



# Corn cob Biochar Production Using Super Sun Retort Combined with Kon-Tiki Kiln

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**Abstract:** In Thailand, crop residues are abundant but underutilized, creating a need for better valorization methods like biochar production. Firewood is commonly used to initiate pyrolysis in biochar retorts, but this process is inefficient and produces high emissions. This study evaluated biochar production from corncobs using the Super Sun retort with heat from the Kon-Tiki kiln, aiming to reduce pollution from firewood burning. Pyrolysis temperature and biochar properties, including electrical conductivity, calorific value, and iodine value, were measured. Each experiment used 20 kg of firewood and 25 kg of corncobs. Results showed complete conversion of corncobs into biochar, with a yield of up to 26%. The Super Sun retort produced biochar at high temperatures (>800 °C) more efficiently than conventional methods. The corncob biochar demonstrated good electrical conductivity and an iodine value of 230 mg/g. Its calorific value was 7300 cal/g. The findings indicate that the corncob biochar obtained in this study has potential applications in soil amendment and in the production of deodorizing charcoal and charcoal briquettes. The results also suggest that the combination of the Super Sun retort and Kon-Tiki kiln could offer a more sustainable and cost-effective solution for biochar production in developing countries.

**Keywords:** Biochar, Corn cob, Crop residues, Kon-Tiki kiln, Super Sun retort

Maize (*Zea mays* L.) residues, especially corncobs are abundant, but they remain underutilized in Thailand (Schweikle et al 2015). Many farmers still practice open field burning of crop residues, which causes both air pollution and health problems (Junpen et al 2018). Therefore, the need exists for a better valorization of biomass residues such as corncobs. Production of biochar from crop residues has been promoted by the government, research institutions, and non-governmental organizations, which intended to eliminate the open field burning of crop residues and create value-added products from biomass waste (Bhatt et al 2022, Mbah et al 2022). Biochar retort made of 200 L steel drum is widely used in Thailand. Firewood was widely used as an energy source to initiate the pyrolysis process in the biochar retort. The current use of firewood in an open fire is associated with low efficiency and high emission. A novel technology called the Kon-Tiki kiln combines the simplicity of traditional kilns with the combustion of pyrolysis gases in a flame curtain similar to retort kilns, which could be used to generate heat for starting-up the pyrolysis process in the biochar retort. This study aimed to evaluate the production of biochar from corncobs with the Super Sun retort by using heat generated from the Kon-Tiki kiln. This approach would help reduce air pollution caused by biomass burning during biochar production. The data on pyrolysis temperature was collected. Biochar properties such as electrical conductivity, calorific value, and iodine value were determined.

## MATERIAL AND METHODS

**Biomass feedstock:** The corncobs were collected from the National Corn and Sorghum Research Center, Faculty of Agriculture, Kasetsart University (Fig. 1a). They were the biomass residues from seed production. The corncobs had already been dried during the seed production process and thus did not require further drying before biochar production. Their moisture contents (wet basis, wb) were less than 9%. The whole corncobs without size reduction were used as the feedstock for biochar production. The corncobs had an average diameter of 25 mm and length of 133 mm. The firewood used in this study was obtained from a wood furniture manufacturer located near Kasetsart University (Fig.1b). The wood furniture manufacturer provided the biomass waste with no charge. The firewood consisted of different kinds of wood and had inhomogeneous size distribution. The moisture contents of the firewood were less than 4%.

**Biochar production equipment:** The Super Sun retort and the Kon-Tiki kiln were the biochar production technology used in this study (Fig. 2). The Super Sun retort was made of a standard 200 L steel drum. The dimension of the steel drum was 89.5 x 59.5 cm (height x diameter). A ceramic fiber was used as insulation material for the biochar retort. The thickness of the insulation material was 2 cm. A metal grate made of steel bars was placed at 10 cm above the bottom of the biochar retort to prevent the blocking of the gas outlets and carry the weight of the biomass feedstocks. In addition, a perforated metal

sheet with round holes of 6.5 mm (diameter) and thickness of 0.5 mm was placed on top of the metal grate, which prevented the corncobs from falling under the metal grate. A chimney with a dimension of 10 x 10 x 93 cm (length x width x height) was installed at the center of the steel drum. There were 12 holes with a diameter of 9 mm at the bottom of the chimney, which were the outlets of the pyrolysis gas. The pyrolysis gas was burnt at the bottom of the Super Sun retort, which heated up the retort and sustained the pyrolysis process.

The Kon-Tiki kiln was made of stainless steel 304 with a thickness of 1.5 mm. The kiln had a cone shape with a wall inclination of 60°. The upper diameter was 72 cm and the height was 35 cm. The diameter at the bottom of the Kon-Tiki kiln was 32.5 cm. A metal frame was constructed with rectangle metal bars. The dimension was 77 x 77 x 41 cm (length x width x height). The metal frame was placed above the Kon-Tiki kiln and the Super Sun retort was put on the frame.

**Biochar production process:** In each experimental run, 25 kg of corncobs were loaded in the Super Sun retort around the chimney. The lid was tightly closed with a galvanized locking ring. A thermocouple was installed in a hole on the lid of the biochar retort. A layer of sand was put on the lid as an insulation material. In the Kon-Tiki kiln, 20 kg of firewood was used. At first, the firewood was loaded until the top of the Kon-Tiki kiln. The fire was ignited on the top of the firewood with some tinder. A thermocouple was attached to the metal frame and used to measure the temperature above the Kon-Tiki kiln. A data logger was used to record the temperature in the Super Sun retort and Kon-Tiki kiln every 10 min. During the experiment, when the temperature in the Super Sun retort decreased, more firewood was loaded in the Kon-Tiki kiln. The pyrolysis process in the Super Sun retort was considered completed, when there was no combustible gas released from the chimney. After the temperature in the Super Sun retort was below 100 °C, the corncob biochar was carefully transferred to an empty 200 L steel drum for cooling. The lid of the steel drum was closed with a galvanized locking ring. The fire in the Kon-Tiki kiln was extinguished with clean water. The weight of the corncob biochar was recorded after 12 h of cooling at room temperature. The biochar was stored in an airtight plastic bag until use.

**Characterization of biochar:**The biochar yield  $Y_{biochar}$  was calculated on air-dried basis (ad), as follows:

$$Y_{biochar, ad} \text{ (wt. \% ad)} = 100 \times \frac{M_{biochar}}{M_{biomass}}$$

where  $M_{biochar}$  is the mass of biochar (kg),  $M_{biomass}$  is the total mass of biomass (kg), and  $Y_{biochar, ad}$  represents the air-dried basis yield of biochar (%).

The electrical conductivity of the corncob biochar was

tested using a conductivity tester with a light bulb. The oven drying method for measuring moisture content (MC) was carried out based on the standard method of German Institute for Standardization (DIN 51718 2002). The determination of iodine number was performed according to the standard method ASTM D4607-14 (2021). The gross calorific value was measured based on the standard method ASTM D5865 (2021).

## RESULTS AND DISCUSSION

### Temperature profiles in the Super Sun Retort and Kon-Tiki kiln:

In the first experimental run, after 30 min the temperature in the Super Sun retort reached 249 °C (Fig. 3). At this temperature, the volatile gases were released from the corncobs. It was observed that at 40 min there was thermal overshoot, where the temperature in the Super Sun retort

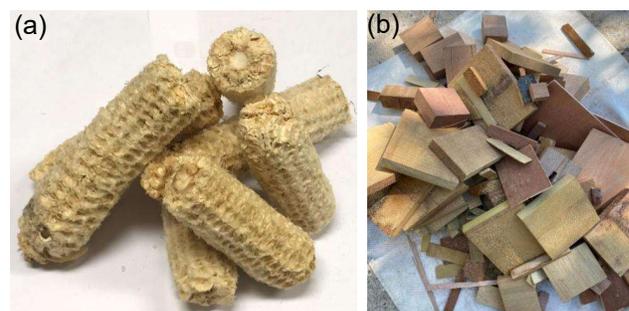


Fig. 1. (a) Corncobs used as feedstock in the Super Sun retort (b) firewood used in the Kon-Tiki kiln

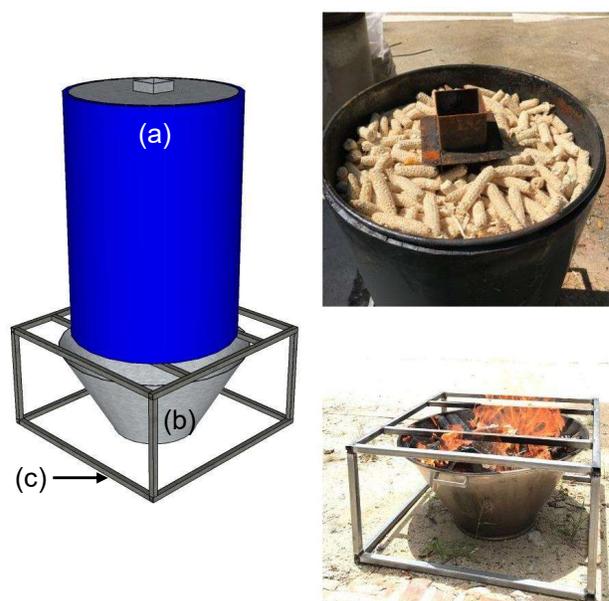


Fig.2. Biochar production equipment including (a) Super Sun retort, (b) Kon-Tiki kiln and (c) metal frame

was significantly higher than that of the Kon-Tiki kiln. This phenomenon was resulted from the exothermic reactions of the pyrolysis process. This result was also reported in the previous study (Intani et al 2016). However, the thermal overshoot in the first experimental run was quite extreme. Therefore, more experiments need to be carried out in the future to verify this phenomenon. In another study, a thermal runaway or uncontrolled ignition/combustion was observed in the pyrolysis of some lignocellulosic biomasses. The thermal runaway happened when there was a sudden release of large quantities of volatile products from the biomass in pyrolysis process (Di Blasi et al 2014). It was also reported that the size of the biomass feedstock had an effect on the thermal runaway (Di Blasi et al 2015). The whole corncobs used in this study might promote high reaction exothermicity and lead to the thermal runaway. The thermal runaway resulted in the highest pyrolysis temperature of 868 °C in the Super Sun retort, while the highest heating temperature in the Kon-Tiki kiln was 469 °C. After 120 min, the pyrolysis temperature reached 868 °C, when all volatile gases in the corncobs were released. Subsequently, the pyrolysis temperature significantly decreased, while no additional firewood was loaded to the Kon-Tiki kiln.

The temperature profiles in the Super Sun retort and Kon-Tiki kiln were different in the second experimental run compared to those of the first experimental run (Fig. 4). This result indicated that the precise control of the temperature in the Super Sun retort and Kon-Tiki kiln is very difficult. In particular, the temperature in the Kon-Tiki kiln showed high fluctuation. Therefore, the position and the method of measuring temperature above the Kon-Tiki kiln should be reconsidered and improved. In addition, the manual control

of the combustion process in the Kon-Tiki kiln was also very challenging. It needs experience, good attention and careful observation. The highest heating temperature in the Kon-Tiki kiln was 561°C, while the highest pyrolysis temperature in the Super Sun retort was 563°C. Therefore, the thermal overshoot and thermal runaway were not observed in the second experimental run. However, the pyrolysis temperature reached the highest value (563°C) after 140 min, which was only 20 min different from the first experimental run. This indicated that the corncobs released all volatile gases within 140 min after starting the pyrolysis process. This information would help for the design of future experiments.

**Biochar yield:** The corncob biomass was successfully converted into biochar in the Super Sun retort using the heat generated from the Kon-Tiki kiln (Fig. 5). Super Sun retort and Kon-Tiki kiln generated lower emission compared to the conventional methods of biochar production in Thailand. In a previous study, it was evident that the Kon-Tiki kiln showed the lowest gas emissions including mainly methane and carbon monoxide (Cornelissen et al 2016). The corncob biochar yield was 26.4 and 26.8% in the first and second experimental run, respectively (Table 1). The corncob biochar yield was similar to the value reported in the previous study (Intani et al 2016). Interestingly, the difference between the biochar yields from the two experiments was not significant, despite of the thermal overshoot and thermal runaway in the first experimental run. This could be due to the size of the biomass feedstock (Di Blasi et al 2015). In this study, the size of the corncobs was not reduced. Therefore, the thermal overshoot and thermal runaway did not significantly affect the biochar yield. Except from the corncob

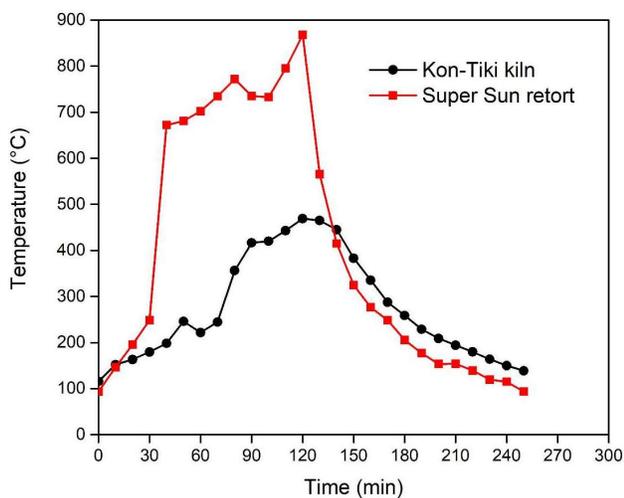


Fig. 3. Temperature profiles in the Kon-Tiki kiln and Super Sun retort in the first experimental run

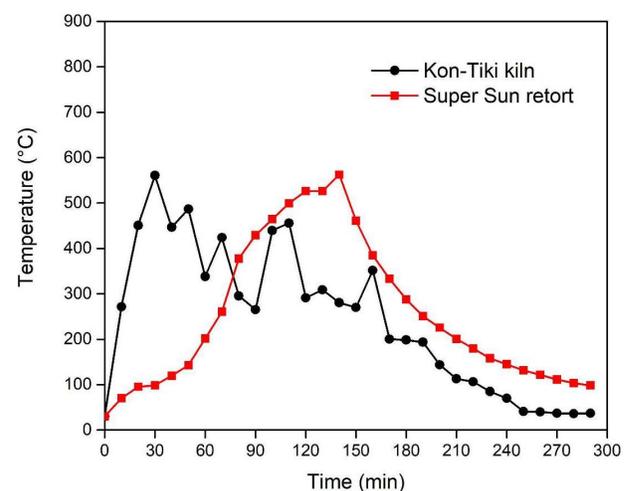


Fig. 4. Temperature profiles in the Kon-Tiki kiln and Super Sun retort in the second experimental run

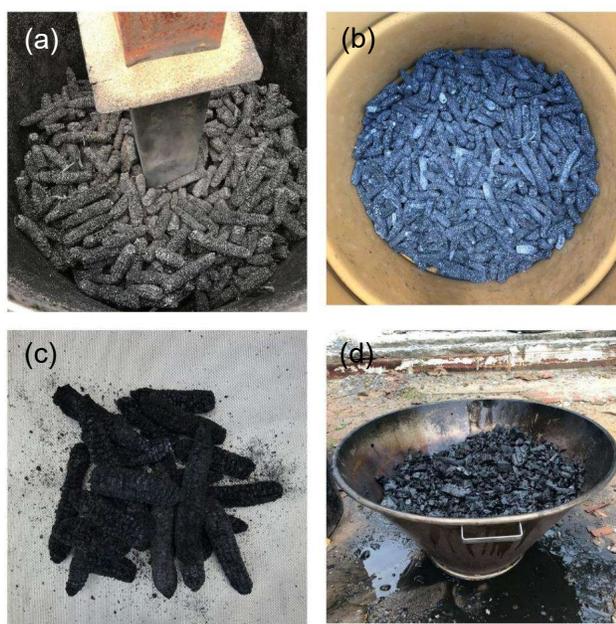
biochar obtained from the Super Sun retort, the biochar from firewood was also produced in the Kon-Tiki kiln. The biochar from the Kon-Tiki kiln was found to be suitable for soil amendment (Pandit et al 2017).

**Biochar properties:** The electrical conductivity of the corncob biochar was moderate. In total 10 samples were tested using a conductivity tester. The result showed that 5 samples had a good electrical conductivity (Table 2). It was reported that the biochar produced at high temperature (>700 °C) had high electrical conductivity (Bartoli et al 2022). The moisture content of the corncob biochar was 7%, which was lower than that of the corncob biomass (8.4%). The iodine number was 230 mg/g, indicating a good adsorption

capacity. This iodine value of corncob biochar was higher than that of the biochar of nut shell (Gorshkov et al 2021). This result implied that the corncob biochar had high porosity. The gross calorific value of the corncob biochar was 7300 cal/g, which was high and indicated the potential to be used as a biofuel. The calorific value of the corncob biochar in this study was comparable to the value (6872 cal/g) reported in the previous study (Intani et al 2016).

**CONCLUSION**

The heat provided by the Kon-Tiki kiln was sufficient to initiate and sustain the pyrolysis process in the Super Sun retort. The amount of corncob biomass was 25 kg, while 20 kg of firewood was consumed. The highest temperature measured in the Super Sun retort was 868 °C. The highest biochar yield of 26.8% was obtained. The corncob biochar showed high adsorption capacity with iodine value of 230 mg/g. The calorific value of the biochar was also high (7300 cal/g). The results indicated that the corncob biochar produced with the sustainable and low-cost techniques in this study had potential to be used for soil amendment and the production of deodorizing charcoal and charcoal briquette.



**Fig. 5.** (a) Corn cob biochar produced in the Super Sun retort, (b) corn cob biochar kept in a sealed steel drum for cooling, (c) close-up image of the corn cob biochar, (d) biochar produced in the Kon-Tiki kiln

**Table 1.** Biochar yield

Experimental run	Corncoobs (kg)	Biochar (kg)	Biochar yield (%)
1	25.0	6.6	26.4
2	25.0	6.7	26.8
Mean	25.0	6.7	26.6

**Table 2.** Biochar properties

Parameter	Value
Electrical conductivity (%)*	50
Moisture content (wt.% wb)	7
Iodine number (mg/g)	230
Gross calorific value (cal/g)	7300

\* 5 out of 10 samples showed good electrical conductivity

**AUTHOR'S CONTRIBUTION**

The experiment was conceptualized by K.T., K.I., D.J. and S.S., and the methodology was applied by K.T., K.I. and D.J.; software was employed by K.T., K.I., P.S. and R.T.; the manuscript was validated by K.T., K.I., D.J., P.S., R.T. and S.S.; formal analysis and investigation were mainly conducted by K.T. and K.I.; resources were acquired and provided by K.I., D.J., R.T., P.S. and S.S.; data curation was conducted by K.T. and K.I.; writing-original draft preparation, K.T. and K.I.; writing-review and editing, K.I., R.T. and S.S.; data visualization was realized by K.T. and K.I.; supervision of the project was conducted by K.I., D.J., P.S., R.T. and S.S.; project administration, K.I. and S.S.; funding acquisition, K.I. and S.S. All authors have read and agreed to the published version of the manuscript.

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