Contribution ID: **22** Type: **not specified**

Multi-Omics Insights into the Anti-Mycotoxigenic Activity of Citrus aurantium Extract Against Aspergillus niger in Stored Cereals

Thursday, 12 March 2026 10:40 (20 minutes)

Mycotoxin contamination of cereals represents a major challenge for food safety and public health. Ochratoxin A (OTA), produced by toxigenic fungi such as Aspergillus niger, is a nephrotoxic and carcinogenic compound frequently detected in stored grains. Understanding how natural bioactive compounds influence fungal metabolism and the cereal-associated microbiome is essential for developing sustainable mitigation strategies.

This study investigates the anti-mycotoxigenic potential of hydroethanolic extract from Citrus aurantium (bitter orange) and explores its molecular mechanisms using a multi-omics framework integrating metabolite profiling and gene expression analysis.

Phytochemical composition of the citrus extract was characterized using UPLC-PDA metabolomic profiling. Antifungal and anti-mycotoxigenic effects were evaluated in vitro against OTA-producing A. niger, assessing fungal growth, sporulation, and OTA production. Transcriptomic responses were examined by RT-qPCR targeting otaA, the polyketide synthase gene initiating OTA biosynthesis. The protective potential of the extract was further evaluated in situ on artificially inoculated durum wheat grains during storage.

The extract displayed a distinctive metabolite profile rich in ferulic acid, luteolin glycosides, and ellagic acid. Significant dose-dependent inhibition of fungal growth and sporulation was observed, accompanied by strong suppression of OTA production. Molecular analysis revealed marked downregulation of otaA, suggesting disruption of the fungal secondary metabolism regulatory network. When applied to wheat grains, the extract significantly reduced fungal colonization and OTA accumulation without altering key grain quality parameters.

By linking metabolomic signatures with transcriptional responses in fungal toxin pathways, this study highlights how citrus-derived bioactive compounds can modulate microbial metabolism within food-associated ecosystems. The results support the valorization of citrus by-products as sustainable bio-solutions to control mycotoxin-producing fungi and improve food safety within the food–environment–health nexus.

Keywords: Multi-omics; Citrus aurantium; Ochratoxin A; Fungal metabolism; Food microbiome

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Session Classification: Microbiome & Multi Omics in Health, Food

Track Classification: General sessions: Microbiome & Multi Omics in Health, Food & Environment