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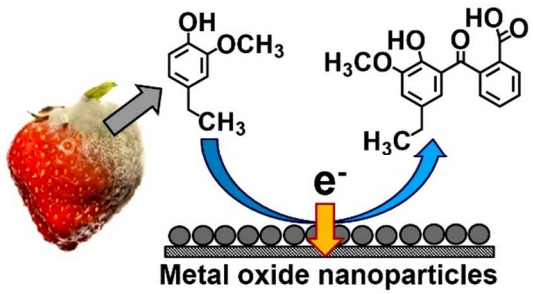
**Table of Content Figure**




High sensitive detection of *p*-ethylguaiacol at low concentrations using $SnO_2$ and $TiO_2$ metal oxide nanoparticles.

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ARTICLE TYPE

# Electrochemical detection of *p*-ethylguaiacol, a fungi infected fruit volatile using metal oxide nanoparticles

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Nanoparticles of $TiO_2$ or $SnO_2$ on screen printed carbon electrode (SP) have been developed for evaluating their potential application in electrochemical sensing of fruits and plants volatiles. These metal oxide nanoparticle modified electrodes possess high sensitivity and low detection limit for the detection of *p*-ethylguaiacol, a fingerprint compound present in the volatile signature of fruits and plants infected with a pathogenic fungus *Phytophthora cactorum*. The electroanalytical data obtained using cyclic voltammetry and differential pulse voltammetry showed that both $SnO_2$ and $TiO_2$ exhibited high sensitivity (174 to 188 for μm $cm^{-2}$) and low limit of detection limits (35 to 62 nM) for *p*-ethylguaiacol detection. The amperometric detection was highly repeatable with RSD values ranging from 2.48 to 4.85%. The interference studies show that the other common plant volatiles do not interfere in the amperometric detection signal of *p*-ethylguaiacol. The results demonstrate that metal oxides are reasonable alternative to expensive electrode materials such as gold or platinum for amperometric sensor applications.

**Keywords:** *Phytophthora cactorum*, *p*-ethylguaiacol, tin oxide, titanium oxide, plant volatile sensor.

## 1. Introduction

The leather rot also called crown rot, is a plant disease caused by a pathogenic fungus *Phytophthora cactorum* which is known to infect a variety of cucurbit crops in southeastern United States.[1] As high as 50% of the 1.3 million tons of strawberries produced in the U.S. are affected by this disease and cause massive agro-economical loss every year.[2] There is an ever-increasing need for advanced detection and prevention of this disease to improve agricultural productivity. Plants produce unique volatile signature when infected by pathogens.[3,4] Detecting these volatiles could help confirm the occurrence or existence of pathogen infection in agricultural crops. Attempts have been made previously to develop electronic nose for plant volatile profiling.[5] Unlike GC-MS or GC/FID, which involves time consuming multiple stages of expert analysis, electronic nose refers to sensor arrays capable of reproducing human senses and pattern recognition systems. Since 1982 electronic noses have evolved to a practical device which could detect and recognize odors and flavors.[6] Since its development, electronic noses have been applied to different areas from poultry, environment protection, food safety and medical care. It has been applied also for organic volatile compounds study.[7-9] The distinctive symptom of leather rot in strawberries is the unpleasant odor produced by volatile compounds. One such symbolic volatile compound produced during *P. cactorum* infection is *p*-ethylguaiacol.[1] Therefore detecting the production of *p*-ethylguaiacol by strawberry plants will be a useful indicator for the confirmation of the leather rot disease. However in order to detect at an early stage, the detection technology must be able to detect the compound at ultra-low concentrations. A variety of methods have been established for *p*-ethylguaiacol detection over the years, including gas chromatography-mass spectroscopy (GC-MS), headspace-solid-phase microextraction-gas chromatography and HPLC-DAD-Fluorescence.[10-13] However, all these methods require detailed sampling and cannot be used for real-time or non-destructive analysis.

Electrochemical sensing is a popular technology for non-destructive, real time detection of target analytes. Amperometric electrochemical sensors possess high sensitivity, high accuracy, high selectivity (when modified with a biomarker), enable rapid detection and are suitable for field application.[14] Although enzymatic biosensors usually demonstrate high selectivity, non-enzymatic biosensors have also been developed and demonstrated before.[15,16] We have previously demonstrated selective amperometric detection of plant volatile compounds on electroactive gold transducers.[17,18] As conceptually shown in Figure 1, the *p*-ethylguaiacol can be detected on the working electrode in an electrochemical cell based on the electrical signal generated during the oxidation of *p*-ethylguaiacol on the surface of the electrode. The working electrode surface is modified with specific functional element that also acts as transducer transmitting the electrical signal from the surface. While gold

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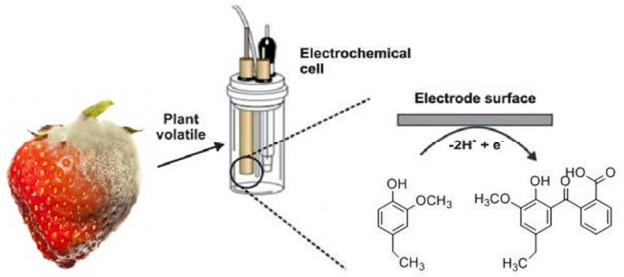


**Fig. 1** Schematic of the electrochemical cell containing metal oxide modified electrode for the detection of *p*-ethylguaiacol which was released from *Phytophthora cactorum* infection.

nanoparticles and carbon nanotubes have been widely explored as electrochemical transducers for amperometric sensors, metal oxides have not been explored in great detail for this application. The rationale for adopting metal oxide nanoparticles in this work was due to their advantages compared to commonly used nanomaterials. The advantages are (1) metal oxide nanoparticles are catalyst for the dehydrogenation of alcoholic compounds such as aliphatic alcohols, acetic acid etc., which could enhance the plant volatile reaction on the transducer,[19] (2) metal oxides are inexpensive compared to noble metal nanoparticles,[20] (3) some metal oxides have large band gap (greater than 3.3 eV) which can enable them for amperometric signal generation in aqueous solution, (4) the preparation method for obtaining required size and shape of these nanoparticles are easier compared to other nanostructure synthesis. In this work, we used two metal oxides – $SnO_2$ and $TiO_2$ as electrochemical detection elements for amperometric sensing. Screen-printed carbon (SP) electrodes were modified with nanoparticles of $SnO_2$ or $TiO_2$ and used for the electrochemcial detection of *p*-ethylguaiacol in simulated fruit volatile samples.

## 2. Experimental

### 2.1. Materials

Tin (IV) oxide (<100 nm) and titanium (IV) oxide (~21 nm) nanoparticles obtained from Sigma-Aldrich were used for preparing nanoparticle suspensions. *p*-ethylguaiacol from Frinton Laboratories, Inc., (New Jersey, US) was used as received. *p*-ethylphenol was purchased from Sigma-Aldrich and used for interference and synthetic real sample studies. *cis*-3-hexenol, hexyl acetate, *cis*-hexen-1-yl acetate, 1-octen-3-ol and 3-octanone obtained from TCI America (Portland, OR) were used as received. All other chemicals used were of analytical grade. All aqueous solutions were prepared using 18.2 MΩ nanopure de-ionized (DI) water. 0.1M electrolyte solution of potassium hydrogen phthalate (KHP) (pH 4) was prepared for all the experiments. Solutions were deoxygenated by purging with pre-purified nitrogen gas for 15 min before each electrochemical measurement.

### 2.2. Apparatus

Cyclic voltammetry and differential pulse voltammetry were performed using CHI model 920c potentiostat. For electrochemical measurements a conventional three-electrode cell assembly consisting of a 3M Ag/AgCl reference electrode and a

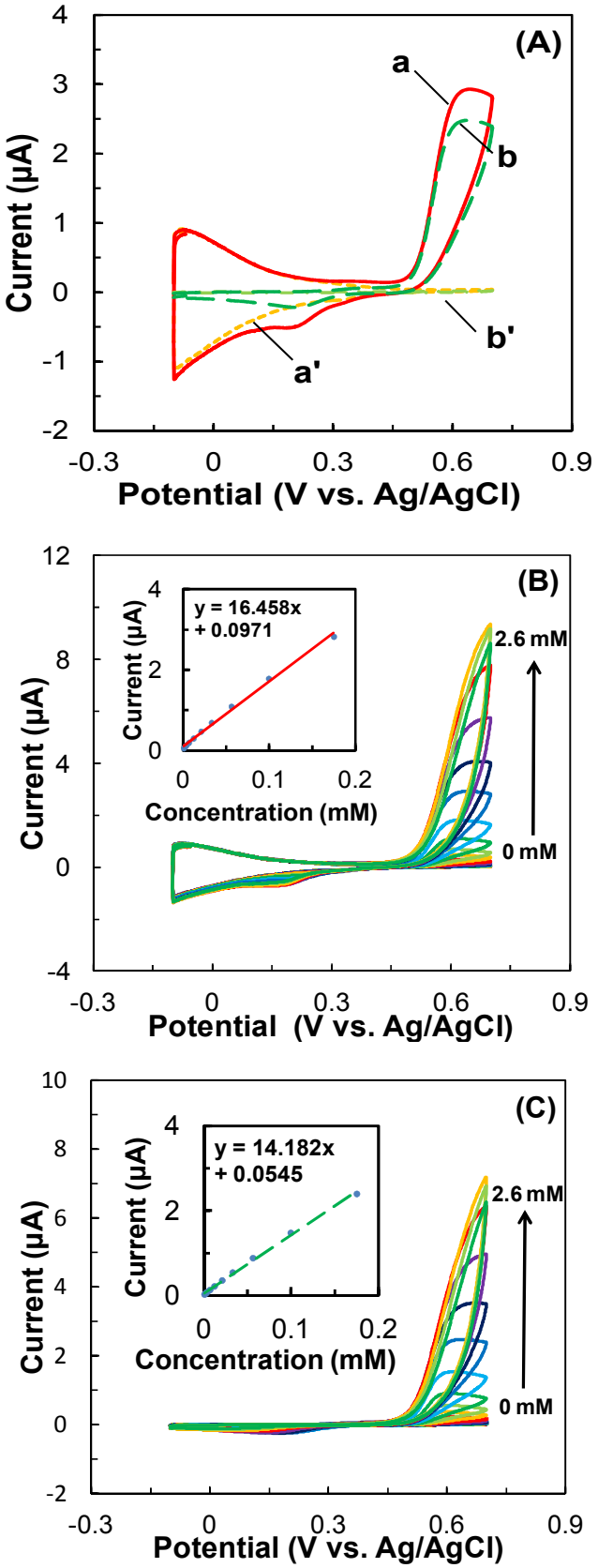


**Fig. 2** CV responses of $SnO_2$-SP (a and a') and $TiO_2$-SP (b and b') with (a and b) and without (a' and b') the presence of 0.17 mM *p*-ethylguaiacol (A); Concentration effect of *p*-ethylguaiacol at $SnO_2$-SP (B) and $TiO_2$-SP (C) electrodes.

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**Table 1** Comparison of sensitivity, linear range, LOD and LOQ of *p*-ethylguaiacol at different electrodes obtained using different electrochemical techniques.

| Electrode | pH | Technique | *E*Pa (V) | Linear range ($R^2$) | Sensitivity ($\mu A\ cm^{-2}\ mM^{-1}$) | LOD(nM) | LOQ(nM) |
|---|---|---|---|---|---|---|---|
| $SnO_2$-SP | 4 | CV | 0.62 | 0.6μM-0.17mM (0.9954) | 232 | 82 | 249 |
| | | DPV | 0.54 | 0.2 μM-0.1mM (0.9932) | 174 | 62 | 188 |
| $TiO_2$-SP | 4 | CV | 0.62 | 0.6 μM-0.17mM (0.9972) | 200 | 126 | 382 |
| | | DPV | 0.54 | 0.2 μM-0.1mM (0.9934) | 188 | 35 | 106 |

Pt wire counter electrode was used for electrochemical measurements. All potentials are reported with respect to 3M Ag/AgCl reference electrode. The working electrode was a screen-printed carbon electrode (SP) modified either with $SnO_2$ nanoparticles or $TiO_2$ nanoparticles. All experiments were carried out at 25 $^oC \pm 2$.

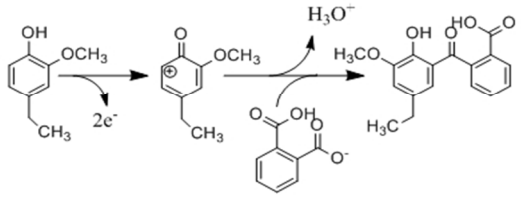
### 2.3. Electrode preparation

$SnO_2$ and $TiO_2$ nanoparticle suspensions were prepared by ultrasonication of 1 mg of the respective nanoparticles in 1 mL DI water. The $SnO_2$ and $TiO_2$ nanoparticle modified SP electrodes were prepared by drop casting 18 µL (in three steps of 6 µL additions) of the nanoparticle suspension on the SP, followed by drying at 70° C. The cyclic voltammogram (CV) and differential pulse voltammogram (DPV) studies were done in a 10 mL voltammetry cell containing $N_2$ saturated 0.1M potassium hydrogen phthalate (KHP) electrolyte for $SnO_2$ as well as $TiO_2$. The potential range scanned for CV studies were for metal oxide modified SP electrodes at the scan rate of 0.02 $Vs^{-1}$. For DPV the potential scanned was from -0.1 to 0.7 V with the increment of 0.004 V, amplitude 0.05 V, pulse width 0.2 s and pulse period 0.5 s for all electrodes.

## 3. Results and discussion

### 3.1. Electrochemical response of *p*-ethylguaiacol on metal oxide modified SPs

The metal oxide modified electrodes were characterized using cyclic voltammetry in the presence and absence of *p*-ethylguaiacol. Although acidic conditions favor *p*-ethylguaiacol oxidation as found in our experiments (data not shown), a pH 4 KHP electrolyte was used in our studies to avoid reaction between metal oxides and electrolyte. The cyclic voltammograms of $SnO_2$ and $TiO_2$ modified electrodes in the presence and absence of *p*-ethylguaiacol are shown in Figure 2a and the results († supplementary data Fig. S1a) demonstrate the better sensitivity of *p*-ethylguaiacol detection by metal oxide nanoparticle modified electrodes when compared with unmodified screen printed (SP) carbon electrode. In the absence of *p*-ethylguaiacol, $TiO_2$ showed no redox activity, and $SnO_2$ exhibited broad redox peaks in the potential window of -0.1 to 0.4 V, which correspond to the adsorption and desorption of phthalate ions, a known behavior for $SnO_2$ in KHP electrolyte.[21,22] In the presence of *p*-ethylguaiacol, both metal oxides exhibited irreversible peaks at 0.62 V (oxidation) and at 0.2 V (reduction). The irreversible oxidation of *p*-ethylguaiacol at 0.62V, occurs as per equation 1, where *p*-ethylguaiacol forms phenoxy radical intermediate, which then reacts with phthalate anion in the electrolyte to form benzoic acid derivative and $H_3O^+$ (second step in equation 1).[23,24] The irreversible reduction peak in the cyclic voltammograms at 0.2 V could be due to the reduction of phenoxy radical to *p*-ethylguaiacol. The result suggests that at potentials below 0.2 V, the *p*-ethylguaiacol oxidation is reversible.




→ [1]

Comparison of *p*-ethylguaiacol oxidation peaks (at 0.62 V) shows both $SnO_2$ and $TiO_2$ possess similar oxidation currents. The effect of *p*-ethylguaiacol concentration on the oxidation currents was studied and reported in Figure 2b and c $SnO_2$ and $TiO_2$ respectively. The stepwise increase in *p*-ethylguaiacol concentration from 0.2 µM to 2.6 mM in the electrochemical cell was achieved by adding *p*-ethylguaiacol from the series of standard concentrations. The above concentration range was chosen by a series of experiments, where the lowest limit was determined based on the noticeable increase in oxidation current upon an incremental addition of *p*-ethylguaiacol into the electrolyte. Similarly, the upper concentration limit was chosen based on the rate of decrease in oxidation current during subsequent additions of *p*-ethylguaiacol. The cyclic voltammetry results in Figure 2b and c show that increasing concentration of *p*-ethylguaiacol increased the oxidation peak current ($I_{pa}$) of *p*-ethylguaiacol oxidation on both $SnO_2$ and $TiO_2$ electrodes. The initial response to *p*-ethylguaiacol additions showed a shift in the *p*-ethylguaiacol oxidation peak potential ($E_{pa}$) from 0.62 V to 0.7 V. This could be attributed to the increase in acidity of the electrolyte due to more $H_3O^+$ formation (refer equation 1).

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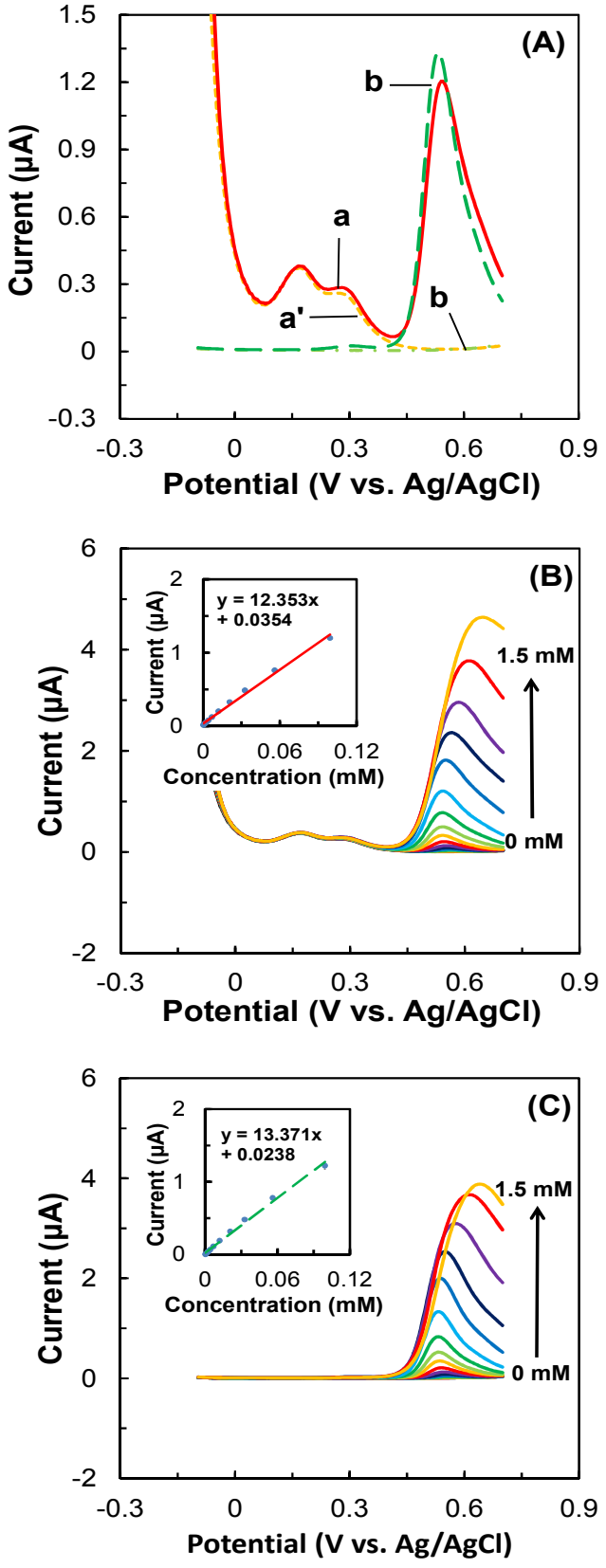


**Fig. 3** DPV responses of $SnO_2$-SP (a and a') and $TiO_2$-SP (b and b') with (a and b) and without (a' and b') the presence of 0.17 mM *p*-ethylguaiacol (A); Concentration effect of *p*-ethylguaiacol on $SnO_2$-SP (B) and $TiO_2$-SP (C) electrodes.

The electroanalytical data such as sensitivity, limit of detection (LOD) at the signal to noise ratio of 3, and limit of quantification (LOQ) of both $SnO_2$ and $TiO_2$ electrodes derived using equation 2, 3 and 4 and are listed in Table 1 respectively.

$$Sensitivity = \frac{Slope\ of\ calibration\ curve\ (A\ M^{-1})}{Area\ of\ electrode\ (cm^2)} \quad \rightarrow [2]$$

$$LOD = 3 \times \frac{Standard\ deviation\ of\ peak\ current\ in\ the\ absence\ of\ analyte}{Slope\ of\ linear\ calibration\ curve\ (A\ M^{-1})} \quad \rightarrow [3]$$

$$LOQ = 10 \times \frac{Standard\ deviation\ of\ peak\ current\ in\ the\ absence\ of\ analyte}{Slope\ of\ linear\ calibration\ curve\ (A\ M^{-1})} \quad \rightarrow [4]$$

Comparison of sensitivity values obtained through cyclic voltammogram given in Table 1 reveals that $SnO_2$ had higher sensitivity, lower LOD and LOQ than $TiO_2$ although the difference was not significant. Though CV provides a firsthand understanding of the electrochemistry of the system, biosensor applications demand chronoamperometric or pulse methods to eliminate the noise caused by the capacitance and resistance in order to improve overall electroanalytical measurement accuracy.[25]

Therefore, differential pulse voltammetry (DPV) was used in a similar manner to CV to study *p*-ethylguaiacol oxidation between -0.1 and 0.7 V. Compared to unmodified SP electrode, $TiO_2$ and $SnO_2$ modified electrodes display higher sensitivity for p-ethylguaiacol detection († supplementary data Fig. S1b). Similar to CV results, DPV also showed peaks in the absence of *p*-ethylguaiacol on $SnO_2$, due to the adsorption and desorption of phthalate ions. In the presence of *p*-ethylguaiacol, the oxidation peaks appeared at 0.54 V ($E_{pa}$) with similar $I_{pa}$ values for both the electrodes as shown in Figure 3a. The *p*-ethylguaiacol characteristic peaks for both $SnO_2$ and $TiO_2$ were similar to that of cyclic voltammograms with ~0.05 V negative shift due to the applied amplitude (0.05 V) during DPV measurements. The peaks currents ($I_{pa}$) for *p*-ethylguaiacol oxidation increased with the concentration in the range of 0.2 µM to 1.5 mM on both electrodes as shown in Figure 3b and c. The inset figures show a linear dependency of $I_{pa}$ on concentration. The empirical electroanalytical values derived from the DPV data are also given in Table 1. Due to the elimination of capacitance as well as adsorption-desorption effects in DPV († supplementary data Fig. S2), the values for DPV showed lower sensitivity, but better detection and quantification limits for both electrodes when compared to their corresponding CV values. However $TiO_2$ exhibited better sensitivity and detection limits than $SnO_2$ according to the DPV results, although the difference is not significant (Table 1). DPV values are better representative of the sensing characteristic of the electrodes due to the elimination of parasitic currents from the true oxidation response of *p*-ethylguaiacol. The results suggest that both $SnO_2$ and $TiO_2$ could be used to construct amperometric sensors for *p*-ethylguaiacol detection at concentrations relevant to typical infected fruit volatiles.

### 3.2. Reproducibility and re-usability studies

Eight $SnO_2$ and $TiO_2$ modified SP electrodes were prepared under similar conditions and tested for *p*-ethylguaiacol oxidation using DPV. The DPV peak currents ($I_{pa}$) at 0.54 V, for all eight electrodes were measured at concentration of 2.5 mM. The high

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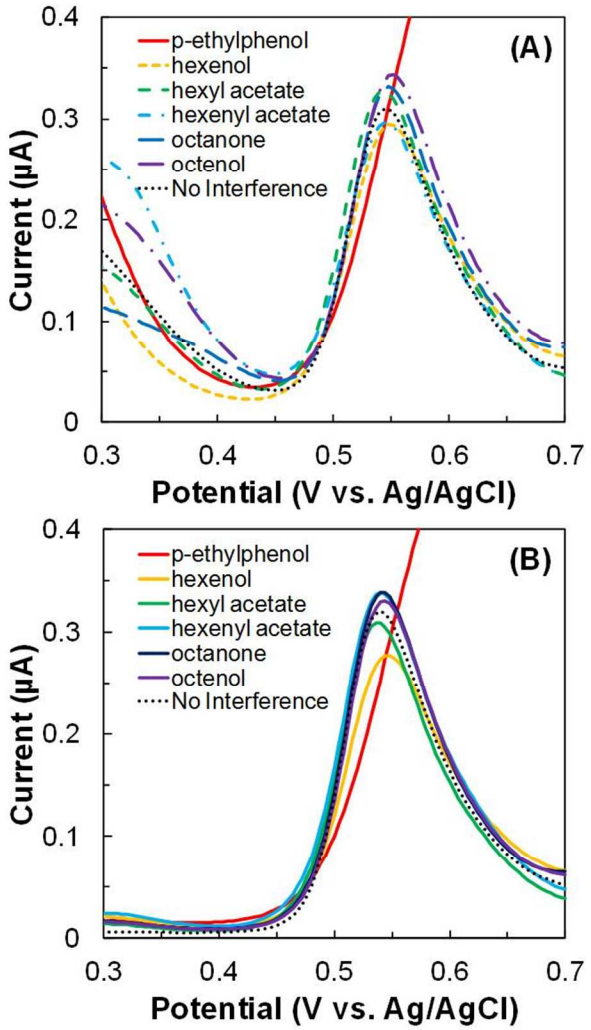


**Fig 4** Interference study of 20.8μM *p*-ethylguaicol with 6 different compounds *p*-ethylphenol, *cis*-3-hexen-1-ol, hexyl acetate and *cis*-3-hexen-1-yl acetate, 3-octanone and 1-octen-3-ol on $SnO_2$-SP (A) and $TiO_2$-SP (B) by DPV.

concentration was chosen to ensure that even subtle changes in measured currents can be determined. The results († supplementary data Table S1) showed that the peak current for all eight electrodes varied within 2.48 and 4.85 % for $SnO_2$ and $TiO_2$ respectively. The low variability indicates high reproducibility of the observed results for both electrodes.

The reusability or stability of $SnO_2$ and $TiO_2$ modified SP electrodes were tested in a series of DPV experiments at 2.5 mM *p*-ethylguaiacol concentration on consecutive days for a period of 15 days. $I_{pa}$ of *p*-ethylguaiacol oxidation in DPVs was measured on each day and percentage decrease in current decrease over time was calculated from the measurements († supplementary data Table S2). The results showed a loss of activity up to 67 % for $SnO_2$ and 81 % for $TiO_2$ after 15 days. Though the currents decreased significantly over time, the rate of decrease slowed down after the first two days with no large decrease beyond the first week. The loss in stability could be attributed to the formation of surface oxides and other adsorption effects from the ions present in the electrolyte that tend to slowly poison the electrode over the long-term.

### 3.3. Interference of other plant volatiles in *p*-ethylguaiacol determination

The infected plant volatile contains other chemical compounds that are non-specific to the infection and often released at much higher concentrations than *p*-ethylguaiacol. A representative set of such compounds was selected and their interference effects on *p*-ethylguaiacol measurements were studied using DPV. The compounds used to study interference were *p*-ethylphenol, 3-octanone, 1-octen-3-ol, *cis*-3-hexenol, hexyl acetate and *cis*-hexen-1-yl acetate. *p*-ethylphenol, 3-octanone and 1-octen-3-ol are present in the chemical signature of the *Phytophthora cactorum* itself.[1] The other three compounds *cis*-3-hexenol, hexyl acetate and *cis*-hexen-1-yl acetate are green leaf volatiles that are common to most plants.[18] The fungi infected plant typically release 0.2 μM of 3-octanone, 0.2μM of 1-octen-3-ol, 10μM of *cis*-3-hexenol, 1.2 μM of hexyl acetate and 20μM of *cis*-hexen-1-yl acetate.[18,26] Therefore these concentrations were used in our interference study. The experiments were conducted separately for each of the six interfering compounds where the *p*-ethylguaiacol concentration was kept constant and as low as possible (20.8 μM), but within the linear response ($I_{pa}$) region obtained in DPV. The results showed characteristic peaks for *p*-ethylguaiacol even in the presence of interfering compounds as shown in Figures 4a and b for $SnO_2$ and $TiO_2$ respectively. On both $SnO_2$ and $TiO_2$ electrodes, the addition of *p*-ethylphenol significantly changed the DPV wave above 0.55 V but not at the peak oxidation potential (0.54 V) of *p*-ethylguaiacol (Figure 4a and b). As shown by the calculated $I_{pa}$ values in Table 2, *p*-ethylphenol interference was limited to ± 6.7 % for $SnO_2$ and $TiO_2$ respectively. Addition of *cis*-hexen-1-yl acetate showed less than 2 % interference on *p*-ethylguaiacol signal on $TiO_2$, but up to 12 % interference on $SnO_2$. The reason for this difference is not clearly understood. Other compounds such as 3-octanone or 1-octen-3-ol or *cis*-3-hexenol or hexyl acetate did not show any significant interference on the *p*-ethylguaiacol signal and the interference was limited to less than 2 %. The studies above indicate *p*-ethylguaiacol detection on metal oxide modified electrodes does not suffer any significant interference from both fungal and green leaf volatile compounds.

### 3.4. *p*-ethylguaiacol determination in simulated fruit volatile

The ability of $SnO_2$ or $TiO_2$ for the determination of *p*-ethylguaiacol in real infected samples was evaluated using simulated chemical mixture that mimics the composition of the real fruit volatile signature. As discussed in the previous section, chemical signature from infected plants will contain both the green leaf volatiles and the volatiles from the pathogen itself. Two sets of samples were used for simulation: (i) only infected fruit volatiles and (ii) both infected fruit and green leaf plant volatiles. The composition of (i) was 20.8 mM *p*-ethylguaiacol, 2.5 mM *p*-ethylphenol, 2.5 μM 3-octanone and 2.5 μM 1-octen-3-ol. The composition of (ii) includes all (i) in addition to 10 μM *cis*-3-hexen-1-ol, 1.25 μM hexyl acetate and 25 μM *cis*-hexen-1-yl acetate. The above concentrations were chosen based on the composition of typical chemical signature of *Phytophthora cactorum* infection.[1,26] The experiments were done using DPV and the *p*-ethylguaiacol oxidation current was measured for detailed analysis. Parameters such as the concentrations added in

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**Table 2** Interference study of 20.8μM *p*-ethylguaicol with 6 different compounds *p*-ethylphenol, *cis*-3-hexen-1-ol, hexyl acetate and *cis*-3-hexen-1-yl acetate, 3-octanone and 1-octen-3-ol by DPV

| Electrode | Compound | Concentration | Current (uA) | Activity (%) |
|---|---|---|---|---|
| $SnO_2$-SP | *p*-ethylphenol | 0 | 0.3212 | 100 |
| | | 2.50mM | 0.3533 | 110.01 |
| | *cis*-3-hexen-1-ol | 0 | 0.2906 | 100 |
| | | 32μM | 0.2956 | 101.73 |
| | hexyl acetate | 0 | 0.3249 | 100 |
| | | 2μM | 0.3274 | 100.76 |
| | *cis*-3-hexen-1-yl acetate | 0 | 0.2672 | 100 |
| | | 32μM | 0.2972 | 111.21 |
| | 3-octanone | 0 | 0.3301 | 100 |
| | | 2μM | 0.3320 | 100.57 |
| | 1-octen-3-ol | 0 | 0.3381 | 100 |
| | | 2μM | 0.3436 | 101.62 |
| $TiO_2$-SP | *p*-ethylphenol | 0 | 0.3459 | 100 |
| | | 2.50mM | 0.3227 | 93.3 |
| | *cis*-3-hexen-1-ol | 0 | 0.2783 | 100 |
| | | 32μM | 0.2782 | 99.96 |
| | hexyl acetate | 0 | 0.3060 | 100 |
| | | 2μM | 0.3092 | 101.08 |
| | *cis*-3-hexen-1-yl acetate | 0 | 0.3336 | 100 |
| | | 32μM | 0.3400 | 101.91 |
| | 3-octanone | 0 | 0.3334 | 100 |
| | | 2μM | 0.3391 | 101.70 |
| | 1-octen-3-ol | 0 | 0.3278 | 100 |
| | | 2μM | 0.3308 | 100.90 |

**Table 3** Simulated sample study using typical chemicals released during *Phytophthora cactorum* infection of plants

| Electrode | Sample | Added (μA) | Found (μA) | Recovery (%) | RSD (%) |
|---|---|---|---|---|---|
| $SnO_2$-SP | Infected fruit | 0.0455 | 0.0417 | 91.65 | 3.65 |
| | | 0.1942 | 0.1947 | 100.26 | |
| | | 0.4816 | 0.4789 | 99.44 | |
| | | 1.5130 | 1.5110 | 99.87 | |
| | Infected fruit with plant | 0.0455 | 0.0495 | 108.79 | 3.88 |
| | | 0.1942 | 0.2011 | 103.55 | |
| | | 0.4816 | 0.4816 | 100.00 | |
| | | 1.5130 | 1.4890 | 98.41 | |
| $TiO_2$-SP | Infected fruit | 0.0421 | 0.0389 | 92.40 | 4.85 |
| | | 0.2218 | 0.2019 | 91.03 | |
| | | 0.5017 | 0.5021 | 100.08 | |
| | | 1.6210 | 1.6500 | 101.79 | |
| | Infected fruit with plant | 0.0421 | 0.0399 | 94.77 | 3.67 |
| | | 0.2218 | 0.2070 | 93.33 | |
| | | 0.5017 | 0.5067 | 101.00 | |
| | | 1.6210 | 1.6420 | 101.30 | |

the experiment, found and relative standard deviation (RSD) obtained from the experiments were calculated from the DPV measurements and are listed in Table 3. The values show that the recovery of *p*-ethylguaiacol in both simulated samples varied from 91 to 101% for both electrodes with RSD values between 4 and 5%. The analysis shows that both $SnO_2$ and $TiO_2$ electrodes can be used for *p*-ethylguaiacol determination.

## 4. Conclusions

Both $SnO_2$ and $TiO_2$ have been demonstrated to show similar detection capabilities for *p*-ethylguaiacol based on amperometric determination. Ultra low limits of detection were achieved by both metal oxide electrodes in DPV measurement. Both electrodes exhibited good reproducibility towards *p*-ethylguaiacol determination. The CV and DPV data along with the chemical reactions established here elucidate the electrochemical reaction mechanisms pertaining to the amperometric sensing of *p*-


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ethylguaiacol. The electroanalytical data presented in this article can be used for both qualitative and quantitative determination of *p*-ethylguaiacol. The synthetic sample studies presented in this work illustrate the approach for the development of *p*-ethylguaiacol sensing during initial stages of *Phytophthora cactorum* infection.

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## Notes and references

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