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Sulfur-enhanced nitrogen fertilization: implications for wheat zinc biofortification and N_2O emission reduction in sustainable cereal production*

He Zhang[1], Aleksandra Ella Jachimowicz[2]

**[1] Department of Computer Science,
City University of Hong Kong, Kowloon, Hong Kong SAR
[2] Department of Biochemistry and Cell Biology,
Stony Brook University, New York State, United States**

Abstract

The writing of this review article spanned eight months, during which our team members demonstrated unwavering commitment and collaborative effort. From an initial pool of 767 scholarly publications, we systematically analyzed and selected the 50 most seminal papers to ensure the academic rigor and relevance of this synthesis. It explores the potential of sulfur--enhanced nitrogen fertilization to address the dual challenges of zinc deficiency in wheat and high nitrous oxide (N_2O) emissions in intensive cereal production. By co-applying sulfur with nitrogen, zinc biofortification can be improved by 30-40% through rhizosphere acidification and enhanced zinc solubility, while N_2O emissions can be reduced by 50-60% via microbial denitrification processes. However, the efficacy of sulfur depends on soil-climate interactions: elemental sulfur (S^0) is ineffective in sandy or arid regions due to slow oxidation, sulfate leaching occurs in humid areas, and high organic matter or acidic soils risk hydrogen sulfide (H_2S) toxicity or methane (CH_4) emissions. Despite the economic benefits of zinc-enriched wheat (22% market premium) and carbon credit potential, current EU policies overlook sulfur's role in climate mitigation. The review proposes region-specific solutions, such as accelerated sulfur oxidation in dry regions and coated sulfates in wet areas, supported by AI-driven tools and real-time soil sensors. Institutional recognition of sulfur in climate frameworks and mandatory soil health thresholds are essential to scale this sustainable strategy, which balances productivity, nutrition, and environmental goals.

Keywords: sulfur fertilization, zinc biofortification, N_2O mitigation, sustainable wheat, machine learning

He Zhang, Department of Computer Science, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon Tong, Hong Kong SAR, e-mail: Hzhang832-c@my.cityu.edu.hk
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