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Role of plant metabolites in plant protection and their potential in integrated pest management

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Abstract
Chemical transformations that occur in the cells of living creatures are classified as metabolism, and these are required for the organism's survival. Metabolites are the end products of metabolic processes as well as intermediates generated during metabolic processes. There are two types of metabolites produce by plants, one is primary metabolites and other is secondary metabolites. A primary metabolite is one that has a direct role in proper growth, development, and reproduction. Plant secondary metabolites provide a variety of functions, including disease, insect, and herbivore defence, stress response, and modulating organism interactions.

Keywords: Metabolites, cell, botanicals, management, organism

Introduction
Primary metabolites serve a physiological purpose in the body. Primary metabolite is known as central metabolite and it is present in many cells and organisms that mean it can be found in any self-growing cell or organism. Primary metabolites examples include lactic acid, certain amino acids and ethanol. Secondary metabolism, as contrast to primary metabolism, refers to metabolic pathways and their associated tiny molecular products that are not required for the organism's development and reproduction (Yang *et al*., 2018) [55]. Secondary metabolic processes in plants produce a variety of chemicals known as plant secondary metabolites (PSMs). PSMs constitute a high number of structurally varied molecules derived either from primary metabolites or intermediates in these primary metabolites' metabolic pathways (Piasecka *et al*., 2015) [40] (Table.1). According to their biosynthetic pathways, PSMs are classified into many large molecular families according to their biosynthetic pathway: terpenes, phenolics, steroids, flavanoids and alkaloids (Kessler *et al*., 2018) [25].

Table 1: Roles of plant primary metabolites

Compounds	Roles in plants
Carbohydrates	Respiration, structural component, energy source, food storage
Proteins	Growth and development, catalyzing reaction, membrane formation, transporters
Lipids	Plant external structure, energy storage, structural component
Hormones	Help in plant to sense light, forming lateral roots, flower development and germination

Plant secondary metabolites, whether constitutive or induced, C- or N-based, play an important role in plant-insect interactions. Insect anti-herbivore defences can be used as repellents, deterrents, growth inhibitors, or direct mortalities. Insects have developed a number of tactics to combat plant poisons, including toxin avoidance, excretion, sequestration, and degradation, eventually leading to a co-evolutionary arms race and co-diversification. Pests are among agriculture's most important issues nowadays. Even though there are numerous methods for reducing or eliminating pests, each has its own set of disadvantages. Commercially available synthetic pesticides include halogenated hydrocarbons or organophosphates, which have longer half-lives in the environment and are thought to have more toxicological features than most natural chemicals. Because of the aforementioned and other considerations, there is an increasing demand for ecologically friendly, toxicologically safe, more selective, and efficacious pesticides and here botanicals play important role.

Plant Defences and Secondary Metabolites

Plants have developed a wide range of herbivore defence tactics, including the creation of a wide range of chemical substances. Chemical defence chemicals can range from low molecular weight molecules known as secondary metabolites to insect-killing peptides and proteins. Organic substances that are not directly engaged in the regular growth, development, or reproduction of plants are known as secondary metabolites (Macias *et al*., 2007) [30]. Plant toxins have a wide range of insecticidal properties: they can operate as repellents or feeding deterrents, or they can cause direct toxicity, resulting in symptoms ranging from larval or insect growth inhibition to death. In constitutive resistance, some of these substances are always synthesised in the plant, whereas in induced resistance others are only synthesised after the plant has been damaged (Baldwin *et al*., 1999) [5]. Only in the case of an insect attack do induced defences rely on mobile metabolites with a low molecular weight that are created at a low cost (Heil *et al*., 2002) [19]. Such molecules frequently contain one or more nitrogen atoms, and their biosynthetic pathways are derived from those of proteic amino acids, with a potential trade-off between N-containing metabolite production and plant development. Constitutive defences, on the other hand, rely on carbon-based metabolites like terpenoids and polyphenols, which can reach high levels of dry matter content in the plant and collect in specialised structures or compartments like the resin canals in coniferous trees' xylem (Sampedro *et al.*, 2011) [47].

Effect of repellent

Observations of insect attraction vs. repellence by plant scents in the field and in the lab have led to ground-breaking research in the field of plant-insect interaction. Linalool, a monoterpene alcohol generated by flowers of *Phlox paniculata*, has been discovered as the primary repellant against the ant *Nasius niger* using genetically engineered plants without smell bouquets (Junker *et al.*, 2011) [23]. Volatile and non-volatile chemicals acting after intimate contact with the insect and the plant can both operate as repellents. Only apigenin, a flavone found in the invasive plant *Lonicera maackii*, appeared to be efficient in discouraging feeding by the generalist insect *Spodoptera exigua*, while the similar flavone luteolin had no impact (Cipollini *et al*., 2008) [11]. The repelling action of the plant chemicals causes a change in the foraging behaviour of the insects. Because insects avoid a certain plant or group of plants those produce repellent compounds, some insects that tolerate or even prefer these compounds have a competitive advantage. By examining the molecular makeup (glucosinolates) and herbivory predation of twelve wild cabbage *Brassica oleracea* populations at the same time it was shown that the plants that produce progoitrin were consistently chosen by aphid *Brevicoryne brassicae* (Newton *et al*., 2009) [34]. Protogoin production was favourably connected with *Brevicoryne brassicae* infection at the population level, but sinigrin production was negatively correlated with damage caused by the whitefly *Aleyrodes proletella*. In natural wild cabbage populations, herbivore differential selection influences the maintenance of considerable inter- and intra-population variance in glucosinolate chemotypes.

Toxic Effects, Growth Inhibitor

Many plant chemicals function as insect growth inhibitors, with effects ranging from delayed development to significant reductions in death and fecundity, depending on the dose ingested. The consumption of luteolin flavone, for example, has severe negative effects on *Spodoptera exigua* caterpillars. Many plant chemicals function as insect growth inhibitors, with effects ranging from delayed development to significant reductions in fecundity and death, depending on the dose ingested. The ingestion of luteolin flavone, for example, caused severe harm to *Spodoptera exigua* caterpillars (Wang *et al*., 2010) [54]. Despite the fact that it had no effect on their feeding activity in a previous study (Cipollini *et al*., 2008) [11]. After 11 days, a 2 g/L concentration caused 43% mortality, and surviving larvae were 50% lighter than control larvae. Furthermore, compared to the control, both pupation and emergence rates were lower. This type of substantial detrimental impact of plant toxins at all stages of insect development slows population expansion and favours insects that can overcome the plant's defences known specialisation.

Tannins' Pleitropic Function

Tannins have important role in plant defence, Because of their propensity to complex proteins, tannins have been extensively studied as plant defence compounds. However, contrary to early beliefs (Feeny *et al*., 1968) [17] and what happens in vertebrate herbivores, tannins appear to have little effect on protein digestion in insect herbivores (Salminen *et al*., 2011) [45]. Studies suggest that toxicity in insect guts with high pH levels is more likely owing to oxidation mechanisms that produce semiquinone radicals and quinones, as well as other reactive species (Barbehenn *et al*., 2008) [6]. However, whether the fatal lesions identified in the midgut, particularly in the peritrophic envelopes of the caterpillar *Orgyia leucostigma*, may be directly linked to the tannins or to oxidative stress is yet unknown. Hydrolysable tannins, whose hydrolysis is aided by the insect digestive tract, are also likely to behave differently than less biodegradable condensed tannins (Salminen *et al*., 2002) [46].

Insects developed strategies to combat plant chemical defences

Insects have evolved a number of strategies to combat plant toxins, including ingestion avoidance, sequestration, excretion, target-site insensitivity and toxin degradation (Despres *et al*., 2007) [14]. Plant poisons function as a deterrent and change insect foraging behaviour in the event of behavioural avoidance. The nutrition dilution hypothesis proposes that insects can reduce toxin ingestion by eating a more diverse food, resulting in little levels of poisons specific to each plant species being consumed (Hagele *et al*., 1999) [18]. Insects defend themselves against plant poisons by decomposing and excreting them through a number of metabolic pathways (Despres *et al*., 2007) [14], often with the assistance of a symbiosis partnership (Despres *et al*., 2007) [14]. Plant chemicals, as like pigments for adult colouring or pheromones (Nishida *et al*., 2002) [35], can be sequestered and employed as a protective agent against predators or infections (Ode *et al*., 2006). The most well-known example is caterpillars of monarch butterfly sequestering the cardenolides released by their host plants like milkweed, the plant's chemical defence is utilised as defence against predators at both the larval and adult stages. As evidenced in the *Utetheisa ornatrix*, arctic moth (Eisner *et al*., 1995) [16], plant poisons may potentially play a significant role in sexual selection.

Role of botanicals

Botanicals, as plant secondary metabolites, provide an appealing and advantageous pest management option (McLaren, 1986) [32]. Plant secondary metabolites also are implicated in plant interactions with other species, particularly in the plant's defence response to pests, according to scientific evidence. As a result, the botanicals, or secondary compounds, represent a substantial reservoir of chemical structures having pesticidal activity (Klocke, 1987). Pesticides can be made from this resource, but it is mainly unexplored. Botanical pesticides have various advantages, including rapid breakdown by sunlight and moisture or through detoxifying enzymes, target specificity, and low phytotoxicity, all of which encourage researchers to use botanicals for pest management. Secondary metabolites produced by higher plants includes terpenes, alkaloids, lignans, phenolics,their glycosides. These play an important part in the plant defence system and provide a variety of structural prototypes for the development of lead compounds that could be used as novel pesticides (Lydon *et al*., 1989) [29].

Table 2: Name of compounds extracted from different plants

Name of compounds	Plants from which compounds extracted
Nicotene	*Nicotiana tabacum*
Pyrethrum	*Chrysanthemum cinerariifolium*
Rotenone	*Derris elliptica,*
Sabadilla	*Schoenocaulon officinale*
Ryania	*Ryania speciosa*
Limonene	*Citrus paradisi*
Azadiractin	*Azadirachta indica*

Botanical pesticides have a longer discovery process than synthetic pesticides, but they have a lower environmental impact, making them an appealing alternative. Despite their prior modest efforts in the production of botanical pesticides, they have had a significant impact in the field of insecticides. The majority of botanicals are non-toxic to plants (non phytotoxic). However, some ornamentals and vegetables and may be hazardous to nicotine sulphate. Botanicals are more expensive than synthetics, and some are no longer available commercially like Nicotine. Some botanicals' strength varies from one source to next. Some botanicals lack data on efficiency and long-term (chronic) toxicity in mammals. Except for nicotine compound from pyrethrum, rotenone, sabdilla, rynia, limonene and azadirachtin, most have little toxicity in animals and birds and have few negative environmental consequences (Prakash *et al*., 1997) [41] (Table.2). Insecticides made from natural ingredients are becoming more popular as crop pesticides in recent times. Organically synthesised insecticides are more dangerous, leave harmful residues in food, and are difficult to biodegrade; in addition, they have negative effects on the public health and environment. Organic insecticides are relatively ineffective against predators, unlike manufactured pesticides that kills both pests and predators altogether. The majority of botanical pesticides are biodegradable, and its supply can be increased at a lower cost by regular cultivation. Though botanical insecticides is not quite as effective as synthetic insecticides, natural insecticides isolated from plants as their semi-purified state have a slow-acting, preventive activity. Rotenone of *Derris elliptica*, pyrethrins from Chrysanthemum cinerariaefolium, nicotine from tobacco leaf & azadirachtin from Azadirachta indica are among the natural insecticides that have reached commercial significance. An in-depth chemical analysis of neem seeds reveals that azadirachtin, a highly oxygenated molecule and complex one from class tetranortriterpenoid, is the most effective growth disruptor and antifeedantto several insects. Antifeedant chemicals do not kill insects right away; rather, when applied to stored grains, insects or sprayed on crops would rather starve to death than eat the treated food. Pyrethrums, derived from *C. cinerariaefolium*, are among the most widely used plant insecticides. They are primarily utilised as a household insecticide because they are nontoxic to humans and warm-blooded animals and are light sensitive. Pyrethrum I and II, as well as cinerin I and II, are the four primary components in Chrysanthemum (Verma *et al*, 1999) [31]. Synthetic pyrethroids made from pyrethrins seem to be chemically identical to pyrethrins, but they are more heat and light stable outside. Pyrethroids are neuroexcitatory, which means, particularly with in sensory nervous system they cause increased repeated nerve activity (Vijverberg *et al*., 1990) [53]. Pyrethrum is the most widely used botanical pesticide, accounting for 80% of global sales (Isman, 2005) [21]. Rutales terpenes have been demonstrated to be beneficial towards stored grain pests (Omar *et al*., 2007). Anise (*Pimpinella ansium*), Cumin (*Cuminum syminum*), eucalyptus (*Eucalyptus camaldulensis*) and oregano (*Origanum syriacum var. bevanii*), essential oils were found to be excellent fumigants towards carmine spider mite (*Tetranychus cinnabarinus*) and cotton aphid (*Aphis gossypii*) (Tuni *et al*., 1998) [51]. In the hunt for botanical pesticides, an antifeedant limonoid, toosendanin found in the bark of the *Melia toosendan* and *Melia azedarach* (Meliaceae) trees, has gotten a lot of interest (Chiu, 1989; Chen *et al*., 1995; Koul *et al*., 2002) [10, 9, 27]. In the People's Republic of China, production of a toosendanin-based botanical pesticide containing around 3% toosendanin (recemic combination) as the active ingredient already has begun (Koul, 2008) [26].

Tulsi (*Ocimum sanctum*)

Ocimum is among the most important genera in the Lamiaceae family, which contains most essential oil-producing plants (Fig.1). More than 150 species have been grown and are found in tropical and temperate climates (Pandey *et al*., 2014) [38]. They are collectively called as "basils," and their fragrant, nutritional, decorative, culinary,therapeutic value and religious continues to drive commercial demand (Patel *et al*., 2016) [39]. Thai or sweet basil (*O. basilicum*), holy basil (*O. sanctum*), tree basil (*O. gratissimum*) and lemon basil are all common basil varieties (Mahajan *et al*., 2013; Juntachote *et al*., 2006) [31, 24]. Diverse basil cultivars have been shown to have the genetic ability to produce and maintain different sets of volatile constituents, resulting in a wide range of chemotypes in the same species (Avetisyan *et al*., 2017) [2]. The essential oils of these basils are mostly phenylpropanoids like estragole, methyl eugenol and eugenol, however, they also contain monoterpenes like neral,ocimene and geranial,, as well as sesquiterpenes like alpha- caryophyllene, gama- muurolene and beta- cubebene (Tangpao *et al*., 2018) [50]. The majority of them are biologically active in living creatures, with antibacterial and antioxidant capabilities for food and medicine (Hussain *et al*., 2008; Ademiluyi *et al*., 2016) [20, 1]. The antibacterial and analgesic properties of eugenol have been discovered in humans (Zabka *et al*., 2014) [57]. Furthermore, essential oils have a variety of biological properties that, in theory, reduce post-harvest degradation. They're commonly employed to control bean weevil (*Acanthoscelides obtectus*) (Rodriguez *et al*., 2019), cotton bollworm (*Helicoverpa armigera*) (Singh *et al*., 2014) [48] and rice weevil (*Sitophilus oryzae*) (Bhavya *et al*., 2018) [7], in insect pest management. The propensity of methyl eugenol to attract fruit flies (*Bactrocera dorsalis*) (Tan *et al*., 2012), among important tropical fruit pest has been highlighted (Canhanga *et al*., 2020; Orankanok *et al*., 2007) [37]. With all of these benefits, it's a good idea to employ essential oil of basil as a biological control at tropical fruit development. The volatility of essential oils at room temperature, as well as exposure of extreme environment, is the drawbacks. Furthermore, in the presence of heat, light, oxygen and humidity, organic volatile molecule degrades quickly (Dharanivasan *et al*., 2017) [15].

Fig 1: *Ocimum sanctum*

Lantana (*Lantana camara)*

An erect shrub *Lantana camara* found across the tropics has insecticidal properties against a variety of insects (Fig.2). The extracted oil contains a variety of secondary metabolite chemicals. Its leaf extract contains Flavonoid, Steroids, Tannins, Saponins and Glycerol in all three solvents, but Alkaloids are only present in the methanol and ethanol extracts compounds, according to early phytochemical screening. These phytochemical compounds are responsible for the plant leaf extract's experimental insecticidal properties (Rajashekar *et al*., 2014) [42].

Fig 2: *Lantana camara*

Neem (*Azadirachta indica*)

The Indian subcontinent's native neem (*Azadirachta indica*) (Meliaceae) is known as the 'Village Pharmacy,' 'Wonder Tree,' 'Botanical Marvel', 'Gift of Nature' and all-can-treat-tree. Neem has a lot of potential in environmental protection, medicine and pest control. Neem's flower, bark, leaf and seed, all have insecticidal properties, but the seed kernel is the most powerful (Fig.3).The neem tree's compounds are effective insect growth regulators and also aid in the control of fungus and nematodes (Subbalakhmi *et al*., 2012). Crude neem extracts had the strongest antifeedant efficacy against pests such as defoliators, sap-feeding insects and beetles (Chandel *et al*., 1995) [8]. Plant extracts and oils, in whatever form, have an effect on egg laying and egg hatching, altering the percentage of young produced. The strong odour of the items, as well as ovicidal activity caused by interference with embryonic development within the egg, may be the primary factors preventing oviposition. Depending on the dosage or insect stage exposed to neem, it may induce early mortality or lengthening of the larval period, as well as morphological abnormalities or the production of intermediates in insect larvae, pupae, and adults. At higher quantities, it has the capacity to kill pests (Venugopala *et al*., 2005).

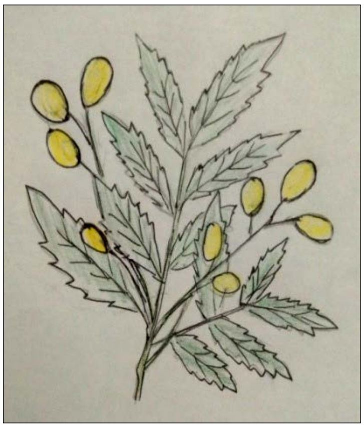

Fig 3: *Azadirachta indica*

Conclusion

Synthetic insecticides are commonly used to control a variety of insect problems. Chemical pesticides have caused a slew of environmental problems, including substantial health concerns for humans and animals, insecticide resistance, the eradication of natural adversaries, and pesticide residues. The use of plant products is one of the most efficient control methods for synthetic chemical hazards. Because of their biodegradability, low persistence, minimal toxicity to non-target organisms, low cost, and ease of supply, plant products are becoming increasingly popular. In recent years, many insect pests have been identified as important limiting factors affecting crop output and productivity. Insect pest scenarios in numerous crops have changed due to changes in crop ecology. To prevent environmental hazards by the use of insecticides it is more convenient to use botanicals for pest management.

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