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ADSORPTIVE PERFORMANCE OF BIOCHAR FROM CASSAVA PEEL ON INDIGOSOL BLUE 04-B DYE IN BATIK WASTEWATER

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ABSTRACT
The study investigates the capacity of biochar from cassava peel (BCP) to work as an adsorbent to get rid of Indigo sol Blue 04-B dyes in Batik wastewater. BCP is produced through a pyrolysis process at temperatures of 300°C, 400°C, and 450°C. The research explored the adsorption characteristics of BCP under varying experimental conditions, including pH variations, weight, and contact time. The adsorption process was examined by assessing factors such as absorbance, initial concentration, equilibrium concentration, and the percentage of dye adsorbed. The results show that BCP adsorbs Indigo sol Blue 04-B dyes with considerable efficiency, significantly influenced by pH levels of 7.0, BCP weight of 75 mg, and contact time of 40 minutes, achieving adsorption capacities of 72.16%, 51.07%, and 63.50%, respectively. The results show that BCP has a lot of potential as an effective adsorbent for getting rid of Indigo sol Blue 04-B dyes. This study demonstrates the significance and positive implications of environmentally friendly waste treatment, inexpensive and efficient alternative adsorbents, and improved waste quality.
Keywords: Biochar, Adsorption, Dyes, Indigo Sol Blue 04-B, Cassava Peel.
SDG 6: Clean Water and Sanitation
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INTRODUCTION

Industrial operations, especially conventional textile manufacturing like batik, produce significant quantities of effluent laden with synthetic dyes, detrimental to aquatic ecosystems and human health. Indigosol Blue 04-B, a dye often used in batik making, is known for being stable and hard to break down, making it difficult to remove with regular wastewater treatment methods. Tackling this topic directly corresponds with the United Nations Sustainable Development Goal (SDG) 6: Clean Water and Sanitation, which seeks to guarantee the availability and sustainable management of water and sanitation for all individuals. A practical way to achieve this goal is by using affordable and locally made materials, like charcoal from cassava peel, which is a common waste product in Indonesia. Cassava (Manihot esculenta Crantz) is a carbohydrate source found in tubers, which are plants in the Euphorbiaceae family.[1] Unutilized cassava peel represents a waste product. Despite the use of some cassava peel as animal feed, concerns persist about potential substances or ingredients that could poison livestock.[2] In 2023, Figures from the Indonesian Central Statistics Agency indicated that national cassava production exceeded 23 million tons annually, or 54,000 tons daily. If the proportion of cassava peel constitutes 10-15% of the cassava's weight, then the daily yield of cassava peel will exceed 5.4 tons. Farmers have only thrown away or burned cassava peel waste so far due to a lack of waste-handling knowledge.[3] Cassava peel consists of lignin, cellulose, and hemicellulose compositions in the ranges 9.0–16.0%, 5.5–15.0%, and 41.0–65.0%, respectively.[4] So that cassava peel can become a raw material in making activated charcoal. Covalent bonds separate the carbon atom configuration of activated charcoal from other elements. It contains different impurities in its pores, which can be removed to make the carbon surface or active centre more comprehensive. This vibrant centre's wider shape makes it better at absorbing things, like batik dye waste.[5] Batik is a cloth with decorative patterns whose manufacture involves dyeing the fabric using a resistance dyeing technique. When the liquid is coloured, the decorative pattern on the cloth is created to intentionally cover some of the wax. The suspended portion of the fabric creates an image of the decorative batik pattern. The substances used for colouring can penetrate deeply into the fabric fibres and last a long time without fading. Batik has

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two types of dyes, namely natural dyes and synthetic dyes. Extracts of natural ingredients yield natural dyes, whereas factories produce synthetic dyes.[6] Because natural dyes are difficult to obtain, the Donggala batik industry now uses synthetic dyes like naphthol and indigo sol.[7] The Donggala batik industry uses indigo sol, a water-soluble dye. The dye solution exhibits a clear colour, but soaking the fabric in it fails to yield the desired colour. However, adding a strong acid like HCl or H_2SO_4 accepts the desired colour.[8] This robust acid solution not only helps with colour formation, but it also functions as a colour key. These synthetic dyes, when used without protection, have short-term effects, namely causing skin irritation, eye irritation, and respiratory tract irritation. In contrast, liver, kidney, and other cell diseases have long-term effects.[9] The dyeing process in textile and similar industries releases approximately 10–15% of dyes into the environment as liquid or solid waste, causing environmental pollution.[10] One alternative for waste processing is using adsorbents as a binder or adsorbents for B3 waste. Adsorbents can adsorb various pollutants, both organic compounds (dyes) and inorganic compounds (heavy metals), using adsorption, filtration, ion exchange, and precipitation mechanisms.[11] Agricultural or plantation waste with high cellulose content, like cassava peels and stems, makes this method efficient and cost-effective.[12] Specifically, this study aimed to characterize biochar from cassava peel based on physical and chemical parameters, such as surface area and porosity, to see the performance of BCP in removing Indigosol Blue 04-B dye from batik wastewater. The most suitable kinetic and adsorption isotherm models were determined to describe the dye adsorption process by biochar. Although many studies have been conducted on the use of biochar as an adsorbent in wastewater treatment, studies exploring biochar from cassava peel waste are still limited, especially those focusing on Indigo sol Blue 04-B as a specific dye commonly used in the batik industry. The use of biochar facilitates efficient dye removal from industrial effluents while also advancing waste valorization and circular economy initiatives. This study looks at how well cassava peel biochar can clean batik wastewater, helping to achieve the goals of SDG 6 by improving water quality, supporting sustainable treatment methods, and encouraging the recycling of treated wastewater.

EXPERIMENTAL

Materials and Methods

Indigosol blue (dye), Buffer solution, Distilled water as solvent, cassava peels as raw material, porcelain cup, furnace for pyrolysis, Sieve for adhering to the PAC Powder Active Carbon standard, Volumetric flask for adsorption process, and Filter paper.

General Procedure

Cassava peels were dried in the sun after washing and cutting them into pieces, followed by a pyrolysis process at temperatures: 300ºC, 350ºC, and 400ºC. The product is a black material, calculated then at 80-mesh size, adhering to the PAC Powder Active Carbon standard. The PAC was then analysed for water and ash content, pore morphology, and determination of carbon and other elements.

Detection Method

Testing of biochar as an adsorbent for indigosol blue 04-B was carried out using UV-Vis with variables for the amount of BCP (25, 50, 75, 100, and 125 mg), contact time (20, 40, and 60 minutes), and the pH (4-8) of the indigosol. The adsorption power is calculated using the percentage adsorption formula.

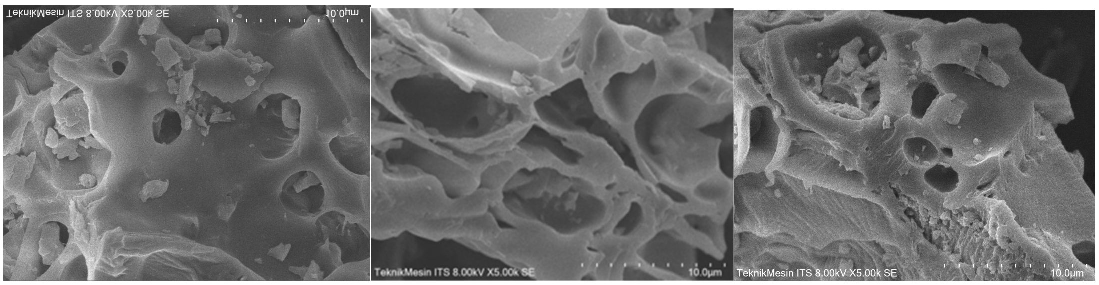
RESULTS AND DISCUSSION

The effect of temperature on the production of biochar from cassava peel (BCP) shows that at higher temperatures, the weight of biochar produced is greater, and the yield percentage tends to decrease. At a temperature of 300℃, the weight of the cassava peel sample used was 53 gr, and after the process, the weight of biochar produced was 21 gr. From calculations, the yield percentage obtained from this process is 39%. At a temperature of 350℃, the weight of the cassava peel sample remained at 53 gr, but the weight of the biochar produced was reduced to 20 gr. Thus, the yield percentage also decreased to 37%. Meanwhile, at a temperature of 400℃, the weight of the cassava peel sample used was much more significant, namely 250 gr, and the weight of the biochar produced was 78 gr. Even though the weight of biochar produced was more important than in the previous experiment, the yield percentage was lower, 31%. Table-1 below displays the results of the calculation of the water and ash content following the activation of the charcoal.

Table-1: Measurements of the Water and Ash Content of BCP

Sampel	Temperature (°C)	Water Content (%)	Indonesian National Standard (SNI) for water	Ash content (%)	Indonesian National Standard (SNI) for Ash
Cassava Peels	300	5.15	15%	7.35	10%
	350	3.40	15%	7.20	10%
	400	3.33	15%	6.35	10%

The table also compares the results of the study with the standards set by the Indonesian National Standard (SNI) for the maximum water and ash content permitted in cassava peel samples. The data explains the effect of temperature on the water and ash content of cassava peel samples. This result showed that temperature affects the water and ash content in cassava peel samples. The sample's water and ash content decrease as the process temperature increases.



(a) (b) (c)

Fig.-1: SEM Image with 5000x Magnification for BCP with Pyrolysis Temperatures of 300°C (a), 350°C (b), and 400°C (c)

The goal of SEM-EDS analysis is to find the surface of a material's pores.[13] Figure-1 illustrates how cassava peels provide the holes, or pores, in biochar. Biochar has a highly porous structure because of the activation process, which creates numerous tiny pores and fissures on its surface.[14] These pores increase the surface area, which is beneficial for adsorption purposes. BCP has irregularly shaped mesopores of varying sizes, 2-50 nm, which are ideal for the adsorption of medium to large molecules such as textile dyes (e.g., Indigosol Blue 04-B). The specific morphology and surface characteristics can vary based on factors like the activation process, temperature, and duration.[15] The holes or pores shown in the SEM-EDS image are likely the result of this porous structure, which is essential for its adsorption capabilities.

Table-2: The Atomic Percentage of the Elements of BCP

Elements	Atomic (%) with Pyrolysis temperature		
	300°C	350°C	400°C
C	54.88	55.54	56.53
N	7.91	6.62	6.56
O	30.63	31.45	32.20
Mg	0.63	0.72	0.81
Al	0.57	0.41	0.00
Si	0.88	0.61	0.40
P	1.12	1.21	0.96
K	0.20	0.32	0.38
Ca	0.99	0.57	0.43
Fe	0.47	0.26	0.23
Zn	1.72	2.18	1.50

Table-2 displays the atomic percentages of various elements present in BCP at different pyrolysis temperatures (300°C, 350°C, and 400°C) as determined by Energy Dispersive X-ray Spectroscopy (EDS) analysis. Carbon is the predominant element in biochar, showing an increase in percentage as the pyrolysis temperature rises. This increase suggests a concentration of carbon due to the removal of non-carbon elements and the decomposition of organic matter. While both elements, Nitrogen and Oxygen, decrease in percentage with increasing pyrolysis temperature. Other Elements (Mg, Al, Si, P, K, Ca, Fe, Zn) show variations in their percentages with different temperatures. Their presence might be attributed to impurities in the raw material or compounds formed during the pyrolysis process.[16] The change in elemental composition with temperature reflects the transformation of the Cassava Peel's constituents during the activation process.[17] The increased carbon content and reduced nitrogen and oxygen content signify the enrichment of carbonaceous structures and the removal of volatile components, contributing to the development of biochar properties suitable for various applications such as adsorption and filtration.[18] To test the adsorption power of BCP on indigo sol blue 04-B contained in batik factory waste, BCP was used, which was produced at a pyrolysis temperature of 400ºC. The adsorption capacity was measured by varying pH, weight, and BCP contact time on batik industry waste containing indigo sol blue 04-B. The percentage of adsorbed indigo sol is shown in Table-3. In this study, the optimum pH was determined in the pH range 4, 5, 6, 7, and 8, using BCP masses of 25, 50, 75, 100, and 125 grams, respectively, and varying the contact time by 20, 30, 40, 50, and 60 minutes. Data from measurements of indigo solubility blue concentration at pH variations are shown in Tables 3-5 below.

Table-3: The Adsorption of Indigosol Blue 04-B by BCP in pH Variation

BCP weight (mg)	Time (min)	pH	Abs	Ci (mg/L)	Ceq (mg/L)	Cb (mg/L)	% indigosol adsorbed
75	40	4	0.831	42.16142	15.07524	27.08618	64.24
75	40	5	0.785	42.16142	14.44596	27.71546	65.74
75	40	6	0.702	42.16142	13.31053	28.85089	68.43
75	40	7	0.587	42.16142	11.73735	30.42407	72.16
75	40	8	0.767	42.16142	14.19973	27.96169	66.32

The data indicates how the pH of the solution influences the adsorption capacity of the activated charcoal. Generally, higher pH levels show increased adsorption efficiency,[19] resulting in a higher percentage of dye removed from the solution by the BCP. This information is valuable in understanding the optimum pH conditions for effective dye removal using activated charcoal derived from Cassava Peels.

Table-4: The Adsorption of Indigo Sol Blue 04-B by BCP in Weight Variation

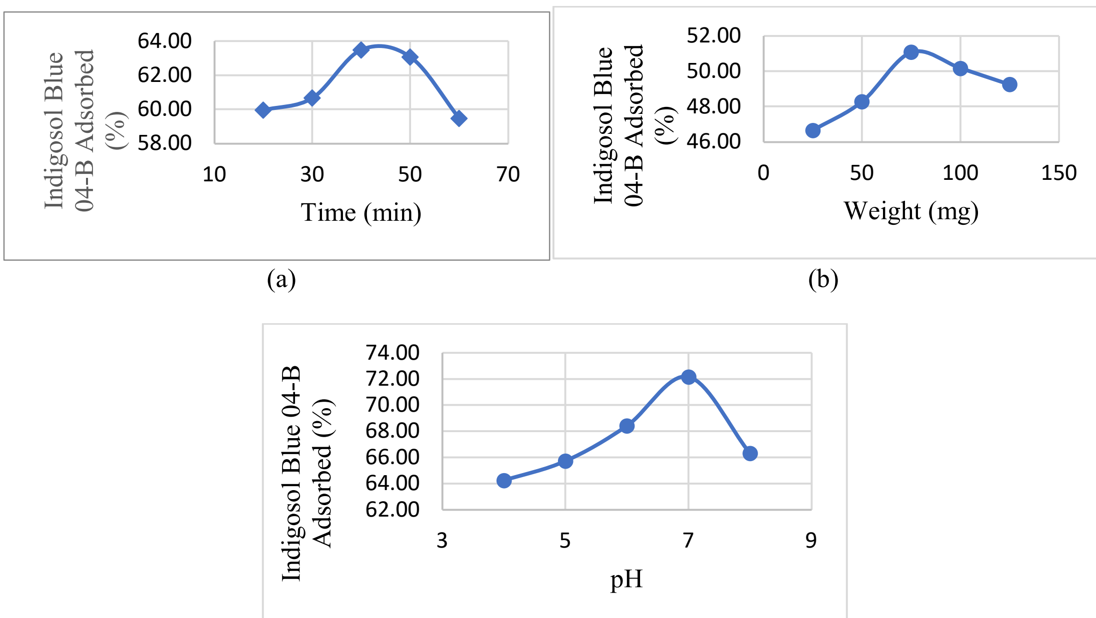
BCP weight (mg)	Time (min)	Abs	Ci (mg/L)	Ceq (mg/L)	CB (mg/L)	% indigosol adsorbed
25	60	1.373	42.16142	22.48974	19.67168	46.66
50	60	1.323	42.16142	21.80575	20.35567	48.28
75	60	1.237	42.16142	20.62927	21.53215	51.07
100	60	1.265	42.16142	21.01231	21.14911	50.16
125	60	1.293	42.16142	21.39535	20.76607	49.25

The data demonstrates how the quantity of BCP influences its adsorption capacity for the Indigo sol Blue 04-B dye. Generally, as the weight of BCP increases, there is an increase in the percentage of dye adsorbed, indicating higher efficiency in dye removal. This information assists in understanding the relationship between BCP quantity and its effectiveness in adsorbing dye from aqueous solutions, aiding in optimizing the adsorption process for various applications.[19]

Table-5: The Adsorption of Indigo Sol Blue 04-B by BCP in Contact Time Variation

BCP Weight (mg)	Time (min)	Abs	Ci (mg/L)	Ceq (mg/L)	Cb (mg/L)	% Indigosol Adsorbed
75	20	0.963	42.16142	16.8810	25.28044	59.96
75	30	0.941	42.16142	16.5800	25.58139	60.67
75	40	0.854	42.16142	15.3898	26.77162	63.50
75	50	0.867	42.16142	15.56772	26.5937	63.08
75	60	0.978	42.16142	17.0861	25.07532	59.47

Table-5 illustrates the adsorption of Indigo sol Blue 04-B by BCP while varying the contact time between the dye solution and the activated charcoal. The data indicates how the duration of contact time between the dye solution and the activated charcoal influences the adsorption capacity. Generally, as the contact time increases from 20 to 60 minutes, the percentage of dye adsorbed initially rises, peaks at 63.50% (at 40 minutes), and then decreases slightly. This information aids in determining the optimal contact time required for the BCP to effectively adsorb the Indigo sol Blue 04-B dye from aqueous solutions, impacting the efficiency of adsorption processes in practical applications. The adsorption graph of BCP is illustrated in Fig.-3. The optimal contact time for BCP in adsorbing indigo sol blue dye waste is 40 minutes, with the amount of dye solution adsorbed being 63.50 (Fig.-2 (a)). After reaching the optimal point, the amount of adsorbed dye decreases. This is because the available active side is reduced.[20] After all, the dye solution forms a layer on the surface of the adsorbent, which covers the adsorbent layer, thereby reducing the adsorption capacity, meaning that the dye waste adsorbent has undergone desorption, namely the release of adsorbed ions due to saturation. Thus, if the optimal contact time is exceeded, the adsorption capacity of activated charcoal will decrease.[21]



(a) (b)

(c)

Fig.-2: The Dye Adsorption Capacity of BCP with the Variation of Variation of Contact Time (a), the Weight (b), and the pH (c)

The optimal adsorption mass of BCP to adsorb indigo sol blue 04B dye waste is 75 mg; the amount of dye solution adsorbed is 51.07% (Fig.-2 (b)). The figure indicated that the more the adsorbent was added, the higher the adsorption capacity. This is because increasing the weight of the adsorbent will increase the number of particles and surface area of the activated carbon adsorbent, thereby causing an increase in the surface area of the adsorbent bound to the dye.[22] However, suppose the amount of adsorbent exceeds the optimal weight. In that case, the adsorption capacity of biochar will decrease because the active surface of the adsorbent is not saturated, thus forming lumps on the activated charcoal, thereby reducing the surface area of the adsorbent.[23] The effect of the optimum pH of indigo sol blue dye waste using BCP at pH 7 with the amount of adsorbed dye solution of 72.16% (Fig.-6). Starting from a low pH value (acidic atmosphere), the higher the pH value, the more the dye solution will be adsorbed.[24] However, if the pH of the dye solution is higher than the optimum pH (alkaline atmosphere), then the amount of dye solution absorbed will decrease. At low pH, the number of H+ ions is more significant, where the H^+ ions will neutralize the negatively charged surface of activated charcoal, thereby reducing obstacles to organic diffusion at higher pH.[25] When the pH exceeds 7, adsorption decreases as OH (OH^-) increases. This is caused by an increase in OH, which can interfere with the adsorption process, resulting in adsorption competition between the –COO group on the biosorbent surface and OH to bind with the Indigo sol blue ion. The adsorption isotherms commonly used are the Langmuir and the Freundlich isotherms.[26] Table-6 shows that the equilibrium model testing is carried out to determine an equilibrium model suitable for research use. Choosing the equilibrium model depends on the high value of the determinant coefficient (R_2).

Table-6: Determination of BCP Langmuir Adsorption Isotherm

BCP Weight (mg)	pH	Abs	Ci (mg/L)	Ceq (mg/L)	CB (mg/L)	x/m (mg/g)	Ceq/x/m
75	4	0.831	42.16142	15.07524	27.08618	3.611491	4.17424
75	5	0.785	42.16142	14.44596	27.71546	3.695395	3.90917
75	6	0.702	42.16142	13.31053	28.85089	3.846785	3.46017
75	7	0.587	42.16142	11.73735	30.42407	4.056543	2.89343
75	8	0.767	42.16142	14.19973	27.96169	3.728225	3.80871

Plotting the Langmuir isotherm typically results in a curved line at lower concentrations that asymptotically approaches a plateau at higher concentrations. Interpreting the Langmuir curve in the context of BCP adsorbing Indigo sol blue dye waste: At low dye concentrations, the Langmuir curve shows a steep increase in adsorption capacity as more dye molecules bind to available sites on the BCP surface. As the dye concentration increases, the curve levels off, reaching a plateau where the adsorption sites on BCP become saturated. By fitting experimental data onto the Langmuir isotherm model, researchers can estimate parameters like *qm* and K, providing valuable information about the adsorption capacity and affinity of BCP for the Indigo sol blue dye waste.

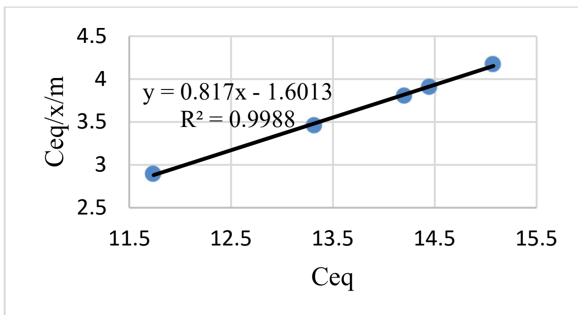


Fig.-3: Langmuir Isotherm Curve for the Adsorption of BCP on Indigo Sol Blue Dye Waste

Based on Fig.-3 in this study, the Langmuir adsorption isotherm equation was used to apply to the adsorption of indigo sol blue dye by BCP. The Langmuir isotherm is used, assuming that the layer formed is a monolayer whose bond between the adsorbent and the adsorbate is substantial due to creating a chemical bond. Based on the picture showing linearity for the absorption of indigo sol blue dye waste at pH variations, the correlation $R_2 = 0.9988$ with a maximum absorption capacity (α) = 2.6198 mg/g. In conclusion, cassava peel-activated charcoal effectively absorbs indigo solubilized blue dye waste because the correlation (R_2) is close to one. This study's results indicate that BCP effectively removes Indigo sol Blue 04-B dye from batik wastewater via adsorption. This finding supports the idea that using materials made from farm waste can be a cost-effective and sustainable way to clean wastewater. Using cassava peel biochar significantly reduces the amount of dye in wastewater, which helps achieve SDG 6 (Clean Water and Sanitation), especially Target 6.3, aimed at improving water quality by reducing pollution, eliminating waste, and lowering harmful substance discharge. The employment of a bio-based adsorbent corresponds with Target 6. A, which advocates for local and community-oriented solutions to improve water and sanitation management. This work provides an eco-friendly solution for waste management by valorizing cassava peels and treating industrial wastewater, which is especially relevant for small-scale batik enterprises in Indonesia. Incorporating this approach into current treatment practices may diminish the environmental impact of textile production and assist communities in achieving international clean water standards.

CONCLUSION

The study results show that BCP has great potential to absorb indigo sol Blue 04-B dyes, with its ability to do so affected by various factors. The Langmuir isotherm model was used to explain how the dye is absorbed, showing a link between the dye concentration and how much BCP can absorb. The Langmuir isotherm model was used to explain how the dye is absorbed, showing a relationship between the amount of dye and how much BCP can hold. The experimental data followed the Langmuir model, indicating monolayer adsorption and finite adsorption sites on the BCP surface. This research contributes directly to the achievement of Sustainable Development Goal (SDG) 6: Clean Water and Sanitation[27], particularly Target 6.3, by demonstrating a method that reduces water pollution through the use of eco-friendly materials. Further research could enhance the practical viability of BCP-based adsorption systems for large-scale dye removal applications by optimizing process parameters and scaling them up.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

The present work is related to *SDG-6 : Clean Water and Sanitation*. All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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