DOI 10.5162/EUROSENSORS2025/M2.3.4

3D-Printed µ-GC Integrated with an E-Nose System for Enhanced Plant Health Prediction

Usman Yaqoob[1], Dylan Limbani[1], Siavash Esfahani[1], Marina Cole[1], Julian W. Gardner[1]
[1] School of Engineering, University of Warwick, Coventry CV4 7AL, UK
J.W.Gardner@warwick.ac.uk

Summary:
This work integrates a low-cost 3D-printed µ-GC with an e-nose system for improved plant health prediction. Metal oxide sensors are placed before and after the µ-GC column and show that ethanol elutes first, followed by trans-2-hexenal with a 1 s and linalool with a 2.5 s delays; demonstrating the column's ability to separate out these pest plant biomarkers. Features are extracted from the sensor time-dependent responses and analysed using partial least squares (PLS) method. They accurately predict the VOC type and concentration. This simple e-nose system may offer a cost-effective solution for real-time plant health monitoring with enhanced prediction capabilities of harmful pests.

Keywords: plant health, micro gas chromatography, VOCs, metal oxide sensors, 3D printing

Background, Motivation and Objective

Several crop plants, including maize (*Zea mays*), release volatile organic compounds (VOCs) such as ethanol, trans-2-hexenal, and linalool in response to herbivore attacks from pests like the fall armyworm (FAW), brown marmorated stink bug (BMSB), and European corn borer (ECB). Ethanol emissions in maize occur due to tissue damage and stress, while trans-2-hexenal, produced by wounded leaves, serves both defensive and communicative roles. Linalool, emitted by plants like *Nicotiana attenuata*, attracts natural predators of herbivorous insects, thereby enhancing indirect defense [1, 2]. VOCs released after pest attacks often form complex mixtures, making it crucial to separate and detect them accurately using systems like e-noses to assess plant health.

Conventional gas chromatography (GC) is accurate and versatile for analyzing complex mixtures, but its high cost, bulk, and power consumption make it impractical for practical field applications. Recent efforts have focused on fabricating µ-GCs on Si substrates using a Lift-off process, which offers precise control over column dimensions for efficient separation. However, this microsystem approach is costly and time-consuming for low-volume applications. In contrast, we use a low-cost 3D printer (Elegoo Mars 4 Ultra) to quickly create micro-channels in plastic resin, providing a faster and more affordable solution. Our apporach is to integrate a low-cost 3D-printed µ-GC column with simple metal oxide gas sensors to seperate and detect different concentrations of three componds including ethanol, trans-2-hexenal, and linalool.

Design, Fabrication and Methodology

Fig. 1 illustrates the overall setup (MOX-µGC-MOX), which includes two sensor chambers containing metal oxide sensors, a sealed µ-GC column, and a microcontroller (Arduino Feather TFT: ESP32-S3). In this configuration, target VOCs flow through the first chamber A, then the µ-GC column, and finally the second chamber B, while the microcontroller monitors the sensor resistances over time. (Nb: an SMR sensor is included by reported elsewhere).

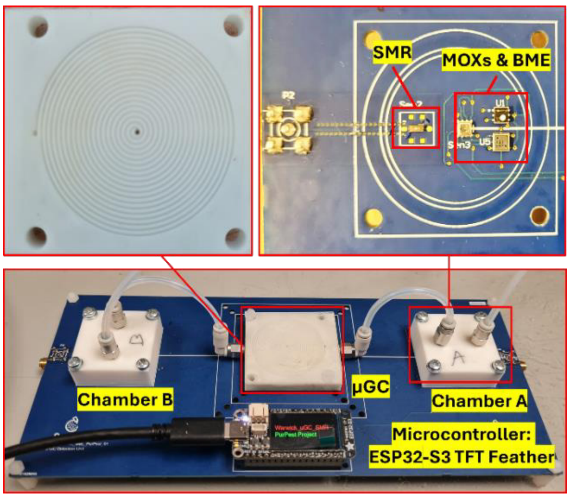

Fig. 1. µ-GC based e-nose. Top shows µ-GC column, commercial MOX gas sensor and Bosch BME280 for ambient temperature and RH.

The µ-GC column was printed using commercial Composite-X UV resin, with overall dimensions

DOI 10.5162/EUROSENSORS2025/M2.3.4

of 40mm × 40mm × 5mm (length, width, and height). The channel measures ca. 1.2 m in length, 0.5 mm in width, and 0.4 mm in depth. The channel was then coated with OV-1 stationary phase (SP). To ensure a uniform SP coating, the column was first functionalized with Polymethylhydrosiloxane (PMHS) and dried at 200°C, followed by the injection of the prepared OV-1 solution. Finally, the column was sealed using UV resin spun coated on the 1.0 mm thick polyethylene terephthalate glycol (PETG) sheet.

Results and Discussions

The MOX-µGC-MOX system was tested with three compounds: ethanol, trans-2-hexenal, and linalool, each at two different concentrations. Due to space constraints, this abstract presents results for one concentration of each VOC, both before and after the µ-GC column. As a proof of concept, two sets of data were collected for each VOC and its concentration, which were used to train and test a partial least squares (PLS) model to predict the VOC class and concentration.

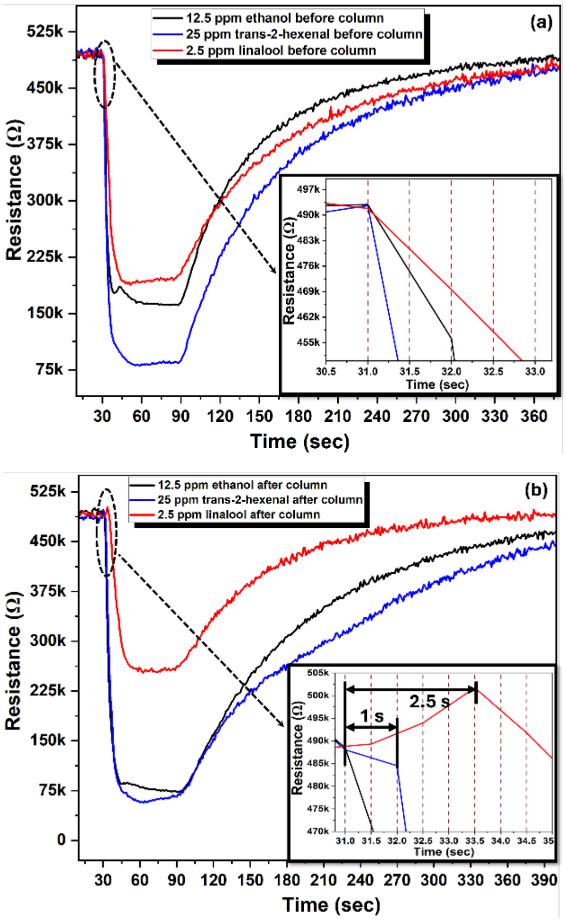

Fig. 2. MOX sensors response, (a) before µ-GC, and (b) after µ-GC.

Fig. 2(a) shows the response of MOX sensor (before column) for all three VOCs, with an inset displaying a magnified view of the initial response curve of MOX to each VOC. The results demonstrate that MOX responds to all three VOCs simultaneously, but with varying curve slopes depending on the concentration and molecular properties of the compound.

Fig. 2(b) presents the response of MOX sensor (after column) response, revealing delays of 1 s and 2.5 s for trans-2-hexenal and linalool, respectively, compared to ethanol (see inset in Fig. 2(b)). These delays were expected due to the differences in molecular size, with lighter molecules eluting first.

Finally, features were extracted from the time-dependent sensor responses (e.g. change in resistance, response time) and used to train and test a PLS model for the prediction of VOC class and concentration levels. Fig. 3 shows confusion matrix for the trained model showed 100% accuracy in predicting unknown ethanol, trans-2-hexenal, and linalool concentrations. Further investigations are needed to control more accurately the inlet velocities of the target VOCs and life of the columns.

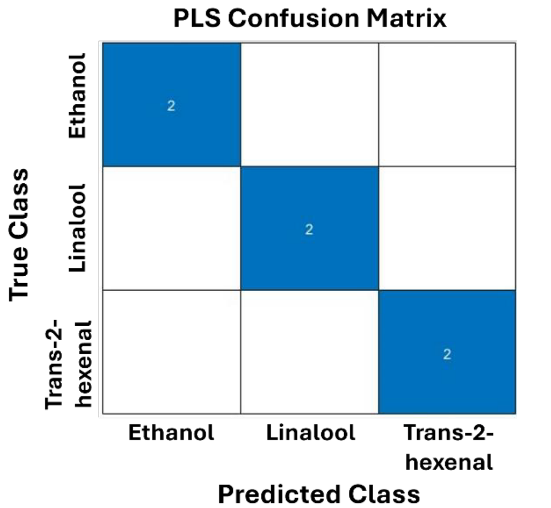

Fig. 3. Confusion matrix for trained PLS model.

References

[1] J.H. Christensen, M V. Kolomiets, The lipid signaling and volatile oxylipin pathways are integrated in maize. Plant, Cell & Environment, 34(10), 1630-1641 (2011). https://doi.org/10.1111/j.1365-3040.2011.02356.x

[2] A. Kessler, I.T. Baldwin, Defensive function of herbivore-induced plant volatile emissions in nature. Science, 291, 2141–2144 (2001). https://doi.org/10.1126/science.1057083.

Acknowledgements

This work is supported by the project “PurPest under Horizon Europe Program (grant #101060634), the Horizon Research and Innovation Action from European Research Executive Agency.