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The Importance of Scent: An Approach to The Case of The *Trichoderma* Fungus

Opinion

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All living organisms produce mixtures of volatile organic compounds (VOCs), a low molecular weight compounds that can vaporize and pass into the gaseous phase at normal atmospheric temperatures and pressures and often have a characteristic odor. For years, VOCs were considered non-essential compounds for the functioning of the organisms that produce them. However, several recent studies have shown that VOCs are of importance at the ecosystem level since they mediate interactions between different organisms, as they are indispensable compounds for communication in various environments, such as soil and foliage[1,2].

In soil environments, fungal VOCs are considered to have evolved for adaptive reasons to facilitate communication and act as developmental signals for many functions. The volatility and diffusibility of VOCs through the gaseous and liquid phases of the soil, confer on them the capacity to act as signaling molecules, being able to move easily in the porous spaces and thus mediate communication even over long distances. Furthermore, different compounds produced by fungi have the ability to modify the profile of VOCs produced by plants in such a way that they can improve their defense against the attack of pests and pathogens or improve their response to different abiotic stress conditions [3]. Depending on the way, amount and moment in which the plant receives the stimulus of fungal VOCs, the response can vary.

In the particular case of fungi of the genus Trichoderma, due to their important use in biocontrol of plant diseases, VOCs have been studied mainly in the context of antagonism by mycoparasitism and antibiosis. However, the wide chemical diversity of compounds and the different metabolic pathways involved suggest that VOCs induce a wide range of responses in the fungus-plant interaction that have been little explored. Therefore, in our research group we think that VOCs also participate in other processes such as competition for space and nutrients, since they can provide protection and competitive advantages during the interaction with plants and other microorganisms, as suggested by previous studies[4,5]. Considering some scientific advances that we have to date, we have established the hypothesis that some VOCs have the function of preparing the conditions for the plant to accept intimate interaction with *Trichoderma* or to condition the area of interaction between plant and microorganisms, which initially involves a certain degree of stress that must be softened with VOCs (antioxidants such as gentisic acid) and other molecules such as hydrophobins and swolenins.

Recent research indicates positive effects and a wide variety of VOCs produced by *Trichoderma*, depending on the parameters under which *Trichoderma* was grown. The variability of VOCs produced is dependent on the species and growth factors such as temperature, culture medium or substrates, acidity levels, and exposure during specific periods to light or darkness; all these variables and their combinations have come to stimulate the production of up to 1000 VOCs in the genus of *Trichoderma* [6]. Therefore, the effects of each of the VOCs will be different and will have different effects depending on their blend.

The production of the different VOCs is related to two pathways, acetyl coenzyme A (Acetyl Co-A) and Shikimate, in which they can originate products such as vitamins, antibiotics, pigments, and amino acids, among other compounds of organic character that serve for Trichoderma to develop in almost any environment [7].Other compounds have the activity of improving the response of plants to any stimulus caused by phytopathogenic microorganisms, thus activating their defense systems and achieving protection induced by VOCs.The most known and researched VOC produced by some strains of *Trichoderma* is 6-n-pentyl-2H-pyran-2-one (6-PP), a lactone with coconut aroma, and used for years as a natural additive in food products. The interest in this compound was increasing so that it was reported to inhibit the development of *Rhizoctonia solani* [8] as well as to increase root branching and root hair development [3] and promote plant growth [9]. Another example of VOCs is terpenes, which are mainly found in plants as essential oils. However, they are also produced by microorganisms. In the case of *Trichoderma*, the most abundant type of terpenes are sesquiterpenes, which have anti-inflammatory, antifungal, antibacterial, antiparasitic, antitumor and antiviral effects [10]. The antifungal effect of sesquiterpenes, specifically trichoacorenol, lies in its mechanism of action, which suppresses the development of the phytopathogenic fungus, through osmotic imbalance in the cell membrane [11], other studies mention that they act as solvents through the membrane, facilitating the passage of toxins. These qualities are attributed to the compound trichoacorenol which was identified in strains from the state of Chihuahua, Mexico, thus giving a positive indication for the investigation of these beneficial fungi for plants.

The variety in VOCs, far from being a problem due to the uncertainty in their identification, is their greatest strength; that is, VOCs produced by one strain can be very useful to induce plant development, while another strain can produce VOCs that suppress the growth of phytopathogenic fungi or produce VOCs with peculiar properties that can be used for other sectors of interest. The antioxidant activity of VOCs has been little reported in several microorganisms; however, in strains isolated by our working group from the state of Chihuahua, Mexico, the compound known as gentisic acid has been found as part of the VOC mixture. Gentisic acid is a phenolic compound derived from benzoic acid and coming from the shikimate pathway; it has been reported in fruits such as grapes (*Vitis vinifera* L.) and fungi such as Penicillium patulum. Studies indicate that gentisic acid exhibits antibacterial properties against *Candida albicans* and *Schizosaccharomyces octosporus*[12]. In humans, gentisic acid exhibits antioxidant, anti-inflammatory, antimutagenic, hepatoprotective, neuroprotective and antimicrobial properties. Therefore, these two examples highlight the potential of VOCs as phytopathogenic fungi control and bacteria of health concern in plants and humans. VOCs produced by *Trichoderma* provide an opportunity for research with promising results in sustainable and environmentally responsible agriculture to favor the balance between conventional and organic chemical use.

Thus, to our knowledge, there are still many questions regarding the differences in the emission of VOCs by different species, including strains, of *Trichoderma* and the different responses they can induce in recipient plants. *Trichoderma* VOCs can modify the plants VOCs and the responses to stressor generate attraction or repulsion towards friendly or enemy organisms. Another important question, which is of interest to us, is whether the plant response comes from a single compound or from a mixture of compounds. In this sense, more research is needed on the function of fungal VOCs; determining the species-specific volatile profiles will be helpful in describing their effects, such as attractants or repellents for insects, promoting growth, and activating defense against phytopathogens in plants. Likewise, the possible applications of VOCs in the food, pharmaceutical and textile industries. We consider it necessary to deepen our knowledge of *Trichoderma* VOCs, deciphering their role in plant-microorganism communication, to improve the activity of these beneficial organisms in order to integrate them into an IPM based on biological control and in order to achieve a sustainable agriculture[13].

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