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Plants are Talking Their Own Languages

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Abstract. Volatiles emitted by stress-induced plants with high specificity indicates are important evidence to the significance of such volatiles in shaping the different ecological communities, through effect on pollinators, herbivores, predators and microbes. Due to the great differences of habit below and above the ground, in addition to the morphological and physiological differences between the plant parts, it is very important to know that the way of communication and the used mechanism will vary greatly. Cross-talk among individuals belong to the same species revealed an increased rate of survival which ultimately can be used in crop production.

Introduction

It is difficult for many people to accept that plants are behaviorally interacting with their surroundings (Edel et al, 2017).

Plant behavior isa form of phenotypic responsesto chemical or physical stimuli as a result of its physiological mechanisms.The plant behavior, however, does not get the same attention as that of the animals' counterpart received. The plant behavior is reported to be of many complicated responses,many of such responses so far have not been well appreciated.Charles Darwin has described the plant active movement since 1880, as triggered by light, gravity, and contact stimuli.The features of plant stimuli are categorized as gravitropism, hydrotropism, heliotropism, phototropism, and thermotropies (Karban, 2008).

The plants are sound for us silent creatures, but recently they have been proved to communicate between each others with their own languages (Gagliano, 2013; Appel and Cocroft, 2014). Accordingly, is it really a "primarily" language making plants appear silent to us? or it's a language still beyond our capability to detect and explain?It has been suggested that many plants used a network of signals to pass information within and between the different populations in much the same manner that we do. Plants listen to their neighbors by detecting the volatile organic compounds (VOCs) that can be emitted either from the root and/or floral parts. These compounds are the most common example of such communication signals (Raguso, 2008).

Plants in their natural ecosystem may be involved in different forms of mutual relationships such as; pollination, seed dispersion, protection, and plants-humans mutualism (Albrecht et al., 2018).

The various organisms respond differently to the released VOCs, ranged from triggering of certain defenses against herbivore attacks to attract specific herbivore-predator to minimize physical damage on the plant (Mitchell et al., 2016; Noman et al., 2019).

Understanding the nature of plant communication helps in more than better understanding of the plant biology, but also more importantly in considerate the plant pest resistance and disease forecasting. This paper is focused onplant behavior and their speaking languages.

Plants andenvironment

The plant responds phenotypically to the environmental conditions in various ways. The phenotypical response of the plant may take several forms of movement, physiological acclimation and change, growth of new tissue or shedding of the existing tissue (Fritz et al., 2018). The plants have large behavior responses as mentioned in the literatures which are summarized byKabran (2008) table (1).

Table 1. Recognized plant behaviors (causes and consequences) After, Kabran (2008).

Behavior	Stimulus	Tissue responding	Consequences
Foraging Movement	Contact, light, and gravity	Many	Improved resource acquisition
Root growth, shedding	Nutrients, Water	Root meristem	Improved resource acquisition
Shoot growth / Shedding	Red and infrared light	Shoot meristem	Improved resource acquisition
Parasitism	Favorable host	Haustoria	Successful parasitism
Enzyme development /Gas exchange	Light	Leaves	Increase Photosynthesis
Reproduction Strategy	Environmental condition, Pollinators	Shoot meristem	Out crossing rates, Reproduction success
Functional gender	Stress resources, floral damage	Reproductive Tissue	Maleness, Femaleness
Seed Germination	Light, Temperature, Other physical factors	Seed Coat, Embryo	Seedling grows in a favorable environment
Defense production, Phytoalexins	Microbes	Many	Improved defense
Accumulation of secondary metabolites	Herbivores and Microbes	Many	Improved defense
Attraction of predators and parasites of herbivores	Herbivores attack	Systemic response	Improved defense

Plant responses

The plant responses are:

1. **Movement and foraging**

The rapid movement of certain plant parts as responding to physical stimuli is one of the most impressive plant response. For instance a legume species are noticed to be sensitive to insects or wounding as indicated by rapidly leaves fold up (Braam 2005; Guo et al, 2015). Other tropical legumes lower their leaves in response to heavy rain. Insects are caught by carnivorous plants when its leaves are rapidly moved and hold the prey (Scorza and Dornelas, 2011). This rapid movement of plant explained either to the changes in osmotic ion concentrations or the plant tissue turgor pressure or electrical signals (Markin et al., 2008;Trewavas, 2017). Plants also possess morphological plasticity which allows for efficient foraging for light. Plant's shoot elongates less with sufficient light. Another example is that dodder as parasitic plant detects, locates, and invadesits host tissue (Yoder, 2001, Runyon et al., 2006). Dodder Recognition of their host tissue explained to be controlled by chemical signals. It is also found to grow towards the higher nutritional quality hosts (Alder, 2003).

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2. **Mating and seed germination**

Plants noticed to display response to the environmental cues reflected in their reproduction. For improving pollination specific plants behave to attract more insect pollinators. The timing of plant seed germination also affected by environmental conditions. Seeds germinate only under favorable plant growth conditions (Corli and Sheppard, 2019).

3. **Responses toPathogens and Herbivores**

The plant response to pathogens and herbivores attack reflected by different chemical, physiological, and morphological characteristics (Agrawal et. al. 1999b). According to these responses, plants become less preferable or susceptible to pests. These defense responses in plants noticed to be rapid and reversible (Isah, 2019). Phytoalexins are secondary metabolites induced as a defense mechanism in plants as a response to physical or chemical or biological stimuli (Arruda et al., 2016; Karban and Baldwin, 1997). Baldwin (1999) reported that when the tobacco plant attacked by herbivore its roots produced nicotine compound. The induced nicotine transported through the xylem and accumulated in the leaves and then the plant becomes lethal to the herbivore.Inaddition, the tobacco plant also reported to release volatile blends of different composition as responding to a herbivorous attack (Karban, 2007a,b).

Other plants also found to be emitted a wide range of volatiles in response to herbivore attack termed herbivore-Induced Plant Volatiles (HIPVs). Several factors affecting the specificity of HIPVs *e.g*. herbivore and the plant species (Takabayashi, 2014). HIPVs also have been extracted from artificially damaged plants and it might activate as a defensive mechanism in the healthy plants against subsequent herbivore attack (Yoneya and Takabayashi, 2014). The plant species like maize and tobacco also reported to emit distinct HIPVs in response to the herbivore attack that in turn will attract a specific type of predators to visit the damaged plant and locate their herbivores. Plants may adopt this kind of indirect defense system to decrease the number of infesting herbivores and minimize their damage (Yoneya and Takabayashi, 2013).

Mutualism

Like most living organisms, plants are incapable to synthesize all the required elements for their growth. The plants, hence involve in a symbiotic association with other living organisms such as mycorrhiza, fungi and bacteria for accommodating extra nutrients. The coexisting living organisms are not just linked to one individual in pairs, but provide a network involving many individuals mutually (Appel and Cocroft, 2014).

It is categorically shown that these channels not only serving in passing nutrients and carbons, it also acts as a transmitting system for passing pheromones as warning signals for nearby members. Furthermore, the created network serving in passing a high level of tannin to the connected unaffected plants to ensure a greatest level of protection against the attackers and prevent or even minimize the damage to the lowest possible limit (Fleming, 2014).

Several studies have demonstrated that the mycorrhizal mycelia in tobacco served as channels to pass signals of early warning messages for infesting herbivores. Releasing pheromones could be easily altered in response to herbivores, which makes the infested plants undesirable for a certain herbivore and attractive to their predators (Gagliano and Grimonprez, 2015).

The interactions between the plant and the pest predators or parasites are beneficial to both. A plant found to be increased extrafloral nectar production as a response to herbivore attack and reduced nectar when risk is diminished or low (Heil et al., 2001; Heil, 2004a). The plant also just rewards pollinators by increasing volatile compounds and nectar production. Another example of mutualism is N- fixing bacteria and legume plants.

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In addition to mutually volatile signals, visual display together with species-distinct shape and color patterns are the other important application used by plants to interact and communicate (Raguso, 2004). For example, there are more than 450 plant species are capable to alter their color, position and shape to endorse more pollinators. For example *Desmodium setigerum* is a legume species was described by Willmer et al. (2009) as a great shape-shifter. It shows striking lilac flowers at the early day pre-pollination, then change its flower into a less noticeable (white and turquoise flowers) after getting pollinated. The total or partial change in both, shape and color of pollinated flowers is a common procedure by which pollinated flowers directed the pollinators to visit other flowers that have not yet been pollinated (Gagliano and Grimonprez, 2015).
Interestingly, the ineffectiveness of the pollination process due to the lack of pollen or its low viability will result in a rapid change in flower properties to appear attractive again and advertising for another round of pollination (Schaefer and Ruxton, 2011).

Characters of plant behavior

Plant behaviorsare:

1. **Rapid**

The behavior of the carnivorous plants response or movement is rabid as that of animals. Many of the plant's behavior occurs within seconds (Pavlovič, 2010).

2. **Complex**

The plant reported to emit different blends of volatile compounds when attacked by special caterpillars. These chemicals attract species of specific parasitoid wasp to locate and attack such caterpillars.The plant emits and parasitoids responses of the precision manner by both the plant and the parasitoid species. Plants are also responding to the volatile cues of neighboring plants to increase resistance against attacks pest (Karban et al., 2006).

3. **Localize**

The clear example of localized plant behavior is the growth of barley roots as responsive to the phosphorus soil level (Fromm, 2019).

4. **Bartering**

The plant behavior depends upon the state of the plant. Plant responses to one environmental condition may constrain its response to other. On other words that plant response to one stimulus lessens its ability to respond to other (Zebelo and Maffei, 2015). For example, the signal to induce resistance to insect may interfere with the signal to induce resistance to the pathogen (Bostock, 2005).

Plant behaviors

The plantengages infourclear recognized behaviors:

1. **Anticipating**

Plant behave in ways that appear to anticipate future conditions. Deciduous trees, for example drop their leaves in autumn in response to the photo period and anticipate winter. Another example the parasitic dodder plant prefer only well nutritious host plant. The cues used in dodder plant decision-making are not known, but recent work suggests that volatile compounds released by the host allow dodder to grow toward better nutritious plant.

2. **Conditioning and memorizing**

In plant, the decision of reproduction for instance is affected by past events. Some perennials respond to cues to flower only after a cold period known as vernalization. The genetic control of winter wheat flowering is found to be when plants are exposed to low temperature, hence inhibit the gene that restrict flowering (Yan et al., 2004). Other examples, that plant responses to a pest or pathogen have

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been primed by an initial attack, it responds more rapidly and efficiently to a second exposure of the same pest or pathogen (Conrath et al., 2006). Priming has also reported for plants attacked by herbivorous. Ton et al., (2007) reported that plants primed by a previous attack become less preferable for herbivores. In conclusion that plants respond more quickly and efficiently when they themselves have experienced a previous attack.

3. **Communicating**

The plants can communicate with other organisms by emitting cues. Plants also respond to stimuli emitted by other organisms. The cues emitted by the damaged plant by herbivores are altered by the behavior of the subsequent invade plant. There are several examples in which the damage plants become less attractive to herbivorous (Heil, 2004b). The plant presents cues for their mutualists to provide beneficial services. Cues as volatile and vesical emitted by plants to locate the nectar and pollen and their quality abundance, rewards for animals that visit the flowers. The flower visitors for these rewards move pollen from one plant to another.

4. **Defending**

The most interesting behavior in plants is that plants can anticipate their future enemies and adjust their defenses accordingly. The defense mechanism in the plant is expressed systemically in a phenomenon termedSystemic Acquired Resistance (SAR) that has been discovered with Tobacco Mosaic Virus (TMV). It is clearly discovered that Jasmonic acid (JA) and Salicylic Acid (SA) are the central hormonal compounds in the SAR. Both acids can be methylated and become volatiles as air born signals for communications (Tamaoki et al., 2013; Maruri-López et al., 2019). Volatile signals have suggested acting not only in the communication between plants, but also within plants (Orians, 2005). Studies on damaged sagebrush (Artemisia tridanta) for example showed that air flow is necessary for systemic resistance induction against herbivores. The systemic induction of extrafloral nectar secretion by wild lama bean (*Phaseolus lunatus*) has the response to beetle attack occurred only when there was air moving freely between plant parts (Bueno 2007). Rhoades reported that the level of plant resistance against herbivores increased in undamaged Sitka willow trees, neighboring to the herbivorous infested tree. The same finding also discovered in popular and sugar maple trees (Baldwin and Schaltz 1983). This indicated the attacked plant had warned their neighbors. The central role of the volatile hormone in tobacco plant is methyl salicylate, which is the signaling of systemic acquired resistance (SAR) (Shulaev et. al. 1997). Another observation that the resistance induction in non infected lama bean towards pathogenic bacteria as responding to VOCs from infected plants.

Types of plant communicates

As indicated above, the plants are not as passive as they might seem, but they are active organisms. The plants have evolved the use of specific chemicals as signals serving to communicate with each other or with other organisms. There are various ways are categorized for plant communicated.

1. **Calling for Help**

The obvious example of plant call for help is after mowing the grass lawn or alfalfa field or cutting flowers a fresh small someone can inhale. These smells figured out to be one of the ways of plants to express a distress call and it is crying out of plant damaged for help. Another example that plants emit a scent to attract pest's natural enemies to help the plant to get rid of or come over its pest. Crying signs of inter- and intra - plant interaction in response to damages is chemically identified as Terpenoids, Sulfur, Nitrogenous compounds, Pheromones, Chironomones, Jasmonate, and Salicylate. In the past fifteen years, the idea that plant is talking has become much more acceptable, but unresolved.

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The wild tobacco plants also behave in the same manner by identifying the hornworm by its saliva and emitting chemical signals or cues to appeal or call the pest's enemies for help.

2. **Eavesdropping**

Plants recognize the chemical signals of their breath or other plants……(SOS) cry are to inform neighbors there is an enemy nearby. Hence, the plant responds to SOS by ramping up their own defenses. The defense proteins identified as trypsin proteinase -inhibitors (TPIs) are discovered to be released by sagebrush. These proteins prevent the hornworm of digesting proteins and that stunt the insect growth. Other neighbors of wild tobacco build this protein inhibitor after receiving the sagebrush distress call.

3. **DefendingTerritory**

The competition between plants is well recognized. Plants compete among each other for resources such as sunlight, water, minerals, and spaces. The interesting example of such behavior that knapweed plant kills competitors to take over large territories. Lupine a plant species, however, can resist the competition of knapweed by secreting oxalic acid through its root. The oxalic acid of the lupine also can protect another neighbor of other plant species.

4. **Recognizingsiblings**

Plants can recognize other plants growing nearby. This recognition help plants to compete for resources, but they can recognize and support their kin as animals do. For example the sea rocket grows stronger with siblings than strangers. Such recognition proved to be chemically controlled.

5. **Communicationwithanimals**

Plants attract insects and other animals in their own ways. For example the carnivorous pitcher plants are discovered to hijack the bat communication system and turning the bat's echolocation to its advantage. Bats are roosting and provide important nutrients to pitcher plants from the bat droppings that distributed in the soil.

Nature of Signals on Plant Communication

The plants must adjust their physiological state either in response or preparation to physical or biological injuries (pathogens, herbivores temperature, and wind). The Plants posses a communication system to transmit network information within and between their populations.Suchcommunication system discovered to be based chemical signals of volatile organic compounds (VOCs). The plant emits VOCs to activate their defense system or communicate to attract pollinators or transmit SOS. The emitted chemical signals are diffused to neighbors and give them the opportunity also to activate defense system. These signals also are cached by the natural enemies of the pest. According to the VOCs concentration and type, different messages are transmitted. The first compound renders plant resistance against herbivores was found to be emitted by Sagebrush (*Artemisia tridentate*) was Methyl Jasmonate (MeJA).MeJA induces resistance by increasing proteinase inhibitor production. It has been reported that VOCs emitted by damaged plants affects all neighbor plants regardless of their species. *Phaseolus lunatus* emits VOCs as a response to spider mite infestations. Accordingly, the emitted VOCs enhance the expression of the resistance gene in intact leaves. In the Arabidopsis plants, the emitted VOCs enhance resistance to pathogens as *Botrytis cinerea* in addition to the herbivores. Methyl salicylate and ethelyn as phytohormones also found to induce systemic resistance in the emitted plants and their neighbors.

Conclusion

Plants in their natural ecosystem may involve in different forms of mutual relationships. It has been suggested that plants used a network of signals to pass information between and within different populations in much the same manner that we do. Volatile Organic Compounds (VOCs) are the most common example of such signals. These Volatile Organic Compounds serve in what become known volatiles-mediated interactions. Plants also listen to their neighbors by detecting these VOCs. Various organisms respond differently to the released VOCs, ranged from triggering of certain defenses against herbivore attacks to attracting specific herbivore's predator which minimize the herbivore damage to the plant. The plant languages, it is a primary that making plants appear silent or it is still beyond our capability to understand. Ultimately, understanding the nature of plant communication helps not only in better understanding of plant biology, but also more importantly in understanding the plant pest resistance and disease forecasting.

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