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Underpinning Plant Intelligence-A New Arena in Plant Cognition

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ABSTRACT

Like other organisms plants also face crucial challenges for survival and better fitness in a wide range of ecological niches. Complex behaviors like learning, memory, information acquisition, communication, resolving problems and decision making abilities for their own benefits in an ever changing environment are also common in plants like humans and other animals. Plants sense and respond to biotic and abiotic factors of the environment to assess resources. Plants are good timekeepers as well. Without having proper brain and nervous system plants are able to interact with themselves and other organisms via chemical talking. In some plant species emissions of certain volatile chemicals during herbivore attacks are indications of social interactions. These are evidences regarding the occurrence of kin recognitions and responses in plant growth and development in complex environmental conditions. Certain species of plants show the act of mimicry. By adopting different dispersal mechanisms plant reduces parent-offspring and offspring-offspring competition. Seed-dispersal mutualism is a complex physiological interaction between plants and animals. For the last few years the relevance of plant cognition and behavioral ecology has received much attention. Collecting various sensory inputs from the surrounding environment (perception), transducing the signals within the body (cognition) and adapting various strategies plant ensures an output for better survival and reproductive fitness. All these mechanisms explore the domain of plant intelligence.

Keywords Adaptive beneficial behaviors, Cognition, Intelligence, Memory, Perception, Plasticity.

INTRODUCTION

The planet earth is dominated by plants. Though plants are good examples of sessile life, investigations in the areas of plant intelligence and behavior specially assessment of circumstance are neglected till date. Like other organisms plants also have to acquire the resources for their growth, must have to deal with diseases, competitors and predators. Plants do overcome all the hindrance in their life by solving problems through learning, memory and experience for improved survival, reproduction and fitness and are considered intelligent (Trewavas 2014). For example, among many imbibed wild seeds in the soil, some seeds germinate receiving proper signals from the environment and assessing the right time of ger-

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mination and also by judging or rightly interpreting the cues for later developments. It is the intelligence that determines the decision of seeds to germinate immediately or remain dormant. Factors influencing this decision include temperature, perception of light, water availability, volatile organic compounds of soil, maternal environmental conditions like maternal experience of day length, quality of light, mineral nutrition, levels of carbon dioxide, competition, fungal infection, defoliation, position in ovary and seed maturation time.

Perception towards surrounding environmental cues

Being highly sensitive to biotic and abiotic signals and acquiring resources from the environment by expending minimum energy, plants show intelligent behaviors. It have been observed that plants are highly sensitive to and specifically respond to the following abiotic factors like intensity, quality and exposure length of light (Trewavas 2014), temperature (Trewavas 2014), proprioreception (Gagliano *et al.* 2017), stress (Teixeira da Silva and Dobránszki 2014), gravity (Teixeira da Silva and Dobránszki 2014), numerous volatile and non-volatile chemicals (Acevedo *et al.* 2015), sound (Chivukula and Ramaswamy 2014) and many more. Plants are also sensitive to signals from biotic factors like mutualism, symbiosis, herbivory, trampling, diseases, cooperation, competition (Trewavas 2014) and others.

Phenotypic plasticity induced by signals

Plasticity means variations which enables living organisms to master its surrounding environment and succeed for better fitness. Plasticity is another important facet of intelligence. Phenotypic plasticity encompasses different variations throughout the life cycle of a plant including length and shape of root, height of shoot, stem thickness, angles and numbers of root and shoot branches, numbers, shape, density, thickness and position of leaves, root and leaf hair numbers, chemical nature of leaf surface cuticle; stem to root ratio and others. In plants, plasticity is induced by different internal signals like mRNA, si RNAs, hormones, various kinds of proteins and peptides, hydraulic and mineral signals (Pierik and De Wit 2014).

In a competitive environment, plant uses various strategies individually within the crowd to access light. Certain phenotypic changes occur within individual plant, like enhanced shoot growth with thinner stem, increased internode distances, fewer leaves with longer petioles, diminished root growth (Pierik and De Wit 2014), positioning of reproductive organs in such a way to facilitate pollination and so on. All these strategies are collectively called “shade avoidance” (Li and Wang 2022). In a crowded environment leaves that touch each other of adjacent plants respond by enhancing the angle of elevation. Shade avoidance response is very much plastic and determine the fitness of survival and reproduction in crowd. Climbers and insectivorous plant uses various intelligent strategies for their survival and fitness. Some plant species mimics different organs of their host plants (Trewavas 2016). Coordinated events are adaptive and show intelligent plasticity. For example, arboreal to sub-tropical regional plants maintain an internal temperature of 21.4±2.2^{o}C, whereas the external temperature ranges from 12^{o}C-26^{o}C. To maintain homeostasis the internal temperature is regulated by six different ways - by controlling the stomatal apertures, manipulating the leaf blade orientations, changing the hairiness of leaves and wax reflectance, changing the movement of chloroplasts inside the cells and number of leaves (Trewavas 2016). These coordinated changes can take several minutes to few weeks to provide a better fitness.

There are evidences of different multilevel selection in plants including kin selection. Through a variety of competitive trait, plants show plastic responses towards kinship (Bawa 2017).

Adaptive beneficial behaviors

Adaptive beneficial behaviors are capabilities to cope up with changes in the environment influenced by signals for better survival and fitness. Plants have the capability to recall. By estimating time and through chemical talking plants do exercise the adaptive beneficial behaviors, which is another example of plant intelligence.

Memory- A component of plant cognition

There are many evidences indicating the presence of memory in plants (Khattar *et al.* 2022). For example, Kalanchoe flowers show upward orientation during day time and downward during night. The plants do the same in the absence of light signal for several cycles. It indicates that they remember light and dark signals even in the absence of diurnal signal. Sunflower flowers are directed to the east in the morning and to the west in the evening. In the night they again return to the east in anticipation of return of sunlight. They memorise the coming of morning even in the absence of sunlight. Diurnal changes in positioning of leaves have been seen in Albizzia. The cycling event also continues in the dark for several days intervals indicates that they remember the day night cycle.

Plants are also well known time keepers. For example, the seeds of Begonia remain dormant when they experience night length of 12 hrs and germinate when exposed to night lengths of 8 hrs or less. The discrimination between night lengths differences by 4 hrs is nothing but the adaptable time keeping behavior of the seeds. Another kind of time keeping which has been found in plants is seasonal flowering and death. Plants are also able to count years. *Corypha elata* maintain vegetative growth for 40 years and after flowering and fruiting they finally dies *Dionaea muscipula*, one kind of carnivorous plant can count the trapping rate and also memorize the number (Böhm *et al*. 2016).

Chemical communications

Chemical communications between organisms are the fundamental basis of adaptive beneficial behavior. Plant uses chemical communications for various purposes like promoting pollination, attracting animals for seed dispersal, escaping from predators.

Chemical emissions from flowers, mainly glycoproteins, phenols, terpenoids and volatile fatty acids attract pollinators like insects and birds. Flowers including Ophrys, Stanhopea, Gongora emit volatiles like methyl-cinnamate and cineole which acts as sexual stimulants of bees. Floral volatiles of Araceae family enhance the effectiveness of volatiles by generating heat in winter and at the same time attract insects with enhanced floral scent. Pollinators are also attracted by the chemical compositions of nectar- glucose, sucrose, fructose and sometimes protein, amino acids or lipids (Zariman *et al.* 2022). Nectar can also acts as repellents to pollinators when contain repellent substances like nicotine. It actually limits the amount of nectar consumption by pollinators from a single flower and encourages their visit to more individual flowers.

Plants also emit volatile chemicals and the emissions enhanced as a consequence of tissue rupture by herbivorus animals specially insects. The emitted volatiles including ethylene and other chemicals have inhibitory effect on the insect herbivores. In addition, the emitted chemicals from the damaged plants also inform their neighboring plants about the attack and induce them to emit the volatiles making them less appealing to those insects. Here, volatiles help in chemical talking between plant and insect, and also among plants (Trewavas 2016). Jasmonic acid and methyl salicylate are very strong volatiles functioning in the communicative system. Like aerial parts of plants, roots of some plants also communicate via chemical talking. For example, when pathogenic bacterium *Pseudomonas syringii* attacks *Arabidopsis roots*, L-malic acid is formed by the roots and malate is added into the soil. Malate has the capacity to recruit *Bacillus subtilis*, a beneficial bacterium which in turn protects the roots from *Pseudomonas syringii*. Thus, the wireless communication among these three organisms by chemical signalling again provides another sphere of beneficial functions in plants.

By offering fruits to animal kingdom, plant uses various strategies for dispersal of seeds. Seeds may remain inside of a fruit or attached to the outside. By providing edible fruits containing large seeds plant takes the advantages from birds and animals to drop or spit out seeds and in case of small seeds bearing fruits they first ingest and then dispersed the seeds with faeces. The seeds of some plants are small with elaiosome. Ants carry those seeds during lipid appetite and also store them for future. It is another way of seed dispersal strategy (Nagendra 2020). Thus by attracting animals with aromas or fruits and taking transportation services from them plants offer wonderful packages which serve as adaptive beneficial behaviors.

All the above evidences of adaptive beneficial behaviors which includes memory, time keeping and chemical messaging without an organized brain and identifiable neurological basis, supports plant intelligence from developmental as well as ecological point of view.

CONCLUSION

After lots of research, Darwin reported that "The tip of the root having the power of redirecting the movements of the adjoining parts acts like the brain of one of the lower animals receiving the impressions of sense organs and directing the several movements" (Darwin 1880). In 1875 an eminent psychologist Von Hartmann after observing the behavior of leaves concluded "If one sees how many means are here to attain the same end, one will be almost tempted to believe that here dwells a secret intelligence which chooses the most appropriate means for the attainment of the end" (Von Hartmann 1875). In 1930 Frits Went discovered one of the important plant hormone auxin and reported "In tropistic movements, plants appear to exhibit a sort of intelligence; their movement is of subsequent advantage to them". According to von Liebig, German scientist of nineteenth century discovered that minerals are very much required for plant growth. According to him plants search for food as if they had eyes (Weaver 1926).

Plants can choose and take decisions from their past behavior, keeping in mind the presence of alternatives and can make a critical assessment of immediate future for their own benefit and improved fitness. These are nothing but "intelligence". So learning, memory and intelligence are very common in plants and are not the sole properties only of organisms having neural systems. Intelligence also does not involve any obvious visible movement. Proper assessment and perception of signals and making responses accordingly without proper brain and complex communications, plant intelligence now are expanding towards a new frontier of plant cognition.

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