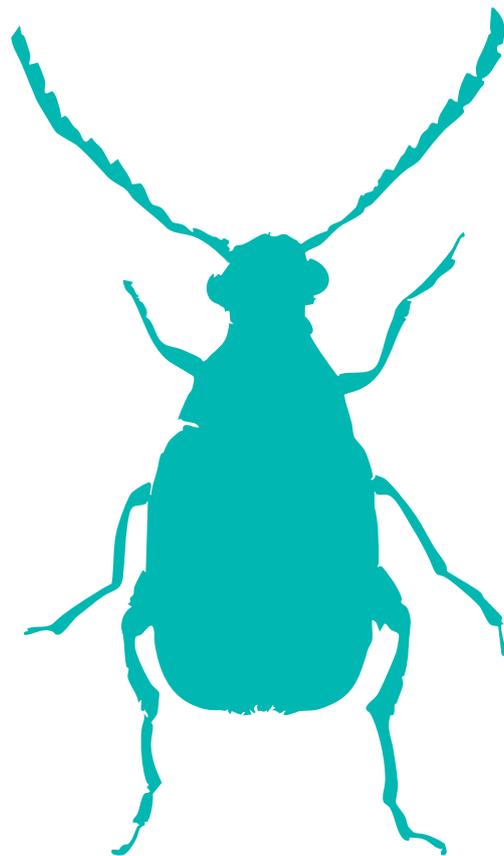# VOC anomaly detection
for stored-commodity pest

Executive summary

Stored commodities are delivered via long, often complex supply chains through which inspection capacity may be limited. Pest infestation could remain undetected until significant damage has already been inflicted. This paper outlines a fast, non-destructive screening method based on the analysis of the volatile organic compounds (VOCs) headspace of a sealed unit capable of robust detection of ongoing insect infestation regardless of intruding species and particular commodity. The detection relies on monitoring VOCs signatures obtained by temperature-modulated metal oxide (MOX) sensor with the model being trained on an uninfested commodity headspace allowing for detection and flagging anomalies possibly indicating ongoing infestation.

Operational challenge

Global trade volumes continue to rise, with greater connectivity, longer routes and increasing speed of transport. This ongoing development, however, could elevate the susceptibility to rapid spread of pests or pathogens present within consignments. Furthermore, climate change alters geographic ranges and life cycles of pests, expanding the spectrum of possible infestations. Infestation by stored-product's insect pests is known to significantly reduce yield and grade of stored commodities, and can create microenvironments that promote further degradation by moulds leading to mycotoxin contamination.

The core component of primary preventive measures in infestation management is effective inspection. However, in the context of the aforementioned factors there are increasing concerns that traditional inspection methods are becoming increasingly insufficient. Only a small fraction of containers, lots, or silo ports can be opened; uniform sampling disperses limited effort.
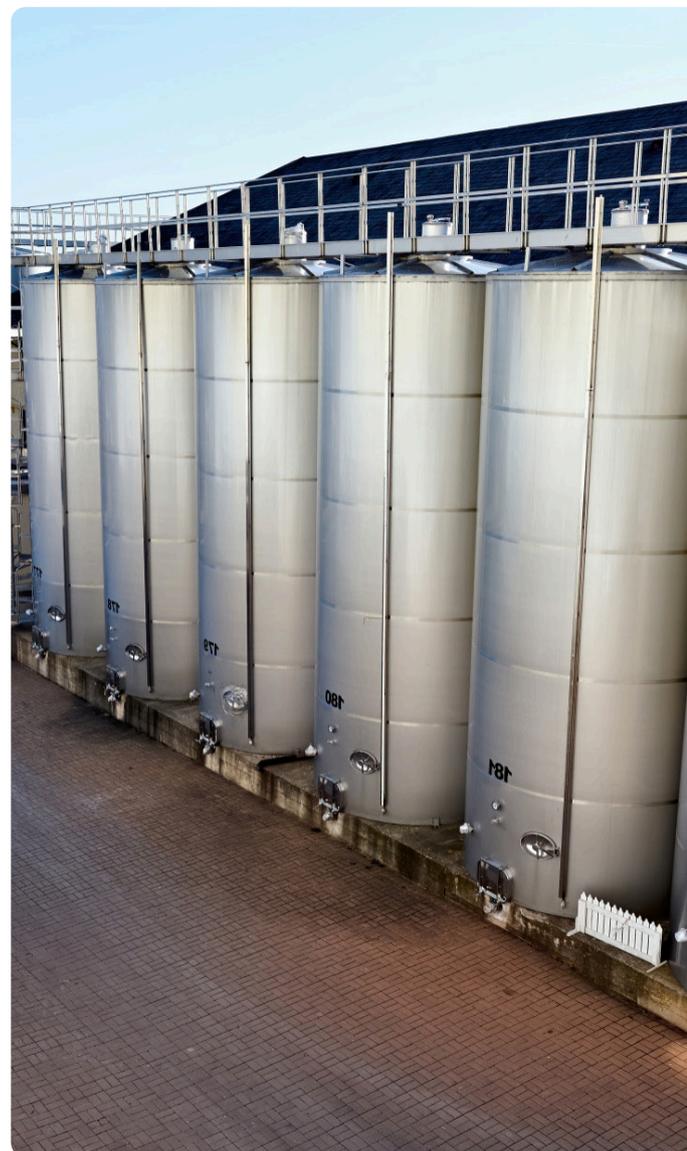
Approach overview

Limited throughput of currently-used approaches could be significantly augmented by adapting a risk-based, effort allocation framework based on an informative, scalable, pre-opening indicator that prioritizes inspections. The operational requirement is a rapid, species-agnostic, commodity-agnostic screening step that tolerates site and device variation and scales to high-throughput logistics. VOC headspace analysis addresses this requirement: commodity in which an ongoing dynamic biological activity exhibits altered volatile signatures, whereas uninfested product maintains a relatively stable profile. Relative to temperature or bulk CO_2 alone, VOCs provide greater discriminatory power without laboratory processing. Relative to specialized approaches such as bioacoustics or airborne eDNA, it offers a more favorable balance of diagnostic value, speed, and field practicality for large-scale triage.

Detection workflow

A short, temperature-modulated MOX sensing routine samples the headspace inside a sealed vessel that contains the commodity. Repeated cycles produce stable patterns that are compared to a learned description of a headspace from uninfested storage. The output is an anomaly score summarized to a single decision for the session. No laboratory processing or invasive sampling is required, and operator training needs are minimal. The procedure could readily be integrated into established workflows at ports, silos, and warehouses and run in parallel with existing inspection protocols. Real-time results appear on a dashboard with scores, trends, and site-level alerts.
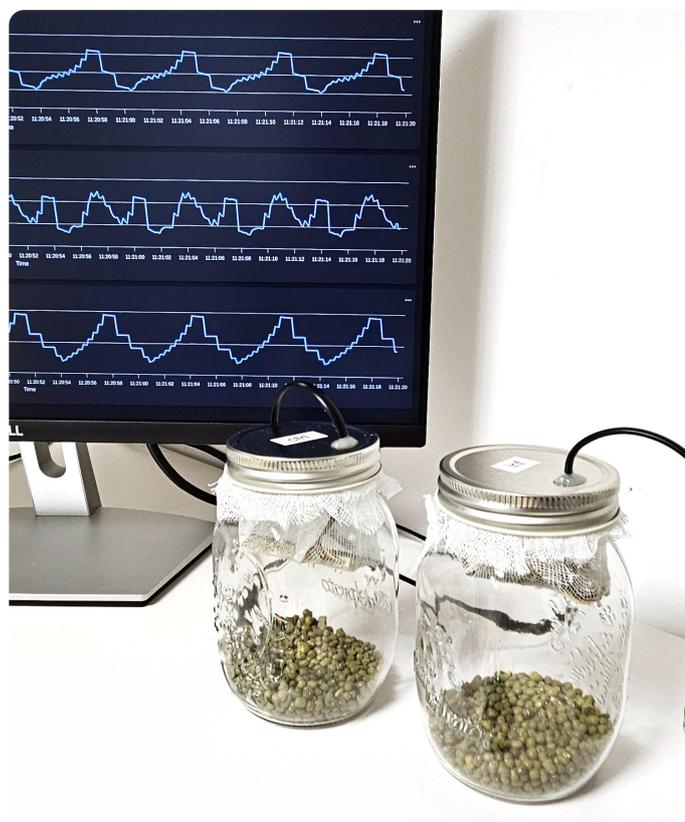
Evidence base

Our findings draw on two experimental series covering both cereals and legumes. A preliminary 43-day run on mung beans examined infestation by Callosobruchus maculatus, providing a full life-cycle view and a clear contrast between infested and uninfested headspace. The main study used oat flakes and included Tenebrio molitor and Tribolium castaneum at larval and adult (imago) stages, with an additional set of dead T. molitor to test persistence of the signal after activity ceased. Sessions were replicated across three MOX units, with environmental air serving as a negative control. Across these commodities and species, the approach consistently separated stable headspace from biologically active headspace, indicating strong potential for operational triage. Performance was consistent across three devices of the same design; device-to-device differences were modest compared with environmental effects.

Conclusion

VOC headspace anomaly screening delivers immediate gains by directing inspections to the highest-risk units. The approach can be seamlessly integrated into existing regimes at ports, silos, and warehouses, providing real-time scores and clear dashboard visibility while aligning thresholds with available capacity. This enables more effective allocation of resources and better protection of product quality and biosecurity across the chain. Because the model learns the profile of clean commodity and flags departures, independent of species or commodity, MOX-based VOC detection offers unique scalability: short sessions, straightforward operation, and consistent decisioning suitable for high-throughput logistics.