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Original article

The Role of E-nose and HIPVs in Modern Pest Detection and Management

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ABSTRACT

Pest infestations cause serious damage to crop production. To overcome this problem, plants have evolved several defense mechanisms in response to pest attack. Herbivore- induced plant volatiles (HIPVs) serve as indirect defenses which enhances natural enemies host searching ability. These volatile compound cues are harnessed by electronic-noses (e-noses) for early and non- invasive pest detections. E-noses are designed to mimic human olfactory sensory system and comes with arrays of sensors (such as metal oxide semiconductors, polymer-based sensors) and pattern recognition softwares (e.g., Artificial Neural Network (ANN), Cluster analysis (CA), Random Forest (RF) etc.) to classify pest-specific volatile organic compounds (VOCs). Several studies conducted have demonstrated the efficacy of e-nose in accurately detecting pests such as *Bactrocera dorsalis* (Hendel) in citrus, stink bugs in cotton, *Rhyzopertha dominica* (Fabricius) in stored wheat grains and whiteflies in tomatoes. However, the widespread use of e-noses are limited because of unidentified HIPVs, varying composition of VOCs due to environmental conditions and tissue dependency. Also, sensors performance is affected by several environmental conditions. Despite these limitations, e- noses provide precision pest management, thus, reducing the reliance on broad-spectrum insecticides and minimizing the post-harvest losses.

Keywords: Herbivore-Induced Plant Volatiles (HIPVs), Electronic-noses (e-noses), Volatile Organic Compounds (VOCs), Pest detection, Precision pest management

INTRODUCTION

Plants are continuously subjected to biotic and abiotic stresses with pest infestation being a major biotic factor for decreasing crop productivity. However, plants have developed several defense mechanisms in response to insect herbivores, classified as constitutive and induced resistance. Constitutive resistance comprises of plant defense mechanisms which are always expressed irrespective of presence of herbivore. An important example is biosynthesis of cyanogenic glycosides by plants which is a secondary metabolite responsible for enzymatic release of hydrogen cyanide (HCN) (a respiratory toxin) upon disruption of plant tissues by herbivore (Zagrobelny et al. 2008). In contrast, induced resistance is activated only after herbivore or pathogen attack. A well-characterized response is the production of jasmonic acid (JA), a phytohormone that mediates defense-related gene expression and the emission of herbivore-induced plant volatiles (HIPVs) (Howe and Jander 2008). These HIPVs serve as indirect defenses by recruiting natural enemies of the herbivores. Plant's defense mechanism operates through direct and indirect defenses against pest infestation. Direct defenses are plant traits that directly affects the growth and survival of herbivores via physical barriers (trichomes, silica deposition, surface waxes, pubescence etc.) and chemical barriers (alkaloid, terpenoids, phenols etc.), which act as a repellent, deterrents and antidigestive compounds for insect pests. For instance, wax bloom on the leaves of crucifer crops deters feeding by diamond back moth (*Plutella xylostella* (Linnaeus)) while DIMBOA (2,4-dihydroxy-7-methoxy-1,4-benzoxazin-3-one) in maize, it suppresses *Ostrinia nubilalis* (Hübner) by inhibiting trypsin and chymotrypsin activity, leading to reduced larval growth and survival. Indirect defenses enhance the activity and effectiveness of natural enemies of herbivore. HIPVs function as olfactory cues for parasitoids and predators, thereby augmenting biological control. This ecological strategy underscores the adaptive significance of plant-insect interactions in sustainable pest management (War et al. 2011).

Herbivore-induced plant volatiles (HIPVs) play a vital role in plant defense mechanism and ecological interactions. Besides attracting and enhancing the effectiveness of natural enemies they also serve as warning signals for neighbouring un-infested plants (Inter-plant signalling) and also for communicating within the same plant (Intra-plant signalling). These volatile organic compounds (VOCs) are released from fruits, flowers, leaves and roots in response to pest infestations. These HIPVs are released into atmosphere in certain amount but their composition and quantity are altered by herbivory. Notably, HIPVs are not only released from damaged plant parts but also from undamaged tissues to enhance the signal strength for better detection. HIPVs are reliable cues for predators and parasitoids as their concenteration increase significantly with herbivore attack. Also, these volatile compounds provide information about the location, activity and may even express about the developmental stage of herbivore to its natural enemy (Baldwin 2010). They are also used by the plants to lure pollinators. Orchids release a blend of green leaf volatiles from their flowers which attract the wasps mistaking the flowers for leaf eating caterpillars and while searching for its prey, pollens get attached to their heads and abdomens, thus playing a part in unintentional pollination (Baldwin 2010). The volatile mixture of HIPVs is specific for insect-plant system and its composition varies with plant herbivore system, developmental stages and physiological conditions of both plants and insects. Plants perceive these volatile signals, leading to expression of defense-related genes and accumulation of defensive metabolites such as terpenoids, proteinase inhibitors and phenolics. Additionally, HIPVs also serve as feeding and oviposition deterrents for herbivore. Tobacco plant when attacked by *Manduca sexta* (Linnaeus) releases mixture of HIPVs, including green leaf volatiles (GLVs) and monoterpenes which interferes with pest's gustatory receptors making the plant unpalatable and thus act as feeding and ovipositional deterrent (Halitschke et al. 2008) (War et al. 2011).

These HIPVs which are specific to insect-plant system are now being utilized for effective pest management. By combining these volatile cues with AI based sensors such as electronic noses (e-noses), early pest detection can be done without causing damage to crop. This facilitates the precision pest management by targeting specific insect infestation, and reducing the reliance on broad-spectrum insecticides.

E-noses are olfactory sensors which are designed to mimic human olfactory system. These devices can detect the volatile organic compounds released from plant in response to pests attack and further analyse and convert VOCs information into electrical signals. The main components of an e-nose system include sensor array, arrays which provide unique response to different VOCs released and transform this information into digital signals and pattern recognition system which analyse these information for pest detection and identification. To enhance the specificity and performance of e-nose different sensors can be employed such as conductivity sensors, gravimetric sensors and optical sensors. Conductivity sensors includes polymer and metal oxide sensors. Polymer sensors measure variation in conductivity while metal oxide sensors measure resistance variation when exposed to VOCs. Metal oxide sensors require high operating temperature and does not perform well with sulphur compounds. Gravimetric sensors are further of two types namely, surface acoustic wave (SAW) and quartz crystal microbalance (QCM) sensors. Both these sensors work on the principle of frequency shift due to the absorption of VOCs. Both these sensors have shorter lifespan and complex manufacturing requirements. Optical sensors detect the chemical changes such as reactivity, redox potential, and acid-base interactions through colorimetry and fluorometry techniques. Colorimetry method detects the colour changes while fluorometry measures wavelength when exposed to VOCs. These sensors are highly sensitive to environment humidity and often variation in humidity causes signal interference. Optical sensors have limited operating lifespan due to dye degradation. Hence, researches are being carried out to develop hydrophobic materials to overcome the problem of humidity effects. (Cui et al. 2018)

E-noses provide both qualitative classification and quantitative prediction of VOCs using advance pattern recognition algorithm. These analytical methods are further categorized into unsupervised and supervised learning methods (Cui et al. 2018).

Cluster analysis (CA) is widely used unsupervised learning method which is based on grouping data based on feature similarities. It utilizes Ward's minimum variance method for clustering data and results are represented in the form of dendograms which show samples relatedness. For instance, e-nose can distinguish between wounded and insects & disease infected plants (cucumber, pepper and tomato plants). CA was successfully able to differentiate between wounded, mites infested and healthy cucumber plants (Laothawornkitkul et al. 2008) (Cui et al. 2018).

Artificial neural networks (ANNs) are part of supervised learning method which is capable of processing complex and non-linear data. They are best known for their ability of dynamic learning through optimization of synaptic weights with iterative training processes which allow real-time adjustment and thus enhances detection precision. Real time self-adjustment capability of ANN along with generalization properties make it suitable for analyzing complex volatile organic compounds detected by e-noses. ANN, requires intensive data training for precise detection, but provide advantage in handling complex data relationships. These networks are not sensitive to noisy data and can effectively model a connection between dependent and independent variables (Cui et al. 2018).

Random Forest (RF), supervised learning algorithm is widely being employed in e -noses for classification of VOCs and besides that it also estimates the quantities or intensities of VOCs released by plants. RF works by creating several decision trees based on different data set with each tree making independent predictions. The final prediction is made by majority voting among trees and intensity estimate is provided by average prediction across the ensemble. RF can handle large datasets but are sensitive to noisy data. Versatility of this method have made it particularly important in analysing the multidimensional data and enables its use in agriculture and environment tracking (Cui et al. 2018).

A brief review of electronic nose application in agricultural pest detection

E-noses have been successfully used to detect pests at early stages, to differentiate between, healthy and insect infested plants. Fruit flies are notorious pests infesting wide range of fruits and vegetables. These pests can be managed successfully through early detection which is difficult as female lay eggs into host tissue and larvae develop inside the fruit. The detection of fruit fly requires destructive fruit sampling which is not economically viable or visual inspection which is ineffective against early-stage detection of infestation. E-nose unlike traditional methods avoids fruit destruction and provides real-time detection of *Bactrocera dorsalis* (Hendel) in less than 30 min with an accuracy of 98.21 %. Citrus fruits were classified into healthy, invasion stage (eggs laid beneath the fruit peel) and incubation stage (growth of larvae inside fruit) infested groups with this method (Wen et al. 2019).

E-noses have been used in cotton ecosystem for the early diagnosis of cotton stink bug prior to the appearance of visual symptoms. Plants infested with stink bugs produced 2.4 times more VOCs than the healthy cotton plants. Cotton plants can be correctly differentiated into infested and healthy bolls under field conditions using this technique (Degenhardt et al.2012).

The reliability of e-nose has been evaluated in storage areas. Grains attacked by *Rhyzopertha dominica* (Fabricius) and *Tribolium castaneum* (Herbst) can be easily discriminated from healthy grains. The insect count can also be predicted using e-nose thus providing real- time solution to reduce post- harvest losses and contributing to food security (Mishra et al. 2018; Xu et al. 2017).

E-nose with 87.4% accuracy has been able to differentiate between whitefly infested, healthy and wounded tomato plants (Cui et al. 2021) and with 86.7% accuracy in discriminating between aphid-stressed and healthy plants (Cui et al. 2019).

E-nose has been successfully demonstrated in estimating the age of brown planthoppers (Xu et al. 2014). Lan et al. demonstrated its significance in distinguishing the gender of stink bugs.

Limitation of e-noses (Cui et al. 2017)

1. VOCs production differs by plant part. For instance, ɑ-thujene, pheromone released by aphids, accumulates in peduncles of pistachio but is rarely present in leaves and fruits (Agostini et al. 2009).
2. VOCs composition can vary among same plant species growing in different locations.
3. Humidity interferes with sensor signals and thus affecting its performance.
4. Open field conditions have high variability in temperature, humidity and gases which masks VOCs detection and also these variations affect sensors detection accuracy.
5. VOCs released by plants under stress conditions can mimic HIPVs, causing false positives.
6. Many HIPVs still remain unidentified.

CONCLUSION

It can be concluded, that e-nose provide non-invasive pest detection method using volatile organic compounds released by plants in response to pest infestations. It facilitates precision pest management by detecting pest specific detection and thus minimizing the dependency on broad-spectrum insecticides and also enables timely intervention through early pests detection. It also contributes to food security by reducing post – harvest loses in stored grains through real-time monitoring of pests. However, more studies should be conducted to enhance the accuracy of e-nose under open field conditions.

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