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Biochar Production - Case from Sugarcane bagasse

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ABSTRACT

Among the agents that pollute the water environment, dyes from production activities in the textile, paper, leather, plastic, and cosmetic industries are especially harmful to humans and aquatic life. Therefore, environmentally friendly and economical materials have attracted the attention of scientists. Biochar is a carbon-rich material, derived from biomass pyrolysis in a closed system with little or no oxygen. Previous research has shown that Biochar has great potential for application in different fields such as soil improvement, increasing crop productivity, sequestering carbon, and minimizing greenhouse gas emissions. Especially, the adsorbent can used to remove pollutants in water such as lead, phosphate, pesticides, chromium, arsenic, cadmium, copper, nickel, and especially dyes in wastewater textile dyeing. This article presents an overview of textile wastewater pollution and research on Biochar production from an agricultural biomass source, sugarcane bagasse, used to treat dyes in wastewater.

Keywords: Pollution; Industry; Pyrolysis; Biochar; Sugarcane bagasse; Biomass; Wastewater; Textile dye; Environmentally.

1. Overview of dye pollution from textile wastewater

The textile industry positively impacts economic development worldwide. China is the most important exporter of all types of textiles, followed by the European Union, India, and then the United States [1]. Next is Vietnam, ranked 5th in the world's largest textile exporter with export turnover contributing about 10% to 15% of annual GDP. However, one of the problems related to textile factories is the problem of wastewater containing dye content, which is very difficult to decompose. The textile industry depends on the type of fabric produced, including cellulosic materials obtained from plants (e.g. cotton, rayon, and linen), protein fabrics of animal origin (wool, silk), and artificially produced synthetic fabrics (e.g. nylon, polyester, and acrylic). Fabric production in textile mills includes dry and wet processes. The wet process uses a significant amount of domestic water and releases a lot of contaminated wastewater (Figure 1). This process includes sizing, de-sizing, sourcing, bleaching, glazing, dyeing, printing, and finishing techniques [2-3].

Figure 1. Some images of textile wastewater causing environmental pollution [2-3]

The dyeing process is an important step in textile production. During this stage, color is added to the fiber and various chemicals may be used to improve the adsorption process between color and fiber. These dyes and chemicals, in addition to their unacceptable and toxic appearance, especially the effects after their decomposition, can contaminate surrounding areas in soil and water environments. sediments and surface water, becoming a concern affecting global resources. In reality, the treatment of textile wastewater is necessary to protect the ecosystem and to enable the subsequent recycling of treated wastewater for irrigation, which is always intended for reuse in the production process of manufacturers of textile machines.

1.1. Study Objectives

This article aims to present the current situation of environmental pollution from textile wastewater, how to treat wastewater color by adsorption method, and then present biochar adsorbent materials and methods for biochar production from agricultural biomass, and finally biochar synthesis from sugarcane bagasse.

2. Textile wastewater treatment methods

Textile wastewater has high color, BOD/COD, and load salt content - high total dissolved solids. Textile wastewater is often heavily polluted due to the presence of reactive dyes that are not easily biodegradable. Some current textile wastewater treatment methods include physical, oxidation, and biological methods [4]. Filtration techniques such as ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO) have been used to recover and reuse textile wastewater [5]. To select the filter and its permeability, it is necessary to consider the content and temperature of the textile wastewater required for separation. In the textile industry, the application of membrane filtration offers the potential for recycling hydrolyzed reactive dyes and auxiliaries used in the dyeing process while also reducing biological oxygen demand (BOD), the need for Chemical oxygen demand (COD) and color from textile wastewater. However, the filtration method has disadvantages such as high investment costs, the possibility of clogging the filter membrane, and the creation of other wastes containing water-insoluble dyes. The physical method is based on the coagulation-flocculation process using flocculating agents. This is a very useful method for decolorizing wastewater containing dispersed dyes. However, this technique is also limited in use due to its low decolorization efficiency and the creation of many sludge-like impurities.

Adsorption methods have attracted considerable attention due to providing higher decolorization efficiency for wastewater containing a variety of dyes. High affinity, capacity for compounds, and ability to regenerate the adsorbent are key characteristics that should be considered during the selection of adsorbents for color removal. Activated carbon is an effective adsorbent for many types of dyes. However, its high cost and difficulty in reproducing it have limited its application for decolorization. To economically apply adsorption methods, some researchers have used low-cost adsorbent materials such as peat, bentonite clay, fly ash and plastic polymers. Some scientists have also tested many agricultural biomass sources such as rice husk ash, processed ginger residue, peanut shells, date peels and potato waste to create Biochar. (Biochar) to decolor textile wastewater. The oxidation method is the most commonly used chemical dye decomposition method due to its ease of use [6]. Oxidation techniques can be classified into two main processes: advanced oxidation processes (AOP) and chemical oxidation processes. These processes are capable of decomposing the original toxic chemicals and their by-products, dyes, pesticides partially or completely under ambient conditions. These oxidation technologies can be used individually as well as synergistically. Advanced oxidation process (AOP) is a process in which hydroxyl radicals are generated

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in appropriate quantities. These hydroxyl radicals are strong oxidizing agents. These oxidizers have an oxidation potential of 2.33 V and exhibit a faster rate of oxidation reaction than common oxidizers such as hydrogen peroxide or potassium permanganate. The hydroxyl radical reacts with most dyes with a high rate reaction constant. These hydroxyl radicals are also capable of oxidizing most of the complex organic and inorganic substances present in textile wastewater. These AOP processes contain strong oxidizing aggressive agents, often created by an ultrasonic irradiation method called acoustic cavitation to penetrate holes, vents, and pipes in equipment. hydraulic equipment of the production line. A major disadvantage of this method is the generation of iron sludge due to the combined flocculation of the reagent and dye molecules.

Chemical oxidation methods use strong oxidants such as O_3 and H_2O_2. Ozone and H_2O_2 form strong non-selective hydroxyl radicals at high pH values. These radicals, due to their high oxidation potential, can effectively break the conjugated double bonds of the dye chromophores as well as other functional groups such as a complex aromatic ring of the dye. The oxidation process creates products that are smaller, colorless molecules that reduce the color of the wastewater. These methods are useful for dye molecules containing double bonds. The main benefit of ozonation is that the oxidizing agent can be used in a gaseous state and therefore does not increase the volume of wastewater and does not produce sludge. However, the major drawback to using ozone is that it can form toxic byproducts from biodegradable dyes in wastewater. Additionally, ozonation is expensive, as continuous ozonation is necessary due to its short half-life of only 10 minutes in water at pH = 7. This short half-life can be reduced by the presence of dye. The stability of ozone is also affected by the presence of salt, pH, and temperature. Ozone decomposition is faster under alkaline conditions with pH > 8.5, making continuous pH monitoring of textile wastewater mandatory.

Decomposition of dyes can also be achieved by combined UV and H_2O_2 treatment due to the production of high concentrations of free radicals. This combination of UV light and H_2O_2 presents the benefit for textile wastewater containing dyes due to its lack of residue and effective reduction of odors in the water environment. Here UV light is used to trigger the decomposition of H_2O_2 into hydroxyl radical. Hydroxyl radicals cause chemical oxidation of dyes or organic substances, composite materials, and mineral materials to CO_2 and H_2O. Parameters such as UV radiation intensity, pH, structure of the dye molecule, and dye bath composition need to be optimized to achieve dye removal rates. The formation of free radicals can be caused by the combination of ozone with hydrogen peroxide H_2O_2 when there is energy consumption of the components. Here UV rays, sunlight, or ultrasound waves are the energy that provides the process of free radical formation. These combined techniques have less processing time than the individual method techniques but are also associated with reduced energy costs.

Biological methods are also used to remove dissolved substances in textile wastewater [7]. Removal efficiency is influenced by the ratio of organic matter/dye and microbial loads, the temperature of the environment, and the oxygen concentration in the system. Based on oxygen requirement, biological methods can be classified as aerobic, anaerobic and anoxic facultative or a combination of both.

The aerobic method uses bacteria to treat textile wastewater in the presence of oxygen while the anaerobic method uses bacteria to treat it in the absence of oxygen. The combination of anaerobic and aerobic methods is often implemented in practice in a stepwise manner in which an anaerobic process is used to treat textile wastewater according to chemical oxygen demand (COD), followed by the use of aerobic methods to treat textile wastewater with low COD content. The anaerobic process can only be performed if the wastewater has a fairly high COD concentration, higher than 3 g/L, which is the case when treating wastewater containing many biodegradable organic compounds such as polyvinyl (PVA).) or starch. Thus, the anaerobic treatment process produces methane biogas with a certain calorific value. In the biological method, microorganisms adapt to textile materials, dyes, and new resilient strains naturally develop to survive, then convert some dyes to less toxic. The biodegradation mechanism for persistent dyes is based on the action of enzymes such as laccase, lignin peroxidase, NADH-DCIP reductase, tyrosinase, hexane oxidase, and aminopyrine N-demethylase.

Biological methods for completely decomposing wastewater textile materials have benefits like (a) environmental friendliness, (b) competitive costs, (c) less sludge generation, (d) creating a metabolite-free environment or complete mineralization, and (e) consuming less water (higher concentration or less dilution required) than physical/oxidative methods. The effectiveness of biological methods for decomposition depends on the adaptability of the selected bacteria and enzyme activity. Therefore, many microorganisms and enzymes have been isolated and tested to degrade certain dyes. Some microorganisms such as bacteria, fungi, and algae have been widely applied because of their ability to decompose many types of dyes in textile wastewater. However, biological methods require high technology, and operating and treatment costs are not cheap.

3. Overview of Biochar

Biochar is a material produced from plant materials (eg twigs, rice husks, straw, bagasse) with high carbon content [8]. Biochar material is created by pyrolysis when burned in a chamber with limited oxygen. Biochar production can be done by traditional composting in soil piles, or more efficiently in metal tanks or in specially designed pyrolysis systems. When heated, the dry plant matter begins to produce flammable syngas consisting of a mixture of hydrogen and carbon monoxide, creating the heat needed to maintain pyrolysis to fragment the raw material to create the product material that has a very large surface area and high cation exchangeability, so it is capable of storing plant nutrients such as Na^+, K^+, Ca^{2+}.

The special advantages of biochar such as large surface area, high porosity, functional group content, high cation exchange capacity, and stability make the material suitable for various applications [9]. Making biochar is also quick and easy, environmentally friendly, reusable, and cost-effective. In addition, the surface properties, composition, and pore size of biochar can be adjusted by treating the raw material (biomass) with appropriate chemical reagents, carbonization temperature, and pressure. Biochar has attracted the attention of many researchers in exploiting its effectiveness in removing various pollutants, especially as a potential adsorbent for the treatment of aquatic and environmental environments. gas field. Biochar can be synthesized from carbon-containing materials such as lignocellulose, animal manure, agricultural and forestry waste, industrial biowaste, plastic waste, microalgae, waste tires, sludge water, marine, and aquatic life through the carbonization process. Among the well-known carbonization processes, pyrolysis, gasification, hydrothermal carbonization, flash carbonization, and chemical-mechanical technology are used to obtain biochar for a variety of applications.

3.1. Pyrolysis method [10]

Organic materials are calcined at temperatures of about 200-900 ^oC in an oxygen-deficient atmosphere. When calcined at high temperatures, biomass decomposes into simple, medium, and longer-chain hydrocarbons which are converted into liquid, gas and solid products and are collected separately. Typically, pyrolysis is carried out in three different thermal stages, initially at temperatures below 500 ^oC called slow pyrolysis, mainly used for biochar production. Next, the heating above 500 ^oC is called fast pyrolysis and is mainly used to make bio-oil. Finally, the heat is stored at an intermediate temperature range of about 500-700 ^oC to create biochar, liquid, and non-condensable gas products. Depending on experimental conditions, biochar can be made according to appropriate pyrolysis methods. Rapid carbonation is a process in which biomass is heated by the passage of a spark at high pressure (>1 MPa). The pyrolysis chamber is filled with biomass and produces a lightning-like flame from the bottom in an upward manner and at the same time, the airflow is maintained in a downward direction. Under these experimental conditions, biomass is converted into gaseous fuel and leaves behind the carbon content in the form of biochar. The rapid carbonation method can produce biochar with higher content, but small porosity compared to the results obtained from conventional pyrolysis and hydrothermal carbonation methods.

Microwave heating is a pyrolysis method in which biomass is heated using radiant energy emitted from a microwave source. It has many advantages such as non-contact heating, fast heating start and stop, higher efficiency, controllable heating rate, higher safety level. Therefore, it is widely used to produce biochar for several applications such as pasteurization, drying process, vulcanization, and food processing. The thermochemical drying method is performed by heating the sample in a narrow temperature range from 200 to 300 ^oC in an inert atmosphere or containing nitrogen gas with a retention time of 15–60 minutes. Under these conditions, biomass or waste slowly undergoes decomposition and releases CO_2 and H_2O.

3.2. Gasification method [11]

Many studies have shown the effective production of gaseous fuels such as H_2, CO, CH_4 from biomass materials by gasification process. In particular, biomass is calcined at high temperatures (>500 ^oC) in the absence of oxygen. Gas product formation is enhanced by continuously transferring a number of gasification agents such as steam, CO_2 and some gas mixtures out of the system; The remaining about 50% of the volume is biochar. Gas fuel extraction from biomass is carried out using equipment such as fluidized bed reactors, and fixed bed reactors.

3.3. Hydrothermal carbonization [12]

Hydrothermal carbonization is also one of the thermochemical methods to produce biochar from various raw materials including cellulose, cellulose biomass, animal manure, food waste, municipal sludge, and industrial sludge. paper and pulp, and algae residue. The reaction is carried out in a hydrothermal reactor at temperatures from 200 to 300 ^oC. This method is also known as wet pyrolysis, and the resulting biochar is called hydrochar.

3.4. Mechanochemical technology [13-14]

Among all the Biochar preparation methods (thermochemical method), mechanochemical technology produces environmentally friendly nano-sized biochar by using high-energy ball mills. In this method, biomaterial powder is placed inside a ball mill to break down cellulose-type organic compounds into small particles. Biochar is made from different types of ball mills such as planetary mills, consumable ball mills and vibrating ball mills. However, the quality of Biochar obtained also depends on the speed, grinding time, baseload, and geometrical parameters of the crusher.

4. Biochar made from sugarcane bagasse

Sugarcane is an important industrial sugar crop in the sugar production industry of many countries around the world. According to FAO statistics, about 200 countries and territories grow sugarcane and output reaches 1.833 million tons. During the sugar cane's old age, people harvest the sugar cane and then press it to get the juice. Sugar cane juice is filtered and concentrated into sugar. The remaining material after sugar extraction is called bagasse. Thus, this source of waste materials is currently being used ineffectively and causing environmental pollution. Due to the large volume of sugarcane bagasse, the problem of handling them is not thorough. Therefore, using sugarcane bagasse to produce biochar is important in environmental treatment, while also bringing significant economic efficiency.

Author Phan Thi Uyen Nhung and her colleagues made biochar from sugarcane bagasse by slow pyrolysis method in a pyrolysis furnace [15]. The process of making biochar is carried out according to the following steps: after being collected, the bagasse is washed several times with water then dried at 105 ^oC, then the bagasse is chopped to a size of about 1-1.5 cm then put into sealed boxes, then the sealed boxes containing biomass are put into the furnace, the conversion of bagasse into biochar is carried out in 3 hours. The resulting biochar material has a porous structure, high carbon content and contains chemical functional groups on the surface of the material. The results of applying materials to treat Ni^{2+} in a water environment show high removal efficiency in a short treatment time. Author Nguyen Thi Kieu Trinh and her colleagues researched the synthesis of biochar from sugarcane bagasse according to a one-stage process [16]. In this study, the bagasse was washed, then cut into ~1 - 2 cm pieces and dried at 120 ^oC, then the bagasse was soaked in 1M NaOH solution, the bagasse was then dried and calcined. at 450 ^oC to obtain biochar.

Research around the world on converting sugarcane bagasse into biochar is quite popular based on many different manufacturing methods such as pyrolysis, and chemical and biological processes to convert biomass into biofuel, biochar and syngas [17]. Among them, thermochemical techniques including pyrolysis, gasification, hydrothermal carbonization, thermal reaction and carbonization heat transfer methods are outstanding techniques for Biochar production.

Figure 2 depicts the conversion of sugarcane bagasse into biochar in a hydrothermal reaction system. In it, sugarcane bagasse is washed, dried and chopped and is fed into a pressure-controlled hydrothermal system through a regulating valve. The experiments were performed at temperatures ranging from 180-260 ^oC. Besides the biochar obtained, the sugarcane bagasse conversion process in the hydrothermal reaction system also yields bio-oil.

Figure 3 presents a diagram of sugarcane bagasse conversion by traditional thermal decomposition in an anoxic environment. Sugarcane bagasse is put into a pyrolysis reactor. After the calcination process, the released gas stream is transferred to a cooling device (condenser) to separate into gas and bio-oil. The bottom of the furnace is biochar. Thus, besides converting sugarcane bagasse into biochar, this process also yields other fuels such as bio-oil and gas.

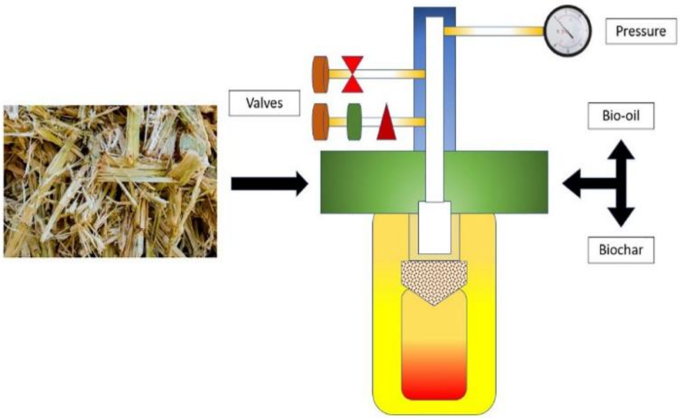

Figure 2. Production of BIOCHAR from sugarcane bagasse in a hydrothermal reaction system [17]

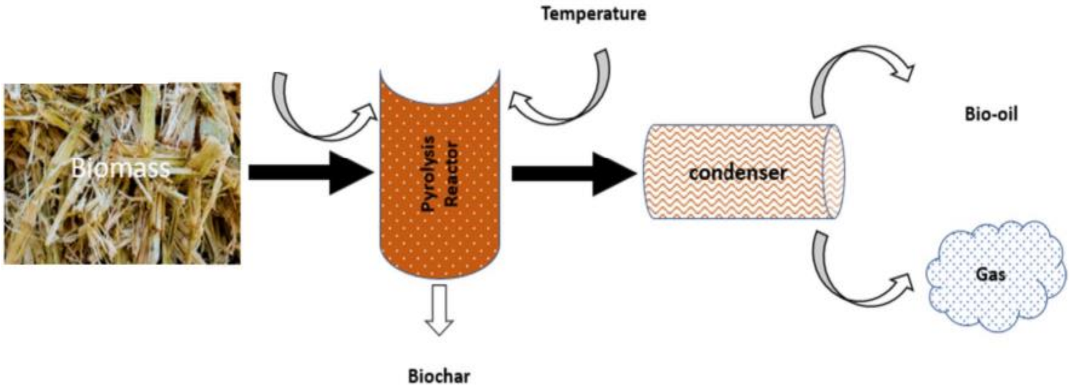

Figure 3. Making biochar from sugarcane bagasse in a thermal furnace [17]

In our study, biochar was prepared by heating raw sugarcane bagasse samples in an anaerobic environment at different temperatures (400 °C, 500 °C, 600 °C, 700 °C) maintained for periods of 1, 2, 3, and 4 hours as presented in Figure 4.

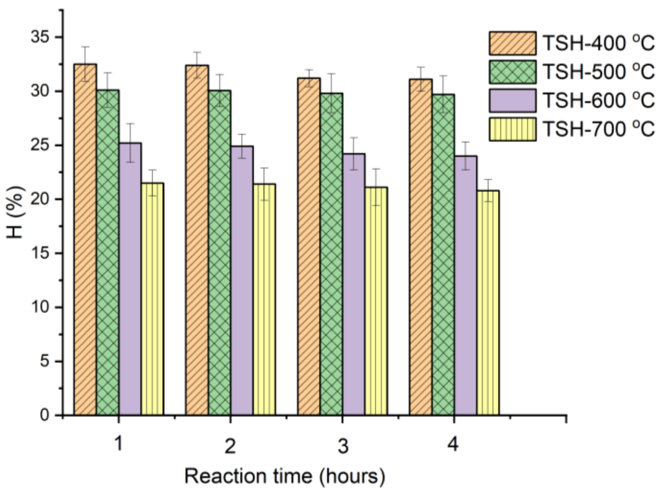

Figure 4. Effect of calcination time and temperature on Biochar production efficiency

The results shown in Figure 4 show that as the pyrolysis temperature increases, the efficiency of biochar formation gradually decreases. Considering the same heating time of 1 hour, the sample calcined at 400 ^oC has the highest efficiency of 32.5%, while the sample calcined at 700 ^oC has the lowest efficiency of 21.5%. The decrease in biochar production efficiency is explained by the loss of volatile organic substances such as hemicellulose and cellulose contained in biomass, the release of moisture as well and the release of more CO_2 gas due to the burns of many C positions in the organic cellulose structural framework of raw sugarcane bagasse biomass. This result is similar to previously published studies [15-16]. A decrease in biochar formation efficiency was also observed at firing times of 2, 3, and 4 hours. However, when considered at the same temperature, time does not have much effect on the efficiency of biochar formation, proving that the conversion of raw sugarcane bagasse into biochar is completed after one hour of pyrolysis and calcination. Longer time does not greatly affect the efficiency of biochar formation. Thus, after 1 hour of heating Biochar has been formed, and the efficiency of biochar formation thereafter does not depend on the heating time but only on the heating temperature.

Figure 5 shows images of biochar samples heated at different temperatures from 400 ^oC to 700 ^oC for 1 hour. Observations show that the biochar samples are black with a brownish tint, and there is not much difference in color between the samples, showing that the Biochar material is quite stable in terms of sensory perception and can be manufactured starting from a temperature of 400 ^oC.

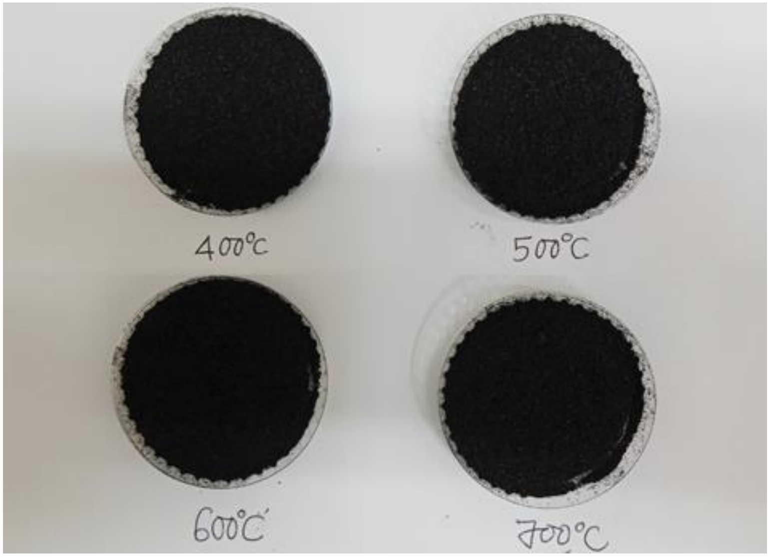

Figure 5. Actual images of bio samples manufactured at different temperatures

5. Conclusion

The process of industrialization and modernization is increasingly being promoted in both width and depth, contributing practically to improving the quality of life for people. However, that process also entails the burden of environmental pollution, including water pollution. Many agents pollute water sources, including chemical agents such as acetic acid, dyes, phenol, detergents, colorants, and heavy metal ions. This article presents methods for making biochar from biomass waste from agricultural activities, especially making biochar from waste sugarcane bagasse. Biochar material has been shown to be a cheap, environmentally friendly, and effective adsorbent material in removing organic pigments in textile wastewater.

Declarations

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This study did not receive any grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

All the authors took part in literature review, analysis and manuscript writing equally.

Availability of data and material

All data pertaining to the research is kept in good custody by the authors.

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