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Production of High-Quality Charcoal Briquettes from Recycled Biomass Residues

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ABSTRACT

The aim of the present study is to produce high-quality charcoal briquettes from biomass residues. Experiments were conducted under conditions of three different biomass residues (rice straw, cotton stems and corn stalks), two binder materials (starch and carton paper) under two different concentrations (5 and 7 wt %) and four operating pressures (0.5, 1.0, 1.5 and 2.0 MPa). The produced charcoal briquettes were evaluated from physical, chemical, thermal and mechanical properties. The charcoal briquettes quality was evaluated and compared with original form of raw biomass residues.Results clarified that high-quality charcoal briquettes could be obtained from cotton residues by operating the press machine under pressure of 1.5 MPa at starch binder material with a concentration of 7 wt%. The previous conditions achieve appropriate charcoal briquette of 400 kg/m^3 bulk density, 85.23 % fixed carbon, 6.10 % volatile matter, 4.05 % ash content, 32.21 MJ/kg calorific value, 83.63 % thermal efficiency and 213.79 kg/cm^2 compressive strength.

***Keywords**:* Biomass residues, Biomass recycling, Charcoal production, Binder material, Briquettes, Product quality

INTRODUCTION

Energy shortage is a great challenge with increasing the total population, so; there is a need for alternative sources of energy that are renewable and eco-friendly. Biomass is the third-largest source of energy in the world Tumuluru *et al*., (2011). Developing countries faced problems with biomass residues management; these problems could be avoided by biomass briquettes for generating energy fuel. In its original shape of biomass, it had minimal bulk density with huge transportation and storage costs. While using briquettes technology, the bulk density was increased and thus easier to handle Ngusale *et al*., (2014). Biomass resources could be classified in terms of characteristics (woody and non-woody biomasses) or sources (agricultural residues and harvested natural materials) according to Bajwa *et al.* (2018). Briquettes were used to generate heat and power. The use of renewable energy from biomass was one of the cost-effective and available technologies that can decrease emissions of CO_2 Trubetskaya *et al*., (2019). Gilvari *et al.* (2019) stated that compressive strength, abrasion resistance, impact resistance, moisture absorption and density considered the most important indicators for durability, stability and quality parameters of densified biomass.

Charcoal briquette investment was a good trend for agriculturists to conserve the global environment and reduce imported energy. Results in a compressed briquettes mixture of sawdust using a manually hydraulic briquette machine showed that starch performed better than the Gum Arabic as a binder Okegbile *et al*., (2014). The better charcoal briquettes were found to have the highest fixed carbon with bulk density. It had been noted that corn cob briquettes have lower moisture content compared to bagasse, while it had higher moisture content than wood charcoal. Also, bagasse and wood charcoal were found to have lower ash content compared to all grades of charcoal produced Zubairu and Gana, (2014). Among the multiple-component briquettes, 50 % coconut shell, 25 % corn cob and 25 % sugarcane bagasse gave the highest calorific value (19951.4 J/g) compared to coconut shell charcoal (21693.3 J/g). The compaction had a significant effect on the briquettes volume displacement due to the increase in the void in the raw materials that could be filled, when a higher compaction pressure was applied Arellano *et al*., (2015). The physical and thermal properties were determined by different proportions from rice straw to sugarcane leaves using molasses as a binding agent. Results showed that the fixed carbon, volatile matter, ash content and moisture content values were ranged from 9.06 to 13.63 %, from 68.14 to 74.67 %, from 7.84 to 12.85 % and from 4.2 to 6.2 %, respectively. The higher heating, density and the compressive strength values were in range of from 16.3 to 17.83 MJ/kg, from 0.53 to 0.58 kg/m^3 and from 32.4 to 44.7 kg/cm^2, respectively. The optimum ratio for briquette was obtained from rice straw to sugarcane leaves at 1:1 Jittabut, (2015). Briquettes that were prepared from biomass wastes as coconut pith, sawdust and sugarcane waste were dried by sun and compressed without the addition of any bonding agents. The results illustrated that the calorific values were 23.98, 20.37 and 18.89 MJ/kg for coconut pith, sawdust and sugarcane briquettes, respectively. The lowest ash content was 1.8 % for sugarcane briquette, while the sawdust briquette recorded the highest value (28.13 %). Efficiency for coconut pith, sawdust and sugarcane briquettes was 63.63, 61.62 and 53.85 %, respectively produced by the modified wood stove Murali *et al*., (2015). The briquette density increased by increasing the applied pressure by the hydraulic

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press at range from 260 to 416 kg/m^3 Thabuot *et al*., (2015). Romallosa and Kraft (2017) found that high-quality fuel briquettes were obtained from a mixture of waste paper with sawdust and carbonized rice husk as a renewable source of cost-effective fuel. Suttibak and Loengbudnark (2018) found that the charcoal briquettes from cassava rhizomes (CR) had more favorable properties than sugarcane bagasse (SB) or water hyacinth (WH). Whereas, the lower heating values of charcoal briquettes from SB, CR and WH were 26.67, 26.84 and 16.76 MJ/kg, respectively. Also, the compressive strength for SB, CR and WH charcoal briquettes were 54.74, 80.84 and 40.99 kg/cm^2, in that order. Ujjinappa and Sreepathi (2018) revealed that the use of Pongamia Cake (PC) created an adverse effect on the properties of briquettes. Therefore, the use of PC as an additive was not recommended. Briquettes with a mixing ratio of 60:40 for Pongamia Shell (PS): Tamarind Shell (TS) under 200 MPa had better quality and met charcoal briquette standards for commercial use, in addition with the overall combustion properties of the briquettes were enhanced compared to the original raw materials. Deshannavar *et al*. (2018) found that using carbonized rice husk with starch and bentonite clay as binders increased each of the briquette bulk density and the compressive strength by increasing the percentage of binder in the mixture up to 6% and then, they decreased with a further increase in binder concentration. Ajimotokan *et al.* (2019) produced the briquettes using a pressure of 5 MPa for 5 min in a hydraulic briquette machine. Results revealed that the increase in the charcoal particles resulted in an increase in the fixed carbon content and heating value of the briquettes. The briquette that included high sawdust gave higher volatile matter content and lower heating value.

The above-mentioned literature found that the possibility of reusing carton paper material, that include a detrimental effect on the environment, so it can be added as binder material under different concentrations comparable with starch binder material in charcoal briquette. The present work is focused on the recycling of biomass residues (rice straw, cotton stems and corn stalks) using different binder materials under different concentrations for producing high-quality charcoal briquettes.

MATERIALS AND METHODS

Experiments were conducted through the year of 2019 at a private workshop store of Belbeis, Sharqia Governorate, Egypt for producing charcoal briquettes from biomass residues.

Experimental setup

Biomass residues

Three collected types of biomass residues (rice straw, cotton stems and corn stalks) were used as raw materials under the present study for producing charcoal briquettes. Some characteristics of the used residues were determined and illustrated in Table 1. Biomass residues were collected from the field, cleaned from dust and chopped.

Carbonizer

Each type of the used raw materials is fed and completed burned in a dedicated closed underground place (carbonizer). The burning process was left for 24 hours at 500ºC temperatures. Carbonization is a process of converting biomass into carbon residue. This process requires the application of heat on the biomass so that the volatile matter and other substances in it would be removed. The resultant powder of burning for each type of biomass residues were used for blending with different binder materials.

Table 1. Some characteristics of biomass residues

Characteristics	Biomass residues		
	Rice straw	Cotton stems	Corn stalks
Cellulose, %	41	38	37
Hemicellulose, %	22	20	25
Lignin, %	18	25	27
Bulk density, kg/m^3	330	400	365
Moisture content, %	5.3	14.8	6.2
Ash content, %	8.3	2.7	5.3
Volatile matter, %	74.6	65.2	73.7
Fixed carbon, %	11.8	17.3	14.8
Heat calorific value, MJ/kg	15.4	17.1	15.8

Binder materials

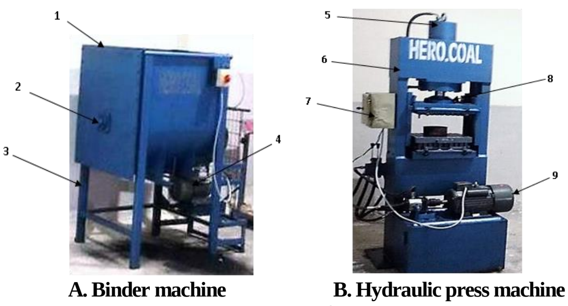
Two types of blending materials (corn starch and carton paper) were used under the present study. These binding materials are available; corn starch was obtained from a normal shop, while the carton paper as waste was derived from the surrounding environment. The binder materials were prepared before mixing them in a binder machine. Starch was dissolved in 100 ml of cold water to form a paste, and then added 400 ml of hot water through pouring the paste in the binder according to Yael *et al.* (2006). Concerning carton paper material preparation, it was immersed in a water tank for 3 days with agitation before mixing.

Binder machine

The binder machine as shown in Fig. 1 (A) was used to blend the mixtures homogeneously with water and coal powder by concentrations of 5 or 7 wt % of binder materials per 10 kg pulverized char powder and 3 liters water. The paste was gradually mixed for about 1 hour with the boiling water and stirred until obtaining a smooth homogeneous solution. The machine was manufactured at local company and consisted of the following specifications: steel material, pan type shape, Gems brand, 0.25 hp power with 100-500 rpm agitator rotating speed and manual feed intake.

Hydraulic press machine

The hydraulic press machine as shown in Fig. 1 (B) was used to press the components after the binder stage, it manufactured by local company, Egypt. The samples were subjected to different pressures during 2 minutes using a parallel rectangle forming pattern. It was powered by motor power of 5 hp under available pressure between 0 to 2.5 MPa.



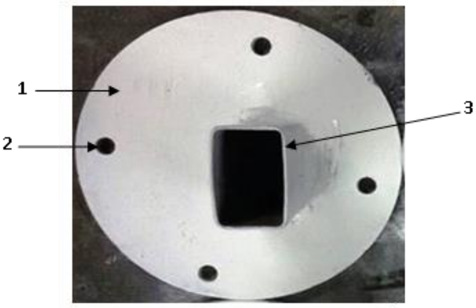
A. Binder machine **B. Hydraulic press machine**

1. Feed intake, 2. Agitator, 3. Binder frame, 4. Binder electric motor, 5. Oil pump, 6. Press machine frame, 7. Control panel, 8. Piston and 9. Press machine motor supply

Fig. 1. The used hydraulic press machine and binder

Forming pattern

The mixtures were placed in the formatting pattern with a circular plate shape as shown in Fig. 2 to be pressed by a hydraulic press machine. The forming briquette is a parallel rectangle shape with dimensions of 10 × 6 × 5 cm. It was installed on the hydraulic press machine by four holes and bolts.



1. Circular Plate frame, 2. Plate hole and 3. Parallel rectangle shape

Fig.2. Briquette forming pattern

Experimental procedure

Preparation of charcoal briquette samples

After the carbonization process for different biomass residues, the resulting powder was mixed with binders in an appropriate proportion. Briquettes of varied biomass concentrations were prepared by blending the biomass with starch or carton binder materials under various concentrations. All the components are mixed and then mechanically pressed into the desired shape. The briquettes are then formed in forming shape for pressing the mixture through the hydraulic briquette machine. Moisture is removed from the briquettes by direct sun drying until constant weight (48 hours). The samples were weighed using a digital balance. The preparation steps for charcoal briquettes are summarized in Fig. 3.

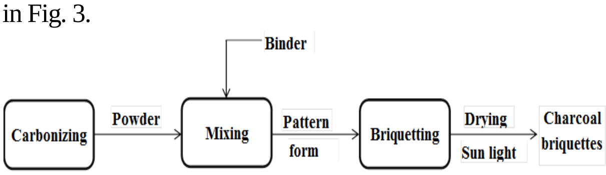


Fig. 3. Schematic of charcoal briquetting process

Experimental conditions

Experimental conditions were carried out under the following treatments as follows:

- Three biomass residues (rice straw, cotton stems corn stalks).
- Two binder materials (starch and carton paper).
- Two binder concentrations (5.0 and 7.0 wt %).
- Four operating pressures (0.5, 1.0, 1.5 and 2.0 MPa).

All readings of the following indicators were taken three times duplicated to obtain the average values under previous parameters.

Measurements and determinations

The product quality was measured in terms of physical, chemical and thermal properties for charcoal briquettes made from different biomass residues.

The following measurements and determinations were conducted as:

➢ **Physical properties**

The physical properties of biomass briquettes are important to be investigated according to Oladeji (2010) as:

- **Bulk density**

The charcoal briquettes density was measured as the ratio of the mass to the briquette volume according to Rabier *et al.* (2006).

- **Moisture content**

The moisture content (*Mc*, wb %) was determined according to BS EN 14774-1 Standard (2009). It was calculated using the following equation:

$$Mc = [(W_0 - W_d)/ W_0] \times 100$$

where

W_0: Original mass of the sample and W_d: Final dried mass of the sample.

➢ **Chemical properties**

Proximate analysis was done to determine the combustion properties of produced briquette samples such as volatile matter, ash content and fixed carbon using different ASTM standard methods. The properties were determined according to Oladeji (2010) as follows:

- **Volatile matter percentage**

It was calculated according to the standard test method for volatile matter ASTM D3175–11 (2011) and Mitchual *et al.* (2014). The dried sample was kept at a temperature of 550 ºC for 10 minutes. The percentage of the volatile matter (*V*) was determined as:

$$V = [(A - B)/ A] \times 100)$$

where:

A: Mass of oven-dried sample (g),

B: Mass of sample after 10 min in the furnace at 550ºC (g).

- **Ash percentage**

The ash content (*AC*) was determined in a furnace at 750ºC for 2 h content using ASTM E830–87 (2004) standard test method for ash. It was calculated by:

$$AC = (C / A) \times 100$$

where:

C: Mass of ash (g), A: Mass of oven-dried sample (g).

- **Fixed carbon percentage**

It was determined according to the standard test method of ASTM D1762–84 (2013) and Mitchual *et al.* (2014). Fixed carbon (*FC*) was calculated using the following equation:

$$FC = [100 - (Mc + V + AC)] \times 100$$

➢ **Thermal properties**

- **Heating calorific value**

The heat calorific value (*HCV*) was calculated according to Bailey and Blankenhorn (1982) and Emerhi (2011) as follow

$$HCV = 2.326\ (147.6\ FC + 144\ V)$$

- **Thermal efficiency**

It was determined by the following equation:

$$Thermal\ Efficiency = (Q_u / Q_g) \times 100$$

$$Q_u = [\ (W_i - W_f\ ) \times C_v] + [(T_f - T_i) \times W_f \times C_p]$$

$$Q_g = W \times C$$

where:

Q_u: Heat used in the pot (kJ), Q_g: Heat produced by the briquette (dry mass) (kJ), W_i: Initial mass of water (g), W_f: Final mass of water (g), C_v: Water vaporization heat (2.23 × 10^{-3} kJ/kg), T_i: Initial water temperature (ºC), T_f : Boiling point (ºC), C_p: Water specific heat (0.00418 × 10^{-3} kJ.ºC/kg), W: Mass of the biomass burnt during the experiment (kg) and C: Calorific content of the charcoal briquette (kJ/kg).

➢ **Mechanical properties**

- **Compressive strength**

It is an indicator of briquette durability according to Richard, (1990). It is very important that affects the quality during storage and transportation to the market (Habib *et al*., 2013). The compressive strengths of the briquettes were determined for all collected charcoal briquettes. The ASTM standards for coal can generally be applied for charcoal, but there is no standard for compression strength according to Vieira (2009). The briquette sample was placed under 2 kN loading rate at a constant rate of 0.5 mm/min until the briquette failed by cracking or breaking according to Jindaporn and Songchai (2007).

RESULTS AND DISCUSSION

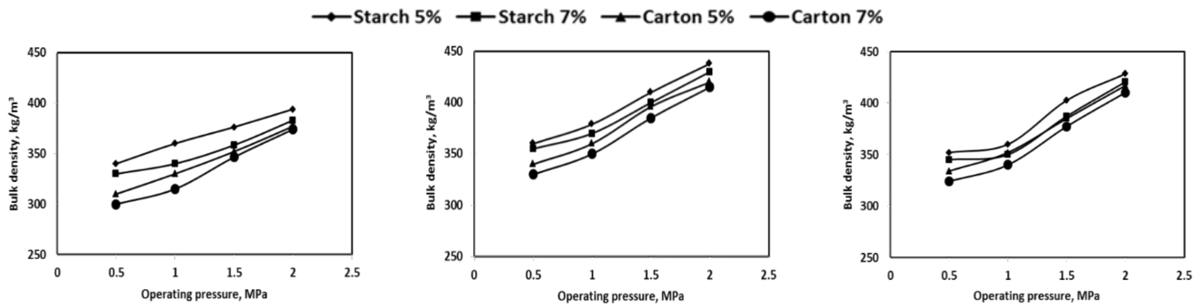
The experimental results will be discussed under the following topics:

1. Briquettes bulk density

The bulk density of the charcoal briquettes is observed to be changed by increasing the operating pressure as shown in Fig. 4. It is a function of the pressure according to Zubairu and Gana (2014). The bulk density values are 340, 360, 376.3 and 394 kg/m^3 for rice straw, while the values are 360, 379, 410 and 438 kg/m^3 for cotton stems and the values are 352, 360, 402.6 and 428.4 kg/m^3 for corn stalks under 0.5, 1.0, 1.5 and 2.0 MPa operating pressures, respectively with 5 wt % starch. Generally, the bulk density is increased by increasing pressure because of the volume displacement and void spaces of the briquettes are compressed by increasing operating pressure. This result is agreed with Arellano *et al*. (2015). The highest bulk density values are obtained for briquettes of cotton residues comparing to the other biomass residues. This increase is due to an increase in the briquette mass of raw residues. On the other side, results reveals that bulk density at a binder concentration of 5 wt % is greater than 7 wt % concentrations Deshannavar *et al.*, (2018). The briquettes that blended by carton paper material gives lower bulk density comparing with briquettes that prepared by a starch binder material.

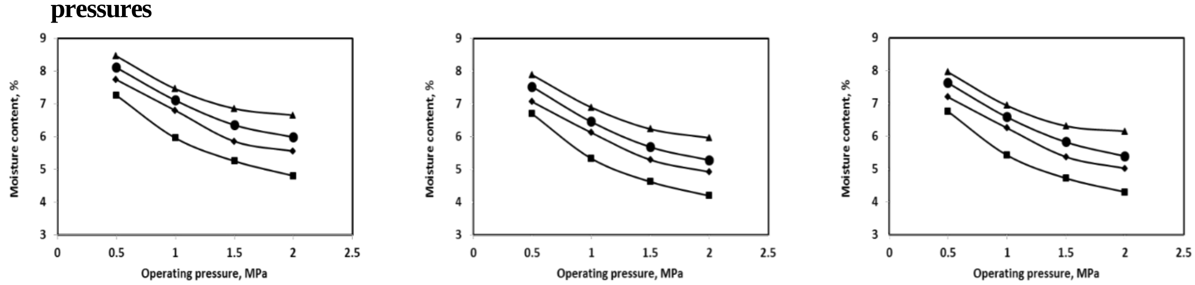
2. Briquettes moisture content

The variation of moisture content for charcoal briquettes made from different biomass residues is illustrated in Fig. 5. The moisture content has a great effect on the charcoal quality and ignition process, so, it should be as low as possible. The average obtained moisture content of charcoal briquettes is about 6.63, 6.01 and 6.11% (wt %) for rice straw, cotton stems and corn stalks briquettes, respectively, this result is an agreement with the recommended moisture content that ranged from 5 to 10 % for good quality briquettes Pallavi *et al.*, (2013). Briquettes moisture contents are decreased by increasing pressure. By the use of 7 wt % starch binder material, the moisture contents of briquettes are 7.25, 5.95, 5.25 and 4.8 % for rice straw, while 6.69, 5.33, 4.62 and 4.19 % for cotton stems and 6.75, 5.42, 4.72 and 4.3 % for corn stalks under 0.5, 1.0, 1.5 and 2.0 MPa operating pressures, respectively. By the use of 7 wt % carton binder material, the briquettes moisture contents are 8.10, 7.10, 6.35 and 5.98 % for rice straw, while 7.52, 6.45, 5.68 and 5.28 % for cotton stems and 7.62, 6.58, 5.82 and 5.39 % for corn stalks under the previously mentioned conditions, in that order. For biomass briquettes, cotton stems give the lowest moisture content compared to other residues. As a result of the substance properties, the carton binder material absorbs and keeps the moisture content than starch. Added to that, the briquette moisture content as a function of the binder concentration, results indicates that the moisture content of briquettes is decreased by increasing the blending concentration from 5 to 7 wt %, these results matches with Zubairu and Gana (2014).



A. Rice straw B. Cotton stems C. Corn stalks

Fig. 4. Bulk density of charcoal briquettes with different blending materials and concentrations under different pressures



A. Rice straw B. Cotton stems C. Corn stalks

Fig. 5. Briquettes moisture content at different operating pressures

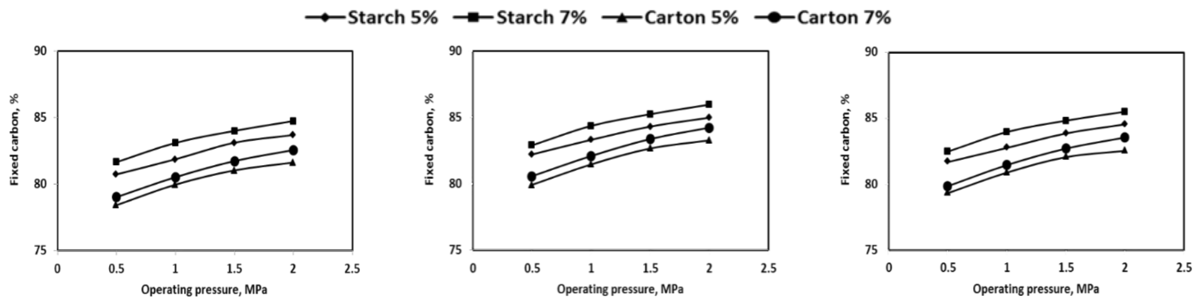
3. Fixed carbon

The effect of different parameters on fixed carbon is shown in Fig. 6. It is noticed that fixed carbon values of briquette samples decrease with increasing each of moisture content, volatile matter and ash contents. Obtained results reveal that the fixed carbon increases by increasing pressure from 0.5 to 2.0 MPa. The fixed carbon values range from 81.64 to 84.73 %, 82.88 to 85.95 % and 82.47 to 85.50 % by increasing operating pressure from 0.5 to 2.0 MPa for rice, cotton and corn charcoal briquettes, respectively. The highest fixed carbon is noticed under using cotton stems for producing charcoal briquettes than other residues. So, cotton stems briquettes are suitable for applications. Concerning binder materials for starch under 7 wt % concentrations give the highest fixed carbon comparing with other treatments. This result is agreed with Zubairu and Gana (2014). On the other side of 1.5 MPa pressure, the fixed carbon values for cotton charcoal briquettes are 84.30 and 85.23 % under 5 and 7 wt % starch binder material, while 82.65 and 83.36 % under 5 and 7 wt % carton binder material, respectively. The fixed carbon content increases with increasing the concentration of the binder.

4. Heat calorific value

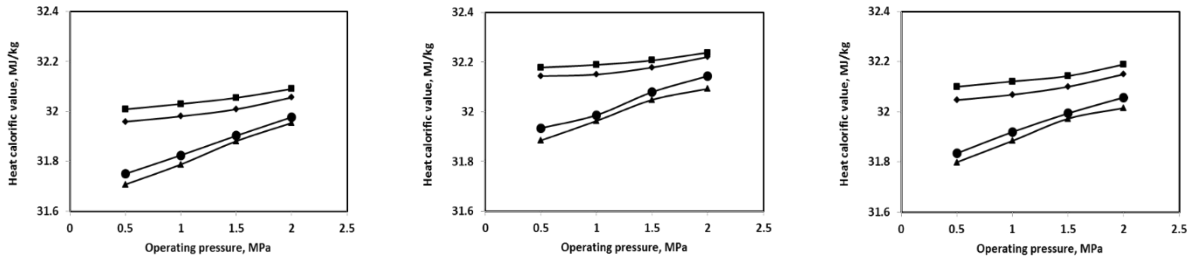
Fig. 7 explains that the calorific value of produced briquettes decrease with moisture content, volatile matter and ash, whereas the calorific value is increased with increasing fixed carbon. Results show that the calorific value is decreased by increasing operating pressure. For rice charcoal briquettes, the values are 32.01, 32.03, 32.05 and 32.09 MJ/kg, while 32.18, 32.19, 32.21 and 32.24 MJ/kg for cotton charcoal briquettes; however the values are 32.10, 32.12, 32.14 and 32.19 MJ/kg for corn charcoal briquettes under 0.5, 1.0, 1.5 and 2.0 MPa operating pressures, respectively with 7 wt % starch.

The calorific value is impacted by ash contents and closely related to fixed carbon. The charcoal briquette with high calorific value is considered high-quality products Kongprasert *et al*., (2019). Cotton briquettes give the highest energy values compared to corn and rice biomass charcoal briquettes. As with other properties, the binder materials and concentration affect the calorific value of the produced charcoal briquettes. Results show that starch binder material with 7 wt % concentration records the highest calorific value compared to the other treatments.



A. Rice straw **B. Cotton stems** **C. Corn stalks**

Fig. 6. Fixed carbon of produced charcoal briquettes at blending materials under different operating pressures



A. Rice straw **B. Cotton stems** **C. Corn stalks**

Fig. 7. Effect of different operating pressures at blending materials on heating calorific value of charcoal briquettes

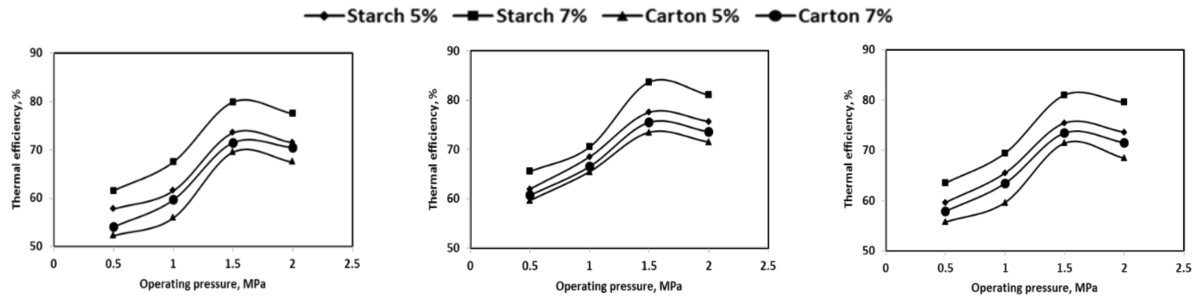
5. Thermal efficiency

Thermal efficiency is increased by increasing pressure until 1.5 MPa and then decreased as illustrated in Fig. 8. The thermal efficiencies of cotton briquettes that blending with 7 wt % starch are 65.50, 70.46, 83.63 and 81.02 % under 0.5, 1.0, 1.5 and 2.0 MPa operating pressures, in that order. Cotton charcoal briquettes give the highest thermal efficiency. At 1.5 MPa, the efficiencies of rice charcoal briquettes are 73.49, 79.87, 69.50 and 71.46 %, while 77.49, 83.63, 73.45 and 75.46 % for cotton briquettes, whilst 75.46, 81.02, 71.46 and 73.46 % for corn briquettes under 5 wt % starch, 7 wt % starch, 5 wt % carton and 7 wt % carton, respectively. Concerning the effect of binder materials, it is evident from the results that the highest efficiency is obtained under starch binder material with 7 wt % concentration.

Compressive strength

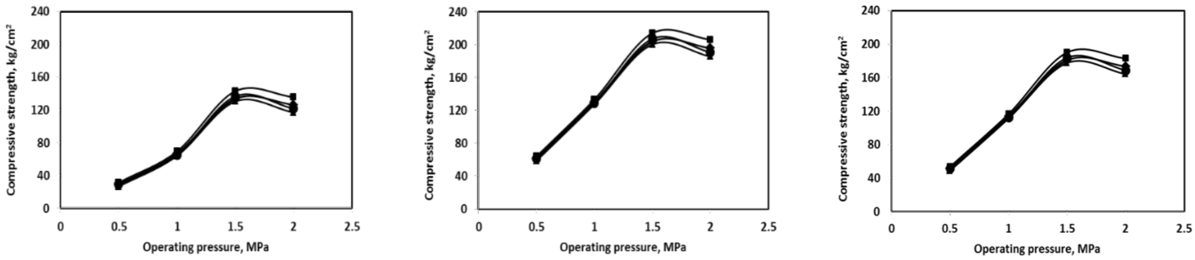
Fig. 9 shows that compressive strength is increased by increasing the pressure up to 1.5 MPa and then decreased. For rice charcoal briquettes, the values are 29.36, 66.76, 133.81 and 126.53 kg/cm^2, while 61.30, 129.93 203.49 and 195.68 kg/cm^2 for cotton charcoal briquettes, however the values are 51.36, 113.76, 180.81 and 173.53 kg/cm^2 for produced corn briquettes under pressures of 0.5, 1.0, 1.5 and 2.0 MPa, respectively with 5 wt % starch.

The use of cotton stems for producing charcoal briquettes gives the highest compressive strength compared to other biomass residues due to the nature of the cotton stems residue, which can reduce the brittleness of the produced briquettes. For binder materials, the use of starch material gives the highest compressive strength comparing with carton paper as a binder. Obtained results reveal that compressive strength shows initial improvement with an increase in the binder concentration from 5 to 7 wt %, this result is in agreement with Manyuchi *et al.* (2016).



A. Rice straw **B. Cotton stems** **C. Corn stalks**

Fig. 8. Effect of different operating pressures on thermal efficiency of charcoal briquettes



A. Rice straw **B. Cotton stems** **C. Corn stalks**

Fig. 9. Compressive strength for charcoal briquettes blending at binder materials and concentrations under different pressures

CONCLUSION

Briquetting technology has a great potential for recycling biomass residues into a superior fuel and environment-friendly manner. It is important to convert biomass residues and reuse waste materials into energy through charcoal briquettes production with high quality. The cotton briquette charcoal is found to be a better fuel that has the highest fixed carbon (85.23 %), low moisture content (4.62 %), high bulk density (400 kg/m^3) and calorific heating value (32.21 MJ/kg) with the least ash (4.05 %) and volatile matter (6.10 %) compared to either the raw biomass material of the same biomass kind or the other briquettes from rice straw and corn stalks under operating pressure of 1.5 MPa and 7 wt % concentration of starch binder material.

It is also recommended to reuse carton paper binder materials with 7 wt % concentration in the charcoal briquette process to avoid harmful effects on the environment.

Competing interest statement

The authors declare no conflict of interest.

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إنتاج قوالب فحم عالية الجودة من مخلفات الكتلة الحيوية المعاد تدويرها

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تتنوع وسائل تدوير المخلفات الزراعية لتعظيم الاستفادة الاقتصادية منها وتهدف هذه الدراسة الى إنتاج قوالب فحم عالية الجودة من مخلفات الكتلة الحيوية.ولتحقيق هذا الهدف أجريت التجارب باستخدام ثلاث بقايا مختلفة للكتلة الحيوية (قش الأرز ، سيقان القطن وحطب الذرة) ، واثنين من مواد الربط (النشا وورق الكرتون) تحت تركيزين مختلفين (٥٪ و٧ ٪ بالوزن) وأربعة ضغوط تشغيل مختلفة (٠,٥ ، ٠,١ ، ١,٥ و ٢,٠ ميجا باسكال). تم تقييم قوالب الفحم المنتجة من حيث الخصائص الفيزيائية والكيميائية والحرارية والميكانيكية. كذلك تم مقارنة جودة قوالب الفحم المنتجة ببقايا الكتلة الحيوية الخام. أوضحت النتائج أنه يمكن الحصول على قوالب الفحم عالية الجودة من بقايا سيقان القطن باستخدام مكبس لتشكيل قوالب الفحم تحت ضغط ١,٥ ميجا باسكال باستخدام النشا كمادة ربط بتركيز ٧٪ وزنا وذلك للحصول على فحم حجري ذو كثافة ظاهرية ٤٠٠ كجم / م^{٣} ، ٨٥,٢٣ ٪ كربون ثابت ، نسبة ٦,١٠ ٪ مادة متطايرة ، ٤,٠٥ ٪ محتوى رماد ، ٣٢,٢١ ميجا جول/ كجم قيمة حرارية ، ٨٣,٦٣ ٪ كفاءة حرارية و مقاومة للإنضغاط يعادل ٢١٣,٧٩ كجم / سم^{٢}. كما يوصى بإعادة استخدام الورق الكرتوني كمادة ربط بتركيز ٧٪ وزنا لإنتاج الفحم المضغوط تجنبا الآثار الضارة على البيئة.