw conveyor, hopper, screw-pressing unit, transmission system, and main frame. The experiment tested feed rates of 80, 100, and 120 kg/h and screw-pressing speeds of 80, 95, 110, and 125 rpm. Results showed that the produced charcoal blocks had an average length of 13.91±1.62 cm, an outer diameter of 4.12±0.05 cm, an internal diameter of 1.23±0.12 cm, and a moisture content of 3.31% (db). When tested at a screw pressing speed of 125 rpm and a feed rate of 120 kg/h, with a mixture ratio of cassava stump charcoal, cassava starch, and water at 3.00:0.45:4.00 kg, the machine achieved a production capacity of 111.7 kg/h, specific energy consumption of 13.35 w-h/kg, a bulk density of 505.3 kg/m³, a charcoal strength ranging from 82.14 to 159.51 kN/m², and a heating value of 5113.3 cal/g. In the future, research should prioritize optimizing the energy efficiency of the machine and investigating alternative binder materials to enhance the quality and sustainability of charcoal blocks. Furthermore, it would be beneficial to study the environmental impact of large-scale implementation to evaluate the overall sustainability of this technology.

Keywords: Charcoal, Charcoal block, Alternative energy

1. Introduction

Biomass processing has gained significant attention in recent years because of its potential for sustainable energy production, particularly in the form of biochar and charcoal derived from agricultural residue. Biomass materials, such as cassava stumps, which are typically considered agricultural waste, are a viable feedstock for renewable energy production. Converting cassava stumps into charcoal blocks can reduce waste, provide an alternative energy source, and support a circular agricultural economy [1]. The production of biomass-based products, including charcoal blocks, relies heavily on the efficiency of equipment used. Machines that compress biomass into blocks or pellets operate under various mechanical parameters, such as feed rate and screw-pressing speed, which significantly affect both the quantity and quality of the final product [2]. Therefore, understanding how these parameters influence the performance of pressing machines is crucial for optimizing the conversion process and ensuring the economic viability of biochar production.

The feed rate refers to the amount of material supplied to the machine per unit time and plays a critical role in the compaction and densification processes during biomass conversion. A higher feed rate generally increases the production capacity, but it can also lead to issues such as inconsistent material compaction or machine blockages if not properly managed [3]. The impact of feed rate on product quality has been extensively studied in pelletizing systems, where higher feed rates typically improve throughput, but may compromise the uniformity of the final product [4]. Research by Kaliyan and Morey [2] highlights that in biomass pelletization, higher feed rates contribute to better compaction and material cohesion, resulting in denser and more durable pellets. However, the authors also noted that excessive feed rates can overload the system, leading to decreased energy efficiency and suboptimal product quality. The same principles apply to charcoal block production, where managing the feed rate is the key to ensuring proper material compaction, block strength, and overall machine performance. Screw pressing speed is another critical factor in biomass processing that directly influences energy efficiency, material throughput, and quality of the final product. According to studies on biomass densification, increasing the screw speed can enhance the production capacity by allowing faster material flow through the press; however, it can also lead to insufficient compaction if the speed is too high [5]. Inadequate compaction reduces the mechanical strength of the blocks or pellets produced, leading to weaker products that may break during handling and storage. In their study on biomass pellet production, Rahimi et al. [6] higher screw speeds typically increased throughput, but at the expense of pellet quality, particularly in terms of mechanical durability. Their findings suggest that while higher screw speeds can improve production efficiency, they must be carefully balanced with the feed rate to avoid compromising product quality. Similar results have been observed in other biomass applications, including briquette production, where faster screw speeds can lead to higher output, but lower product density and strength [2]. The interaction between feed rate and screw pressing speed plays a significant role in determining the performance of biomass-pressing machines. Studies have shown that adjusting both parameters simultaneously can optimize production efficiency and product quality [3]. For example, increasing the screw speed without adjusting the feed rate can result in inadequate compaction, whereas increasing the feed rate without sufficient screw speed can lead to machine blockages or material overflow. In their work on biomass briquetting, Liu et al. [7] they emphasized the importance of balancing the feed rate and screw speed to achieve optimal densification. They found that higher feed rates require higher screw speeds to maintain product uniformity and strength; however, if the balance is not carefully managed, it can lead to either overcompression or undercompaction, both of which affect product quality.

Although much research has been conducted on biomass pelletization and briquetting, studies focusing specifically on cassava-stump charcoal block production are limited. However, the principles governing the relationship between the feed rate, screw pressing speed, and machine performance in other biomass applications can be applied to this process. Cassava stumps are fibrous and woody materials, and achieving consistent compaction and block formation is challenging. Therefore, optimization of the feed rate and screw speed is essential for ensuring the efficient conversion of cassava stumps into high-quality charcoal blocks. By managing these parameters, operators can improve the mechanical strength, density, and durability of charcoal blocks, making them more suitable for energy applications. Additionally, optimizing these variables can enhance the energy efficiency and reduce machinery wear and tear, contributing to the overall economic viability of the process [5].

In summary, previous studies have highlighted the critical influence of the feed rate and screw pressing speed on the performance of biomass pressing machines. While increasing the feed rate can enhance compaction and production output, it must be carefully balanced with the screw speed to prevent overloading and inconsistencies in the final product. Similarly, higher screw pressing speeds can boost production capacity, but if not properly regulated, they may compromise the quality of the end product. These insights are particularly relevant to the production of cassava-stump charcoal blocks, where optimizing both parameters is crucial for achieving efficient production and maintaining a high product quality.

2. Materials and methods

The following procedures were employed to investigate the effects of the feed rate and screw pressing speed on the performance of the cassava-stump charcoal block-pressing machine.

The charcoal block production process was first analyzed to understand its essential machinery, which included a size reduction machine, mixing unit, and pressing unit. The insights gained from this investigation helped identify potential challenges and inform the design of a prototype charcoal block-pressing machine that integrates mixing, conveying, and pressing functions into a single unit. Unlike commercial machines, which may have separate or less integrated components, this prototype features a compact and modular design, allowing for improved operational efficiency and easier maintenance. Additionally, the prototype's ability to adjust key operational parameters, such as the feed rate and screw pressing speed, provides a level of flexibility that is often limited in standard commercial machines. As shown in Figure 1, the main components of the prototype machine include a mixing tank, screw conveyor, feeding hopper, screw press unit, power transmission system, and frame, all of which work together to optimize the charcoal block production process specifically for cassava-stump biomass.

This experimental study aimed to assess the impact of various feed rates and screw pressing speeds on the charcoal pressing performance. The cassava stumps were first charred in 200-liter barrels, an appropriate method for small-scale production using simple and cost-effective technology [8]. The produced cassava-stump charcoal was then ground using a hammer mill with a 3-mm sieve, as described in Laloon et al. [9] . The ground charcoal used in the experiments had a moisture content of 7.31% (wb).

For the experiment, eucalyptus bark charcoal powder was mixed with cassava starch and water in a ratio of 1:0.1:0.75 kg [10]. This mixture was in accordance with previous studies and was mixed for 5 min at a blade speed of 90 rpm. The moisture content of the final charcoal mixture was measured at 7.46% (wb).

The performance of the machine was tested at three feed rates (80, 100, and 120 kg/h) and four screw-pressing speeds (80, 95, 110, and 125 rpm). These speeds corresponded to linear velocities of 0.106 m/min, 0.120 m/min, 0.146 m/min, and 0.166 m/min, respectively, as shown in Figure 2. Each treatment was repeated thrice, and the time taken for each trial was recorded. After each trial, the weight of each sample was measured to calculate its production rate. The power consumption during each trial was measured using a multimeter and the specific energy consumption was calculated accordingly.

The moisture content of the pressed charcoal blocks was recorded, and the blocks were air-dried in sunlight until the moisture content dropped to below 8% (db). The drying process was monitored every 24 hours. Once the desired moisture content was achieved, the bulk densities of the charcoal blocks were determined. The mechanical strength of the blocks was evaluated using a Universal Testing Machine (UTM), and the calorific value was measured using a bomb calorimeter.

The performance evaluation was conducted using key indicators such as the output capacity, specific energy consumption, bulk density of the charcoal blocks, compressive strength, heating value, and utilization efficiency. To analyze the performance of the charcoal block pressing unit, different drum speeds and concave clearances were tested. A 3 × 4 factorial experiment was implemented within a completely randomized design (RCBD) with three replications to ensure statistical accuracy and reliability in assessing the operational efficiency of the machine across varying conditions.

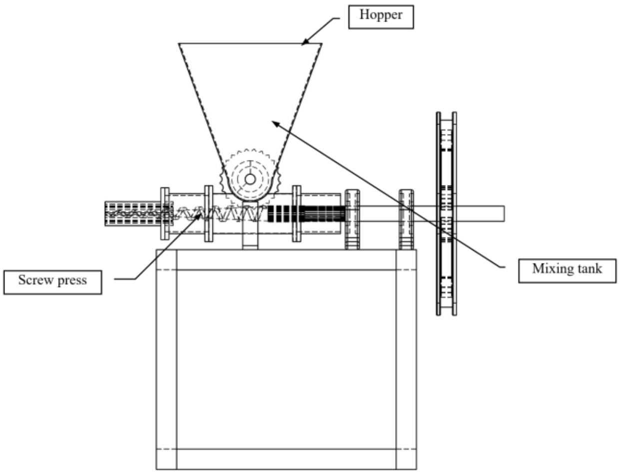

Figure 1 Charcoal Block Pressing Machine.

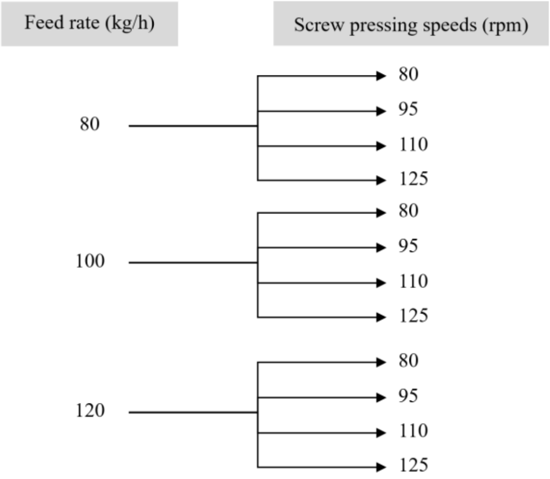

Figure 2 Factorial experiment setup

3. Results and discussion

The study on the charcoal block pressing machine, based on a screw pressing mechanism, produced charcoal blocks with an average length of 13.91 ± 1.62 cm, an outer diameter of 4.12 ± 0.05 cm, and an inner diameter of 1.23 ± 0.12 cm, as shown in Figure 3. ANOVA (analysis revealed several key factors affecting the performance of the cassava stump charcoal block-pressing machine. First, the feed rate significantly affected both the capacity and specific energy consumption, with F values of 331.474 and 92.664, respectively. This indicates that optimizing the feed rate can substantially improve the machine output while reducing the energy use. Second, the screw pressing speed plays a critical role in both the capacity (F = 368.495) and charcoal block strength, affecting the integrity of the material in both the vertical and horizontal directions. As reported by Adapa et al. [11], increasing the screw speed typically enhances both the production efficiency and product quality. Furthermore, although the interaction between feed rate and screw speed had no significant impact on capacity or energy consumption, it significantly affected the structural integrity of charcoal blocks, which is a crucial factor for ensuring product durability [7]. Interestingly, neither the feed rate nor the screw speed affected the heat value of charcoal, highlighting that the energy content remains primarily determined by the intrinsic properties of the feedstock. Finally, both feed rate and screw speed significantly influenced charcoal density, which is a key quality metric for fuel performance, emphasizing the importance of optimizing these operational parameters for maximum efficiency and product quality [6].

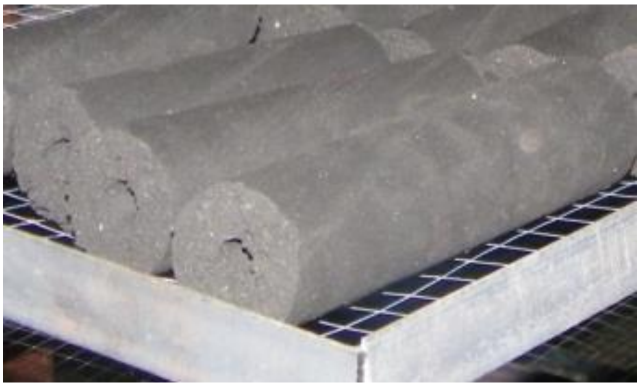

Figure 3 Charcoal Block.

Table 1 ANOVA: Impact of Feed Rate and Screw Press Speed on the Performance of the Charcoal Block Pressing Experimental Unit

SOV	df	F-value					df	F-value
		capacity	specific energy consumption	charcoal block strength		heat value		charcoal density
				Vertical	Horizontal			
block	2	0.638^{ns}	0.054^{ns}	0.404^{ns}	0.100^{ns}	0.128^{ns}	4	0.766^{ns}
feed rate (A)	2	331.474**	92.664**	412.57**	526.842**	0.728^{ns}	2	62.866**
screw pressing speed (B)	3	368.495**	168.492**	74.837**	79.499**	1.498^{ns}	3	9.784**
A*B	6	27.716^{ns}	3.995^{ns}	23.711**	21.487**	1.803^{ns}	6	1.810^{ns}
Error	22						44	
Total	35						59	

*** Denotes significance at the 1% level; * denotes significance at the 5% level; ns indicates no significant effect; df refers to degrees of freedom.*

Figure 4 shows the screw-pressing capacity at various pressing speeds and feed rates. As the screw-pressing speed increased from 80 to 125 rpm, the capacity increased at all feed rates (80, 100, and 120 kg/h). Capacity growth is more pronounced at higher feed rates, indicating that higher feed rates combined with faster pressing speeds enhance the throughput efficiency. At 125 rpm, the capacities converged to approximately 111.7 kg/h for all feed rates, suggesting a potential operational limit or an optimal performance threshold at this speed. The relationship between the screw pressing speed and capacity, as shown in the figure, indicates that increasing the speed leads to a higher capacity across all feed rates. However, the capacity growth began to plateau at higher speeds, indicating potential operational limits [6]. This suggests that, while higher speeds improve throughput, they may also result in energy inefficiency as the system approaches its mechanical constraints. Furthermore, optimizing the feed rate is essential; the 120 kg/h feed rate outperforms the others, but careful balancing of the speed and rate is required to avoid a system overload [11]. As the capacity converges at high speeds, mechanical limitations such as motor power and friction within the system must be considered. Pushing the system beyond these limits may increase energy consumption without further improvement in capacity [7].

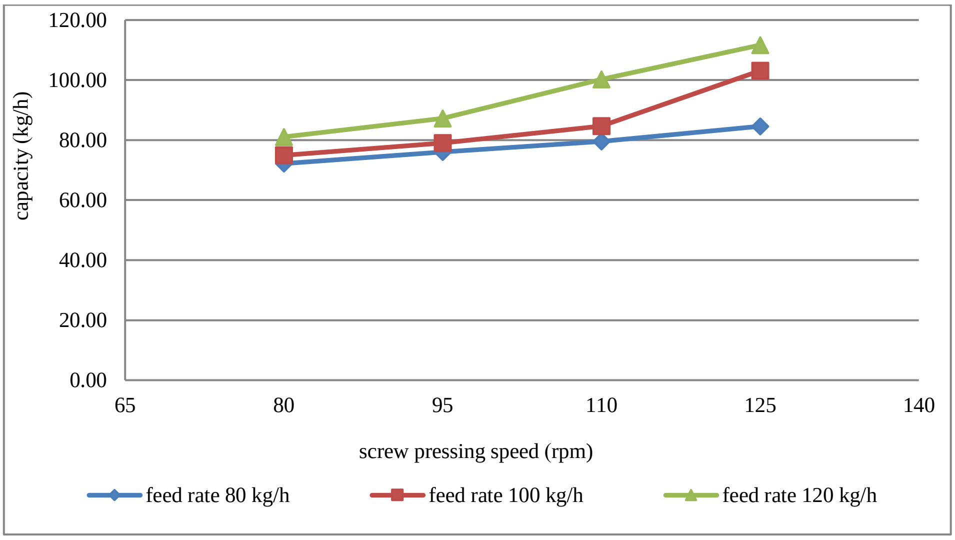

Figure 4 Relationship between screw pressing speeds and its capacity on feed rate

Figure 5 shows that as the screw pressing speed increases, the specific energy consumption decreases for all feed rates, suggesting that higher screw speeds improve the energy efficiency. This trend indicates that faster speeds allow for more efficient material flow and compression, thereby reducing the energy required per kilogram of output [6]. Furthermore, the feed rate of 120 kg/h consistently shows the lowest energy consumption, indicating that higher feed rates are more energy-efficient. In contrast, the 80 kg/h feed rate exhibited the highest energy consumption, reinforcing the need to optimize the feed rate to reduce overall energy usage [11]. The interaction between the feed rate and screw speed is also important, as higher feed rates benefit more from increased screw speeds in terms of energy efficiency. This finding aligns with previous research, which emphasizes the need to optimize both parameters to minimize the energy consumption [7]. However, while increasing the screw speed and feed rate improves energy efficiency, operators should also consider potential trade-offs such as increased wear on machinery and potential impacts on product quality [6].

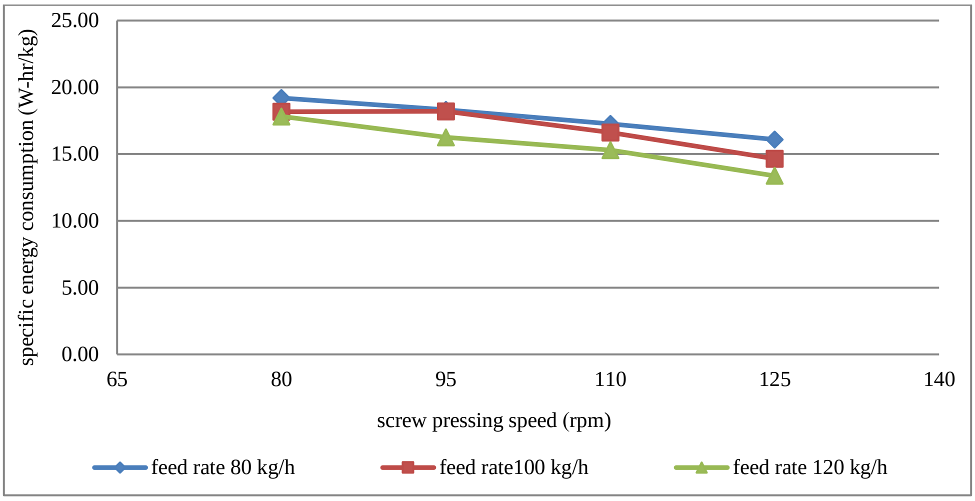

Figure 5 Relationship between screw pressing speeds and its specific energy consumption on feed rate

Figure 6 shows the relationship between screw pressing speed and charcoal bulk density at three different feed rates: 80, 100, and 120 kg/h. As the screw-pressing speed increased from 85 rpm to 125 rpm, the charcoal bulk density decreased at all feed rates. The feed rate of 120 kg/h maintained the highest bulk density across all speeds, followed by 100 kg/h, whereas the 80 kg/h feed rate consistently exhibited the lowest bulk density. This suggests that higher feed rates help maintain bulk density even as pressing speeds increase, whereas lower feed rates may lead to a significant reduction in bulk density at higher speeds. This trend indicates that both feed rate and screw speed play important roles in determining the bulk density of the charcoal produced, with the optimal combination required to maintain product quality. The figure shows that increasing the screw pressing speed leads to a decrease in the charcoal bulk density, indicating that higher speeds can reduce the compaction of charcoal, potentially resulting in lower product quality. Low-density charcoal typically exhibits poor combustion characteristics, which can negatively affect its efficiency in energy applications. This underscores the need to optimize screw speed to maintain adequate material compaction and ensure product quality [6]. Furthermore, the feed rate plays an important role in maintaining the bulk density. The 120 kg/h feed rate resulted in the highest density across all speeds, suggesting that higher feed rates contributed to better compaction and produced more uniform and efficient charcoal. Conversely, lower feed rates, such as 80 kg/h, consistently resulted in lower densities, thereby emphasizing the importance of optimizing feed rates in biomass processing [7]. The interaction between the feed rate and screw speed is crucial, as higher feed rates appear to mitigate the negative effects of increased screw speed on bulk density. This reinforces the need to balance both parameters to maintain product quality while optimizing the production throughput [11].

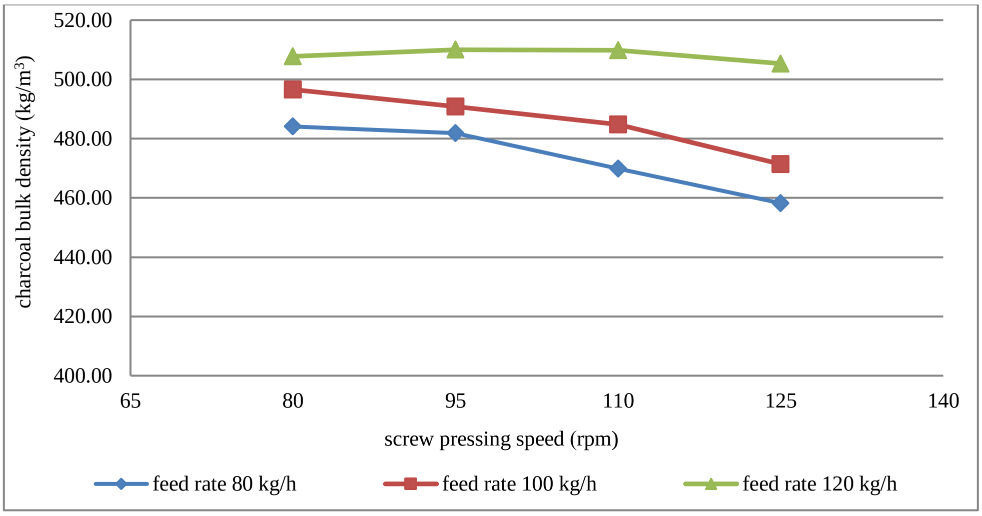

Figure 6 Relationship between screw pressing speeds and its charcoal bulk density on feed rate

As the screw pressing speed increased, the charcoal strength decreased across all feed rates (Fig.7), with the most noticeable decline occurring at a feed rate of 80 kg/h. This reduction in strength is likely caused by inadequate compaction at higher speeds, which weakens the particle bonding and reduces the structural integrity of the material. Rahimi et al. [6] suggested that high compression speeds may adversely affect cohesiveness by providing sufficient time for proper compaction. Therefore, balancing the screw speed with the optimal feed rate is crucial for maintaining the strength and quality of charcoal, particularly in industrial applications, where product durability is vital. In contrast, the 120 kg/h feed rate maintained a higher charcoal strength across all screw pressing speeds, indicating that increased feed rates led to better material compaction and stronger bonding. This finding aligns with that of Liu et al. [7] , who reported that higher feed rates improved compaction efficiency and boosted product strength. The higher the feed rate, the more material was provided for compression, resulting in stronger charcoal even at faster pressing speeds. This underscores the importance of feed rate optimization in mitigating the negative effects of higher screw speeds on product strength. The results also show a trade-off between the production speed and product quality. Although higher screw speeds increased the throughput, they reduced charcoal strength, particularly at lower feed rates. Adapa et al. [11] observed a similar trade-off in biomass processing, in which faster speeds improved the output, but weakened the product strength and durability. Industrial operators must carefully balance these parameters to achieve a high output without compromising quality. A slight reduction in screw speed combined with a higher feed rate can help maintain product strength while ensuring adequate production capacity. In conclusion, optimizing the feed rate is key to maintaining product strength during high-speed operations. The consistent performance of the 120 kg/h feed rate demonstrates that higher feed rates help preserve strength, even at faster screw speeds. Rahimi et al. [6] noted that a higher feed rate enhances structural integrity by allowing for better compaction, emphasizing the need to optimize the feed rate and speed for both production efficiency and quality in industrial biomass processing.

The results showed that the feed rate and screw pressing speed did not significantly affect the calorific value of charcoal blocks. The average calorific value of the charcoal produced in this study was 5113.33 cal/g. This indicates that regardless of changes in the feed rate or screw speed, the energy content of the charcoal blocks remained consistent, suggesting that these operational parameters do not significantly influence the inherent calorific properties of the charcoal.

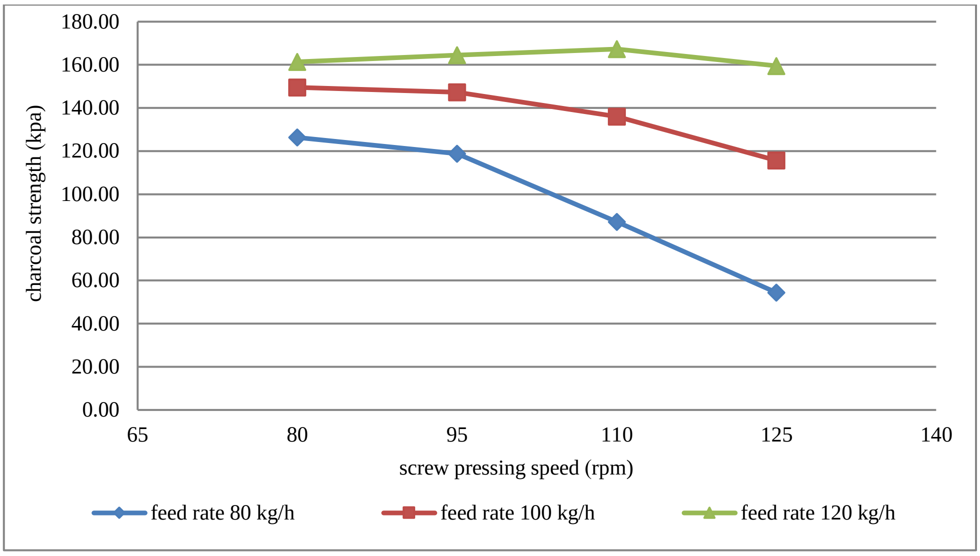

Figure 7 Relationship between screw pressing speeds and its charcoal strength on feed rate

4. Conclusions

This study of cassava-stump charcoal block pressing machines revealed several significant findings. Both the feed rate and screw pressing speed significantly affected the machine output and specific energy consumption. A higher feed rate increased the production capacity, while optimizing the screw pressing speed reduced the energy consumption and improved the overall efficiency. Additionally, the interaction between feed rate and screw speed was found to have a substantial effect on the strength of charcoal blocks. However, neither variable influenced the calorific value of the charcoal. Testing conducted at a screw pressing speed of 125 rpm, a feed rate of 120 kg/h, and a mixture ratio of cassava stump charcoal, cassava starch, and water at 3.00:0.45:4.00 kg yielded a production capacity of 111.7 kg/h, specific energy consumption of 13.35 w-h/kg, charcoal bulk density of 505.3 kg/m^3, charcoal strength between 82.14 and 159.51 kN/m^2, and a heating value of 5113.3 cal/g. These findings suggest that the calorific value of charcoal is determined primarily by the feedstock's intrinsic properties rather than the machine's operational settings. In conclusion, optimizing both the feed rate and screw pressing speed is critical for enhancing production efficiency and ensuring high-quality products in biomass processing systems. This study underscores the importance of parameter adjustments in improving the machine performance while maintaining the structural integrity of the final product. Future research should investigate the long-term effects of these parameters on the machine wear and product durability in large-scale production settings.

5. Acknowledgements

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