Debunking Biochar Myths | Volume 3

Examining Chemical Properties

BIOCHAR TODAY

Examining Biochar’s Chemical Properties

The third installment of our "Debunking Biochar Myths" series examines biochar's often-oversimplified chemical properties. Broad generalizations, such as the widespread presumption that all biochars are chemically identical inert carbon residues with predictable behavior, significantly impede accurate understanding and effective application.

This volume systematically dismantles these pervasive myths by rigorously examining the underlying scientific realities pertaining to the chemical properties of biochar. Common myths about biochar’s chemistry are readily grouped into four key themes revealing the complexity of biochar's chemical composition and reactivity:

- **Formation & Basic Composition:** Challenges the idea that biochar is a simple, uniform carbon structure, regardless of its origin, debunking myths about its identical nature, simple burning process, complete organic matter conversion, and fixed porosity.
- **Reactivity & Surface Properties:** Address assumptions about biochar's interactive capabilities, dissecting myths about uniform reactivity, consistent surface hydrophobicity/hydrophilicity, and its surface charge.
- **Elemental Behavior & Mineral Matter:** Clarifies the role of non-carbon components, debunking myths regarding proportional element retention, always low ash content, and sulfur availability.
- **Production Method & Environmental Influences:** Explores how manufacturing and external conditions dictate biochar's chemical makeup, challenging misconceptions about temperature's sole influence, yield maximization, heating rates, identical production methods, and uniform environmental behavior.

Ultimately, understanding this inherent chemical variability—shaped by feedstock and thermal degradation—is essential for selecting and effectively using biochar, thereby maximizing its intended benefits and unlocking its full potential. It represents an indispensable step toward advanced knowledge and optimized biochar utilization.

Shanthi Prabha, PhD
Science Editor, Biochar Today

EXAMINING CHEMICAL PROPERTIES

All biochars are chemically identical, regardless of how they're made

Biochars exhibit a vast range in composition and chemistry. This is due to the diverse biological feedstocks and the complex thermal degradation conditions (like temperature, heating rate, and gas environment) used in their production.

Tomczyk et al., 2020

DEBUNKING BIOCHAR MYTHS

High temperatures always maximize biochar yield

Biochar production decreases significantly at High Heat Treatment Temperatures (HTTs) between 300°C and 600°C due to the increasing importance of liquid- and tar-forming pathways. Above 600°C, a gas-forming pathway dominates, further minimizing biochar yield.

Osman et al., 2023

EXAMINING CHEMICAL PROPERTIES

Biochar is just charred wood; its formation is a simple burning process

Biochar formation involves intricate parallel pathways including biochar- and gas-forming, liquid- and tar-forming, and gasification and carbonization. These pathways are driven by free-radical processes and complex chemical reactions, not just simple combustion.

Amalina et al., 2022

DEBUNKING BIOCHAR MYTHS

Biochar's chemical properties are solely determined by the final pyrolysis temperature

While overall pyrolysis temperature is vital, biochar's chemical properties are also shaped by the distinct decomposition temperatures of its components—hemicellulose (200–350∘C), cellulose (305–375∘C), and lignin (250–500∘C). This differential degradation means biochar's final chemical nature reflects a complex interplay of these specific breakdown processes, not just a single, uniform temperature effect.

Amalina et al., 2022

EXAMINING CHEMICAL PROPERTIES

Biochar is a uniform, amorphous carbon structure

Biochars, especially those produced at higher HTTs, consist primarily of an intimate mixture of two solid carbon phases: amorphous carbon and polyaromatic graphene packets, which evolve and coalesce during the carbonization process.

Pusceddu et al., 2019

DEBUNKING BIOCHAR MYTHS

All the original organic matter in feedstock is converted into biochar

A significant fraction of the initial carbonaceous material is released as oily and tarry vapours during thermal degradation. At lower HTTs (below 500°C), some of these vapours condense in the biochar pores, but the majority are recovered as bio-oil.

Rambhatla et al., 2025

EXAMINING CHEMICAL PROPERTIES

All biochars are equally reactive and universally suitable for thermochemical applications

Biochar's reactivity is highly variable, decreasing with higher production temperatures due to fewer functional groups and a lower H/C ratio. This temperature-dependent change in chemical properties means not all biochars are equally reactive or beneficial for specific thermochemical conversions.

Singh Yadav et al., 2023

DEBUNKING BIOCHAR MYTHS

All elements in the feedstock are retained in the biochar proportionally

During thermal degradation, elements like oxygen and hydrogen are lost in proportionally greater amounts than carbon. Highly mobile ions like potassium and chlorine can also vaporize at relatively low temperatures.

Osman, Zhang, et al., 2023

EXAMINING CHEMICAL PROPERTIES

Biochar always has a low ash content

Biochar ash content varies significantly depending on the feedstock. While woody feedstocks generally have low ash, materials like rice husk can have as much as 24wt% ash, and chicken-litter biochars can have up to 45% mineral matter.

de Oliveira Paiva et al., 2024

DEBUNKING BIOCHAR MYTHS

The only carbon in biochar is in the solid carbon matrix

Biochar can contain residual bio-oils on its surface, which are composed of various organic molecules, including N-heterocyclics, substituted furans, phenols, benzenes, carbocyclics, and aliphatics.

Buss et al., 2015

EXAMINING CHEMICAL PROPERTIES

Biochar surfaces are uniformly hydrophobic or hydrophilic

Biochar surfaces exhibit a rich and varied chemistry, displaying both hydrophilic and hydrophobic properties. The relative contributions depend on the feedstock and the thermal degradation process used.

Yaashikaa et al., 2020

DEBUNKING BIOCHAR MYTHS

Biochar's surface chemistry is mainly set by its carbon functional groups

In high-mineral ash biochars, some functional groups can contain metals. Additionally, the surfaces of entrained mineral phases contribute to the overall surface chemistry with their own distinct properties.

Kercher et al., 2003

EXAMINING CHEMICAL PROPERTIES

All nitrogen in biochar is in the same chemical form

Nitrogen functional groups in biochar vary with temperature. At lower temperatures, pyrrolic or pyridinic amines are common, while at higher temperatures, pyridinic and quaternary groups become more prevalent.

Ojewumi et al., 2024

DEBUNKING BIOCHAR MYTHS

All sulfur in biochar is readily available for biological processes

Not all biochars release sulfur equally. Biochar made via pyrolysis (500–600 °C) has more readily available sulfate for plants, while biochar from gasification (850 °C) has more sulfur tied up in organosulfur forms, which are less immediately available. This means the method of biochar production significantly impacts how well it can provide sulfur as a nutrient.

Cheah et al., 2014

EXAMINING CHEMICAL PROPERTIES

Biochar's surface charge is constant regardless of the surrounding environment

The surface charge of mineral phases in biochar can vary with solution pH. Amphoteric sites on oxide surfaces become positively charged under acidic conditions and negatively charged under alkaline conditions.

Ambaye et al., 2021

DEBUNKING BIOCHAR MYTHS

Only electrostatic forces govern how metals sorb onto biochar

While electrostatic forces play a role in metal sorption onto biochar, they are not the sole governing factor. Transition metals with exposed π-orbitals can also interact with the π electrons within the biochar's graphene structure, alongside electrostatic interactions at oxidized surface sites.

Ambaye et al., 2021

EXAMINING CHEMICAL PROPERTIES

Organic molecules sorb equally well to all biochar surfaces

Many organic sorbates, particularly amphoteric ones like phenols and anilines, exhibit optimal sorption at solution pH values near their points of zero charge, highlighting the influence of surface properties and solution chemistry.

Kah et al., 2017

DEBUNKING BIOCHAR MYTHS

Hydrothermal conversion produces biochar identical to pyrolysis

Hydrothermal conversion, occurring immersed in water at lower temperatures and autogenous pressure, aims to fix the entire carbon into a solid phase. Unlike pyrolysis, it yields essentially no liquid or tar when completed and the final solid is hydrophilic.

Ojewumi & Chen, 2024

EXAMINING CHEMICAL PROPERTIES

Biochar porosity is fixed during initial formation

While very high temperatures (much higher than typical soil conditions) can lead to graphitization of biochar carbon, under normal environmental conditions, biochar remains largely non-graphitic, retaining its unique properties over extended periods.

Sohtun et al., 2025

DEBUNKING BIOCHAR MYTHS

Biochar is a simple, uniform material with predictable chemical properties

Biochar presents a unique mixture of phases and micro-environments. Its chemical complexity rivals that of incipient soils, leading to a unique set of chemical properties for each feedstock and process combination.

James E. Amonette, 2012

EXAMINING CHEMICAL PROPERTIES

The only significant volatile products during biochar formation are water and carbon dioxide

While water and carbon dioxide are released, lignocellulose degradation also yields hydrocarbons, tarry vapours, carbon monoxide, and hydrogen, particularly at higher temperatures.

Greco et al., 2021

DEBUNKING BIOCHAR MYTHS

Biochar's carbon structure is fully graphitic

While graphene sheets nucleate and grow during carbonization, some models include non-graphitic rings interspersed in the nominally graphene sheets (e.g., 70% aromaticity rather than 100%), and larger multi-ring voids.

Kercher & Nagle, 2003

EXAMINING CHEMICAL PROPERTIES

Fast heating rates always produce more biochar

Faster heating rates can lead to transitions between carbon degradation regions occurring at higher temperatures due to heat- and mass-transfer limitations, which can reduce biochar yields by favoring volatilization.

Demirbas, 2004

DEBUNKING BIOCHAR MYTHS

All biochars have uniform properties and behave identically when applied to soil

Biochars are inherently complex and heterogeneous. Their properties, including the varying proportions of mineral phases, amorphous carbon, graphitic carbon, and labile organic molecules, are highly dependent on both the original feedstock and the pyrolysis conditions used during their production. This means their chemical behavior, such as acting as electron donors or acceptors in soil, is not universal but specific to how they were made.

Gul et al., 2024

EXAMINING CHEMICAL PROPERTIES

Higher pyrolysis temperatures always result in a more chemically reactive biochar

While high-temperature biochar (600–700 ∘C) has well-organized carbon, it loses critical H- and O-containing functional groups, which actually lowers its ion exchange capacity and chemical reactivity. Lower temperature biochar (300–400 ∘C) retains more diverse functional groups, making it potentially more chemically active in soil

Tomczyk et al., 2020

REFERENCES

Amalina, F., Razak, A. S. A., Krishnan, S., Sulaiman, H., Zularisam, A. W., & Nasrullah, M. (2022). Biochar production techniques utilizing biomass waste-derived materials and environmental applications – A review. Journal of Hazardous Materials Advances, 7(June), 100134. https://doi.org/10.1016/j.hazadv.2022.100134

Amalina, F., Syukor Abd Razak, A., Krishnan, S., Sulaiman, H., Zularisam, A. W., & Nasrullah, M. (2022). Advanced techniques in the production of biochar from lignocellulosic biomass and environmental applications. Cleaner Materials, 6. https://doi.org/10.1016/j.clema.2022.100137

Ambaye, T. G., Vaccari, M., van Hullebusch, E. D., Amrane, A., & Rtimi, S. (2021). Mechanisms and adsorption capacities of biochar for the removal of organic and inorganic pollutants from industrial wastewater. International Journal of Environmental Science and Technology, 18(10), 3273–3294. https://doi.org/10.1007/s13762-020-03060-w

Buss, W., Mašek, O., Graham, M., & Wüst, D. (2015). Inherent organic compounds in biochar-Their content, composition and potential toxic effects. Journal of Environmental Management, 156, 150–157. https://doi.org/10.1016/j.jenvman.2015.03.035

Cheah, S., Malone, S. C., & Feik, C. J. (2014). Speciation of sulfur in biochar produced from pyrolysis and gasification of oak and corn stover. Environmental Science and Technology, 48(15), 8474–8480. https://doi.org/10.1021/es500073r

de Oliveira Paiva, I., de Morais, E. G., Jindo, K., & Silva, C. A. (2024). Biochar N Content, Pools and Aromaticity as Affected by Feedstock and Pyrolysis Temperature. Waste and Biomass Valorization, 15(6), 3599–3619. https://doi.org/10.1007/s12649-023-02415-x

Demirbas, A. (2004). Effects of temperature and particle size on bio-char yield from pyrolysis of agricultural residues. Journal of Analytical and Applied Pyrolysis, 72(2), 243–248. https://doi.org/10.1016/j.jaap.2004.07.003

Greco, G., Videgain, M., Di Stasi, C., Pires, E., & Manyà, J. J. (2021). Importance of pyrolysis temperature and pres
sure in the concentration of polycyclic aromatic hydrocarbons in wood waste-derived biochars. Journal of Analytical and Applied Pyrolysis, 159. https://doi.org/10.1016/j.jaap.2021.105337

Gul, S., Wahid, M. A., Hashem, A., Fathi, E., Allah, A., & Ibrar, D. (2024). Biochar Production and Characteristics, Its Impacts on Soil Health, Crop Production, and Yield Enhancement: A Review. Plants, 1–18.

James E. Amonette, S. J. (2012). Characteristics of biochar: microchemical properties. In Biochar for environmental management. In Biochar for Environmental Management (pp. 65–84). Routledge,. https://doi.org/10.4324/9781849770552

Kah, M., Sigmund, G., Xiao, F., & Hofmann, T. (2017). Sorption of ionizable and ionic organic compounds to biochar, activated carbon and other carbonaceous materials. Water Research, 124, 673–692. https://doi.org/10.1016/j.watres.2017.07.070

Kercher, A. K., & Nagle, D. C. (2003). Microstructural evolution during charcoal carbonization by X-ray diffraction analysis. Carbon, 41(1), 15–27. https://doi.org/10.1016/S0008-6223(02)00261-0

Ojewumi, M. E., & Chen, G. (2024). Hydrochar Production by Hydrothermal Carbonization: Microwave versus Supercritical Water Treatment. Biomass (Switzerland), 4(2), 574–598. https://doi.org/10.3390/biomass4020031

Osman, A. I., Lai, Z. Y., Farghali, M., Yiin, C. L., Elgarahy, A. M., Hammad, A., Ihara, I., Al-Fatesh, A. S., Rooney, D. W., & Yap, P. S. (2023). Optimizing biomass pathways to bioenergy and biochar application in electricity generation, biodiesel production, and biohydrogen production. In Environmental Chemistry Letters (Vol. 21, Issue 5). Springer International Publishing. https://doi.org/10.1007/s10311-023-01613-2

Osman, A. I., Zhang, Y., Lai, Z. Y., Rashwan, A. K., Farghali, M., Ahmed, A. A., Liu, Y., Fang, B., Chen, Z., Al-Fatesh, A., Rooney, D. W., Yiin, C. L., & Yap, P. S. (2023). Machine learning and computational chemistry to improve biochar fertilizers: a review. In Environmental Chemistry Letters (Vol. 21, Issue 6). Springer International Publishing. https://doi.org/10.1007/s10311-023-01631-0

Pusceddu, E., Santilli, S. F., Fioravanti, G., Montanaro, A., Miglietta, F., & Foscolo, P. U. (2019). Chemical-physical analysis and exfoliation of biochar-carbon matter: From agriculture soil improver to starting material for advanced nanotechnologies. Materials Research Express, 6(11). https://doi.org/10.1088/2053-1591/ab4ba8

Rambhatla, N., Panicker, T. F., Mishra, R. K., Manjeshwar, S. K., & Sharma, A. (2025a). Biomass p
yrolysis for biochar production: Study of kinetics parameters and effect of temperature on biochar yield and its physicochemical properties. Results in Engineering, 25(December 2024), 103679. https://doi.org/10.1016/j.rineng.2024.103679

Rambhatla, N., Panicker, T. F., Mishra, R. K., Manjeshwar, S. K., & Sharma, A. (2025b). Biomass pyrolysis for biochar production: Study of kinetics parameters and effect of temperature on biochar yield and its physicochemical properties. Results in Engineering, 25(November 2024), 103679. https://doi.org/10.1016/j.rineng.2024.103679

Singh Yadav, S. P., Bhandari, S., Bhatta, D., Poudel, A., Bhattarai, S., Yadav, P., Ghimire, N., Paudel, P., Paudel, P., Shrestha, J., & Oli, B. (2023). Biochar application: A sustainable approach to improve soil health. Journal of Agriculture and Food Research, 11(December 2022), 100498. https://doi.org/10.1016/j.jafr.2023.100498

REFERENCES (CONT.)

Sohtun, P., Deb, D., Bora, N., Goswami, R., Choudhury, P. K., Boddula, R., Sarangi, P. K., Kataki, R., & Kurniawan, T. A. (2025). Agriculture biomass-derived carbon materials for their application in sustainable energy storage. In Carbon Letters (Vol. 35, Issue 2). Springer Nature Singapore. https://doi.org/10.1007/s42823-025-00884-9

Tomczyk, A., Sokołowska, Z., & Boguta, P. (2020). Biochar physicochemical properties: pyrolysis temperature and feedstock kind effects. Reviews in Environmental Science and Biotechnology, 19(1), 191–215. https://doi.org/10.1007/s11157-020-09523-3

Yaashikaa, P. R., Kumar, P. S., Varjani, S., & Saravanan, A. (2020). A critical review on the biochar production techniques, characterization, stability and applications for circular bioeconomy. Biotechnology Reports, 28, e00570. https://doi.org/10.1016/j.btre.2020.e00570

BIOCHAR TODAY

Biochar Today
biochartoday.com

© 2025 Felice Mosca, LLC