AI-based soft sensor for real-time assessment of CO_2 and mycotoxins in hazelnut storage

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Hazelnuts are a globally significant crop: their nutritional value and widespread use in confectionery products have driven increasing demand. However, hazelnuts are highly susceptible to fungal contamination during storage, particularly by mycotoxigenic fungi such as *Aspergillus*, *Penicillium*, and *Fusarium* species. These fungi can produce harmful mycotoxins—especially aflatoxins—under specific environmental conditions (i.e. temperature and humidity). These compounds pose serious health risks and can lead to economic losses due to product rejection or recalls.

Mycotoxin contamination is difficult to detect and even harder to eliminate, as these compounds are heat-stable and persist through processing. Traditional analytical methods for detecting mycotoxins (TLC, LC-MS and HPLC) are time-consuming, costly, and often inadequate for a real-time monitoring.

Recent studies have identified a correlation between CO_2 production and fungal activity, suggesting that measuring CO_2 levels during storage could serve as an early indicator of mycotoxin synthesis. This insight paves the way for innovative, non-invasive monitoring solutions to enhance food safety and quality control in the hazelnut supply chain.

The proposed system integrates environmental data and storage parameters to estimate the evolution of carbon dioxide levels and the potential presence of mycotoxins without requiring direct chemical analysis. By leveraging machine learning algorithms (mainly based on ARX model) trained on experimental data, the soft sensor provides accurate and continuous estimations that support early detection of quality degradation and enhance decision-making in post-harvest management.

This non-invasive approach reduces the need for costly and time-consuming laboratory tests, enabling more sustainable and scalable quality control in the hazelnut supply chain. The results demonstrate that the soft sensor achieves high predictive performance under various storage conditions, offering a promising tool for industrial implementation. In particular, few tests are needed for model calibration, that can be successfully used to predict the evolution of CO_2 production during storage, as well as the total mycotoxins produced.

Keywords: *Hazelnut storage, Mycotoxins, Fungal contamination, CO_2 monitoring, Soft sensor / Artificial intelligence.*