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OBSERVATIONS AND STUDIES ON THE INTELLIGENCE OF PLANTS

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ABSTRACT

Intelligence is the ability to solve problems and plants are amazingly good in solving their problems. Each choice a plant makes is based on a type of mathematical calculation. The bottom of the plant may be the most sophisticated of all though. Plants are complex communicators and communicate in a wide variety of ways. They use chemical volatiles, electrical signals and even vibrations. The strength of this evolutionary choice is that it allows a plant to survive even after losing ninety percent or more of its biomass. Plants are built of a huge number of basic modules that interact as nodes of a network. Plants have evolved an incredible variety of toxic compounds to ward off predators. When attacked by an insect, many plants release a specific chemical compound. If plants can do all these then they must be intelligent. Recent advances in plant molecular biology, cellular biology, electrophysiology and ecology, unmask plants as sensory and communicative organisms, characterized by active, problem solving behavior. Unfortunately scientists have not yet discovered any brain or neuronal network in plants. It is said that the reactions within signaling pathways may provide a biochemical basis for learning and memory in addition to computation and problem solving. One of most enigmatic and astounding characters of plants, especially trees is the ascent of sap or upward movement of water through stem, which is up to 300 ft in height. The water moves up to this height from the roots which are spread very deep in the soil. Amazingly, it largely occurs by a passive process called transpiration pull. We have made so much advancement in science and technology but we are unfortunately cannot emulate this feet of plants. This paper is a compilation of observations, experiments and studies made to understand the amazing and unresolved aspects of intelligence in plants.

KEYWORDS: plants' intelligence, evolution, molecular biology, and electro-physiology.

INTRODUCTION

Plants make up more than ninety nine percent of biomass of the earth. Sentient or not sentient, intelligent or not, the life of the planet is fascinating and enigmatic. I believe we only know one percent of the complexity of life in plants. The life on the Earth is possible just because plants exist (Mancuso and Viola, 2015). Daniel Chamovitz presented an intriguing report as to how plants experience the world. He highlighted the latest research in plant science, explained the lives of different types of plants, and draws parallels with the human senses to reveal that we have much more in common with sunflowers and oak trees than we may realize (Chamovitz, 2013). It is amazing and fascinating to even imagine how plants themselves experience the world. From the colors they see to the schedules they keep and the communication that they make. For centuries Western philosophy and science largely viewed animals as unthinking organisms and plants do not have any intelligence at all. Just because we have not discovered the brain in plants or plants do not have a localized brain. But research in recent decades has shattered that view. We now know that not only are chimpanzees, dolphins and elephants thinking, feeling and personality-driven beings, but many others are as well. Octopuses can use tools, whales sing, bees can count, crows demonstrate complex reasoning, paper wasps can recognise faces and fish can differentiate types of music. All these examples have one thing in common: they are animals with brains. But plants do not have a brain. How can they solve problems, act intelligently or respond to stimuli without a brain? Plants face many of the same problems as animals, though they differ significantly in their approach. Plants have to find energy, reproduce and stave off predators. Plants have evolved an incredible variety of toxic compounds to ward off predators. When attacked by an insect, many plants release a specific chemical compound. If plants can do all these then they must be intelligent. This paper is a compilation of observations, experiments and studies made to understand this amazing and unresolved intelligence of plants.

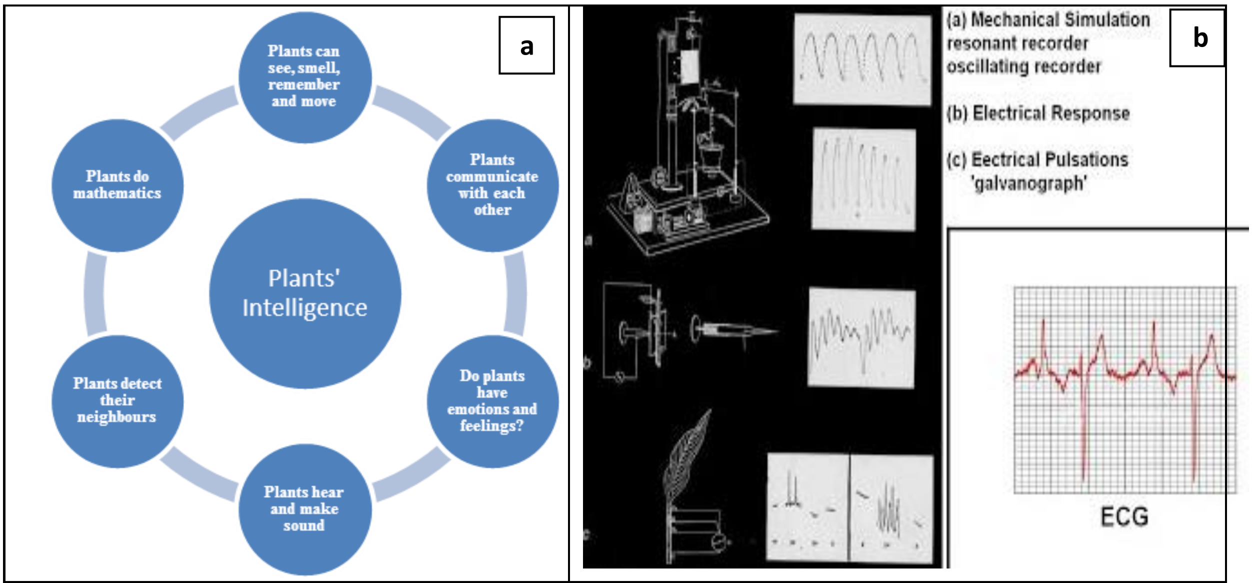


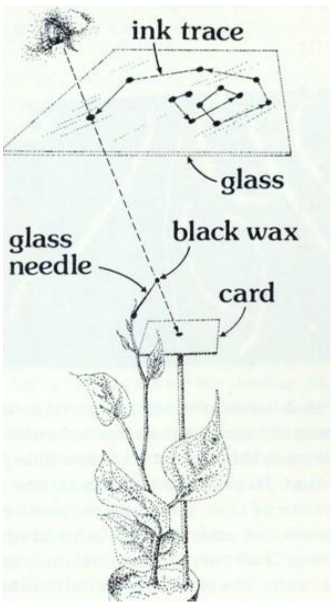
Fig-1a: Plants' intelligence- different aspects; 1b: Sir Jagadish Chandra Bose's experiment. He is the first to study the action of microwaves in plant tissues and corresponding changes in the cell membrane potential. He researched the mechanism of the seasonal effect on plants, the effect of chemical inhibitors on plant stimuli and the effect of temperature. From the analysis of the variation of the cell membrane potential of plants under different circumstances, he hypothesised that plants can "feel pain, understand affection

Intelligence is the ability to solve problems and plants are amazingly good in solving their problems. Plants are able to grow through shady areas to locate light and many even turn their leaves during the day to capture the best light. They are able to do it in the form of activities like etiolation and shade avoidance. Plants have photoreceptors like phytochromes, cryptochromes, phototrophins and zeaxanthins which are structurally more or less similar those light receptors found in animals. Some plants have taken a different route, however, supplying themselves with energy by preying on animals, including everything from insects to mice to even birds. The Venus flytrap may be the most famous of these, but there are at least 600 species of animal-eating plants. In order to do this, these plants have evolved complex lures and rapid reactions to catch, hold and devour animal prey. Each choice a plant makes is based on this type of calculation. The bottom of the plant may be the most sophisticated of all though. Scientists have observed that roots do not flounder randomly but search for the best position to take in water, avoid competition and garner chemicals. In some cases, roots will alter course before they hit an obstacle, showing that plants are capable of "seeing" an obstacle through their many senses. Humans have five basic senses. But scientists have discovered that plants have at least 20 different senses used to monitor complex conditions in their environment. Plants have senses that roughly correspond to our five, but also have additional ones that can do such things as measure humidity, detect gravity and sense electromagnetic fields (Mancuso and Viola, 2015).

Intelligence is not a term commonly used when plants are discussed. However, I believe that this is an omission based not on a true assessment of the ability of plants to compute complex aspects of their environment, but solely a reflection of a sessile lifestyle. The concept of plant intelligence, as proposed by Anthony Trewavas (2002, 2003), has raised considerable discussion. However, plant intelligence remains loosely defined; often it is either perceived as practically synonymous to Darwinian fitness, or reduced to a mere decorative metaphor. A more strict view can be taken, emphasizing necessary prerequisites such as memory and learning, which requires clarifying the definition of memory itself. It is crucial to appreciate that all intelligent behaviour in both animals and plants has evolved to optimize fitness. Plants must then have access to an internal memory that specifies the optimal ecological niche in which maximal fitness, usually regarded as the greatest number of viable seeds, can be achieved. When the niche is sub-optimal, plasticity in growth and development intervenes to counterbalance and to attempt to recover as far as possible the benefits of the optimal niche. The sub-optimal niche can then, in some way, be compared with the optimal niche to specify the necessary extent of plasticity in growth and development (Trewavas, 2003). Quite remarkably, the suite of molecules used in signal transduction is entirely similar between nerve cells (Kandel, 2001) and plant cells (Trewavas, 2000; Gilroy and Trewavas, 2001).

Intelligence is a term fraught with difficulties in definition. Spearman (1904) acknowledged that there are different types of intelligence but argued that they are all correlated. However it is the capacity for understanding; ability to perceive and comprehend. I think plants by all means very well fit in to this definition. Peter Tompkins and Christopher Bird (1973) wrote a book 'The Secret Life of Plants' and in that book they state that plants are intelligent and even respond to us. The book received to wide acclaim and criticism. But in the scientific arena it was classified as nonsense, because large parts of their research could not be replicated and did not meet scientific requirements. Stenhouse (1974) examined the evolution of intelligence in animals and described intelligence as ‘Adaptively variable behaviour within the lifetime of the individual’. The more intelligent the organism, the greater the degree of individual adaptively variable behaviour. Because this definition was used to describe intelligence in organisms other than humans, it is a definition useful for investigating the question in plants. Do plants exhibit intelligent behaviour? The use of the term ‘vegetable’ to describe unthinking or brain-dead human beings perhaps indicates the general attitude. At the heart of this problem is a failure to appreciate different living time-scales: plants generally do not move from the spot where they first became rooted, whereas animals are constantly changing their location. Nevertheless, both animals and plants show movements of their organs; but, as mentioned, these take place at greatly different rates (Baluška et al, 2009). The unicellular alga, *Chlamydomonas* is incredible example. Even though it is classified as a plant, it is capable of locomotion and vision. It processes flagella for movement and eye spot for seeing (see fig-5D).

Plants are complex communicators and communicate in a wide variety of ways. They use chemical volatiles, electrical signals and even vibrations. Many plants will even warn others of their species when danger is near. If attacked by an insect, a plant will send a chemical signal to other members of their species. The strength of this evolutionary choice is that it allows a plant to survive even after losing ninety percent or more of its biomass. Plants are built of a huge number of basic modules that interact as nodes of a network. Without single organs or centralised functions plants may tolerate predation without losing functionality. Hence even parts are removed or cut off the plants can still survive and regenerate. A plant's powers of regeneration are also impressive.



Darwin devised a simple apparatus for studying circumnutation:

1. A glass needle was glued to a plant shoot.
2. Black wax was put on the end of this needle.
3. A card with a black dot on it was set beneath the needle.
4. A glass sheet was set up above the plant.
   Darwin marked the glass with an ink dot so that it, the dot on the card, and the black wax blob were all in line.
5. Later, he recorded the movement of the shoot tip.

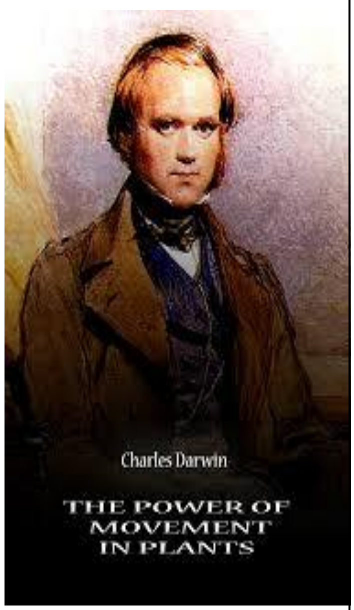


Fig-2: Darwin's experiment on plants' power of movement in *Clematis vitalba*:

Witnessing the amazing ways in whichtrees can renew themselves would have been wonderfully mysterious to people and given them the impression that trees have powers of life beyond the normal.By comparison, bees can only retain memories of places to find honey for three days. But the touch me not plant, *Mimosa pudica* appeared to be able to "remember" the difference between an apparent and a real threat and retained this discrimination in their memory (see fig-5A). Orchids use sex pheromones to attract insects rather than the enticing smell of nectar. The insects are drawn inside because they experience a chemical message from the orchid similar to the one they get from a female of the same species (see fig-5C). Having entered the orchid, attracted by this scent, they are then manipulated by the orchids in intriguing ways: They are taken through mazes, in which they pick up pollen, or flip trap doors that shut them inside the orchid. When the bees fly out, they are super-charged sexually and so attract more females. If a tree is attacked by insects, pheromonic chemicals are distributed through the mycorrhizal fibers beneath the soil, as well as being blown through the air by the trees, to warn other trees that an insect attack is imminent and to prepare themselves by producing more tannin in their leaves.

Oscillations and overshoot in the approach of seedling shoots or roots to the vertical after horizontal displacement have been reported, for example, by Johnsson and Israelsson (1968). Johnsson (1979) lists a further 23 earlier references that report this behaviour. Bennet-Clerk and Ball (1951) detailed the gravitropicbehaviour of many individual rhizomes and report overshoot, undershoot, growth initially in the wrong direction and sustained oscillations. Bose (1924) used continuous recording to report that the behaviour of petioles, roots, styles and leaflets of *Mimosa* to thermal, mechanical and light stimuli often oscillated in their approach to a new state of growth. When leaves are deprived of water, stomata reduce aperture size, but a tendency to overshoot and oscillations in the new steady state have both been reported (Raschke, 1970). It was detected oscillations of the average stomatal aperture determined by porometry in different regions of maize leaves. Following mild water stress there is often a period of compensatory growth after re-watering, indicating an error-correction mechanism (Stocker, 1960). Trees can abscind sufficient leaves to adjust numbers to current water supplies. This is why deciduous trees shed their leaves during winter when there is scarcity of water. Some trial-and-error mechanism must determine when sufficient have been dropped (Addicott, 1982). Similar mechanisms must be present for all phenotypically plastic processes. Thus, for example, stem thickening in response to wind sway must be able to access the goal of optimal wind sway and a trial-and-error assessment of how far the individual is from that goal. Resistance to drought or cold can be enhanced by prior treatment to milder conditions of water stress or low temperature (Griffiths and McIntyre, 1993). Such well-known behaviour (acclimation) requiring physiological and metabolic changes are analogous to animal learning. Mammalian sex hormones such as 17-beta-estradiol and rosterone, testosterone or progesterone, are reported to be present in 60-80% of the plant species investigated. Enzymes responsible for their biosynthesis and conversion were also found in plants (Janeczko and Skoczowski, 2005).

One of most enigmatic and astounding characters of plants, especially trees is ascent of sap or upward movement of water through stem which is about 300 ft tall. The water moves up to this height from the roots which are spread very deep in soil. Amazingly it largely occurs by a passive process called transpiration pull. We have made so much advancement in science and technology but we are unfortunately cannot emulate this feet of plants. If we can achieve we will be able to save a huge amount of energy spent on pumping water in sky scrapers.

Plants display all the necessary “components” of intelligent behavior assuming that their plastic, flexible development is behavior they continuously record and evaluate a complex field of external stimuli, forming thereby something which could be described as an “inner representation” or a “cognitive map” of the environment, including information about qualitative and quantitative aspect of light conditions, humidity, temperature and other biotic and abiotic environmental inputs (Trewavas, 2009). Plant’s behavior attributes to the intelligence of any other system that simultaneously exhibits observable behavior (e.g., development), individual variability and adaptivity, which can be understood as Darwinian fitness, it will also involve some aspects of learning and memory. Plants store a wealth of data about their history in the structure of their bodies. Given the permanent character of cell walls, every branch and twig holds information about the past. Plants, like many other living beings, modify their metabolic, regulatory and developmental processes according to the conditions of the environment, including novel stimuli. Convincing examples of gradual adaptation of plants modifying their size and growth rate in the presence of an herbicide (phosfon D) or ether, i.e., compounds they never met before (Trewavas, 2005).

EXPERIMENTS ON THE INTELLIGENCE OF PLANTS

Paranormal perception in plants

The notion that plants are capable of feeling emotions was first recorded in 1848, when Gustav Fechner, a German experimental psychologist, suggested that plants are capable of emotions and that one could promote healthy growth with talk, attention, attitude and affection (Michael, 2004). Indian scientist, Sir Jagadish Chandra Bose (1924) conducted experiments on plants in the year 1900 (see fig-2). Bose invented various devices and instruments to measure electrical responses in plants. In the 1960s Cleve Backster, conducted research that led him to believe that plants can communicate with other living organisms.

Plants' brain

Recent advances in plant molecular biology, cellular biology, electrophysiology and ecology, unmask plants as sensory and communicative organisms, characterized by active, problem solving behavior (Baluška et al, 2009). Charles Darwin conducted several experiments together with his son Francis, which represent a breakthrough in plant biology. Darwins concluded that the 1.0–1.5-mm region from the root tip is the most sensitive zone. Recent researchers' findings have supported the "Darwins' 'Root-Brain Hypothesis". According to which transition zone in roots acts as 'brain-like' command center in plants (see fig-1).

Baluška et al, (2009) have also confirmed similar zones in maize roots and also in the root apices of *Arabidopsis thaliana*, rapid cell elongation, the hallmark for the elongation region. transition zone of the root plays a unique role in the continual development of the actin cytoskeleton as the cells within the root are gradually displaced from apex to base by their own growth and division. From a perinuclear F-actin network with no particular orientation and which is characteristic of meristematic cells, is fabricated a system of prominent actin bundles in the form of inverted conical arrays which contact perpendicularly and then align in parallel with the transverse cross-walls where they proceed to reassemble as dense meshworks of F-actin. One of the first proteins shown to be involved in the local polarized recycling of membranes within cells of root apices was the auxin efflux carrier, PIN1. Findings suggest that PIN efflux carriers transport auxin into both the endosomes and the endocytic recycling vesicles, the interiors of which topologically correspond to extracellular space. Growing root apices are well-known to screen the numerous abiotic and biotic parameters of their environment and to respond to them with either positive or negative tropisms. Sensory areas are typically at the apices of organs whereas the responsive motoric areas are located basally which implicates long-distance transmission of sensory signals. This, in effect, is an animal-like sensory-motoric circuit which allows adaptive behavior. More often than not, roots live in darkness. If dark-grown roots are illuminated, they perform a negative phototropism, apparently in an attempt to escape to a dark environment.

Illumination of *Arabidopsis* roots is associated with a speeding-up of root growth, further supporting the idea of an escape response.

Vision in plants

There is no doubt about the fact that plants can see. Plants definitely have vision and it was Charles Darwin who revealed this in describing how a potted plant grows towards a window (see fog-3A). Although plants are sessile organisms, almost all of their organs move in space and thus require plant-specific senses to find their proper place with respect to their neighbours. Recent studies have suggested that plants are able to sense shapes and colours via plant-specific ocelli (Baluška and Mancuso, 2016). Light plays a major signaling role in plant development is not surprising. The photosynthetic productivity of the plant depends on its capacity to sense, evaluate and respond to light quality, quantity and direction. Plants have their own light sensors throughout their stems and leaves. These allow them to differentiate between red and blue and even see wavelengths that we cannot, in the far red and ultraviolet parts of the spectrum. Plants also see the direction light is coming from, can tell whether it is intense or dim and can judge how long ago the lights were turned off. As sessile organisms, plants have acquired a high degree of developmental plasticity to optimize their growth and reproduction in response to their ambient environment, such as light, temperature, humidity, and salinity. Plants utilize a wide range of sensory systems to perceive and transduce specific incoming environmental signals. Light is one of the key environmental signals that influence plant growth and development. In addition to being the primary energy source for plants, light also controls multiple developmental processes in the plant life cycle, including seed germination, seedling de-etiolation, leaf expansion, stem elongation, phototropism, stomata and chloroplast movement, shade avoidance, circadian rhythms and flowering time. Plants can monitor almost all facets of light, such as direction, duration, quantity and wavelength by using at least four major classes of photoreceptors: phytochromes primarily responsible for absorbing the red (R) and far-red (FR) wavelengths (600–750 nm) and three types of photoreceptors, cryptochromes, phototropins and zeaxanthins perceiving the blue, ultraviolet-A (UV-A) region of the spectrum (320–500 nm).

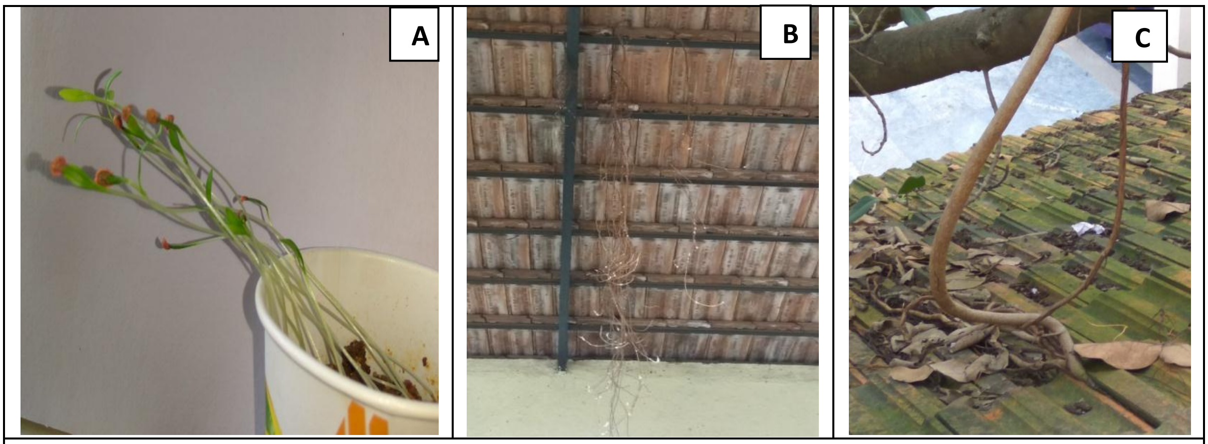
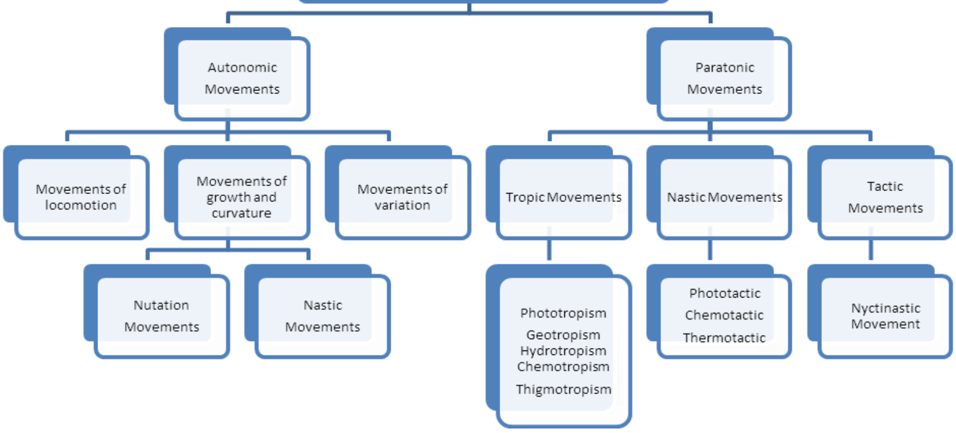


Fig-3: Intelligent plants. 3A- Coriander seedlings showing phototropism; 3B-Prop roots of banyan plant coming through the tiles of roof, a geotropic movemesnt; 3C-Prop roots of banyan plant piercing through the tiles of roof.

Movements in plants

The movement of plant structures in response to stimuli is very interesting. It involves a cascade of biochemical and biological activities and hence it is unquestionably an act of intelligence. When observing plants, usually it will not be clearly noticeable to see them moving by their own. They seem relatively immobile, stuck to the ground in rigid structures. But for careful watchers as Darwin was in the 19 century, it is quite clear that plants do produce movements and sometimes rapid ones. Plants not only produce movement but these movements can be quite rapid such as the closing traps of carnivorous plants, the folding up of leaflets in some It is interesting study the aerial prop roots in banyan trees. They grow into thick woody trunks which, with age, can become indistinguishable from the main trunk. Old trees can spread out laterally, using these prop roots to cover a wide area (see fig 3A and 3B). Leguminosae species and the movement of floral organs in order to increase cross pollination. There are several types of in plants which are broadly classified into paratonic (induced) and autonomic (spontaneous) movements. These two basic types are further divided an in the figure (see fig-4). Rapid plant movement encompasses movement in plant structures occurring over a very short period, usually under one second. For example, the Venus flytrap closes its trap in about 100 milliseconds (Forterre et al, 2005). The dogwood bunchberry's flower opens its petals and fires pollen in less than 0.5 milliseconds. The record is currently held by the white mulberry tree, with flower movement taking 25 microseconds, as pollen is catapulted from the stamens at velocities in excess of half the speed of sound—near the theoretical physical limits for movements in plants (Taylor et al, 2006).

Fig-4: Movements in Plants



Stomatal guard cells are unique as a plant cell model and, because of the depth of present knowledge on ion transport and its regulation, offer a first look at signal integration in higher plants. A large body of data indicates that Ca^{2+} and H^{+} act independently, integrating with protein kinases and phosphatases, to control the gating of the K^{+} and Cl^{-} channels that mediate solute flux for stomatal movements. Oscillations in the cytosolic-free concentration of Ca^{2+} contribute to a signaling cassette, integrated within these events through an unusual coupling with membrane voltage for solute homeostasis (Blatt, 2000).

Plants' response to sound and music

There is no doubt that plants do not have specialized structures to perceive sound like animals, but a new study on *Arabidopsis thaliana* has found that plants can discern the sound of predators through tiny vibrations of their leaves and beef up their defenses in response. Scientists of University of Missouri have found a hearing process in plants, called "priming," can be triggered by sound alone. The study revealed that, despite not having brains or nervous systems in the traditional sense, plants are surprisingly sophisticated. They can communicate with each other and signal impending danger to their neighbors by releasing chemicals into the air. Peter Tompkins and Christopher Bird (1973) documented many scientific, statistically-significant studies done on the fascinating relationship between sound and music and plants. They opined that the right sounds can produce tremendous improvements in growth of plants and the wrong sounds can do just the opposite. Plants are said to be more aware of their surroundings than we know. This is a highly complex mechanism which needs to be understood fully. Singh, TC of Annamalai University in India, conducted many experiments with Indian plants and music, with amazing results (Peter

Tompkins and Christopher Bird, 1973). Eventually, he stimulated rice harvests that were from 25-60% higher than average and nearly 50% higher for peanuts and tobacco. Experiments were done on many other plants and had "proven beyond any shadow of doubt that harmonic sound waves affect the growth, flowering, fruiting and seed-yields of plants". Two researchers at the University of Ottawa did trials with high-frequency vibrations in wheat. Plants responded best to a frequency of 5000 cycles a second. They were baffled and could not explain why audible sound had nearly doubled wheat harvests.

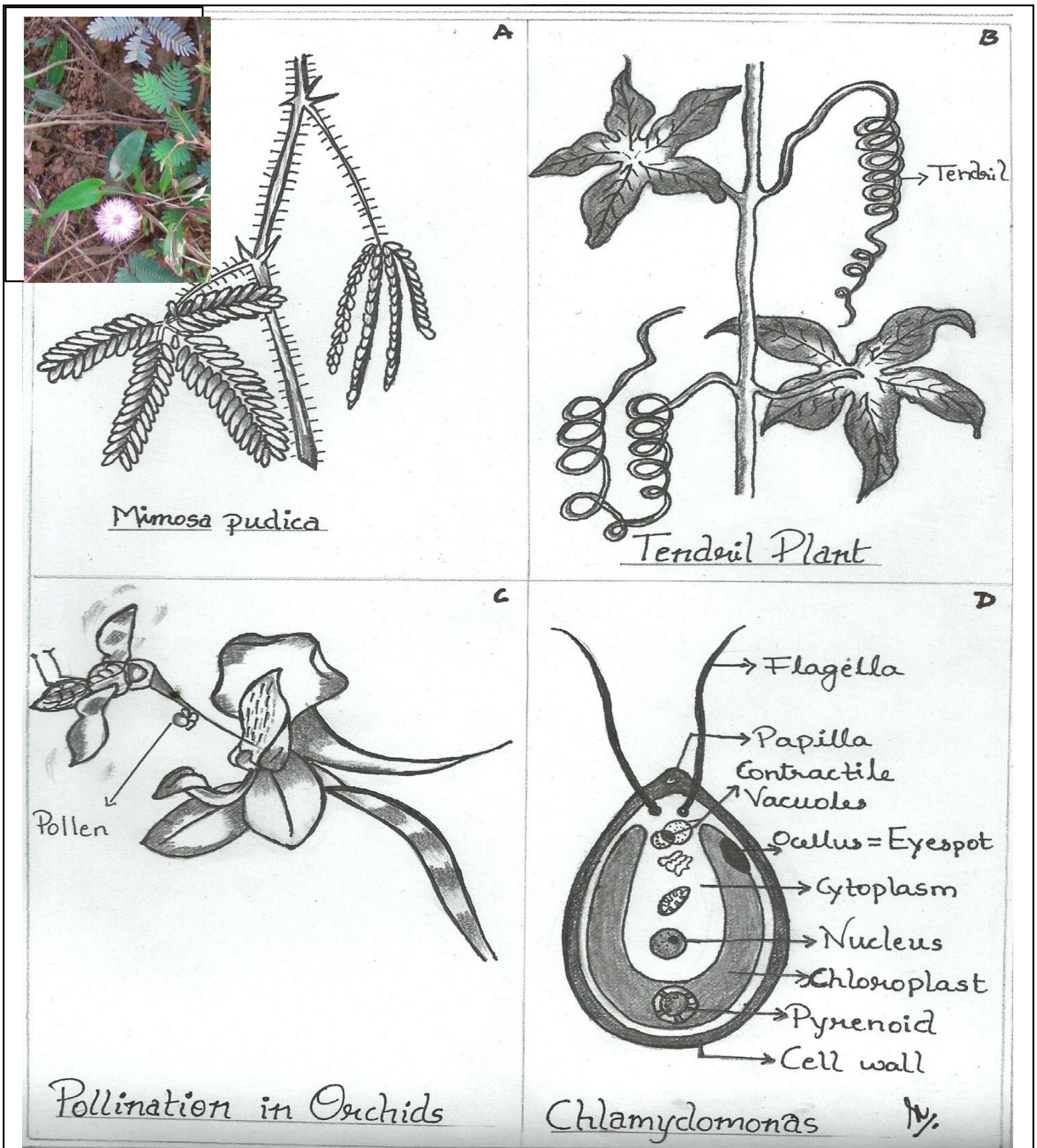


Fig-5-Intelligent plants: 5A-*Mimosa pudica* showing thigmonastic movement; 5B Curvature movements shown by tendrils: 5C- Insect pollination in orchids is an example of co-evolution; 5D- *Chlamydomonas* shows phototactic movements and it is used as a model organism for various studies

Allelopathy

Allelopathy is widely understood as the harmful effect that one plant has on another plant due to chemicals it releases into the environment. It is beneficial or harmful effects of one plant on another plant, both crop and weed species, from the release of biochemicals, known as allelochemicals, from plant parts by leaching, root exudation, volatilization, residue decomposition and other processes in both natural and agricultural systems. Allelochemicals are a subset of secondary metabolites not required for metabolism (growth and development) of the allelopathic organism. Allelochemicals with negative allelopathic effects are an important part of plant defense against herbivory (Stamp, 2003). Allelopathic inhibition is complex and can involve the interaction of different classes of chemicals, such as phenolic compounds, flavonoids, terpenoids, alkaloids, steroids, carbohydrates and amino acids, with mixtures of different compounds sometimes having a greater allelopathic effect than individual compounds alone. Selective activity of tree allelochemicals on crops and other plants has also been reported. For example, *Leucaena leucocephala*, the miracle tree promoted for re-vegetation, soil and water conservation and livestock nutrition in India, contains a toxic, non-protein amino acid in its leaves that inhibits the growth of other trees but not its own seedlings. *Leucaena* species have also been shown to reduce the yield of wheat but increase the yield of rice.

CONCLUSIONS

Plants are bombarded by a myriad of signals. As a consequence, they have evolved a remarkably sophisticated system of receptors and signal transduction pathways that generate appropriate responses. The difficulty in studying any plant behaviour is that time scales differ from those in animals. Whereas human beings operate in seconds, plants usually operate in weeks and months. Even though bamboos can grow a centimetre an hour, without some sort of recording device it would be extremely difficult for any human to observe this phenomenon. The other problem that botanists have with using the words 'plant intelligence' are incorrect assumption about animal intelligence, which is often equated with human intelligence. Apart from the fact that the major form of expression of animal intelligence is movement rather than growth and development, as defined here for plants. Does it matter if intelligence is used to describe plants' intelligent behaviour? If intelligent behaviour is an accurate description of what plants are capable of, then why not use the term? The next question that arises immediately is how it is accomplished in the absence of a brain.

Intelligent behaviour is indeed an emergent property that results from cellular interactions in plants, just as it is in the brains of animals. Whatever the mechanism, the end result usually comes from the distinctive behaviour of meristems. There must then be important conduits of proper information flow, as distinct from nutrients, from the rest of the plant into meristems. We must not sacrifice some potentially interesting observations that plants exhhibit for the sake of mere safety. We should raise the status of plant intelligence from a mere metaphor to an explanatory network akin neural network. Nevertheless, even on the basis of the mere memory criterion we could exclude some phenomena that were promising at the first glance but turned out to be explainable by models not including memory. We do not claim that such memory-less models are correct; we merely suggest that phenomena without clear involvement of memory should be left out from the discussion on plant intelligence until at least some less controversial cases are well characterized. Plants respond magnificently to environmental stimuli by movement and changes in morphology. They also very successfully communicate while actively competing for resources. Sometimes they do it better than humans. In addition, plants accurately compute their circumstances, use sophisticated cost–benefit analysis and take tightly controlled actions to mitigate and control diverse environmental stressors. Unfortunately scientists have not discovered any brain or neuronal network. It is said that the reactions within signaling pathways may provide a biochemical basis for learning and memory in addition to computation and problem solving. Never the less plants'intelligence should be appreciated and investigated with the help its complex network of signaling, memory, response to countless stimuli and many such astonishing characteristics.

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