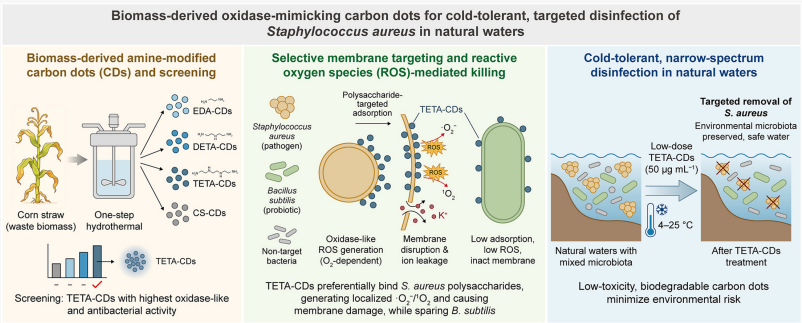
Turning crop waste into precision weapons against waterborne pathogens

GA, UNITED STATES, January 7, 2026 /EINPresswire.com/ -- Antimicrobial resistance and ecological disruption caused by broad-spectrum disinfectants have created an urgent need for precision strategies that remove harmful bacteria without damaging beneficial microbial communities. This study presents a biomass-derived nanomaterial capable of selectively eliminating Staphylococcus aureus, a widespread and resilient pathogen in aquatic environments. By converting agricultural waste into amine-modified carbon dots with intrinsic oxidase-like activity, the research demonstrates a targeted disinfection approach that operates efficiently across a wide temperature range, including cold conditions. The nanomaterials preferentially bind to pathogen-specific cell wall components, triggering localized oxidative stress and membrane damage while sparing non-target and probiotic bacteria. This work offers a sustainable and environmentally compatible alternative to conventional disinfectants.



Biomass-derived carbon dots enable cold-tolerant, selective disinfection of Staphylococcus aureus in water.

Staphylococcus aureus is a persistent pathogen found in diverse water environments, including freshwater, wastewater, and even cold natural waters, where it poses ongoing public health risks. Conventional disinfectants and antibiotics often lack selectivity, leading to ecological harm, microbial imbalance, and the acceleration of antimicrobial resistance. Many existing antibacterial strategies are also temperature-sensitive or environmentally persistent, limiting their real-world applicability. Meanwhile, large quantities of agricultural biomass waste remain underutilized, despite their potential as sustainable material sources. Based on these challenges, there is a strong need to develop environmentally friendly, low-cost, and species-specific disinfection technologies capable of operating effectively under diverse environmental conditions.

Researchers from the Harbin Institute of Technology reported on December 24, 2025, in Environmental Science and Ecotechnology the development of a novel class of biomass-derived carbon dots that selectively eradicate Staphylococcus aureus in water. Using corn straw as a raw material, the team synthesized amine-modified nanomaterials that act as oxidase mimics,

enabling targeted bacterial inactivation without harming beneficial microorganisms. The study demonstrates effective disinfection at low doses and across temperatures ranging from near-freezing to physiological conditions, highlighting strong potential for real-world water treatment applications.

The researchers synthesized a series of amine-modified carbon dots using a one-step hydrothermal process, introducing different amine chain lengths to tune antibacterial performance. Among them, triethylenetetramine-modified carbon dots exhibited the strongest and most selective activity. At low concentrations, these nanomaterials achieved near-complete inactivation of Staphylococcus aureus within one hour, while showing negligible toxicity toward probiotic bacteria such as Bacillus subtilis and common Gram-negative species.

Mechanistic investigations revealed that selectivity arises from preferential binding between the carbon dots and polysaccharide components on the pathogen's cell wall. This targeted adsorption enabled localized production of reactive oxygen species, primarily superoxide radicals and singlet oxygen, leading to membrane disruption, potassium ion leakage, and irreversible metabolic damage. Importantly, these effects were highly localized, preventing collateral damage to surrounding microbial communities.

The antibacterial activity remained robust at temperatures as low as 4 °C, addressing a major limitation of many existing disinfection methods. Additional tests in real water matrices—including tap water, river water, and wastewater effluent—confirmed sustained performance and long-term stability. Environmental safety assessments further showed low cytotoxicity toward mammalian cells and rapid photodegradability, supporting the ecological compatibility of the approach.

"This work demonstrates how material design can fundamentally change the way we think about disinfection," said the study's corresponding author. "By leveraging biomass waste and molecular-level selectivity, we can eliminate harmful bacteria without disturbing beneficial microorganisms or introducing persistent pollutants. The ability to function at low temperatures and in complex water environments makes this strategy particularly relevant for real-world applications, especially in cold regions and decentralized water systems."

The findings point to a new generation of precision disinfectants that combine sustainability, safety, and effectiveness. By transforming agricultural waste into functional nanomaterials, the approach supports circular economy principles while addressing critical public health challenges. Potential applications include drinking water treatment, wastewater management, and ecological water restoration, particularly in cold or seasonally variable climates. Unlike conventional broad-spectrum agents, these selective nanomaterials help preserve microbial balance, reducing ecological disruption and resistance risks. With further development, such materials could be integrated into filtration membranes or continuous-flow treatment systems, offering scalable and environmentally responsible solutions for pathogen control in water infrastructures worldwide.

References
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