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INFLUENCE OF BIOMASS COMPOSITION ON THE SURFACE AREA DEVELOPMENT OF BIOCHAR: MINI REVIEW

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Abstract. Biochar surface area depends on both pyrolysis severity and biomass composition. Lignocellulosic structure, ash content, mineral catalysis, and tissue morphology control pore formation during carbonization. Woody biomass typically yields the highest surface area, while agricultural residues and leaves show variable behavior depending on mineral content and structure, as seen in Platanus orientalis. Algae and sludge produce lower surface areas unless activated. Understanding these factors is essential for designing biochars for pollutant adsorption.

Keywords: Biochar; BET analysis; specific surface area; pore size distribution; biomass composition; lignocellulosic structure; ash and mineral content; pyrolysis conditions; pore development; Platanus orientalis leaves.

Annotatsiya. Bioko‘mirning sirt maydoni piroliz sharoitlari va biomassa tarkibiga bog‘liq. Lignosellyulozali tuzilma, kul miqdori, mineral kataliz va to‘qima morfologiyasi karbonizatsiya jarayonida g‘ovak hosil bo‘lishini belgilaydi. Yog‘och odatda eng yuqori sirt maydonini beradi, qishloq xo‘jaligi qoldiqlari va barglar esa, jumladan Platanus orientalis, o‘zgaruvchan natija ko‘rsatadi. Suv o‘tlari va loy aktivatsiyasiz past sirt maydoniga ega. Bu omillarni tushunish adsorbentlarni yaratishda muhimdir.

Kalit so‘zlar: Bioko‘mir; BET tahlili; solishtirma sirt maydoni; g‘ovak o‘lcham taqsimoti; biomassa tarkibi; lignosellyulozali tuzilma; kul va mineral tarkib; piroliz sharoitlari; g‘ovak rivojlanishi; Platanus orientalis barglari.

Аннотация. Удельная поверхность биоугля определяется как условиями пиролиза, так и составом биомассы. Лигноцеллюлозная структура, зольность, минеральный катализ и морфология тканей контролируют формирование пор при карбонизации. Древесина обычно обеспечивает наибольшую поверхность, тогда как сельскохозяйственные остатки и листья демонстрируют вариабельность, как у Platanus orientalis. Водоросли и илы дают более низкую поверхность без активации. Понимание этих факторов важно для разработки адсорбентов.

Ключевые слова: Биоуголь; БЭТ-анализ; удельная поверхность; распределение пор по размерам; состав биомассы; лигноцеллюлозная структура; зольность и минеральный состав; условия пиролиза; развитие пористой структуры; листья Platanus orientalis.

INTRODUCTION.

Surface area and porosity are central determinants of biochar performance in adsorption, soil remediation, and environmental catalysis. Across feedstocks, pyrolysis temperature strongly influences pore evolution, but biomass composition sets the structural "starting point" for how pores are generated and stabilized during devolatilization and secondary carbonization [1], [4]. The composition of lignin, cellulose, hemicellulose, ash, and extractives affects char yield, volatile release, aromatic condensation, and mineral templating, thereby shaping BET surface area and pore network development [5], [6]. This mini review synthesizes evidence thematically, emphasizing how biomass class controls surface area development and how these trends translate into pollutant adsorption relevance.

RESEARCH METHODOLOGY. This mini-review systematically synthesizes both recent and foundational literature addressing the relationships between biomass composition, pyrolysis behavior, and the development of biochar porosity. Emphasis was placed on studies that explicitly correlate precursor characteristics—such as lignocellulosic composition, ash content, mineral matter, and structural morphology—with BET-derived parameters, including specific surface area, total pore volume, and pore size distribution [1], [3], [7].

The analysis was organized comparatively by biomass category rather than by individual study, enabling the identification of consistent trends across major feedstock groups. Particular attention was given to biomass types widely investigated for adsorption applications, including woody materials, agricultural residues, leaf-derived biomass, and non-lignocellulosic precursors such as algae and sludge [8], [10]. Reported BET surface area values are presented as representative ranges and are included only when supported by multiple literature sources to ensure reliability. Where possible, observed porosity trends were interpreted in the context of the thermal decomposition behavior of cellulose, hemicellulose, and lignin, as well as the catalytic and inhibitory effects of ash and mineral constituents on pore development during carbonization [4], [5]. In addition, the analysis considers the implications of BET-derived structural properties for adsorption performance, particularly in the removal of heavy metals and dyes, as these applications are strongly governed by surface area and pore accessibility [9].

DISCUSSION AND RESULTS.

Biomass Composition and Its Role

Biochar precursors differ in the relative abundance of lignin, polysaccharides, minerals, and tissue-bound inorganic matter. Lignin-rich

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biomass generally favors char formation because aromatic crosslinking and thermal recalcitrance promote solid residue retention [5], [7]. By contrast, cellulose and hemicellulose contribute more readily to volatile release and pore-opening through depolymerization, fragmentation, and secondary condensation processes [6], [7]. Mineral-rich feedstocks, especially rice straw and other silicaceous residues, may show elevated ash and distinctive pore development but can also experience pore blockage or reduced accessible carbon fraction [2], [8].

Machine-learning analyses of multi-feedstock datasets identify ash and pyrolysis temperature as major predictors of specific surface area, underscoring that mineral content is not merely a passive impurity but a compositional variable that materially influences porosity development [9], [10]. Functional-group retention and aromaticity also change with temperature and precursor composition, affecting both surface chemistry and accessible surface area [3].

Mechanisms of Surface Area Development

Surface area development in biochar proceeds through several coupled mechanisms. First, devolatilization removes labile components and creates incipient voids; this is most pronounced in the 350–550 °C range, where pore formation often accelerates [4], [1]. Second, aromatic condensation and secondary char-forming reactions stabilize the carbon matrix, preventing structural collapse and preserving micropores [5]. Third, inorganic constituents may catalyze cracking, alter mass-transfer behavior, or template microstructural rearrangement, but excessive ash can also fill pores and reduce accessible surface [11], [9].

Component interactions are important. Lignin tends to enhance char formation, while cellulose can promote micropore generation when blended with lignin-rich matrices; however, the balance is feedstock dependent [7], [12]. Hemicellulose decomposition contributes early volatiles and can intensify pore initiation, though its higher reactivity may also increase structural fragility if carbonization is not sufficiently advanced [6], [13]. At higher temperatures, surface functional groups decline while aromatic ordering increases, often raising surface area but lowering oxygenated functionality [3].

Table 1.

Influence of biomass type on biochar surface area development

Biomass class	Dominant compositional features	Typical BET surface area trend*	Key implications for pore development	Notes on adsorption relevance

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Woody biomass	High lignin, relatively low ash, dense cellular structure	Commonly high; often tens to several hundred m^2/g, with activated materials higher [1], [2]	Lignin-rich matrix supports char yield and pore preservation; favorable for hierarchical pore formation [5], [14]	Strong baseline for metal and dye adsorption due to accessible carbon surface and tunable functionality
Agricul-tural residues	Variable cellulose/hemicellulose; often higher ash/silica in cereals	Broad range; ~100–400 m^2/g reported for straw-derived chars under optimized pyrolysis [15], [8]	Pore development can be strong but is strongly modulated by mineral content and temperature; silica may raise recalcitrance yet limit access [2]	Effective for wastewater treatment; performance depends on ash, pore size, and surface chemistry

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Leaves / foliage	Intermediate lignin, lower density, species-specific ash and extractives	Usually moderate; often lower than wood but can be enhanced by pyrolysis/activation [16], [1]	Thin tissues may generate porous structures, but higher mineral or wax content can affect pore continuity	Suitable for adsorption where low-cost feedstocks are prioritized; leaf species selection is decisive
Algae / sludge	High ash, proteins, lipids, inorganic salts; non-lignocellulosic	Generally lower unless activated; often tens of m^2/g to low hundreds depending on pretreatment	Mineral-rich matrices can inhibit accessible surface development; activation frequently required	Adsorption possible, but performance is often dictated by surface chemistry more than intrinsic BET area

*Ranges are approximate and synthesis-based; exact values vary strongly with pyrolysis temperature, residence time, and activation strategy [1], [10].

Woody feedstocks consistently emerge as superior precursors for high-surface-area biochars because their lignin-rich structure promotes char retention and graphitized aromatic condensation [1], [2]. Agricultural residues, especially straw and husk materials, can also yield large surface areas, but their performance is more composition-sensitive due to silica, potassium, and other ash-forming components [15], [8]. Leaf-derived biomasses are less uniform: their thin laminae and biochemistry can favor rapid devolatilization and pore opening, yet higher extractive and ash fractions may limit final BET area compared with woody substrates [16]. In this context, *Platanus orientalis* leaves are of particular interest because foliage-based biochars from broadleaf species may offer useful adsorption surfaces, but the available literature remains less extensive than for straw or wood, warranting cautious interpretation.

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Algae- and sludge-derived biochars generally show weaker intrinsic surface-area development because their matrices are dominated by salts, proteins, lipids, and ash-forming inorganic matter rather than lignocellulose [1], [9]. Consequently, these materials often require activation or blending to achieve competitive adsorption surfaces.

The compositional hierarchy of surface area development can be summarized as lignin-rich woody biomass > compositionally optimized agricultural residues > leaves/foliage biomass > algae or sludge, though substantial overlap exists. This ordering is not absolute: rice straw and wheat straw can reach very high surface areas when pore opening is maximized under appropriate thermal regimes [15], while woody chars may show only moderate values if temperatures are too low or volatile release is incomplete [2]. The strongest predictor remains pyrolysis temperature, yet feedstock composition determines whether that temperature produces microporosity, pore collapse, or ash blockage [1], [10].

The adsorption relevance is clear. Higher BET surface area and hierarchical pores generally improve uptake of dyes and heavy metals by increasing the number of accessible sites and facilitating diffusion into the carbon matrix [1]. However, adsorption is not governed by area alone: oxygenated functional groups, ash-derived mineral sites, and graphitic domains contribute to electrostatic attraction, complexation, and π–π interactions. For metal ions, oxygen-containing surface groups and mineral phases can be particularly important; for dyes, accessible microporosity and aromatic surfaces are critical. This explains why some lignin-enriched chars or cellulose-modified chars show strong adsorption even when surface area is not maximal [12], [17]. Leaf-derived biochars, including those from *Platanus orientalis*, may therefore be promising when both porosity and surface chemistry are optimized, even if their BET values are not exceptional.

CONCLUSION. Biomass composition is a primary determinant of biochar surface area development. Lignin promotes char yield and structural retention; cellulose and hemicellulose facilitate volatile-driven pore formation; and ash/minerals can either catalyze or constrain porosity depending on abundance and speciation [5], [1]. Woody biomass generally offers the most favorable route to high-BET biochars, agricultural residues can deliver very high surface areas under optimized conditions, leaves are compositionally variable and underexplored, and algae or sludge usually require activation to attain comparable porosity. Future studies should better resolve species-specific foliage precursors, including *Platanus orientalis*, and couple compositional analysis with adsorption testing to align surface area development with pollutant-removal function.

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