Research Article

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Adsorption and sugarcane-bagasse-derived activated carbon-based mitigation of 1-[2-(2-chloroethoxy)phenyl]sulfonyl-3-(4-methoxy-6-methyl-1,3,5-triazin-2-yl) urea-contaminated soils<https://doi.org/10.1515/chem-2020-0185>

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Abstract: Burgeoning pesticide usage in agriculture sector required to be evaluated by assessing the adsorption rate in soils. The herbicide triasulfuron was used in this research to analyze its sorption behavior in seven distinct soils using batch equilibrium methodology. The adsorption coefficient (K_d) values ranged from the 3.32 to 29.7 $\mu\text{g/mL}$. Peshawar soil displayed the highest K_d value because of the distinct physiochemical properties when compared with the other six samples. Gibbs free energy exhibited negative values displaying less contact between soil particles and pesticides, showing the exothermic nature of the phenomena. A negative association was observed between the pH of the soil samples and K_d ($R^2 = -0.71$) but a direct relation with the organic content ($R^2 = 0.74$). Triasulfuron mitigation was performed by the economical remediation of soils using acid-activated charcoal prepped from *Saccharum officinarum* husk. Activated carbon derived from biomass displayed the great potential for triasulfuron removal from soils.

Keywords: sorption, herbicide, exothermic, removal, activated carbon, sugarcane bagasse

1 Introduction

The protection of environment and food crops from harmful organisms requires utilizing different chemical compounds commonly known as pesticides. Moreover, they are used for mitigating any nuisance-causing

organisms that are harmful for the crops. After World War II, pesticides were commonly utilized in agronomic sectors for crop protection and production. Pesticides when sprayed on to the crops not only stop the growth of pests but also cause dreadful impacts on our ecosystem and contaminate the soil. These chemical substances from the soil are leached into the ground water and thus contaminate the water reservoirs. Leaching of pesticides depends upon the concentration, type, persistency into the soil, and life span of the pesticides. Pesticides are also injurious to the human health. It causes many chronic diseases such as cancer and diabetes, disorders such as reproductive disorders and many respiratory problems. Pesticides also have toxic effects on human estrogen. Around 75% of agrochemicals are utilized in the United States for agronomic purposes. The world population is growing very rapidly, which in turn demands more food. Therefore, pesticides are used to increase crop production to meet the demands of the growing population. Disproportionate use of xenobiotics significantly distresses the ecosystem, contaminates the water bodies, and also reduces the soil fertility. Through these pesticides, hazardous chemicals are released into the environment through anthropogenic activities [1]. Although the hazardous effects of pesticides are known, yet it is used excessively to increase crop production. To reduce the contamination of the soil, the use of pesticides has to be limited [2]. To lessen the destructive impacts of pesticides, it is vital to obtain knowledge about their sorption process. The binding of pesticide molecules to soil matrix controls the passage of pesticides through percolation [3]. Basic soils possessing low carbon percentage have the highest level of adsorption [4]. The fate of pesticides in soil can be analyzed using different adsorption parameters [5].

Triasulfuron, 1-[2-(2-chloroethoxy)phenyl]sulfonyl-3-(4-methoxy-6-methyl-1,3,5-triazin-2-yl) urea, is from sulfonylurea group and present in white powder form (Figure 1). Triasulfuron is a herbicide used to destroy the broad-leaved herbs. It is adsorbed by the roots and leaves. It also inhibits the synthesis of amino acid in plants. Herbicides belonging to sulfonylurea group possess

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Figure 1: Structure of triasulfuron.

high potency even at low temperature. It is used to control the weeds that grow in wheat and barley crops [6]. It contaminates the soil, reduces the soil fertility, and changes the soil structure and its formation [7]. It is slightly toxic to bacteria but highly toxic to aquatic plants. Molecular weight of triasulfuron is 401.8 g/mol. Triasulfuron is slightly soluble in methylene chloride, acetone, chloride hexane, and organic solvents. Its melting point is 186°C and it decomposes before boiling. Its solubility in water is 815 mg/L.

Activated carbon (AC) is produced from the materials that naturally contain high amount of carbon content. It is prepared from walnut shells, peanuts shells, coconut shells, wheat bagasse, and saw dust. Through heating, these carbonaceous materials are converted into AC by adjusting temperature. AC is used to remove certain heavy metals from the water [8]. The major and significant application of AC is that it is used to remove pollutants from soil, water, and air. This is only possible because of its large surface area and the pores on its surface. With the help of these pores, AC can purify air, soil, and water. AC adsorption criteria depend upon the pores on its surface, pH, and chemical nature of AC. The physicochemical properties are significant in adsorption capacity [9]. The research about pesticides encourages us to discern the comportment of pesticides in our ecosystem. The investigation of their fate is exceptionally beneficial, so the dangers are detected. Agricultural zones are the main sufferers of agrochemical contamination. The excessive use of pesticides in agriculture can cause serious adverse effects.

The aspiration of the study is to scrutinize the behavior of triasulfuron (herbicide) in the soils of Pakistan and remove the pesticides from the soil using cost-effective AC methodology, which is prepared by using *Saccharum officinarum* bagasse. Removal through biomass-derived AC is a very effective method because it manages the waste and it is economical [4,10]. Triasulfuron remediation from soils has not been previously reported by using biomass-based AC.

2 Experimental

2.1 Chemicals

Triasulfuron of analytical grade is acquired from Sigma Aldrich. Its analytical standard was 99% pure. NaCl (anhydrous), methanol, and acetone were also used (99% pure). Distilled water (DW) was used to prepare the stock solution of triasulfuron.

2.2 Soil sampling and processing

The soils were sampled from seven regions in Pakistan, including Peshawar, Attock, Taxila, Sohawa, Chakwal, Mirpur, and Karachi (Figure 2). After the collection, soils were stored in polythene bags. Air-drying of soil samples was done in green house for a couple of days. The samples were disintegrated with mortar and pestle followed by passing through 2 mm sieve. These were stored in petri dishes until further experimentation.

2.3 Adsorption experiment

Stock solution of triasulfuron was prepared following the standard protocol [11,12]. Triasulfuron (10.3 mg) was weighed and dissolved in a few drops of acetone followed by mixing in DW to prepare 10 ppm stock solution. Multiple dilutions were prepared to assess the adsorption process. These dilutions were prepared in the following concentrations: 0, 0.25, 0.5, 0.75, 1, 2.5, 5, and 7.5 ppm. Triasulfuron adsorption experiments were performed following the methodology adopted by Ahmad [13]. Standard batch equilibrium method was followed according to the OECD guidelines. One control and one blank sample was also prepared for the adsorption experiments. NaCl of 10 mL 0.1 M was also added to each dilution for electrolyte balance. The vials were placed in shaker for 24 h at 90 rpm. The vials were then centrifuged for 20 min at 3,500 rpm. They were filtered through 0.2 μ m nylon filters and analyzed by UV-visible spectrophotometer. Adsorbed triasulfuron was calculated following the adsorption distribution coefficient equations [14]. Univariate ANOVA and regression were applied on the experimental results in Microsoft Excel (2013) and Minitab 17 statistical package.

Figure 2: Map of Pakistan displaying sampling sites for triasulfuron adsorption.

2.4 Synthesis of biomass-derived AC

Saccharum officinarum-bagasse-derived activated carbon (SAC) was prepared by the technique followed by Ahmad [14]. Prepared SAC was stored in airtight media bottle.

2.5 Iodine test

The synthesized SAC was characterized by iodine test devised by Hassler [15]. The adsorption of iodine to SAC was tested and confirmed by the change in the color of the iodine solution from brown to yellow.

2.6 FTIR characterization

The change in functional groups in raw *S. officinarum* bagasse and SAC, i.e., before and after the formation of AC was studied through FTIR spectrometry. Sample pallets were prepared following the methodology devised by

Nabiyouni and Ghanbari [16]. Sample was run in FTIR from 400 to 4,000 cm^{-1} .

2.7 SAC-aided triasulfuron removal

Removal of triasulfuron from soils through SAC was done by the methodology of Ahmad [12]. Herbicide removal was checked in two concentrations, i.e., 5 and 7.5 ppm. Removal was checked as a function of time at 3 and 6 h by UV-visible spectrophotometric analysis. A 10-mL quantity of each, 5 and 7.5 ppm, dilution, previously prepared from the stock solution, was added to the 15-mL centrifuge tube. Soil sample of 0.5 g was then added to each tube. Absorbance was measured by UV-visible spectrophotometer. UV was again checked before and after (3 and 6 h) the addition of the synthesized biomass-based AC. This process was repeated for all the soil samples.

Ethical approval: The conducted research is not related to either human or animal use.

Table 1: Physiochemical properties of the soil

Samples	pH	OM (%)	Texture	Sand (%)	Silt (%)	Clay (%)	TC (%)	TN (%)	EC ($\mu\text{S}/\text{cm}$)	Saturation (%)	Heavy metals (ppm)			
											Pb	Ni	Zn	Cd
Attock	7.59	1.10	Loamy sand	54	36	10	0.64	0.55	143.0	35	3.4	—	0.277	0.04
Mirpur	7.62	1.35	Silty clay loam	3.0	62	35	0.78	0.67	334.0	48	0.1	—	0.159	0.04
Karachi	7.68	0.70	Loam	82	3.0	15	0.41	0.35	2,120	26	0.7	0.29	0.025	0.12
Taxila	7.62	1.15	Clay loam	44	39	17	0.66	0.57	280.0	50	2.9	0.20	0.015	0.70
Peshawar	7.05	1.40	Silty clay loam/clay loam	20	42	38	0.81	0.70	397.0	29	1.1	0.41	0.124	0.04
Chakwal	7.50	0.52	Clay loam	53	38	9.0	0.30	0.26	291.0	50	3.9	0.35	0.005	0.06
Sohawa	7.28	1.25	Sandy loam	44	41	14	0.72	0.62	0.710	31	2.9	0.04	0.101	0.05

3 Results and discussion

3.1 Properties of soil samples

Physicochemical properties of the soil samples were observed (Table 1). These properties play a significant role in predicting the soil–pesticide association. The pH values of the soil samples were in the range of 7.05–7.68. It was noted that the soil from Peshawar possessed the lowest pH among all soils, whereas the soil from Karachi possessed the highest pH value. Pakistani soils displayed an overall alkaline trend. Previous research revealed an abundance of sodium content in soils from this location [17]. The organic matter (OM) percentage of the samples ranged from 0.52 to 1.4, with the highest percentage from Peshawar region. Peshawar district possesses very fertile land. A main reason for this might be the two rivers flowing through it, giving it a rich soil [18]. Uzoma *et al.* stated that alkaline soils tend to possess less OM [19]. The elevated pH levels cause the paucity of organic biomass in soils resulting in reduced OM and organic carbon contents [20]. OM in turn is responsible for influencing several other soil properties. Soils were also analyzed for the amount of total carbon (TC). Soils of Peshawar contained the most amount of the TC content (0.81%). Furthermore, soil textural examination displayed the highest percentage of clay content in Peshawar soil (38%), whereas Karachi possessed the most amount of sand (82%), due to its coastal setting near the Arabian sea [21]. The Peshawar soil was thus classified as clay loam, whereas the soil of Karachi region was categorized as loamy sand. Electrical conductivity was used to assess the extent of salinity hazard in soils [22]. The highest value of electrical conductivity was observed in soil from Karachi region (2,120 $\mu\text{S}/\text{cm}$). Hence, the soil from Karachi can be excogitated to be the most probable to soil salinity risk. Heavy metal analysis of soils was also performed to assess the risk associated with the heavy metal concentration in soils. Previous research have shown that the pH of soils greatly influences the metal toxicity of soils [9]. The soil from Chakwal was found to possess the highest amount of lead (3.9 ppm). It has been concluded in a previous research by Raza *et al.* that high amount of lead in soils from this region is mainly due to the inherent nature of ground rock of that geographical strata [23]. The highest amount of nickel was found in Peshawar soil (0.414 ppm). It was stated by Ishaq *et al.* that in the Peshawar region nickel was distributed by the flow of river water followed by evaporation [24]. Most of the

zinc was found in the Attock soil (0.27 ppm). The soil of the Taxila region demonstrated the highest amount of cadmium (0.7 ppm). Various researchers have shown that cadmium adsorption by soil particles increased with the elevated pH levels [25]. Chang et al. displayed the increasing cadmium adsorption by soil particles with high pH values [26].

3.2 Adsorption isotherms

Triasulfuron adsorption phenomenon in soils was investigated by UV-visible analysis. Two adsorption isotherm models, i.e., linear and Freundlich, were utilized to evaluate the adsorption parameters of triasulfuron on soils (Table 2 and Figure 3). All soils exhibited varying adsorption rates due to their diverse soil physicochemical properties. The linear adsorption coefficient (K_d) values of all soils for triasulfuron adsorption ranged from 3.32 to 29.7 $\mu\text{g/mL}$. The adsorption distribution constant (K_d) trend in all soils was $S3 > S7 > S4 > S5 > S2 > S6 > S1$.

Soil sample S3 displayed the highest rate of triasulfuron adsorption (29.7 $\mu\text{g/mL}$). According to the experiment, the soil samples with the highest OM and lowest pH exhibited the highest rate of adsorption. Furthermore, the sample was clay in nature. K_d is the most crucial linear adsorption parameter which can be used to assess the potential and risk of pesticide transport. Higher values of K_d are indicative of a vigorous interaction of pesticide and soil molecules. On the contrary, the low K_d determines a more probability for the movement of pesticide in soils. In this research, sample S3 displays the highest rate of adsorption, thus exhibiting the strongest affinity for pesticide attachment. In this regard, sample S1 shows the lowest affinity for pesticide binding, thus increasing the likelihood for triasulfuron leaching. The R^2 value for linear isotherm ranged from 0.71 to 0.92,

representing goodness of fit to this model. Triasulfuron mobility in soils can be determined by another parameter for organic carbon-based adsorption coefficient (K_{oc}). Different pesticide mobility groups have been made based on the K_{oc} values [27]. The K_{oc} values below 50 comprise the highest pesticide movement group. Values from 50 to 100 indicate a great mobility group and the values between 150 and 500 depict mediocre mobility of pesticide in soils. Current experiments displayed the K_{oc} ranging from 811 to 3,675 $\mu\text{g/mL}$. It is quite obvious from the results that triasulfuron displayed very low percolation. It was also perceived that soil exhibiting the greatest triasulfuron adsorption displayed highest K_{oc} . This justified the fact that pesticide mobility and its K_{oc} values were inversely proportional to each other. In another research, Ahmad (2017b) exhibited mediocre mobility potential of triasulfuron in soils [13]. The change in mobility pattern of triasulfuron depends upon the physicochemical properties of each soil sample. The soils were also assessed for K_{om} values, which ranged from 475 to 2,126 $\mu\text{g/mL}$. Sample S3 displayed the highest K_{om} value and also possessed the highest K_d and OM values. The Gibbs free energy (ΔG), a thermodynamic parameter, was also studied to evaluate the interface between soil particles and pesticide molecules. The value of $\Delta G \leq -40 \text{ kJ/mol}$ represents the phenomena of physisorption and exothermic reaction [28]. It further implies that the reaction is spontaneous with weak van der Waal's forces between the pesticide and the soil particles.

Triasulfuron adsorption pattern was also assessed by Freundlich isotherm. The Freundlich adsorption coefficient (K_f) values ranged 0.92–4.12 $\mu\text{g/mL}$. Freundlich adsorption constants in Italian soils revealed lower values of K_f in loamy and clay loam soils with comparatively higher pH values of 8.0 and 8.3 [29]. In an experiment by Pusino et al., triasulfuron has exhibited similar rate of adsorption to montmorillonite mineral in soil [30]. In another research conducted by Pusino et al.,

Table 2: Triasulfuron linear and Freundlich adsorption parameters in soil

Sample #	Location	K_d ($\mu\text{g/mL}$)	R^2	K_{om} ($\mu\text{g/mL}$)	ΔG (kJ/mol)	K_{oc} ($\mu\text{g/mL}$)	K_f ($\mu\text{g/mL}$)	R^2	K_{foc} ($\mu\text{g/mL}$)	η_a
S1	Karachi	3.32	0.73	475.0	-15	811.0	0.92	0.91	231.0	0.6
S2	Chakwal	10.7	0.72	2,065	-18	3,556	2.62	0.95	868.0	0.8
S3	Peshawar	29.7	0.90	2,126	-18	3,675	4.12	0.97	510.0	1.3
S4	Mirpur	24.3	0.81	1,804	-18	3,122	3.95	0.92	508.0	1.1
S5	Taxila	11.9	0.93	1,039	-17	1,811	2.94	0.80	447.0	1.2
S6	Attock	6.24	0.71	568.0	-15	976.0	1.22	0.87	191.0	0.5
S7	Sohawa	24.9	0.92	1,993	-18	3,460	4.02	0.91	559.0	0.9

Figure 3: Comparative linear and Freundlich isotherm model of triasulfuron adsorption on soils.

triasulfuron exhibited high rate of Freundlich adsorption, which can be attributable to the presence of comparatively higher percentages of OM [4]. The R^2 for Freundlich adsorption ranged from 0.80 to 0.97, indicating the best fit for adsorption isotherm. The K_{foc} in all samples varied significantly based on the organic content present in the soils. In the current research, the values of K_{foc} were from 191 to 868 $\mu\text{g}/\text{mL}$. Previously, Ahmad had reported the K_{foc} value of triasulfuron in four distinct soils ranging from 177 to 909 $\mu\text{g}/\text{mL}$ [13].

3.3 Soil physicochemical properties and adsorption

The interaction of soil and pesticides depends greatly on the soil physicochemical properties. The soils with high K_d values were found to possess low pH but rich in OM content and carbon percentage. On the contrary, the soils with low K_d value showed high pH but low carbon content and low OM content. In the current study, Peshawar soil possessed high OM content and organic carbon (1.40 and 0.81%) but a low pH was observed (7.05) among all samples, thus displaying the highest rate of adsorption ($K_d = 29.7 \mu\text{g}/\text{mL}$). Karachi's soil pH was 7.68 and contained low OM (0.70%) and organic carbon (0.41%) and consequently K_d value (3.32 $\mu\text{g}/\text{mL}$) was lowest among all soil samples. Furthermore, Karachi soil sample contained the highest sand content (82%). More the amount of sand content hinders the attachment of molecules to soil. Peshawar soil possessed highest clay percentage, which also aided in more adsorption. Previous adsorption studies of various pesticides have shown the same trend of dependency of the rate of adsorption on soil properties [5,12–14].

3.4 FTIR spectrometry of AC

Analysis of functional groups of the raw material and SAC was performed through FTIR. These functional groups could act as potential attachment sites for the pesticide molecules. The difference in functional groups before and after the activation of AC is presented in Table 3.

In both the samples, before and after activation, very minor vibrations appeared at peak frequency of 563 and 597 cm^{-1} , respectively, in the finger print region (400–500 cm^{-1}). These bands are indicating the C–H oop of the aromatic compounds [39,40]. Moreover, in accordance with the references [34,35,39], the presence of these minor figure print vibrations may also be associated with the alkyl halides [34,35,39].

The analysis of raw *S. officinarum* bagasse revealed small vibration of 665.46 cm^{-1} , representing the alkynes bending. The presence of alkynes is indicative of different unsaturated hydrocarbons, which are part of the natural composition of the different flora such as *S. officinarum* [31,32]. The C–H oop of aromatics was observed at the frequencies of 868 and 908 cm^{-1} . The observance of the aromatics was due to the presence of bioactive compounds such as phenolic compounds. The phenolic compounds are the prime representatives of the aromatic compounds [34,36]. Therefore, C–H was proposing the phenol chemical compounds of *S. officinarum*. The presence of phenolic compounds was furthered validated by C–O stretching, representing the alcohol and carboxylic acid at 1,051, 1,161, and 1,244 cm^{-1} . The peaks at frequencies of 1,051 and 1,244 cm^{-1} were also signifying the presence of C–N stretching of the aliphatic amines, indicating the presence of amines in the raw material without aromatic ring [36,37]. Furthermore, Table 3 and Figure 4 are depicting the alkane at 1,373 and 1,427 cm^{-1} , exhibiting C–H rock and C–H bending, respectively. The

Table 3: Functional group in AC identified with the help of FT-IR

Sr. no.	Before activation by acid			After activation by acid			Functional groups
	Peak position (cm ⁻¹)	Bonds	Assignments ^a	Peak position (cm ⁻¹)	Bonds	Assignments ^a	
1	563	C–H	oop	597	C–H	oop	Aromatic compounds (phenolic compounds)
2	665	–C=C–H:C–H	δ	—	—	—	Unsaturated hydrocarbons alkynes
3	—	—	—	800	N–H	ω	1° and 2° amines and aromatics
4	868	C–H	oop	873	C–H	oop	Aromatic compounds (phenolic compounds)
5	908	C–H	oop				Aromatic compounds
6	1,051	C–O	υ	1,030	C–O	υ	Alcohol and carboxylic acid
		C–N		1,097	C–N		Aliphatic amines
7	1,161	C–O	υ	1,161	C–O	υ	Alcohol and carboxylic acid
8	1,244	C–O	υ	1,199	C–O	υ	Alcohol and carboxylic acid
		C–N			C–N		Aliphatic amines
9	1,323	C–N	υ	1,261	C–N	υ	Aliphatic amines
10	1,373	C–H, N–O	ρ, υ	—	—	—	Alkane (saturated hydrocarbons) and nitro compounds
11	1,427	C–H	δ	1,415	C–C	υ	Alkane (saturated hydrocarbons)
12	1,514	C–C	υ	—	—	—	Aromatics
		N–O	υ				Nitro compounds
13	1,604	N–H	δ	1,620	N–H	δ	Primary amines
14	1,633	N–H	δ	—	—	—	Primary amines
15	1,732	C=O	υ	1,703	C=O	υ	Carboxylic acid
16	2,931	C–H	υ	2,962	C–H	υ	Alkanes
17	3,389	OH and H	υ and δ	3,429	O–H	υ	Alcohols and phenols

^a υ = stretching, δ = bending, ρ = rocking, ω = wagging.

presence of alkane was attributed to the saturated hydrocarbons [34–37]. The peak at 1,372 cm⁻¹ is also indicating the N–O stretching of nitrocompounds which is supported by another vibration at 1,541 cm⁻¹. This peak

vibration is corresponding to the C–C of aromatic compounds and may also represent N–O stretching of nitro compounds that can be observed in the raw *S. officinarum*. The presence of amines in the raw sugarcane

Figure 4: FTIR spectrum of raw sugarcane bagasse and SAC.

bagasse was again shown by N–H bend at two peak frequencies of 1,604 and 1,633 cm^{-1} . This N–H bending is related to the category of primary amines [34,36,37]. In Figure 4, the vibrational peak at 1,732 cm^{-1} is corresponding to C=O stretching, which was attributed to the presence of carboxylic acid in the raw material. However, this stretching vibration is also related to the chelated ketone group [31]. The minor peak of alkanes was again observed at 2,931 cm^{-1} in the raw sugarcane. Nevertheless, a broad and strong vibration was found at 3,389 cm^{-1} corresponding to OH stretching and H bending, proposing the presence of alcohols and phenols. This broad vibration is endorsing the phenolic compounds in consistency with the earlier described aromatic and carboxylic groups. Thus, the overall FTIR vibrational analysis was demonstrating that *S. officinarum* was composed of different compounds having aromatic, amine, carboxylic and phenol groups. The major constituents of the raw *S. officinarum* (before activation) were amines and phenolic compounds, according to the interpreted functional groups in Table 3 and Figure 4.

However, after activation by acid, nearly same groups were observed but with different intensities of vibrational peaks. The peak of phenolic compounds at 3,429 cm^{-1} became much broader when compared with that of the raw material, and the peak intensities of alkanes (2,962 cm^{-1}) and nitro compounds (1,703 cm^{-1}) comparatively reduced. The broader and stronger peak was observed at 1,620 cm^{-1} of primary amines. It can further be seen in Figure 4 that numerous minor peaks were removed after activation such as the peaks in the frequency range of 1,500, 1,300, 900 and 600 cm^{-1} disappeared after acid treatment. It is also worth noticing that after activation a very strong sharp peak was observed at 800 cm^{-1} corresponding to the functional groups of N–H wag, indicating that emergences of primary (1°) and secondary (2°) amines after activation with acid [31,32]. Further, this peak can be associated with C–H oop of aromatics compounds [34,36,37], thereby verifying the 1° and 2° amines having nitrogen atom attached to the aromatic ring [38]. As discussed earlier that the raw sugarcane bagasse material mainly consisted of amines and aromatic compounds, accordingly,

the presence of these functional groups was also observed after activation. However, the change in vibration peak position of the respective functional group was due to reaction with acids for activation. Moreover, the FTIR spectra obtained by Carrier *et al.* of sugarcane bagasse biochar were well matched with the FTIR of SAC from the current experiments. Almost similar bonds were observed with slight shifting at wavelengths, most probably due to the difference in the synthesis method. C=O stretch was observed at 1,702 cm^{-1} ; whereas in the current experiment, it was observed at 1,703 cm^{-1} . The C–C stretch was observed at 1,598 cm^{-1} ; however, in the present research it was found at 1,415 cm^{-1} . The C–O stretch was observed at 1,092 cm^{-1} , which was detected at 1,097 cm^{-1} in this research. The C–H bending was observed at 798 cm^{-1} , which was observed at 873 cm^{-1} in the present research [31]. Furthermore, the FTIR spectra of AC was also compared with the study by Foo *et al.*, which displayed a close resemblance to the AC also prepared from sugarcane bagasse [32]. In summary, FTIR after acid activation successfully demonstrated the preparation of SAC from the raw sugarcane bagasse. The well-defined and prominent functional groups of SAC related to raw sugarcane bagasse are reported as the efficient active sites for organic molecules, such as pesticides, to adsorb by soil amendment [31].

3.5 Iodine test

Iodine solution turned to light yellow after the addition of SAC. This indicated the adsorption of iodine molecules to SAC, resulting in the decoloration of the solution. The change in color displayed the correct synthesis of SAC.

3.6 Statistical analysis

Statistical analysis of triasulfuron adsorption was performed based on their physiochemical properties (Table 4). Regression analysis on the samples displayed an indirect

Table 4: Statistical analysis of regression and correlation of triasulfuron with soil physicochemical properties

Adsorption coefficient	Property (x)	Correlation coefficient (r)	Probability level (p)	Intercept (a)	Slope (b)
$K_{d \text{ ads}}$	pH	−0.71	0.071	7.7	−0.017
	OM	0.74	0.012	0.6	0.024
	TOC	0.91	0.010	0.3	0.013

relation of K_d with pH and a direct relation with OM and total organic content. This confirms the fact that greater the amount of OM, higher the rate of adsorption, whereas the trend will be opposite to the pH value of soil samples. The statistical analysis justified the experimental results of the current research exhibiting the highest K_d value for Peshawar soil which possessed the highest OM. ANOVA was also performed on the adsorption results. Univariate ANOVA revealed p value less than the α value (0.05), indicating the significance of the results. Residual plots were graphed in Minitab 17 to observe the association of adsorption coefficient K_d with pH, OM, and TOC (Figure 5). The plots displayed the normal distribution of data and a constant variance indicating the goodness of fit.

3.7 Removal of triasulfuron

Prepared SAC was utilized as an environmental remediation, i.e., for the decontamination of soil from pesticides. Triasulfuron was removed in two concentrations from the soil samples (Table 5). A maximum triasulfuron removal of 44% was observed in 5 ppm concentration. Removal from 7.5 ppm concentration triasulfuron solution was 63%. Mirpur soil sample displayed the highest removal

of triasulfuron through SAC (63%), whereas the lowest removal was from Karachi (21%). Time and concentration can play a significant role in the removal of pesticide from soils through SAC (Figure 6). Laurella et al. adsorbed carbendazim on silica for its removal [33]. The experimental data fitted best to the first-order reaction kinetics. Their results indicated the formation of type I isotherm, depicting the difficulty in adsorption with the increase in concentration. The researchers fitted their data to Langmuir and Freundlich models. Based on the r^2 values, their experimental data fitted well to Langmuir model.

4 Conclusion

Diverse soils from various different areas were analyzed for the triasulfuron adsorption alongside its exclusion by AC prepared from sugarcane bagasse. It can be concluded from the results that triasulfuron adsorption depends largely upon the physiochemical properties of soils. Highest K_d and K_f values reveal that soils have greater ability of adsorption. AC-mediated elimination of triasulfuron was beneficial both economically and environmentally. Around 50% triasulfuron was easily detached from soils by this methodology. This method provides promise

Figure 5: Residual plots of adsorption coefficient K_d with soil properties pH, OM, and TOC.

Table 5: SAC-aided elimination of triasulfuron from various soils

Location	Triasulfuron concentration 5 ppm					Triasulfuron concentration 7.5 ppm				
	Before addition of AC	After 3 h	After 6 h	Average removal	Percentage (%)	Before addition of AC	After 3 h	After 6 h	Average removal	Percentage (%)
Attock	1.08	0.33	0.11	0.38	35	0.26	0.15	0.08	0.19	75
Chakwal	1.36	0.51	0.16	0.59	43	0.50	0.45	0.02	0.46	93
Karachi	2.06	0.43	0.03	0.45	21	0.21	0.02	0.02	0.03	16
Mirpur	1.22	0.74	0.19	0.84	63	0.17	0.08	0.03	0.07	42
Peshawar	1.35	0.49	0.20	0.60	44	0.31	0.04	0.11	0.09	30
Sohawa	1.39	0.43	0.14	0.50	36	0.20	0.01	0.68	0.13	65
Taxila	1.07	0.36	0.16	0.44	41	0.18	0.05	0.05	0.07	42

Figure 6: Triasulfuron elimination from soils via SAC (a) 5 ppm initial herbicide concentration and (b) 7.5 ppm initial herbicide concentration. UV spectrum of triasulfuron removal (c) highest elimination in Mirpur (5 ppm), (d) lowest elimination in Karachi (5 ppm), (e) highest exclusion in Chakwal (7.5 ppm), and (f) lowest exclusion in Karachi (7.5 ppm).

for future remediation studies because of its less cost and nonrequirement of synthetic AC. It is advisable to use different waste materials to prepare AC pesticide remediation from soils as it not only removes the pesticides but is also an auspicious method for waste reduction. It is the first report on triasulfuron removal by biomass-

derived AC, thus acting as a milestone for further studies for herbicide remediation.

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