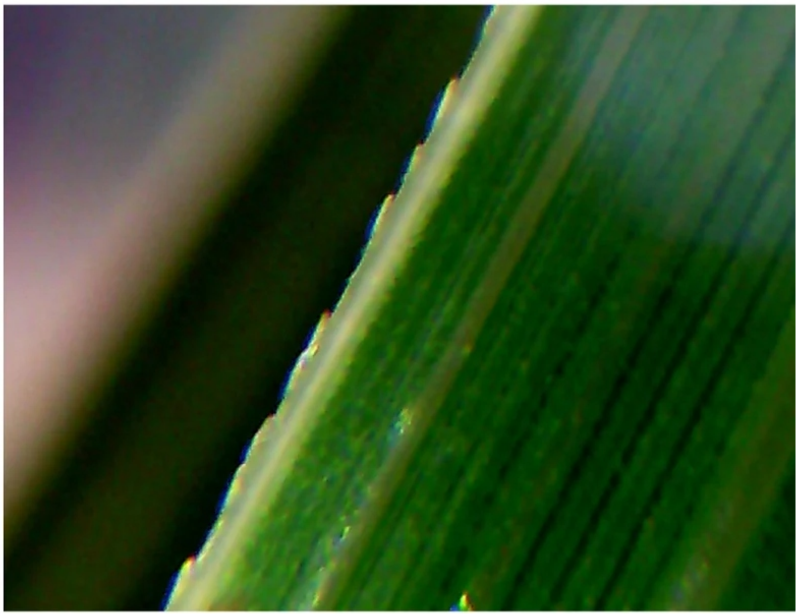
HANDBOOK OF PLANT DEFENCE

Shailendra Singh Gaurav
Shakuli Saxena



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CHAPTER 1

AN OVERVIEW OF THE COMPLEX REALM OF PLANT DEFENSES

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ABSTRACT:

Plants devote a significant amount of energy and resources to the development of their stems, leaves, roots, and reproductive organs, leaving them open to herbivore feeding. Plant features that reduce herbivore damage are favoured by natural selection, which promotes the development of different defence systems. This study examines the many tactics used by plants to discourage herbivores and lessen the damage they do. Both constitutive and induced defences are present in plants. Constitutive defences include structural elements like spinescence, trichomes, and stiff leaves, which are always present in the plant. Plant resilience is aided by chemical defences like secondary metabolites and inorganic substances like calcium and silica. When an herbivore is present, injured, or given environmental signals, induced defences are triggered, which lowers the expense of maintaining defences when they are not required. Secondary metabolites, which may either be qualitative (toxic) or quantitative (requiring greater concentrations), are used by plants as chemical defences. These supplementary compounds may discourage herbivores or lessen the plant's ability to be digested. Phytoliths and calcium oxalate crystals are examples of inorganic, elemental defences that further dissuade herbivores and may induce kidney stones in individuals who ingest them. By attracting herbivore and predator predators, plants may also indirectly protect themselves.

KEYWORDS:

Chemical Defences, Elemental Defences, Herbivores, Organic, Plant Defences.

INTRODUCTION

Predatory insects get energy-rich rewards from extrafloral nectaries and food sources, while volatile organic compounds (VOCs) warn herbivores of their presence and draw in their natural adversaries. Some plants even interact with their neighbours, releasing VOCs that activate defence mechanisms. Another tactic used by plants is the creation of spatial and temporal refuges. These areas are considered refuges, as are fleeting flowering intervals that correspond with herbivore hibernation. Associational resistance occurs when plants alter their volatile organic compounds (VOCs) to fend off herbivores or make the environment more complicated, making it difficult for herbivores to find their favourite host. Overall, a wide range of complicated mechanisms, including structural, chemical, and indirect tactics, are used by plants to defend themselves against herbivores. The delicate interaction between plants and herbivores has been shaped by these defences through millions of years, with ramifications for ecology, agriculture, and human health. Understanding these defence systems is essential for dealing with problems caused by herbivores and comprehending how plants and herbivores have evolved together.

The relationships between plants, herbivores, and their predatory foes are exploited via indirect defences. Plants may emit volatile organic compounds (VOCs) to tempt or attract predators by offering food rewards. This covert defence mechanism may lessen herbivore harm. In order to lessen the effects of herbivores, plants may also hide from them in refuges in space or time, alter their appearance to deter overconsumption, or even change their development cycles. A complex interaction of adaptations and counter-adaptations has resulted from the co-evolution of plants and herbivores. Herbivores have developed methods to get beyond plant defences, and some even take advantage of them. In addition to being essential for ecological study, understanding plant defences against herbivory has applications in both agriculture and medicine. Human food, medications, and pest control all benefit from the use of several plant compounds having defensive qualities [1], [2].

To produce stems, leaves, roots, and reproductive parts, plants must expend energy and nutrients. The reduced capacity of plants to produce progeny as a result of herbivores consuming these tissues. Natural selection thus favours plant characteristics that reduce the harm caused by herbivores. Some plants have developed a resistance to herbivory, developing replacement tissues so quickly that reproduction may sometimes increase in the presence of light damage. Other plants, in contrast, have acquired resistance to herbivores or features that lessen their consumption. Natural selection favours herbivores that outcompete plant resistance because herbivores depend on plants for food, which causes plants to develop new defence mechanisms in response. Terrestrial plants have developed a broad range of resistance features as a consequence of this evolutionary struggle between plants and herbivores, including decreased apparency to herbivores and structural, chemical, and indirect defences. More information on these resistance characteristics is provided below.

Some plants reduce their visibility to herbivores or "hide" from them in refuges in space or time. Inaccessible to or concealed from herbivores physically, as when plants grow on cliff ledges and plateaus in the case of geologic refuges, these habitats are known as spatial refuges. Areas above or below the reach of herbivores, such as when grazing spurs plant growth close to the ground for non-woody plants, or above the browse line for trees and shrubs, may serve as additional spatial refuges. As an alternative, some plants benefit from transitory refuges by expanding or blooming while herbivores are infrequent or dormant. Biotic refuges also known as associational resistance occur anytime a plant lowers the likelihood that herbivorous animals would discover and eat nearby plants of a different species. A number of mechanisms may lead to associational resistance. First, certain plants have the ability to exude volatile organic compounds (VOCs) that either cancel out or overwhelm the production of another plant's VOCs, which would typically attract herbivores. Alternatively, although there isn't much proof of this, plants may release VOCs that deter herbivores. The alternate host theory, in which associational resistance for one plant species is combined with associational susceptibility in another plant species, describes how plants may provide an alternative food source that lures herbivores away from another plant. In contrast to resistance, connection with the less favoured plant leads to associational susceptibility from the standpoint of the plants that act as the alternative food source. Finally, plants may modify the physical environment by altering the microclimate or making an area more complicated structurally, making it difficult for herbivores to locate or reach their chosen host. A poorly protected plant may become complicated when it is surrounded by dense vegetation or mixed in with other species of the same colour. Some herbivores can be avoided by plants using refuges, but tiny, mobile, or temporally adaptable herbivores are more difficult to fend off. Some plants utilise crypsis instead of refuges to elude herbivores. For instance, when touched, the sensitive plant's leaves fold and droop to resemble the look of a dead or withering plant. Stone plants, on the other hand, seem less because, as their name suggests, they resemble stones.

Structured defences may prevent herbivores from consuming a plant after they have located and accessed it. Spinescence, trichomes, large leaves, and minute sand- and needle-like particles found within plant tissues are some of these features. Sharp extensions of the epidermis known as prickles or thorns are examples of spinescence, as are modified stems or leaves known as thorns or spines, respectively. Large herbivores may be deterred by these pointed, angular projections, while smaller, more nimble herbivores like insects often aren't as well. Some plants have a coating of trichomes, or plant hairs, to protect them against herbivorous insects. Trichomes, which are epidermal extensions, may prevent insect eggs from adhering to a plant, obstruct insect movement, and, because of their disagreeable texture, restrict the ingestion of big herbivores. Trichomes may function as glands that release sticky resins or abrasive chemicals to deter big herbivores from grazing when used in conjunction with chemical defences. For instance, stinging nettle makes trichomes that are fragile when touched and release unpleasant chemicals like a syringe to deter big creatures from grazing [3], [4].

By developing stiff, unyielding leaves and stems that are difficult to chew, plants might further discourage herbivory. Woody substances like cellulose and lignin help to strengthen the stem and the toughness of the leaves. These substances have little to no nutritional value and can only be broken down by symbiotic bacteria, which may be found, for instance, in the stomachs of cows and termites. Therefore, structural components are linked to low nutritional qualities, which are often stated as high carbon-to-nutrient ratios, which reduce the advantages of eating a plant.

As a type of physical defence, certain plants retain non-toxic elements from the soil, such calcium or silica. Insect mouthparts and vertebrate teeth are subjected to increased wear from phytoliths, which are formed when silica is released into the gaps between cells. In cell walls, vacuoles, and trichomes, calcium ions may be linked to the organic anion oxalate to produce crystals that may penetrate oral tissues and cause swelling and irritation, similar to dumb cane. Feeding on plants with these structural defences increases the risk of kidney stones, which may be uncomfortable and even fatal. This is because both calcium oxalate crystals and silica phytoliths can cause kidney stones.

DISCUSSION

Chemical substances that directly dissuade herbivores from eating on a plant are examples of chemical defences. Plants develop organic chemical defences as secondary metabolites, chemicals unrelated to the fundamental metabolic processes, or endophytic mutualistic fungi. Comparatively, environmental defences must be condensed from inorganic chemicals known as elemental defences. Qualitative and quantitative defences are included in organic chemical defences. Because qualitative defences are usually successful, they are created in small amounts. The majority of qualitative defences are used in tissues with short-term susceptibility, including young, fragile leaves or seeds, and are often recycled when no longer required. For instance, certain plants generate cyanide-containing substances in their seeds that, when ingested in small amounts, may kill herbivores. The nitrogen contained in these molecules is recycled for plant development when the danger of herbivory decreases. Although generalist herbivores are often resistant to qualitative defences, specialists have evolved strategies to get around or even hijack these defences. For example, to ward against predators, monarch butterfly caterpillars stockpile superior chemical defences from milkweed in their bodies. Qualitative defences, which are a valuable resource for certain specialists, might attract herbivores, transforming the advantages of plant defence into a disadvantage.

Quantitative defences, as contrast to qualitative defences, are often effective against all herbivores but need for higher dosages. Because of this, these substances are often mass-produced and seldom recycled. Common quantitative defences known as "condensed tannins" attach to proteins and interfere with digestion, perhaps resulting in malnutrition. Other quantitative defences include substances that, when contacted, induce discomfort, swelling, or inflammation in the mouth or skin, as with stinging nettle or poison ivy. Growth rate, nutrition availability, or how easy it is for herbivores to find a plant may all have an impact on how much it depends on qualitative or quantitative defences. Organic chemical defences, regardless of how they work, lessen the motivation for herbivores to eat on a plant and, as a result, the amount of harm done.

Organic chemical defences are often found in food and pharmaceuticals used by humans. Caffeine, for instance, is among a group of qualitative defences that suppress drowsiness-inducing brain impulses. Pharmacology and ethnobotany are the areas that study the uses of defensive and other secondary substances. Toxic substances like nickel, zinc, cadmium, and lead that plants unintentionally absorbed from the soil are likely what spurred the evolution of inorganic, elemental defences. Many plants prevent poisoning by encapsulating these substances away from cell machinery in cell walls, vacuoles, or trichomes, where they remain until the plant dies or is eaten, at which point they are released. Since most herbivores are poisoned by these substances as well, plants that accumulate toxic substances known as "metal hyperaccumulators" benefit from decreased herbivory [5], [6].

Not all herbivores are intended to be deterred by chemical defences. Many plants have developed defences that exclusively target harmful herbivores because they interact with mutualistic herbivores, such pollinators or seed dispersers, for mutual benefit. For instance, chilli seeds are safe for birds to eat and are distributed in their droppings, but they are destroyed when consumed by mammals. Unsurprisingly, birds are unaffected by capsaicin, the chemical that gives chillies their fiery flavour. Indirect defences work by raising the possibility that herbivores will be attacked, chased away, or tormented by predators like ants, wasps, and mites rather than actively fighting against them. Indirect defences are frequently referred to as tritrophic or biotic defences because they depend on a third trophic level, or feeding level, in the food web. By attracting and maintaining predators on a plant with food rewards, refuge from severe weather, or chemicals signalling prey availability, plants boost the predation of herbivores. Many plants create food rewards that are high in energy to entice predators, yet they stop producing when herbivores or predators are not around or active. Nectar from extrafloral nectaries and solid food bodies are food incentives utilised in plant defence. The main purpose of EFNs, in contrast to floral nectaries, is to attract predators rather than pollinators. EFNs encourage defensive mutualisms in a variety of plants, from those that are absolutely necessary for life in myrmecophytes to those that are advantageous but not necessary. From delicate layers of nutrient-rich tissue to fruit-like appendages, solid food bodies may take many different shapes. Lipids, carbohydrates, and proteins found in these structures are a significant investment made by the plant. As a result, food bodies are exclusively found on myrmecophytes and are connected to other indirect types of defence like domatia.

Predators are protected by domatia from hostile environments and other predators. The intricacy of domatia may vary from simple shallow crevasses coated with trichomes, as in certain avocado kinds, to intricate hollow tissues with several chambers and ornate openings, like in various acacia. Domatia and food incentives may not attract predators directly, but they may make it more likely that they will stay on a plant and discourage herbivory. Volatile organic compounds are the only indirect defences that actively entice predators. These gaseous signals, which announce the existence of prospective prey, are often generated from injured plant tissues. To attract predators most suited for a certain herbivore, VOCs may change depending on the time of attack or the identity of the herbivore. For instance, broad bean plants attacked by various aphid species generate various VOCs that attract various predators. In addition to deterring predators, many VOCs also repel herbivores, such as adult hawkmoths, which avoid depositing their eggs on tobacco plants that generate predator-attracting VOCs.

Therefore, VOCs provide two protective functions by both immediately discouraging herbivores and indirectly lowering herbivory via predator attraction.

In terms of energy, resource, and opportunity costs, the resistant qualities mentioned above may be expensive. Due of the limited resources available to plants, each gain in growth or resistance must be offset by a drop in the other, a connection known as a tradeoff. Therefore, compared to slower growing species, fast-growing plant species are often less resistant to herbivory. A plant may not be able to maximise all kinds of resistance against all potential herbivores due to trade-offs that may exist across resistance features. As a consequence, plants may exhibit various resistance features that reduce consumption by various herbivores in various environments or at various periods [7], [8].

Many plants retain low baseline, or constitutive, defensive levels until increased, or provoked, by herbivore damage, VOCs, light availability, or day length. This helps them escape adverse impacts of tradeoffs. Many direct and indirect resistance features, in fact, don't manifest until after being induced by a stimulus. Plants are able to avoid devoting resources to useless resistance qualities in this manner, freeing up resources for increased growth and reproduction. A variety of plant adaptations known as host-plant resistance or plant defence against herbivory help plants survive and reproduce by lessening the negative effects of herbivores. Because they can feel when they are being touched, plants have a number of ways to protect themselves against herbivores' harm. Allelochemicals, which are secondary metabolites produced by many plants, have an impact on the survival, development, and behaviour of herbivores. These chemical defences may serve as poisons or repulsives to herbivores, or they may lessen the digestibility of plants. Plants may defend themselves by altering how appealing they are. Plants vary their appearance by altering their size or quality, slowing down the pace at which they are devoured, to avoid overconsumption by big herbivores.

Other defence mechanisms used by plants include evading or avoiding herbivores at any time or location, such as by growing in a spot where they are difficult for herbivores to find or access, or by altering their seasonal growth patterns. Another strategy encourages herbivores to consume non-essential portions or improves a plant's capacity to recover from herbivory-related harm. Some plants promote the presence of herbivores' natural enemies, which in turn defend the plant. Each sort of defence may either be induced or constitutive. The most major herbivores in the past have been insects, and insects and land plants share a strong evolutionary relationship. Other plant defences have developed that are targeted towards vertebrate herbivores like birds and mammals, even though most plant defences are geared towards insects. The study of plant defences against herbivory is crucial from an evolutionary point of view, as well as for their direct effects on agriculture, including food sources for people and livestock, as useful "biological control agents" in biological pest control schemes, and in the hunt for plants with medicinal value.

Around 450 million years ago, during the Ordovician epoch, the first terrestrial plants diverged from aquatic plants. Since iodine is solely necessary for animal cells, many plants have modified their metabolism in order to survive in an iodine-deficient terrestrial environment. Animal cells' ability to transport iodide is blocked, blocking the sodium-iodide symporter, which has significant antiparasitic effects. Many plant pesticides are glycosides and cyanogenic glycosides that release cyanide, which is harmful only to a major portion of parasites and herbivores and not to plant cells, in which it seems advantageous during the seed dormancy period due to its ability to inhibit cytochrome c oxidase and NIS. Although vegetable peroxidase transforms iodide into iodine, which is a potent oxidant capable of eliminating bacteria, fungus, and protozoa, iodide is not a pesticide.

The emergence of additional plant defence systems occurred throughout the Cretaceous epoch. The dramatic explosion of insect speciation at that period is linked to the diversity of flowering plants. A significant selective factor in the development of plants, this diversity of insects selected for plants with defensive capabilities. Early insect herbivores were mandibulate and bit or chewed vegetation, but when vascular plants developed, new types of herbivories, such sap-sucking, leaf mining, gall formation, and nectar-feeding, also evolved alongside them. The degree of defensive chemicals in the various species may have a role in determining the relative abundance of various plant species in ecological communities such as forests and grasslands. It is also possible that plants growing in locations with limited water and nutrients may devote more resources to anti-herbivore defences, resulting in slower plant development, since the cost of replacing damaged leaves is greater under resource-constrained settings.

Leaf of *Viburnum lesquereuxii* with insect damage; Ellsworth County, Kansas, Dakota Sandstone. Three sources provide information on herbivory in geological time: the shape of herbivore mouthparts, plant detritus found in fossilised animal faeces, and fossilised plants, which may have preserved signs of defence or herbivory-related damage. Herbivory is shown practically as soon as fossil evidence for it, despite it having been long believed to be a Mesozoic occurrence. The earliest land plants, as previously mentioned, appeared some 450 million years ago; nonetheless, herbivory and the consequent requirement for plant defences probably developed among aquatic creatures in prehistoric lakes and seas. There is proof that plants were being devoured within 20 million years after the first fossilised sporangia and stems, which were discovered towards the end of the Silurian, some 420 million years ago. Early Devonian plant spores were consumed by animals, and the Rhynie Chert also shows that creatures consumed plants using "pierce and suck" feeding methods. Many plants from this era have surviving enations that resemble spines; these enations may have acted as a defence before becoming leaves.

Plants developed a variety of increasingly complicated organs throughout the subsequent 75 million years, from roots to seeds. Each organ evolved over a period of 50 to 100 million years before it was consumed. Early Permian fossils show evidence of hole feeding and skeletonization, and by the end of that time period, surface fluid feeding had developed. Before eating, a simple tiger *Danaus chrysippus* caterpillar creates a moat to prevent the protective compounds of the plant Calotropis [9], [10]. Despite the development of a broad array of plant defences, herbivores are reliant on plants for sustenance and have developed strategies to get this food. Herbivore adaptations to plant defence are similar to offensive features in that they permit higher feeding on and utilisation of a host plant. Co-evolution, often known as reciprocal evolutionary change, frequently results through relationships between herbivores and the host plants they consume. An herbivore chooses plants that can mount a defence when it consumes them. The species are believed to have co-evolved in situations when this interaction exhibits specificity and reciprocity. According to the "escape and radiation" theory of co-evolution, speciation has been fueled by adaptations in herbivores and their host plants, which have also contributed to the diversification of insect species throughout the angiosperm era. Some herbivores have developed strategies to take advantage of plant defences for themselves by storing these compounds and utilising them to ward off predators. Since plant defences against herbivores are often insufficient, plants also frequently develop some level of tolerance to herbivory.

There are two types of plant defences, constitutive and induced. In contrast to induced defences, which are created or mobilised at the location of an injury to a plant, constitutive defences are always present. Constitutive defences come in a broad variety of compositions and concentrations; they include digestibility-reducing agents, poisons, and mechanical defences.

Due to their high production and mobilisation costs, many exterior mechanical defences and quantitative defences are constitutive. The mechanisms of constitutive and induced defensive reactions are studied using a number of molecular and biochemical methods. Secondary metabolites, morphological, and physiological alterations are examples of induced defences. When herbivory is unpredictable, inducible defences have an advantage over constitutive ones in that they are only created when necessary and may thus be less expensive. Systemic acquired resistance and plant-induced systemic resistance are two examples of induced defence mechanisms.

Due to the high tannin content of the persimmon (genus Diospyros), the immature fruit, as shown above, has an astringent and bitter taste. The formation of chemical compounds unrelated to the vital photosynthetic and metabolic processes is associated with the evolution of chemical defences in plants. Secondary metabolites are organic chemicals that are often created as by-products during the synthesis of main metabolic products. They are not directly engaged in the normal growth, development, or reproduction of organisms. These byproducts include tannins, flavonoids, and phenolics as examples. Although a meta-analysis of recent relevant research has revealed that these secondary metabolites have either a more minimum or more complicated participation in defence, they have historically been assumed to have a significant role in defences against herbivores. Additionally, plants have the ability to produce volatile organic molecules to alert nearby plants to stressful situations. These poisonous substances may be employed to repel herbivores or even draw in their predator. Finally, certain plants have the capacity to create plant defence proteins, which, when consumed by herbivores, poison them.

Additionally, plants may communicate verbally. The production of pheromones and other odours may be recognised by leaves, which control the immunological response of plants. To put it another way, plants create volatile organic molecules to alert other plants to danger and alter their behavioural state so they can better withstand dangers and survive. The uninjured trees are able to provocatively activate the essential defence systems thanks to the warning signals sent by the sick neighbouring plants. To help the surrounding, unharmed trees build their defence and immune system, the plant itself broadcasts warning, nonvolatile signals as well as airborne signals. Poplar and sugar maple trees, for instance, showed that they ingested tannins from neighbouring harmed plants. In sagebrush, wounded plants release airborne chemicals, such as methyl jasmonate, to unharmed plants, increasing the synthesis of proteinase inhibitors and herbivore tolerance. Additional findings showed that injured plants communicate with reception plants by releasing different VOCs and hormones that are used for defence and immune system regulation.

CONCLUSION

In summary, the complex and varied defence mechanisms used by plants to protect themselves against herbivores are evidence of the continuous evolutionary conflict between these two groups of species. Physical, chemical, and indirect defences have all been created by plants to lessen the damage inflicted by herbivores. For herbivores, physical defences like spines, trichomes, and structural modifications produce obstacles or pain. Herbivores are often discouraged from feeding by these defences or find it difficult to do so. Secondary metabolites and poisonous substances that may poison, repel, or make plants harder to digest are produced as a result of chemical defences. These chemical substances may be generated naturally or artificially in response to herbivore assaults. In conclusion, research into how plants protect themselves against herbivory sheds light on the dynamics of ecosystems and the co-evolutionary processes that have shaped the natural world. In their continuing battle for survival and reproduction, both plants and herbivores exhibit extraordinary resilience.

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CHAPTER 2

STRATEGIES AND MECHANISMS OF PLANT DEFENSES AGAINST HERBIVORES

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ABSTRACT:

To defend themselves against herbivores, plants have evolved an amazing variety of defence systems. These defence mechanisms may be divided into a number of types, such as interactions with other species, physical barriers, and secondary metabolites. This summary gives a broad overview of the complex realm of plant defences. Production of secondary metabolites, sometimes referred to as antiherbivory chemicals, is one of the main defence strategies. Alkaloids, terpenoids, phenolics, and other chemicals that discourage herbivores and may potentially have pharmacological effects on people and other animals are among these molecules. Alkaloids, for example, may produce an unpleasant bitter taste and interfere with a number of metabolic processes. Compounds like cyanogenic glycosides and glycosinolates, which are poisonous when consumed by herbivores, are stored in plant vacuoles. These substances cause cellular respiration to be disrupted, which has a number of negative consequences for herbivores. Phenols have a variety of functions in plant defence, from antibacterial capabilities to endocrine impacts. They are distinguished by an aromatic 6-carbon ring with a hydroxyl group. A complex subclass of phenolics called polyphenols has antioxidant properties and helps give plants their vibrant colours. One phenolic molecule employed in plant defence is condensed tannins, which prevent herbivores from digesting plant proteins.

KEYWORDS:

Herbivores, Leaves, Metabolites, Plant Defenses, Spices.

INTRODUCTION

Numerous secondary metabolites involved in plant defence have developed in plants. These molecules, commonly referred to as antiherbivory compounds, may be divided into three subgroups: nitrogen compounds, terpenoids, and phenolics. Numerous amino acids may be converted into alkaloids. Numerous substances, such as nicotine, caffeine, morphine, cocaine, colchicine, ergolines, strychnine, and quinine are examples of the over 3000 recognised alkaloids. Alkaloids affect both humans and other animals pharmacologically. Some alkaloids change the storage of carbohydrates and fats by preventing the creation of the phosphodiester linkages necessary for their breakdown, or they may block or activate enzymes. Certain alkaloids may interfere with protein synthesis, disrupt DNA repair pathways, and bind to nucleic acids. Alkaloids may also interfere with nerve signalling by weakening, collapsing, or leaking cells via altering the cytoskeletal structure and cell membrane. Alkaloids affect many different metabolic processes in humans and other animals, but virtually all of them produce an offensively bitter taste.

Plant vacuoles store cyanogenic glycosides in dormant forms. They become poisonous when herbivores consume the plant, rupturing cell walls so that glycosides may interact with cytoplasmic enzymes and release hydrogen cyanide, which prevents cellular respiration. Similar to how cyanogenic glucosides are activated, glycosinolates may also result in salivation, diarrhoea, and mouth irritation in addition to gastroenteritis. Some grasses include secondary defensive metabolites called benzoxazinoids, such DIMBOA. They are kept in the plant vacuole as inactive glucosides, much as cyanogenic glycosides. When tissue is damaged, they come into touch with chloroplast-derived -glucosidases, which catalytically release the poisonous aglucones. While certain benzoxazinoids are inherently present, others can only be produced in response to a herbivore infestation and are hence regarded as inducible plant defences [1], [2].

The five-carbon isoprene units that make up terpenoids, also known as isoprenoids, are organic compounds that resemble terpenes. Terpenoids come in more than 10,000 different varieties. The majority are multicyclic structures that vary from one another in terms of both functional groups and the building blocks of carbon. Volatile essential oils like citronella, limonene, menthol, camphor, and pinene are examples of monoterpenoids, which continue beyond 2 isoprene units. Diterpenoids, which contain four isoprene units, are found in large quantities in latex and resins and are very poisonous. Diterpenes are what give rhododendron leaves their toxic nature. Terpenoid precursors, such as vitamin D, glycosides, and saponins, are used to make plant steroids and sterols.

In phenols, also known as phenols, an aromatic 6-carbon ring is joined to a hydroxyl group. While certain phenols affect endocrine function, others have antimicrobial characteristics. Phenolics include anything from simple tannins to more complicated flavonoids, which are mostly responsible for plants' red, blue, yellow, and white hues. Polyphenols are a class of complex phenolics that have a wide range of effects on people, including antioxidant qualities. Among the phenolic compounds that plants utilise for defence are lignin, silymarin, and cannabinoids. Condensed tannins, which are polymers made up of 2 to 50 flavonoid molecules, prevent herbivores from digesting plant proteins by adhering to them and making them more difficult for animals to digest as well as by obstructing the action of digestive enzymes and protein synthesis. Some plants also employ peptides, amino acids, and derivatives of fatty acids as defences. Cicutoxin of water hemlock, a polyyne produced from the metabolism of fatty acids, is a cholinergic toxin. The grass pea produces the neurotoxic amino acid oxalyldiaminopropionic acid as a protective metabolite. One instance of the utilisation of tiny molecules to interfere with an herbivore's metabolism, in this case the citric acid cycle, is the creation of fluoroacetate in a number of plants.

This raspberry plant has prickles on its stem as a mechanical barrier against herbivory. See the well-regarded and still current overview of mechanical defences by Lucas et al. from 2000 for further information. Many plants have structural defences on their exteriors that deter herbivory. By preventing herbivores from eating, structural defences are morphological or physical characteristics that provide the plant a fitness advantage. Plant structural defences on stems and leaves may dissuade, harm, or even kill a herbivore depending on its physical qualities. For instance, resins, lignins, silica, and wax coat the epidermis of terrestrial plants and change the texture of the plant tissue. Some defensive substances are created inside but discharged onto the plant's surface. For instance, holly bushes' very smooth and slick leaves make eating challenging. Insect-catching gummosis or sap is produced by certain plants.

Sharp prickles, spines, thorns, or trichomes hairs on the leaf that often include barbs and may carry irritants or poisons can be found on a plant's leaves or stem. By limiting the pace at which the herbivores may consume or by wearing out the molars, plant structural elements like spines, thorns, and awns discourage big ungulate herbivores from grazing on them. Trichomes are typically linked to decreased rates of insect herbivores consuming plant tissue. Raphides are sharp calcium oxalate or calcium carbonate needles found in plant tissues that make eating uncomfortable, harm a herbivore's mouth and gullet, and increase the effectiveness with which the plant's poisons are delivered. To lessen the effect of herbivores, a plant's structure, including its branching and leaf arrangement, may have evolved. New Zealand shrubs have developed unique, broad branching adaptations that are thought to be a reaction to moas and other browsing birds. African Acacias, which are relatively secure from herbivores like giraffes, have large spines low in the canopy but extremely small spines high in the canopy [3], [4].

Coconut trees wrap its fruit with numerous layers of armour to safeguard it. Trees like palms cover their fruit in numerous layers of armour to protect it, making it necessary to use strong instruments to get to the seed's contents. In order to protect themselves against both vertebrate and invertebrate herbivores, several plants, most notably grasses, produce indigestible silica. Plants absorb silicon from the soil and store it as solid silica phytoliths in their tissues. These are efficient against herbivores above and below ground because they mechanically decrease the digestibility of plant tissue, causing fast wear on vertebrate teeth and insect mandibles. The technique could provide future eco-friendly pest control methods.

Some plants utilise thigimonastic motions, which happen in reaction to contact, as a kind of defence. *Mimosa pudica* is a sensitive plant whose leaves quickly shut in reaction to direct contact, vibration, electrical, and thermal stimulation. A sudden shift in the turgor pressure in the pulvini at the base of leaves brought on by osmotic phenomena is the primary source of this mechanical reaction. This is then dispersed throughout the plant using electrical and chemical methods; only one leaflet has to be disturbed. By presenting the underside of each leaflet to herbivores, this reaction reduces the surface area accessible to them and gives the plant a wilted look. Additionally, it could physically eject tiny herbivores like insects.

Examples of plants that have independently developed carnivory include the butterwort, pitcher plant, and the Venus flytrap. Many of these plants have developed in low-nutrient soil, despite the common belief among those outside of the scientific community that they have excellent defences. They must use a different technique in these circumstances to get enough nutrition. They eat tiny birds and insects to supplement their carnivorous diet with the nutrients they need. Rather of using carnivory as a form of defence, carnivorous plants utilise it to get the nutrients they need.

Plant mimicry: Some plants pretend that there are insect eggs on their leaves, which deters some bug species from depositing their eggs there. Some species of neotropical vines of the genus Passiflora have physical structures resembling the yellow eggs of *Heliconius butterflies* on their leaves, which discourage oviposition by butterflies because female butterflies are less likely to lay their eggs on plants that already have butterfly eggs.

DISCUSSION

The complicated and varied tactics that have developed over millions of years are shown by the study of plant defences against herbivores. Plants have developed a variety of defence mechanisms to fend off herbivores and safeguard their life and procreation, ranging from the synthesis of secondary metabolites to the creation of physical barriers and symbiotic partnerships. Alkaloids, terpenoids, and phenolics are examples of secondary metabolites that have become effective chemical defences. These substances affect the physiology of both humans and animals in addition to discouraging herbivores. Toxic substances like cyanogenic glycosides and glycosinolates, which are deadly when consumed and impair essential cellular functions, are stored in plant vacuoles. Because of their wide diversity, terpenoids provide plants a wide spectrum of chemical defences. With the help of volatile oils or by acting as strong poisons in latex and resins, they may discourage herbivores. Phenols, which are known for their fragrant rings and use as antimicrobials and a component of plants' brilliant colours. Condensed tannins provide additional defence by obstructing herbivore digestion.

In order to physically dissuade herbivores, several plant species have developed structural defences including spines, thorns, trichomes, and prickles. These physical obstacles may hurt herbivores or make it difficult for them to ingest plant tissue. Some plants, especially in nutrient-poor areas, have adopted a different strategy by evolving carnivorous characteristics, catching insects and small animals to replenish their food intake. Additionally, plants have developed mutualistic interactions with herbivore natural predators by luring them with semiochemicals. These interactions create a delicate equilibrium in ecosystems that is advantageous to both the plants and those who preserve them. The danger of herbivores, the value of plant components, and the expense of defence all influence the development of plant defences, which is not random. The trade-offs that influence various defence methods may be better understood by using the Optimum Defence Theory and the Carbon:Nutrient Balance Model.

Peptides, amino acids, and fatty acid derivatives are also used by plants as protective metabolites. These chemicals have the ability to impair essential cellular functions and interfere with herbivore metabolism. Plants use physical defences like spines, thorns, trichomes, and even prickles to repel herbivores in addition to chemical defences. The capacity of herbivores to ingest plant tissue may be physically harmed or hampered by these structural defences. Instead of depending exclusively on defence systems, some plants have developed carnivorous methods that allow them to catch insects and small animals for extra sustenance. Particularly prevalent in regions deficient in nutrients is this adaptation. In order to control their habitats and draw in herbivore predators naturally, plants may create mutualistic interactions that are advantageous to both themselves and their defenders. Allelochemicals, for example, play a significant part in these interactions by luring predators to plants with herbivore infestations. The danger posed by herbivores, the value of plant components, and the expense of defence all have an impact on how plant defences evolve through time [5], [6].

The characteristics of plants that increase the likelihood of attracting herbivores' natural enemies constitute another area of plant defences. The term "enemy of my enemy" mutualism is used to describe this kind of relationship. Semiochemicals are one such characteristic that plants emit. A class of volatile organic molecules called semiochemicals are engaged in interactions between organisms. Allomones, which play a protective function in interspecies communication, and kairomones, which are employed by organisms at higher trophic levels to find food sources, make up one class of semiochemicals called allelochemicals. When a plant is assaulted, it exudes allelochemics, which have an aberrant ratio of these plant volatiles caused by herbivores. Predators are drawn to the wounded plant and the eating herbivores when they detect these volatiles as food signals. The resultant decrease in herbivore activity benefits the plant's fitness and exemplifies semiochemicals' capacity for indirect defence. However, there are disadvantages to induced volatiles since some research indicates that they may lure herbivores. Domestication of crops has sometimes reduced HIPV production while increasing yield. By combining companion planting with artificial predator attractants, Orre Gordon et al. (2013) tries a number of techniques for artificially reestablishing the plant-predator alliance. They discuss both successful and unsuccessful techniques.

Plants sometimes support "biotic" defence mechanisms, or natural adversaries of herbivores, by giving them shelter and food sources. For instance, the thin stem walls of trees of the genus Macaranga have evolved to provide the perfect homes for an ant species, which in turn shields the plant from herbivores. The plant offers the ant its only source of food, which is derived from the food bodies the plant produces, in addition to habitat. Similar to this, a number of Acacia tree species have evolved stipular spines with enlarged bases that create hollow structures that serve as homes for defenceless ants. For the benefit of the ants, these Acacia trees also generate nectar in extrafloral nectaries on their leaves. It is usual for plants to deploy endophytic fungus as a defence. Endophytes are microbiological organisms that dwell within the majority of plants. Others defend plants from herbivores and dangerous microorganisms while some induce illness. Endophytes may benefit the plant by creating poisons that are detrimental to other species that would otherwise attack it, such as the fungus that produce the alkaloids that are prevalent in grasses like tall fescue, which is infected with *Neotyphodium coenophialum* and would otherwise attack the plant.

In order to increase their chances of survival, trees of the same species make alliances with other tree species. Through linkages in the soil known as subterranean mycorrhiza networks, they are able to exchange water and nutrients, different signals for predatory assaults, and dependencies while also defending their immune systems. When a tree is being attacked in a forest, it sends out communication distress signals, alerting other trees to change how they are behaving. Symbiotic relationships exist between trees and fungus. Fungi help plants discover nutrients by facilitating communication between them via the roots of the trees. A portion of the sugar that trees photosynthesize is given to the fungus in exchange. In addition to slow-pulsing electric impulses, trees can communicate with one another via chemical and hormonal signals. Using a voltage-based communication system akin to an animal's nervous system, farmers studied the electrical impulses that exist between trees. When a tree experiences difficulty, it sends out a warning signal to other trees.

There have been theories that leaf shedding may act as a defence mechanism against some pests and illnesses, including gall-forming insects and leaf miners. Other reactions, such the change in leaf colour before the autumn, have also been proposed as adaptations that could work to hinder herbivores' ability to disguise themselves. It has also been proposed that the colour of fall leaves serves as a sincere indication of defensive commitment against insect pests that move to trees in the autumn. The resources needed for defensive structures and chemicals, which plants might otherwise utilise to maximise growth and reproduction, are expensive. In certain cases, when the majority of the nutrients are being utilised to produce toxins or regenerate plant components, plant development slows down. To understand how and why certain plants invest in these herbivore defences, several models have been put forward. The optimum defence theory aims to clarify how the possible types of defences a certain plant may use reflect the dangers each unique plant must contend with. This model takes into account three primary variables: the danger of an assault, the value of the plant component, and the price of defence [7], [8].

Risk is the first consideration when developing the best defence: how probable is it that a plant or certain plant components will be attacked? This is also connected to the plant apparency theory, which claims that when a plant is readily detected by herbivores, it would spend extensively in widely effective defences. Long-lived trees, shrubs, and perennial grasses are a few examples of seeming plants that create generalised defences. On the other hand, covert plants, such as those with brief lifespans in the early phases of succession, selectively invest in modest quantities of high-quality poisons that are effective against all but the most specialised herbivores.

The importance of protection is the second aspect to consider. Would the plant be less able to live and reproduce if a herbivore removed a portion of its structure? Because not all plant components have the same evolutionary significance, the more valuable components have stronger defences. The change in fitness that results from feeding a plant depends on its developmental stage at the moment. In an experiment, a plant structure's fitness value is assessed by removing it and evaluating the results. Generally speaking, reproductive parts are more difficult to replace than vegetative parts, terminal leaves are more valuable than basal leaves, and the loss of plant parts in the middle of the growing season has a more detrimental impact on fitness than removal at the start or end of the season. Particularly seeds often have excellent protection. For instance, amygdalin and other cyanogenic glycosides may be found in the seeds of many edible fruits and nuts. This is a consequence of the effort required to strike a balance between the requirement to make the fruit attractive to animal dispersers and the necessity to prevent the animal from destroying the seeds. The last factor to take into account is cost: how much would a certain defensive tactic cost a facility in terms of energy and materials? This is crucial because energy utilised for defence cannot be utilised for other processes like growth and reproduction. According to the optimum defence theory, plants will devote more energy to defence when the advantages of defence exceed the disadvantages, particularly when there is severe herbivore pressure.

According to the carbon, nutrient balance theory also referred to as the environmental constraint hypothesis or the Carbon Nutrient Balance Model, different plant defences are retaliations to changes in the amount of nutrients in the surrounding environment. According to this theory, the secondary metabolites that plants synthesise depend on the carbon:nitrogen ratio. For instance, although plants thriving in low-carbon conditions are more likely to develop nitrogen-based poisons, those growing in nitrogen-poor soils will deploy carbon-based defences. Furthermore, according to the idea, plants may modify their defences in reaction to nutritional changes. For instance, plants will use a defensive strategy made up of inherent carbon-based defences if they are cultivated in low-nitrogen environments. These carbon-based defences will weaken if further increases in nutrient levels occur, such as those caused by the use of fertilisers.

According to the growth rate theory, which is also known as the resource availability hypothesis, a plant's natural growth rate, which is in turn influenced by the resources that are accessible to it, determines how to defend itself. A key presumption is that the maximal development rate of a plant species is limited by the resources that are available. According to this hypothesis, as growth potential declines, spending in defence will rise. Additionally, plants in resource-poor environments often have sluggish growth rates and long-lasting leaves and twigs, and the loss of these plant parts might result in the loss of rare and priceless nutrients.

To examine whether trade-offs between growth rate and defences constrain species to one environment, one test of this model used reciprocal transplantation of seedlings of 20 species of trees between clay soils and white sand. Seedlings from clay outgrew those from nutrient-poor sand when planted in white sand and shielded from herbivores, but in the presence of herbivores, the seedlings from white sand performed better, probably because they had more constitutive carbon-based defences. These findings imply that certain plants' habitats are constrained by defensive measures. Hypothesis of the growth-differentiation balance. According to the growth-differentiation balance theory, "growth-related processes" and "differentiation-related processes" in various settings trade off to produce plant defences. "Processes that enhance the structure or function of existing cells" are what are referred to as differentiation-related processes. Only when energy from photosynthesis is available can a plant generate chemical defences, and the plants with the largest concentrations of secondary metabolites are those with an intermediate level of accessible resources.

The GDBH takes into consideration trade-offs between growth and defence along a gradient of resource availability. Carbon availability is projected to restrict both development and defence in circumstances when resources constrain photosynthesis. The conditions necessary to enable photosynthesis are satisfied as resource availability rises, allowing for the buildup of carbohydrates in tissues. These carbon molecules may alternatively be divided into the synthesis of carbon-based secondary metabolites since resources are insufficient to fulfil the high demands of growth. When growth-related resource needs are satisfied, carbon is transferred from secondary metabolism to rapidly dividing meristems at the cost of secondary metabolism. Therefore, it is hypothesised that plants that develop quickly would have lower quantities of secondary metabolites, and vice versa. In addition, a recent research on Salix species suggests that the tradeoff suggested by the GDBH may alter with time. There is a tonne of evidence in the literature to support this idea, and some researchers think the GDBH is the most developed plant defence theory [9], [10].

Most plant defences against herbivores are either unconnected to one another or have a strong correlation. Because the secondary metabolites involved are negatively associated with one another, Pastinaca sativa's resistance to different biotypes of *Depressaria pastinacella* and *Diplacus aurantiacus'* resistances are two examples of negative correlations. Growth rate and *Peronospora parasitica* resistance are adversely associated in *Brassica rapa*. Overcompensation and mutualism in plants. In order to protect themselves against herbivores, many plants lack secondary metabolites, chemical reactions, or mechanical defences. Instead, when threatened by herbivores, these plants depend on overcompensation. When a herbivore attacks, overcompensation is regarded as having greater fitness. This is a symbiotic connection; after a meal, the herbivore is content, and the plant soon begins to develop the missing portion. These plants are more fit and have a better possibility of reproducing.

CONCLUSION

Agriculture, ecology, and human health all depend on an understanding of the intricate world of plant defences. We learn more about the complex and dynamic interactions between plants and herbivores in the natural world by examining these tactics and processes. Understanding plant defences has practical consequences for agriculture and human health in addition to ecological relevance. Researchers may create more environmentally friendly pest management strategies and learn more about the intricate relationships within ecosystems by figuring out the processes behind these defences. Finally, the diversity of plant defences against herbivores is evidence of nature's flexibility and inventiveness. In order to survive in a world full of herbivores, plants have evolved an astounding diversity of techniques including chemical interactions, physical characteristics, and symbiotic relationships. Our knowledge of the complex web of life on Earth continues to be expanded via the study of these systems.

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CHAPTER 3

HISTORICAL DISCOVERIES TO MODERN AGRICULTURAL SOLUTIONS: A COMPREHENSIVE REVIEW

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ABSTRACT:

The entire review of plant defences against herbivores and their importance for agriculture and pest control is provided in this abstract. It recounts the development of knowledge about plant pest susceptibility through time and highlights the crucial role that plant resistance plays in resolving socioeconomic problems like the restoration of the French wine industry after the phylloxera insect invasion. It draws attention to the advancement in the study of plant resistance to insects made by experts like Reginald Henry Painter and Vincent Dethier. Various elements of plant defences are also covered in the abstract, including the usage of secondary plant chemicals as pesticides and their implications for human medicine. It talks about the value of genetic variety in agricultural plants for improved pest resistance and highlights the necessity for environmentally friendly pest control methods that go beyond chemical inputs. In-depth discussion of several plant defence strategies, including physical obstructions, chemical deterrents, and tolerance features, is provided in the abstract. It emphasises how crucial it is to match certain defence systems to the kind of herbivore while also taking into account possible conflicts and interactions between these mechanisms. It also investigates novel tools for assessing plant responses to insect pests and discovering desirable plant features, such as high-throughput phenotyping and imaging methods. This summary offers a thorough and instructive review of plant defences against herbivores, emphasising their diversity, historical relevance, and possible uses in contemporary agriculture and pest control.

KEYWORDS:

Agriculture, Development, Diversity, Pesticides, Plant Defense.

INTRODUCTION

Even in the earliest days of human agriculture, the variety in plant vulnerability to pests was presumably understood. The discovery of such differences in susceptibility has historically led to the solutions of significant socioeconomic issues. Infested by the hemipteran phylloxera pest bug, which was brought to France from North America in 1860, it devastated over a third of the country's vineyards in only 25 years. Vitis labrusca is an American plant that Charles Valentine Riley observed was Phylloxera-resistant. Riley and J. E. Planchon made the suggestion to graft the delicate yet premium grapes onto Vitis labrusca root stocks, which helped restore the French wine industry. In his 1951 book Plant Resistance to Insects, Reginald Henry Painter widely considered as the father of this field of study detailed the formal study of plant resistance to herbivory for the first time in great detail. While this discovery paved the way for more research in the US, additional research in the USSR was built on the work of Chesnokov. Prussic acid, which sometimes occurs in high concentrations in newly-grown grass, may harm grazing cattle. The main reason grasses produce cyanogenic compounds is to protect themselves from herbivores. Cooking, a human invention, may have been especially useful in getting past numerous plant defence compounds. Cooking denatures several enzyme inhibitors in cereal grains and pulses, such as the trypsin inhibitors common in pulse crops, making them edible.

Since the late 17th century, it has been recognised that plants contain poisonous substances that insects avoid. In 1690, nicotine was isolated from tobacco and employed as a contact insecticide, marking the beginning of humankind's usage of these substances as insecticides. In 1773, plants with pest infestations were given a nicotine fumigation treatment by heating the tobacco and letting the smoke fall on them. Pyrethrin, an effective pesticide, is found in the blooms of several chrysanthemum species. Later, the uses of plant resistance emerged as a significant topic of study in agriculture and plant breeding, especially since they may be used as an affordable and safe substitute for pesticides. Vincent Dethier and G.S. Fraenkel first discussed the crucial part secondary plant compounds play in plant defence in the late 1950s. Azadirachtin from the neem, d-Limonene from citrus species, Rotenone from Derris, Capsaicin from chilli peppers, and Pyrethrum are only a few famous examples of the many botanical pesticides that are used [1], [2].

Plant resistance is also brought on by naturally occurring substances in the environment. The EPA has certified both chitosan and cyst nematodes as biopesticides to lessen the need for harmful pesticides. Chitosan, which is produced from chitin, triggers a plant's natural defence response against infections, illnesses, and insects like cyst nematodes. Selection against the plant's inherent resistance mechanisms occurs often throughout the selective breeding of agricultural plants. Because of this, agricultural plant variants are more vulnerable to pests than their wild cousins. The source of the resistance genes in host-plant resistance breeding is often the wild relatives. These genes have also been supplemented by recombinant procedures, which enable the introduction of genes from entirely other species. These techniques are used in conjunction with traditional ways to plant breeding. Incorporating genes from the bacterium species Bacillus thuringiensis into plants is the most well-known transgenic technique. The bacteria produces proteins that, when consumed by lepidopteran caterpillars, render them dead. When the host plant's genome has the gene producing these extremely toxic proteins, the plant acquires resistance to caterpillars when those poisonous proteins are generated there. However, owing to the potential for ecological and toxicological negative effects, this strategy is debatable.

Opium, aspirin, cocaine, and atropine are just a few of the medications that were developed from the secondary metabolites that plants produce to defend themselves against herbivores. These substances have developed to have highly precise effects on the biochemistry of insects. Yet many of these biochemical pathways are present in both insects and vertebrates, including people, and they affect human biochemistry in ways that are comparable to those of insects. Therefore, it has been proposed that research into plant-insect interactions may aid in bioprospecting. There is evidence that human use of plant alkaloids in pharmaceuticals dates back to 3000 B.C. Although the majority of medicinal plants' active ingredients have just recently been discovered, these chemicals have been used as pharmaceuticals throughout human history in the form of teas, medicines, potions, and poisons. For example, Cinchona trees generate a range of alkaloids, the most well-known of which is quinine, to fight off herbivory by the larvae of various Lepidoptera species. The bark of the tree is quite bitter due to the presence of quinine. Jesuit's bark is also a fever-reducing substance that is particularly effective in the treatment of malaria. Mandrakes have historically been prized for their purported aphrodisiac powers. The alkaloid scopolamine, which at high concentrations works as a central nervous system depressant and renders the plant very hazardous to herbivores, is also present in significant amounts in the mandrake plant's roots [3], [4]. Later research revealed the medical application of scopolamine for motion sickness prevention and pain control before and during labour. Taxol, an anticancer medication, was first isolated from the bark of the Pacific yew, *Taxus brevifolia*, in the early 1960s and is one of the most well-known terpenes with therapeutic use.

DISCUSSION

Defence Mechanisms Against Herbivores Herbivores, both big and tiny, aggressively devour plants for food. Different defence mechanisms have been created by plants to deter or eliminate intruders. Plants have an unbroken, impermeable barrier made of bark and a waxy cuticle that serves as their first line of defence. Both safeguard plants against herbivores. Hard shells, thorns, and spines are a few more defence mechanisms against herbivores. They deter animals by harming them physically or by triggering allergic responses and rashes. Some Acacia tree species have evolved mutualistic connections with ant colonies; in return for the ants defending the tree's leaves, they provide the ants with refuge in their hollow thorns. The Acacia collinsii's broad, hollow stipules, which resemble huge thorns, provide refuge for ants, who in turn defend the plant against herbivorous animals. Cactus plants have modified leaves called spines that serve as a mechanical deterrent to predators.

Mechanical damage may undermine a plant's outer defences, opening the door for disease entrance. The plant must switch to an alternative set of defence mechanisms, such as toxins and enzymes, if the initial line of defence is compromised. Compounds known as secondary metabolites are not produced by photosynthesis directly and are not required for respiration or the growth and development of plants. Many metabolites are poisonous to animals and may even be fatal if they consume them. Some metabolites are alkaloids, which deter predators with unpleasant tastes or odours. Other alkaloids influence herbivores by either inducing excessive stimulation or the opioid-related lethargy. Some substances only become hazardous after being consumed; for example, the cassava root's glycol cyanide only releases cyanide when it is consumed by a herbivore. Foxgloves generate a number of poisonous substances, including cardiac and steroidal glycosides. Vomiting, hallucinations, convulsions, and even death, may result after ingestion. Foxgloves: The fatal cardiac and steroidal glycosides are among the many poisonous substances that foxgloves release. Vomiting, hallucinations, convulsions, and even death, may result after ingestion.

Mechanical injuries and predator assaults trigger the activation of defence and protection mechanisms in the injured tissue as well as long-distance signalling or activation of these mechanisms in locations further away from the source of the injury. While some defensive responses take just a few minutes, others might take many hours. Long-distance signalling also triggers a physiological reaction intended to ward off predators. Jasmonates may encourage the manufacture of chemicals that are poisonous to predators when tissue is destroyed. Additionally, jasmonates cause the creation of volatile substances that attract parasitoids insects that spend their infancy within or on top of another insect before ultimately devouring their host. If the damaged tissue cannot be repaired, the plant may cause abscission to occur.

2500 species of agricultural crops are said to have been domesticated, and this process required artificially selecting for features that would increase crop productivity and quality. While breeding for agronomic aims in situations with high inputs has effectively enhanced agricultural output worldwide, it has a tendency to result in current crop varieties with very modest levels of genetic variation. The availability of cultivars suited for crop production under suboptimal circumstances can be constrained by this decreased genetic diversity. As a result of selection for other desirable qualities, domesticated plants may lack or express plant defence traits poorly. Since it seems that contemporary cultivars will do poorly in low input systems with limited pesticide usage, this presents a unique challenge for enhancing the sustainability of food production. Despite an improvement in agricultural yield over the previous century, weeds, pests, and diseases may cause up to 40% of the world's crop losses. Over 20% of the net plant production is lost by herbivores that graze on leaves, sap, and roots. These losses persist despite increasing pesticide usage over the last several decades, emphasising the need for sustainable pest management methods that rely less on chemical inputs. Plant defensive features might be more frequently used in crop protection techniques to address issues with human health, environmental safety, and pesticide resistance [5], [6].

This review, which focuses on arthropod herbivores as pests, aims to highlight opportunities and technologies for improving the identification and deployment of plant defensive traits, particularly to achieve sustainable pest management under a changing environment. First, it summarises the documented plant defence strategies in agricultural crops. Second, it considers the potential utility of various types of crop defence. Most ecosystems have been successfully colonised by plants, and part of this success may be attributed to their capacity to fend off or endure attacks by herbivores. The approach created by Stout is especially helpful in discriminating between two plant defence tactics and the underlying traits: tolerance and resistance, in the context of crop protection. Resistance develops when a plant's physical characteristics or chemical composition discourage animal eating and reduce the amount of harm that herbivores do to the plant. When plant features mitigate the detrimental impacts of herbivore damage on crop output, tolerance arises. A high risk pest should be reduced to low densities or exterminated, while a low risk pest may be tolerated up to a particular abundance level. This differential can enable defence features to be matched to the danger presented by the target insect. We require a fundamental knowledge of the processes behind defensive characteristics and how environmental factors impact trait expression in order to select viable plant features for crop protection against particular pests.

The degree to which defensive features will provide long-lasting pest management is a crucial factor. Since plant resistance features often prevent herbivores from grazing, they are probably going to put a lot of pressure on the herbivore to evolve ways to get around plant resistance. Plant tolerance characteristics, on the other hand, are often thought to have little impact on herbivore fitness and are hence unlikely to impose selection on the herbivore. Stinchcombe questions this assumption, arguing that under specific conditions, tolerance characteristics can affect herbivore performance. However, few research have looked at this possibility, especially in the context of crop protection. Tolerance traits are predicted to be more stable and have a higher likelihood of delivering long-lasting pest control than resistance traits, which are anticipated to exert a stronger selection pressure owing to more severe implications on pest fitness. Depending on the stage of insect establishment that a particular plant resistance trait influences, the method by which it discourages herbivore eating is likely to change. Here, we include characteristics that reduce plant palatability, discourage pest landing, and hinder attachment and feeding in order to increase crop resistance to herbivores.

Chemical Pest Settling and Feeding Deterrence

Herbivore oviposition and eating may trigger plant defences, such as the release of herbivore-induced plant volatiles, which have been suggested as a new area of attention for agricultural pest resistance and biocontrol. HIPV production indicates the presence of herbivores, which may draw in the pest's natural enemies. It can also indicate a danger from herbivores and trigger defence mechanisms in nearby plants. The results of a recent meta-analysis of HIPV investigations imply that certain biosynthetic capacities have been lost during crop breeding since domesticated plants tend to generate volatiles in greater numbers but of simpler composition than their wild cousins. Landraces may give genetic variety in HIPV production and natural enemy attraction, and wild relatives provide a genetic resource for reintroduction these qualities into crops. It is possible to engineer agricultural plants to create more volatile compounds. For instance, wheat plants that were genetically engineered to produce insect alarm pheromone both attracted and repelled aphids in controlled environments, albeit this did not result in better aphid management in the field.

Plant defences may be quickly induced during a future herbivore assault if they have been "primed" by signs that indicate herbivore danger. An appealing concept for crop breeding is priming of inducible responses, which enables plant defence allocation to be balanced against the intensity of herbivore pressure. For numerous crop species, the identification of plant elicitors and mechanisms of defence induction are beginning to emerge. This creates potential for crop breeding to take use of features that prime and induce defence [7], [8].

Plant cuticle and trichome density are two structural characteristics that are of special interest in crop security because they may physically prevent arthropod pest attachment, feeding, and oviposition. Epicuticular waxes provide a slick layer or crystals that prevent pests from sticking to, ovipositing on, or eating on the surface of the plant. Trichomes may reduce insect migration and inhibit pest adhesion to crops. Non-glandular trichomes act as a physical deterrent while glandular trichomes are thought to have a chemical basis for their effect. Oviposition by the generalist phytophagous mite, *Tetranychus uticae*, was significantly reduced on raspberry genotypes with high leaf trichome densities. Through their influence on the behaviour of herbivore natural enemies, trichomes may also have indirect impacts, both beneficial and detrimental, on the target pest. For instance, the amount of leaf trichomes was positively correlated with the quantity of the predatory mite *Typhlodromus pyri* on grapes, whereas its victim, the European red mite, preferred grape varietals with low trichome density. In addition, trichomes tend to prevent sap-feeding or leaf-chewing insects to a greater degree than those eating inside plant tissues, making them more effective against insects that are tiny compared to trichome size.

Alkaloids, benzoxazinoids, glucosinolates, and terpenoids are a few examples of plant chemicals that might increase crop resistance to pests because they are poisonous to arthropods or interfere with their ability to digest their food. These compounds can also be formed naturally or as a result of herbivore damage. Due to their negative impact on crop quality for consumption, excessive levels of defensive chemicals have often been selected against in plant breeding. Although it's important to examine any potential indirect impacts of plant quality on biocontrol by natural enemies, tissue-specific engineering of chemical resistance into crops may be possible with targeted production of defensive chemicals in non-harvested organs. A further fascinating approach is the symbiosis of cereal grasses with Epichlo fungal endophytes, which enables crops to gain from the generation of insecticidal alkaloids by the fungus. Numerous plants leave behind mineral granules in their tissues that prevent insect assault and eating. A well-known example is the buildup of silica in grasses, which is abrasive, harms the feeding mechanisms of herbivores, and decreases digestibility. The presence of genetic markers for silica buildup may make it possible to use crops for insect resistance.

Less is known about the features that support or preserve plant fitness after harm, as well as their genetic underpinnings. Herbivore tolerance may be conferred by the expression of characteristics both before and after an infestation. The physiological processes that are altered by plant tolerance characteristics include photosynthetic activity and growth, phenology, and the utilisation of nutrients that have been stored. We concentrate on the first two categories because there aren't many instances of plants using stored nutrient reserves as a tolerance strategy, despite the fact that storage organs are crucial for a plant's ability to recover from damage and provide protection from unforeseen herbivore attack if there isn't a trade-off with plant productivity.

A frequent physiological reaction to leaf injury is compensatory photosynthesis, which many plant species show increases photosynthetic rate in the remaining plant tissues. Increased photosynthetic activity, however, is not always a response to herbivory and does not always promote compensatory growth. This may be because resources are sometimes diverted towards resistance characteristics. Depending on the herbivore, changes in photosynthetic rate and growth may or may not occur. For instance, Mexican bean beetle does not cause compensatory photosysthesis, whereas numerous insect herbivores of soybean and drybean do. Aphid feeding on the perennial crop red raspberry, however, often promotes plant development and alters nitrogen physiology, which may indicate resistance to aphid herbivory via improved plant vigour. Similar to sugarcane, higher plant vigour was connected with clonal heterogeneity in whitegrub tolerance. In a wide variety of plant species, plant vigour may contribute to tolerance to herbivory; greater abundance and fitness of several insect herbivore groups on robust host plants may reflect improved capacity of vigorous plants to withstand assault. Despite the likelihood that several loci regulate plant vigour, quantitative trait loci research has found genetic markers for vigour that might be used in crop breeding. Another sort of compensatory growth strategy that enables plants to rebound from herbivore assault involves the activation of latent buds following removal or damage to blooming or vegetative meristems. Crop species with numerous meristems may benefit from this process. Growth overcompensation is sometimes seen, which might be a desirable characteristic for enhancing crop tolerance in rich agricultural situations, however any effects on the harvested product's quality would need to be considered [9], [10].

Herbivore tolerance may be increased via delayed growth, flowering, and fruit production after herbivore injury by delaying plant development until the danger of attack has gone. For instance, it is believed that the tolerance of the western corn rootworm in herbivore-tolerant maize is supported by delayed resource delivery to roots. The usefulness of these features depends on whether delayed development reduces production and quality if it causes crop blossoming, pollination, or ripening under less-than-ideal circumstances.

Depending on the sort of harm the pest causes direct feeding damage, resource loss, visual deterioration, or plant disease transmission defensive features should be matched to herbivore types to maximise pest management. For keeping disease vector infestation concentrations below threshold levels, resistance characteristics are more desirable. Although this must be weighed against the likelihood of pest spillover to neighbouring crops or between cropping cycles, tolerance characteristics are expected to be helpful against non-vector pests that normally cause harm by taking nutrients and limiting plant development. Whether the goal protective characteristic negatively affects populations of beneficial creatures, especially natural enemies of the pest, is a crucial factor to take into account. In contrast, leafminers on tomato and their parasitoids are deterred by leaf trichomes, but trichomes and HIPVs have antagonistic effects on insect behaviour. For instance, high trichome densities can reduce the abundance of insect pests on cotton, but trichomes can also reduce the searching effectiveness of herbivore natural enemies. In certain circumstances, it may be preferable to include plant features that improve natural enemy seeking behaviour than to improve pest resistance qualities.

Large-scale plant genotyping technology advancements might hasten the selection of genotypes with desired features, such as herbivore defence. In order to characterise desired features in huge plant populations, high throughput phenotyping is increasingly the rate-limiting step. Imaging techniques enable semi-automated collecting of light signals from the surface of plants across a broad range of wavelengths, from visible to infrared, opening up new possibilities for large-scale visualisation of plant populations in controlled and field settings. Indicators of plant performance may be connected to attributes retrieved from images that offer details on the temperature of the canopy, the makeup of the pigments, and the state of the water supply. There is tremendous promise for employing imaging methods to phenotype plant responses to insect pests. HTP approaches using imaging are currently giving genetic markers for agricultural performance under abiotic stress. Imaging techniques, for instance, could offer non-destructive markers of physiological processes, such as stomatal conductance and water status, leaf pigment composition or photosynthetic activity, or plant vigour, that reveal genotypic variations in the capacity to withstand or resist insect pest attack above and belowground.

The genetic regulation and expression of characteristics is likely to entail a suite of features produced to fight against many pests above- and below-ground, while studies of plant defensive traits generally concentrate on a single trait and target pest. It may be possible to concentrate on a specific protective characteristic, such as silica buildup, which is beneficial against a variety of herbivore species, depending on the predominant crop pests. Although there is surprisingly little evidence for trade-offs in plant investment between various defences, crop breeders still have a huge difficulty in understanding the genetic regulation of numerous characteristics. Utilising protective characteristics linked to several crop kinds cultivated as cultivar- or species-mixtures is an alternate strategy. Plant diversity in crop systems frequently increases natural enemy populations, controls arthropod pest populations, and minimises crop damage by giving natural enemies a more complex habitat and heterogeneous resource, lowering the density of preferred host plants, and interfering with the location and/or quality of host plants for herbivores. The detrimental effect of onions co-cropped with potatoes on the attraction of potato aphids is an excellent illustration of the latter effect. Increased production stability and resource efficiency are two additional advantages of increasing plant variety in agricultural systems. While there are several instances of how growing crop combinations may be advantageous, notably the 'push-pull' systems created in sub-Saharan Africa for pest biocontrol, there is also a lot of room for improvement in terms of breeding crops with features that maximise performance in mixtures.

CONCLUSION

Plant defences against herbivores has a long and illustrious history that dates back to the earliest forms of agricultural practise. Humans have developed and used a variety of defence mechanisms throughout the ages to shield their crops from the damaging impacts of herbivorous pests. We have consistently looked for novel ways to reduce pest damage, from grafting resistant rootstocks to developing botanical insecticides and researching naturally occurring elements like chitosan and cyst nematodes. The complicated biochemical interactions between plants and herbivores are highlighted by the use of secondary plant chemicals, some of which have been developed into significant medicines. The importance of comprehending plant-insect interactions for bioprospecting and medical research is highlighted by the dual function of these chemicals, acting as both protective mechanisms and sources of useful medications. From physical barriers like bark and spines to the generation of harmful secondary metabolites, plants use a variety of defence strategies. The resistance and tolerance methods that these systems fall under may each be distinguished by their benefits and possible downsides. Herbivores are discouraged from eating by resistance strategies, yet plants may survive harm from herbivores and recover thanks to tolerance strategies.

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CHAPTER 4

INTERACTION BETWEEN PLANTS AND HERBIVORES AT THE THIRD TROPHIC LEVEL

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ABSTRACT:

In order to defend themselves against herbivorous insects, plants have developed a variety of defence mechanisms, ranging from structural barriers to the creation of complex secondary compounds. This extensive analysis focuses on the interaction between plants and herbivores at the third trophic level as it analyses the many defence mechanisms used by plants to fend off herbivore assaults. In order to attract predatory mites and parasitic wasps that feed on herbivores, plants must emit volatile organic compounds (VOCs) and extrafloral nectar (EFN). Specific VOCs released by herbivore-damaged plants serve as signals for their natural enemies to find and fight the herbivores. EFN and VOC emissions are crucially triggered by jasmonic acid, a hormone produced in response to herbivore damage. Trees have internal defence systems because they are immobile. For instance, some trees respond to the saliva of herbivores by increasing the salicylic acid and tannin content of their leaves, making them less appetising and more difficult for herbivores to digest. Secondary plant metabolites might be qualitative or quantitative. While quantitative metabolites, which are present in high amounts, impair digestibility, qualitative metabolites alter herbivore metabolism. These substances are used by plants to repel herbivores, and their efficacy varies according on the herbivore's area of expertise.

KEYWORDS:

Damage, Extrafloral Nectar (EFN), Herbivore, Insect, Plants, Plant Defense, Volatile Organic Compounds (VOCs).

INTRODUCTION

By luring creatures from the third trophic level, plants may ward against herbivores by releasing special VOCs and extrafloral nectar. For instance, plants that have been harmed by caterpillars emit chemicals that direct parasitic wasps to attack their victims. These chemicals are most likely produced by glands in the leaves that burst when a herbivore chews on them. A crucial role in controlling immunological responses is played by the hormone jasmonic acid, which is produced when the damage caused by herbivores triggers the release of linolenic acid and other enzymatic events in an octadecanoid cascade. Jasmonic acid causes the emission of EFN and VOCs, which attract predatory mites and parasitic wasps to look out and feed on herbivores. To prepare for prospective attacks, these volatile organic chemicals might also be distributed to other surrounding plants. As these signals are specific to herbivore damage, studies have demonstrated that third trophic level species can easily identify the volatile molecules released by plants. According to an experiment measuring the VOCs emitted by developing plants, signals are immediately released during herbivore injury and gradually decrease once the harm has ceased. Additionally, it was found that plants emit their highest signals during the times of day when animals are most active in their foraging.

Due to their sessile nature, trees have developed special internal defence mechanisms. For instance, some trees emit substances that make their vegetation less appetising when they are subjected to herbivory. The cells of the tree get a chemical signal from the herbivores' saliva that was left on its leaves. In response, the tree cells produce more salicylic acid at a higher concentration. A phytohormone called salicylic acid is one of the primary hormones for controlling the immune systems of plants. This hormone then instructs the tree to produce more tannins, which are compounds, in its leaves. Tannins impact how well plants taste and digest while also boosting the concentration of growth hormones, which promotes the development of new leaves. Deer find the leaves less tempting to eat because of the increased tannin synthesis, which makes them harder for them to digest. A set of field-grown saplings of European beech and sycamore maple trees were able to detect if a deer was especially nibbling at their leaves, according to a study trial conducted by Bettina Ohse and colleagues. The scientists' experiment comparing broken leaves with and without saliva revealed that saliva increased the concentration of tannin. The tannin content of the leaves increased and the growth of the tree's leaves increased in the leaves that included the deer saliva, but these changes did not occur in the leaves without the deer saliva. One internal defence mechanism used by trees to resist mobile predators like deer is an increase in tannin content. The immune system of the trees produces more tannin, which is a crucial defence mechanism employed by all plants [1], [2].

The classification of secondary metabolites as qualitative or quantitative is common. Toxins known as qualitative metabolites are those that disrupt a herbivore's metabolism, often by obstructing certain biochemical processes. Plants contain qualitative compounds, which are non-dosage dependent and found at relatively low amounts. They can be quickly synthesised, transported, and stored with very minimal energy cost to the plant since they are typically tiny, water-soluble molecules. Atypical generalist herbivores are often successfully combatted by qualitative allelochemicals. Quantitative chemicals, which are found in large concentrations in plants and are equally efficient against both specialised and generalist herbivores, are substances that are present in plants. The majority of quantitative metabolites are digestibility reducers that make animal digestion of plant cell walls impossible. Quantitative metabolites have dosage-dependent effects, and the less nourishment a herbivore can get by eating plant tissues, the more of these compounds it consumes. These defences frequently need more time to synthesise and transfer since they are often big molecules, which makes them energy-intensive to create and sustain. To protect itself against Japanese beetles, the geranium, for instance, creates the amino acid quisqualic acid in its petals. The herbivore is rendered paralysed by the drug within 30 minutes of intake. The beetle is often eaten by its own predators at this period, even though the poison typically wears off after a few hours.

Plant features that increase yield, improve quality for human consumption, and make the crop more suited to current farming techniques have been the main targets of agricultural domestication in recent decades. Currently, nevertheless, there is more emphasis on enhancing agriculture's sustainability through lowering dependency on pesticides and other chemical inputs. According to the research mentioned below, there is a lot of room for using HIPVs, physical defences, and plant vigour to shield crops from specific pests and encourage the activity of natural enemies. The longevity of crop protection under a changing environment, which is expected to increase pest load on crops, is a significant area of uncertainty. Elevated CO_2 might reduce herbivore numbers but increase consumption, whereas periodic water stress can improve performance in certain herbivore guilds. Elevated temperatures are anticipated to accelerate insect development and increase the number of insect generations each season. It is unclear how different climatic conditions, acting alone or in combination, would affect the development of plant defence characteristics. The development of these tolerance/resistance features may be strengthened by elevated temperature and CO_2, which also enhance plant growth and the generation of volatiles and may alter defence signalling. This suggests that crop protection from these physical and chemical resistance traits may be compromised under a changing climate. On the other hand, these climate factors tend to reduce plant nutritional quality and decrease allocation to defensive compounds and physical structures, thus promoting plant consumption by herbivores. Crop scientists should be able to identify traits and trait combinations that are resilient to a changing environment and that can be deployed as part of an integrated approach for sustainable crop protection by applying imaging methods for HTP of target traits under conditions that mimic future climates and optimising crop defensive traits in mixtures [3], [4].

DISCUSSION

Over 350 million years have passed since the beginning of plant and insect coexistence. Both have developed ways to get through each other's defence mechanisms via co-evolution. Plants have evolved a sophisticated defence mechanism that can recognise non-self-molecules or signals from damaged cells, much as animals can, and initiates the plant immune response against herbivores as a consequence of the evolutionary arms race between plants and insects. Plants develop specialised morphological features, secondary metabolites, and proteins that are poisonous, repulsive, and/or antinutritional to herbivores in order to defend against their assault. Plants fight against herbivores indirectly via other species like natural enemies of insect pests and directly by influencing host plant selection or survival and reproductive success (direct defence). Plant traits that have an impact on the biology of herbivores, such as mechanical defences on the plant's surface (such as hairs, trichomes, thorns, spines, and thicker leaves), or the production of toxic chemicals (such as terpenoids, alkaloids, anthocyanins, phenols, and quinones) that either kill or delay the development of herbivores, are mediating direct defences.

The release of a mixture of volatiles that specifically attracts the herbivores' natural enemies, as well as providing food (such as extra floral nectar) and shelter to increase the efficiency of the natural enemies, are examples of indirect defences against insects. Research on plant-herbivore interactions is one of the most significant and multidisciplinary endeavours in plant biology, involving various disciplines to describe chemical and ecological processes influencing the interactions. Our knowledge of how plants use chemical signals to interact with their surroundings, symbionts, pathogens, herbivores, and with their own "bodyguards" the natural enemies above and below ground, is still in its infancy. From an ecological perspective, this is an intriguing region with a lot of potential for use in crop protection. Designing agricultural plants with improved defences against herbivores will benefit greatly from understanding the nature of gene expression of plant defensive characteristics. As a result, less toxic pesticides will need to be used to control insects. Herbivores may co-evolve in response to the resistant plant genotypes as the arms race between plants and herbivores continues. To maximise the development of novel crops, knowledge of the intricate chemical interactions between plants and herbivores is necessary.

Defences of the Host Plant Against Insects

Plants defend themselves against herbivore assault using a complex and dynamic system that includes structural barriers, poisonous compounds, and the attraction of the pests' natural enemies. Both types of defence (direct and indirect) may be generated as a result of herbivore injury or may be present on a regular basis. One of the key elements of pest management in agriculture is induced response in plants, which has been used to decrease the population of insect herbivores. The study of induced responses in plants to various stimuli has advanced significantly over the last several decades and has become a crucial subject in evolutionary biology and ecology. The majority of these compounds are generated in reaction to herbivore assault, therefore even if induced responses have some metabolic costs, they are crucial for reducing the stress of immediate concern. Due to induced defences, plants are phenotypically flexible, which reduces the likelihood that attacking insects will be able to adapt to the produced compounds.

Changes in a plant's defence mechanisms as a result of an insect assault make the plant environment unpredictable for insect herbivores, which in turn alters the fitness and behaviour of the herbivores. Early induced response is particularly beneficial to the plant since it lessens ensuing herbivore and pathogen assault and boosts the plant's overall fitness. Progress in insect-plant interactions has improved our understanding of the evolution of defensive approaches utilised by the plants against herbivory; however, the underlying mechanisms of defence are less clearly understood. Plants with high variability in defensive chemicals exhibit a better defence compared to those with moderate variability.

Direct Deterrence

The first physical defence against herbivore feeding is provided by plant structural characteristics like wax on the leaf surface, trichomes or thorns, and cell wall thickness/ and lignification. The second line of defence is provided by secondary metabolites that act as toxins and also affect growth, development, and digestibility reducers. Additionally, the defence mechanism of plants against invasion herbivores is strengthened by the combinatorial effects of many protective components. When consumed alone, tomato's alkaloids, phenolics, proteinase inhibitors (PIs), and oxidative enzymes have a diminished effect, but when consumed combined, they work synergistically to impact the insect during ingestion, digestion, and metabolism. Trypsin proteinase inhibitors and nicotine expression in *Nicotiana attenuata* both worked in concert to help the plant defend itself against *Spodoptera exigua* (Hub.). Below, we'll talk about how morphological and biochemical components contribute to host plant resistance (HPR) and induced reactions to insect damage.

Morphological Elements

The initial line of defence against herbivory is provided by plant structures, which are also crucial to host plant resistance (HPR) against insects. The construction of a physical barrier, such as a waxy cuticle or the growth of spines, setae, and trichomes, is a plant's first line of defence against insect pests. Structural defences include morphological and anatomical characteristics that give the plant a fitness advantage by directly discouraging herbivores from feeding. These characteristics can range from conspicuous features on a plant to minute modifications in cell wall thickness brought on by lignification and suberization. Plants are primarily protected from herbivory by structural characteristics like spines and thorns (spinescence), pubescence, toughened or hardened leaves (sclerophylly), incorporation of granular minerals into plant tissues, and divaricated branching (shoots with wiry stems produced at wide axillary angles). Sclerophylly, or stiffened leaves, actively aids in a plant's defence against herbivores by making the tissues less palatable and digestible, which lessens herbivore damage. Plant parts like spines, thorns, and prickles are considered to be part of spinescence. According to reports, it protects the plants against a variety of insects. The layer of hairs (trichomes) that extend from the epidermis of the above-ground plant components, such as the stem, leaves, and even fruits, is known as pubescence. Trichomes may take on a variety of shapes, including straight, spiral, stellate, hooked, and glandular ones. According to report, sorghum *Sorghum bicolor* was resistant to the shoot fly *Atherigona soccata* (Rondani) due to leaf glossiness, plumule, and leaf sheath coloration [5], [6].

Trichomes, which have both poisonous and deterring actions, are essential for plant defence against a variety of insect pests. The ovipositional behaviour, eating, and nutritional status of insect pest larvae are adversely affected by trichome density. Additionally, thick trichomes have a mechanical impact on herbivory, obstructing insect and other arthropod movement on the plant surface and limiting their access to the leaf epidermis. These may be glandular or nonglandular and can be straight, spiral, hooked, branching, or unbranched. A mix of structural and chemical defence is created by the secondary metabolites secreted by glandular trichomes, such as flavonoids, terpenoids, and alkaloids, which may poison, deter, or trap insects and other creatures.

Numerous plants have been observed to induce trichomes in response to insect harm. Since the number of trichomes on already existing leaves does not alter, this rise in trichome density in response to injury may only be seen in leaves emerging during or after insect attack. Dalin and Bjorkman reported that *Phratora vulgatissima* L., an adult leaf beetle, caused the damage. inside Salix cinerea L. increased the trichome density in the next generation of fresh leaves. The density of the trichomes increased in S. There have also been reports of cinera in reaction to coleopteran injury. In *Lepidium virginicum* L., an increase in trichome density after insect damage has also been seen. as well as *Raphanus raphanistrum* L. After Pieris rapae (L.) fed on black mustard, trichome density and glucosinolate levels increased. *Alnus incana* Moench's trichome density rose as a consequence of beetle damage. Typically, trichome density increases in response to herbivory range from 25 to 100%, although there have also been reports of increases between 500 and 1000%. Following insect damage, changes in trichome density can place days or weeks later. Additionally, herbivory also causes a shift in the relative percentage of glandular and non-glandular trichomes. Natural enemies have been shown to be positively correlated with trichome density. Trichome exudates are used as extra floral nectar (EFN) by the scelonid egg parasitoid Gryon pennsylvanicum of squash bugs.

Metabolites Secondary And Plant Defence

Secondary metabolites are substances that lessen the flavour of the plant tissues in which they are generated but do not impair a plant's regular growth and development. In response to an insect or microbe assault, the defensive (secondary) metabolites may be either induced or constitutively stored in inactive forms. Both are referred to as phytoalexins for the former and phytoanticipins for the latter. During herbivory, glucosidase primarily activates the phytoanticipins, which then mediates the release of different biocidal aglycone metabolites. Glucosinolates, which are degraded by myrosinases (endogenous -thioglucoside glucohydrolases) after tissue rupture, are the standard illustrations of phytoanticipins. Benzoxazinoids (BXs), which are extensively distributed among Poaceae, are among the other phytoanticipins. In response to tissue injury, plastid-targeted -glucosidases hydrolyze BX-glucosides to produce biocidal aglycone BXs, which are crucial for plant defence against insects. Isoflavonoids, terpenoids, alkaloids, and other phytoalexins affect how well and how long herbivores survive. The plants' secondary metabolites not only protect them from various challenges, but also improve their fitness. It has been reported that maize HPR to corn earworm, *Helicoverpa zea* (Boddie) is mainly due to the presence of the secondary metabolites C-glycosyl flavone maysin (2"-O-a-L-rhamnosyl- 6- C - (6-deoxy- xylo -hexos-4-ulosyl) luteolin) and the phenylpropanoid product, chlorogenic acid Compound, 4, 4- dimethyl cyclooctene has been found to be responsible for shoot fly. A resistance to soccata in sorghum *S. bicolor* [7], [8].

Secondary metabolites have mostly been investigated as direct defence mediators, but much more research is needed to identify unknown or newly developing signalling pathways. This subject has become more fascinating and cost-effective because to the use of mass spectrometry for secondary metabolite profiling and high-throughput sequencing for gene expression studies. Discovering novel signalling molecules involved in plant resistance to herbivores and other pressures may result from research on secondary metabolites. In the end, it could be possible to pinpoint the genes and enzymes responsible for the manufacture of these metabolites. secondary metabolites' function in plant defence.

Plant-based phenols

Plant phenols are one of the most prevalent and frequent groups of defensive chemicals among secondary metabolites, and they play a significant role in HPR against herbivores like insects. Phenols serve as a defence strategy for plants not just against herbivores but also against competitive plants and microbes. It is a common occurrence for phenols to change qualitatively and quantitatively and for oxidative enzyme activities to increase in response to insect assault. A key component of plant defence against pests and diseases is lignin, a phenolic heteropolymer. It restricts pathogen penetration by physically obstructing them or making the leaf tougher, which diminishes herbivore eating and lowers the leaf's nutritional value. The production of lignin has been discovered to be stimulated by herbivore or pathogen attack, and its rapid deposition inhibits the growth of the pathogen or herbivore fecundity33. Increased expression of lignin-associated genes (CAD/CAD-like genes) in plants infected with pests and pathogens has also been observed.

Plants may use the polyphenol oxidase (PPO) and peroxidase (POD)-catalyzed oxidation of phenols to protect themselves against herbivorous insects. Alkylation of amino acids decreases the nutritional value of plant proteins for insects, which in turn negatively affects the insect growth and development.34 Phenols also play a significant role in the cyclic reduction of reactive oxygen species (ROS), such as superoxide anion and hydroxidic oxygen. Quinones formed by oxidation of phenols bind covalently to leaf proteins and inhibit the protein digestion in herbivores. Salicylic acid (SA) is significantly more significant as a phytohormone than as a deterrent. Simple phenolics (salicylates) function as antifeedants to insect herbivores like *Operophtera brumata* (L.) in Salix leaves, and there is a negative association between the salicylate levels and the larval development.

Flavonoids

Flavonoids are essential to many aspects of plant life, notably in interactions between plants and their environment. These protect plants against a variety of biotic and abiotic stressors, such as UV rays, diseases, and insect pests. Through complexation, flavonoids interact with many enzymes and are cytotoxic. The behaviour, growth, and development of insects are all influenced by flavonoids and isoflavonoids, which defend the plant from insect pests36. Flavonoids also scavenge free radicals, including ROS, and lessen their synthesis by chelating metals. Anthocyanins, flavones, flavonols, flavanones, dihydroflavonols, chalcones, aurones, flavan, and proanthocyanidins are some of the several groups of flavonoids. There have been reports of more than 5,000 flavonids in plants. Many flavones, including flavonols, flavones, proanthocyanidins, flavan 3-ols, flavonones, flavans, and isoflavonoids, have been studied for their potential to act as feeding inhibitors against a variety of insect pests. *Tephrosia villosa* (L.) was the source of flavonoids such the flavones 5-hydroxyisoderricin, 7-methoxy-8- (3-methylbutadienyl)-flavanone, and 5-methoxyisoronchocarpin. indigo (L.), and T. Angustone A, licoisoflavone B, angustone B, and angustone C. have all been discovered to act as feeding inhibitors against Spodoptera exempta (Walk.) and Spodoptera littoralis Bios, respectively.38 Overexpressing a transcription factor controlling flavonoid production in Arabidopsis has been reported to confer resistance against *Spodoptera frugiperda* (J.E. Smith). In addition to acting as feeding inhibitors for insects, the isoflavones licoisoflavone A, luteone, licoisoflavone B, and wighteone have also been discovered to exhibit antifungal action against the fungus *Colletotrichum gloeosporiode* (Penz.) and *Cladosporium cladosporioides* (Fres.). At 100 ppm, the isoflavonoids judaicin, judaicin-7-O-glucoside, 2-methoxyjudaicin, and maackiain function as an antifeedant against *Helicoverpa armigera* (Hubner). A deterrent to S was also discovered to be judaicin and maackiain. atlantica and S. likewise, frugiperda. The native American butterfly, *Pieris napi oleracea* L., is substantially inhibited from eating by cyanopropenyl glycoside and alliarinoside, whilst isovitexin-6"-D-glucopyranoside works as a direct feeding deterrent to the late instars [9], [10].

Tannins

Tannins have a substantial negative impact on phytophagous insects, affecting their growth and development by attaching to proteins, their ability to absorb nutrients, and the formation of midgut lesions. Many insect pests are discouraged from feeding on tannin-rich plants because they are astringent (mouth puckering) bitter polyphenols. They precipitate proteins by covalent or hydrogen bonds with protein -NH_2 groups, including the digestive enzymes of herbivores. The metal ions are also chelated by tannins, which lowers their bioavailability to herbivores. Tannins diminish the protein's ability to be digested when consumed, which lowers the nutritional value of plants and plant parts to herbivores. Numerous plants have been investigated to determine how tannins function in plant defence against different stressors and how they are produced in response to insect attack. For instance, in *Pinus sylvestris* L. and the *Populus species*. *Quercus serrata* (Thunb.) and *Betula pendula* Roth, on the other hand, did not show any effects of herbivore damage on tannin content. Tannins, like proteinase inhibitors and oxidative enzymes, have been shown to be systemically activated in nearby leaves of the wounded plant.

Proanthocyanidins, commonly referred to as oligomeric or polymeric flavonoids, are what make up condensed tannins. They have a variety of structures and roles. They prevent several insects from eating, including *Lymantria dispar* (L.), *Euproctis chrysorrhoea* (L.), and *O. brumata*. Condensed tannins in the leaves of *Quercus robur* L., include (+)-catechin, (+)-gallocatechin, and vanillin. Winter moth larvae were impeded, *O. brumata*. In groundnut, procyanindin polymers have been identified as an *Aphis craccivora* (Koch) feeding deterrent. The pupal mass and survival of *Rheumaptera hastata* (L.) larvae were decreased by Alaskan paper birch condensed tannins, which were coated on birch leaves at a rate of 3% dry weight. Induction of tannins in *Populus tremuloides* Michx has been described. By activating the flavonoid pathway transcriptionally, leaves respond to herbivores and wounds. The expression of a condensed tannins regulatory gene, PtMYB, which is also stimulated by damage, activates genes that are involved for tannin formation in response to injury. Additionally, UV exposure and light stress also encourage tannin induction in hybrid poplar. However, some polyphagous insect species are able to tolerate gallotannins. For example, *Shistocerca gregaria* (Forsk.) can tolerate tannins by hydrolyzing them quickly to prevent any negative effects, restricting the passage of tannins by adsorbing them on the thick peritrophic membrane, and by inhibiting the formation of tannin protein complexes by surfactants in the midgut.

CONCLUSION

This emphasises how plants respond to herbivore assaults by activating defence systems, a process known as induced responses. Because induced responses render plants phenotypically adaptable, herbivores are less likely to develop a resistance to the protective chemicals. First lines of defence against herbivores are morphological components like trichomes and thorns. In particular, trichomes act as both physical and chemical defences by impeding herbivore mobility and having the ability to produce harmful substances. The study also explores the realm of secondary metabolites, concentrating on plant phenols, flavonoids, and tannins that are essential for plant defence. These substances are effective deterrents because they may disrupt herbivore development, growth, and nutrition intake. The significance of comprehending plant-herbivore interactions for crop security and sustainable agriculture is emphasised by this review. Having a better understanding of the complex chemical interactions that are involved can help us create more efficient and ecologically friendly pest control techniques as the coevolutionary arms race between plants and herbivores continues.

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CHAPTER 5

PLANT DEFENSE MECHANISMS: ADAPTING TO BIOTIC AND ABIOTIC STRESSES

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ABSTRACT:

In their native environments, plants encounter a variety of difficulties, including biotic and abiotic pressures, as vital elements of our ecosystems. Their life is continuously under danger from both biotic stresses like disease invasion and insect feeding as well as abiotic stressors like severe temperatures, scarce water supplies, and poor soil conditions. The amount and quality of agricultural plants may be drastically decreased as a result of this intricate interaction between plants and their natural enemies, which include nematodes, bacteria, viruses, pathogenic fungus, and insect pests. Plants have developed a complex range of defence systems in response to these dangers. Understanding these defence mechanisms and the substances they are linked to will have a big impact on crop protection and agricultural genetic engineering. Interest in using endogenous resistance mechanisms for crop protection has been reignited by recent developments in our understanding of plant defence responses and control. Investigating the ecological and biological underpinnings of induced plant defences is essential to completely understanding the variables affecting plant defence systems. Although plants cannot escape from herbivores, they use a variety of defence measures, such as the development of poisonous or deterrent secondary metabolites.

KEYWORDS:

Chemical, Defences, Herbivore, Insect, Plant.

INTRODUCTION

Some plants release volatile organic chemicals in response to herbivore assaults, which operate as chemical signals and attract the herbivores' natural enemies as an induced defence mechanism. Both from an evolutionary standpoint and in terms of agriculture and biological pest control, research on plant defences against herbivory is crucial. The two main types of plant defence systems are static (constitutive) defences and inducible (developed) defences. Physical barriers like waxes, thick cell walls, thorns, and trichomes are examples of static defences that exist before insect assaults. This kind of protection keeps insects from feasting. Additionally, plants may have specialised cells called idioblasts that produce crystals or dangerous substances that might harm an insect's mouthparts. On the other side, chemical defences are used after insect herbivores begin eating. Secondary metabolites, often known as "secondary metabolites," are produced by plants and perform a significant defensive function while not being directly engaged in regular growth, development, or reproduction. Depending on how they affect herbivores, these secondary metabolites might be categorised as qualitative or quantitative. While quantitative metabolites, which are present in greater amounts, diminish digestibility and nutrition, qualitative metabolites alter herbivore metabolism.

In their natural habitat, plants are subject to a range of pressures, such as biotic and abiotic stresses. Extremes in temperature, water availability, and worsening soil conditions are examples of abiotic stress. Biotic stress is brought on by disease invasion, insect feeding, etc. Plants often come into contact with a range of natural enemies that might harm them. These creatures include nematodes, bacteria, viruses, pathogenic fungus, insect pests, and nematodes.

Both the number and quality of crop plants might be significantly reduced as a result of biotic stress. In order to survive, plants have evolved and created a variety of defence systems. The discovery and isolation of any compounds associated to the defence response may be employed in crop protection, and genes connected to the plant defence mechanism can also be used for genetically engineering additional crop plants if necessary, making research on plant-defense processes extremely significant [1], [2].

The potential to exploit endogenous resistance mechanisms for crop protection has once again come to light thanks to recent developments in our understanding of defence responses in plants and their regulation. As a result, in connection to the biochemical interactions between plants and other creatures, it is important to thoroughly research the variables influencing the mechanisms of defence in plant species. The present study concentrated on comprehending the ecological and biological foundations and induced plant defences, as well as their potential use in the control of insects.

Although plants are unable to flee from oncoming herbivores, they use a variety of defence mechanisms, including the production of secondary metabolites that are poisonous to or repulsive to the intruders and serve as defence chemicals. Some plants respond to insect herbivore eating or disease assault by releasing a variety of volatile organic chemicals that function as a chemical signal and may draw the herbivore's natural enemies to the injured plant as an induced defence. Studying plant defences against herbivory is crucial from both an evolutionary and practical standpoint since these defences have a direct bearing on agriculture and "biological control agents" in biological pest management systems.

The two broad kinds of these plant defence systems are static (constitutive) defences and inducible (developed) defences. Inducible defences are those that are triggered as a result of an insect assault, as opposed to static defences, which are made up of physical and chemical barriers that are present before an insect attack. Naturally, following an insect assault, certain static defences can reach even greater levels. Given that they need less metabolic energy to support plants, and inducible defences, which are more pest-specific, have been the subject of study over the last several decades. Figure 1 plants' insect defence mechanisms.

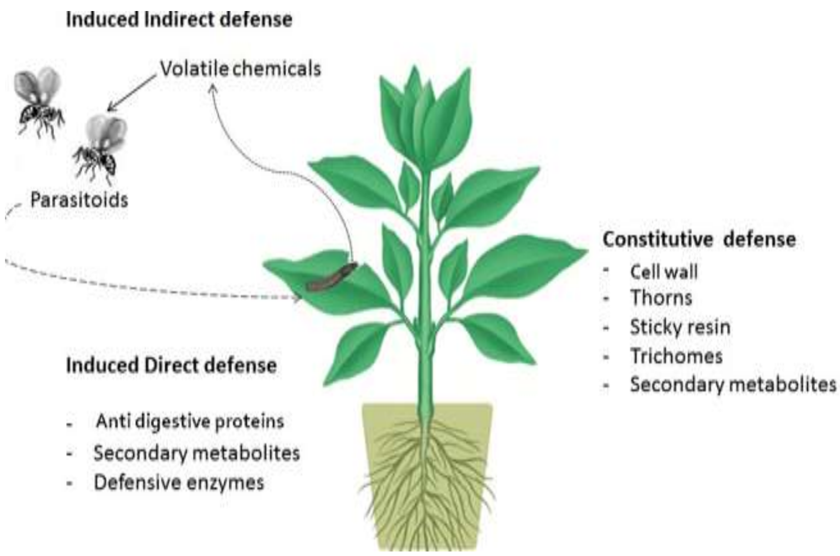

Figure 1: Plants' insect Defence Mechanisms.

The first line of plant defence is static defence. They participate in the overall defence system of the plant and act as preventative measures when the attacker is not around. Physically, certain insects are deterred from attacking by waxes on the surface of leaves, strong cell walls, thorns, or sticky resin. Many plant species have trichomes, which are little, closely spaced spines or hairs that cover the surface of the leaves. Its pubescence, which physically prevents insects from accessing the plant surface below, may serve as a repellent. According to Lamb, the flea beetle *Phyllotreta cruciferae* caused more eating damage to mustard pods when the trichomes on those pods were removed. Heavy pubescence on a plant may prevent little sap-sucking insects from using their mouthparts to reach the surface. The hairy soyabean leaves' mesophyll cells and vascular bundles are inaccessible to *Empoasca fabae Harris*' 0.2 to 0.4 mm long proboscis, much as in the case of the leafhopper.

Plant cell walls may also raise mechanical barriers and make plant tissues more difficult for insects to consume . Lignin, a heterogeneous polymer made up of phenolic chemicals, is a common component of plant cell walls. It makes the cell wall stiff and makes it possible for insects to eat such lignified tissues. Some plant cells are highly specialised for plant defence, such as idioblasts, which defend plants against herbivores by containing poisonous compounds or crystals that may sever an insect's mouthparts while it feeds.

DISCUSSION

Numerous insect herbivores are nevertheless able to feed on plant tissues despite the physical defence present on the plant surface. Once they consume the plant, however, they enter a world where chemical defences are common. Many plant species have developed chemical defences against herbivores, and they create a huge array of compounds for this purpose. It was previously noted, that these substances are referred to be "secondary metabolites". These substances are organic chemicals necessary for the everyday operation of plants but not directly engaged in normal growth, development, or reproduction. They are often created as by-products during the synthesis of main metabolic products. According to estimates, plants have the ability to produce more than one million distinct organic compounds, giving them a vast arsenal of defensive substances to utilise in the event of an assault by herbivores.

The classification of secondary metabolites as qualitative or quantitative is common. Toxins or poisonous compounds that disrupt a herbivore's metabolism, often by obstructing certain biochemical processes, are referred to as qualitative metabolites. These compounds do not rely on dose and are found in plants in very low quantities. They can be quickly synthesised, transported, and stored for the plant at relatively minimal energy costs since they are often tiny, water soluble molecules. The general effectiveness of the qualitative allelochemicals against non-adapted specialised and generalist herbivores. The insects that these pesticides often work best against are those that specialise in other plant species as well as generalist insects that feed on several plant species. Pelargonium x hortorum, the zonal geranium An unusual illustration of phytochemical defence is the L.H. Bailey plant. Quisqualic acid, a newly discovered unique molecule in its flower petals, protects flowers against Japanese blight [3], [4].

The quantitative metabolites are those that are found in plants in large quantities that are harmful to both specialised and generalist herbivores. The majority of them act as reducers of digestibility, rendering plant cell walls indigestible to consumers. Their effects vary on the dosage, and a larger percentage of these substances in the insect's diet indicates that the herbivore may get less nourishment from eating these plant tissues. If *Spilosoma obliqua* is involved larvae who ingested more cowpea leaves did so at the expense of weight increase, while those that consumed fewer castor leaves did so at the expense of weight gain. Tannins in oaks are one kind of substance that decreases digestion. These defences frequently take longer to synthesise and transfer since they are often big molecules, which makes producing and maintaining them energy-intensive.

Physical barriers, such as spines, thorns, trichomes, and waxes; chemical barriers, such as secondary plant metabolites; or specialised herbivore-induced defence proteins are all examples of static defence. Physical obstacles are not the main issue in this situation. In recent years, phenolic compounds, which are sometimes referred to as resistance compounds, have taken on a significant role among the anti-herbivore chemicals produced by plants. The word "phenolics" has been used to refer to a class of structurally varied plant secondary metabolites that include an aromatic 6-carbon ring and one or more hydroxyl groups linked to it. Phenolic acids are common across the plant kingdom and are aromatic secondary metabolites that plants biosynthesize. Plant phenolics may range in chemical composition from a simple monomeric to monomeric aglycon units in different ratios to highly polymerized structures. An area of research that has received a lot of attention over the last several decades is the relationship between phenolic chemicals found in plants and herbivory or herbivore performance, which is convincing proof of their crucial function in anti-herbivore defence. Due to their protective effects on human health against certain agricultural pests, phenolic acids have also attracted a lot of research in recent years. Based on their effectiveness as deterrents and poisons, several arguments support the idea that phenolic acids decrease herbivore damage. Higher phenolic concentrations in plants or the application of pure phenolic compounds to leaves inhibited caterpillar growth, development, and survival, demonstrating the phenolics' antifeedant activity. By generating free radicals that attach to plant proteins ingested by herbivores and prevent their absorption, they may hinder digestion.

The common amino acids are used to create the nitrogen-containing chemical compounds, such as glucosinolates, alkaloids, and cyanogenic glycosides. Plant vacuoles store cyanogenic glycosides in dormant forms. They are created through oxime synthesis from amino acids, followed by glycosylation. When herbivores eat them, they get poisonous. Consuming the plant causes cell membranes to rupture, enabling glycosides to interact with cytoplasmic enzymes and release hydrogen cyanide, which prevents cellular respiration. Glucosinolates are mostly found in the Brassicaceae, Capparidaceae, and Caricaceae groups of plants. They are made of glucose and amino acids, and they are nitrogen and sulphur containing. Myrosinase, an enzyme, breaks them down, resulting in the creation of isothiocyanates, nitriles, and other substances.

The most well-known nitrogen-containing secondary chemical compounds found in plants, alkaloids are derived from either purines and pyrimidines or amino acids . Alkaloids may also include oxygen, sulphur, and, less often, additional elements like chlorine, phosphorus, and bromine, in addition to carbon, hydrogen, and nitrogen. They are believed to number over 10,000 and are present in roughly 20% of angiosperm species, but are often missing from ferns, mosses, and gymnosperms . There is strong evidence that alkaloids are employed efficiently as defensive agents and may be transported throughout the plant to areas that need more protection as it is growing and developing. The alkaloid nicotine, which is derived from ornithine, is produced by plants of the Nicotiana genus. Tropane alkaloids, such as atropine, and quinolizidine alkaloids, which are generated from lysine and are often present in lupins, are present in the majority of the Solanaceae family plants. The *Senecio vulgaris* L. plant contains pyrrolizidine alkaloids. Throughout the coffee plant, Coffea Caffeine, a purine alkaloid found in arabica L., is abundant in tissues that are susceptible to herbivory. Since the majority of alkaloids are very poisonous, they may be used by plants to defend themselves against herbivores [5], [6].

In order to impact an insect's capacity to digest and absorb food, plants may create proteins that target the digestive system and serve a crucial defensive function. Plant protease inhibitors are another name for these proteins. Plants generate a variety of protein inhibitors in response to attacks by insect herbivores that may disrupt the digestive enzymes of insects, lower the value of ingested nutrients, and hinder insect growth and development. Proteases and amylases are the two main categories of digestive enzymes found in insect digestive systems. The tissues of plants contain a large number of inhibitors of both enzymes, particularly in seeds. Ryan and his colleague made the first discovery of digestive enzyme inhibitors as a defence mechanism. Inhibition of these regulating enzymes may result in chemical harm, which will prevent insect development and growth or cause insect mortality.

The pH of the lumen is substantially reflected in the makeup of insect digestive proteases. Coleoptera, Hemiptera, and Hymenoptera, which have acidic midguts, utilise aspartic and cysteine proteases, but Lepidoptera typically have alkaline midguts and virtually exclusively use serine proteases. Lepidopteran larvae have received a lot of attention in research because of how they affect commercially significant crops. Due to their remarkable capacity to work in the alkaline lepidopteran mid gut, these larval digestive enzymes are of interest as a target for insect control. Extracellular proteases with high pH optimalities have been shown to make up the majority of the mid gut proteolytic enzymes in lepidopteran larvae, and these enzymes are well adapted to the alkaline environment of the mid gut. Studies of the proteases found in digestive organs are crucial since proteolysis is required for food digestion in those organs. As precipitating agents for nutritional protein, plant allelochemicals bind to proteins and block insect digestive enzymes, decreasing digestibility, and precipitating agents for dietary protein. Disrupting insect midgut physiology and/or digestive biochemistry has been a recurring subject in the development of alternative pest control techniques.

Some plants overproduce proteases in response to insect assault, which may break down insect structural proteins after they have been absorbed into the insect stomach and harm the herbivore physically. after the proteases. When it is swallowed into an insect's stomach, it breaks down the peritrophic matrix and digests the gut proteins, which prevents the insect from growing and developing. Defence substances may similarly harm insect herbivores chemically. Different processes including kinases, phosphatases, and regulatory proteases control how insects grow and develop. For instance, after being consumed by insects, certain secondary metabolites might block their kinase or phosphatase activity. At the maize insect feeding site, protease builds up quickly and confers resistance to lepidopteran insect pests. The peritrophic matrix of caterpillars is disrupted by this enzyme, which has the harmful effect of weakening the digestive system of insects. Cysteine proteases are crucial in protecting papaya plants against herbivorous insects since these insects release latex when they are attacked. Lepidopteran larvae perish when fed on latex-containing fig leaves, but not when the latex is washed away. This implies that defence compounds are present in latex [7], [8].

Plants were previously only known to protect themselves constitutively. The term "induced response" refers to a process when plants actively respond to herbivore assault. Because defences are often regarded to be expensive, plants with inducible defences have lower metabolic costs. Additionally, induced defence enables the plant to customise its response to a particular kind of herbivore assault since there are several assailants. They are created or transported to the area where a plant is hurt. Thus, inducible defences are crucial for imposing effects on herbivorous insects, such as increased toxicity, a delay in larval development, or an increase in parasitoid insect attacks. According to Agrawal, constitutive defence systems are considered to damage plant fitness, while inducible defences may be more resilient. Induced direct defence and induced indirect defence are the two categories into which plant-induced defences fall.

Bitrophic systems are examples of induced direct defence, in which a herbivore assault triggers a plant defence response that directly targets the attacker. According to Kessler and Baldwin, every characteristic in a plant that affects how susceptible it is to insects or how well they function would improve plant fitness. They might endanger the insects' lives or hinder their ability to digest food, slowing their growth. The length of time that a herbivore is exposed to possible predators and parasites rises as its growth rate slows. Proteins having recognised enzymatic activities, such as proteinase inhibitors and polyphenol oxidases, are present in some induced defences. Proteinase inhibitors are anti-digestive proteins that are produced when plants are injured or when herbivores eat them [9], [10].

Protease inhibitors have a complicated method of action that affects larval function by triggering a feedback process that causes an overproduction of digestive proteases and a depletion of critical amino acids. The nutritional value of the plant tissue is decreased by polyphenol oxidases that either catalyse the oxidation of phenolic secondary compounds or cross-link proteins. The creation of several hazardous secondary metabolites is also stimulated by herbivores. These induced defences are often also present constitutively, but their concentration rises in response to herbivory, as shown by Traw's observation that Pieris rapae feeding on black mustard causes an increase in trichome density and glucosinolate levels. Similar to tobacco, when plants are injured or attacked by herbivores, nicotine concentration is induced.

CONCLUSION

Plant defence systems include phenolic compounds, nitrogen-containing substances like glucosinolates, alkaloids, and cyanogenic glycosides, as well as defensive proteins generated from plants, such protease inhibitors. Herbivores may be harmed by these substances chemically or physically, which can affect their development and digestion processes. Additionally, plants have the ability to activate defence systems in response to herbivore assaults. Defences that may be induced are more focused on a particular pest and use less metabolic energy. These defences may make plants more poisonous, postpone the development of larvae, or attract parasitic insects. For a thorough understanding of plant defence systems, it is essential to comprehend how constitutive and inducible defences interact. To sum up, the study of plant defence mechanisms includes a wide spectrum of tactics used by plants to defend themselves against a variety of biotic and abiotic challenges. The potential for improving crop protection and developing agricultural techniques is enormous.

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CHAPTER 6

PLANT PROTEINS: GUARDIANS OF PLANT HEALTH IN INSECT INTERACTIONS

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ABSTRACT:

Plant protective proteins are essential components of both species' survival strategies and play a critical part in the complex ecology of insect-plant interactions. The sturdy host plants that can serve as both a source of food and a place for oviposition and mating are what insects are always looking for. Insect physiology may be greatly impacted by any imbalance in how insects consume and use plant proteins. This abstract explores the many features of plant protection proteins and how they affect interactions between insects and plants. When plants are under stress, such when they are being attacked by insects, the quality and amount of their proteins alter dynamically. Protein profiles change as a result of changes in gene expression, and these changes are essential for intercellular signalling and oxidative defence. Notably, certain plant proteins are resistant to insect digestion and may even pass the stomach wall and get into the insect's bloodstream. Predicting these proteins' toxicity and modes of action may be made easier by comprehending the structural and post-translational alterations that lead to their stability in the herbivore gut. The ability of lectins, a class of proteins that bind carbohydrates, to kill homopteran, lepidopteran, and coleopteran insects has been established. Due to their interaction with certain carbohydrate residues on cell membranes, mannose-binding lectins in particular have shown effectiveness against sucking insects. In order to increase their resistance to insect pests, lectin-coding genes have been introduced into a number of plants.

KEYWORDS:

Defence, Health, Insect, Intercellular Signalling, Plant Protein.

INTRODUCTION

Plant defence against herbivores depends heavily on enzymes like peroxidases (PODs), polyphenol oxidases (PPOs), and lipoxygenases (LOXs). PODs generate reactive substances that prevent insects from absorbing nutrients, while PPOs support decreased digestibility and toxin formation. On the other side, LOXs are involved in triggering plant defences by producing chemicals like jasmonic acid. Plants' indirect defences include drawing in herbivores' natural enemies. Plants emit volatile substances known as herbivore-induced plant volatiles (HIPVs) in reaction to insect assault. These substances either make herbivores poisonous and repel them, or they attract the herbivores' natural predators and parasitoids and deplete their number. Depending on the insect-plant system, different plants emit different HIPV blends, and these substances are crucial in mediating plant-arthropod interactions. With significant quantities in storage organs like seeds and tubers, proteinase inhibitors (PIs) are another well-known family of protective proteins that are present in plants. Insects' digestive enzymes are inhibited by PIs, which prevents protein digestion and results in amino acid shortages that might stunt growth or result in famine. For effective long-term plant defence measures, it is crucial to understand how insects overcome the many kinds of PIs that plants create in response to stressors.

Plant defence mechanisms depend on proteins from the plant, including lectins, proteinase inhibitors, and enzymes including peroxidases, polyphenol oxidases, and lipoxygenases. For example, homopteran, lepidopteran, and coleopteran insects have all been proven to be susceptible to the effects of lectins. When consumed by insects, these proteins may cause systemic toxicity and even upset the digestive systems of herbivores. Proteinase inhibitors attach to the stomach enzymes of insects and prevent them from digesting food, resulting in nutritional deficits and decreased insect development. The co-evolutionary arms race between plants and herbivores is highlighted by the fact that certain insects have evolved defences against these inhibitors [1], [2].

Peroxidases, polyphenol oxidases, and lipoxygenases are a few examples of the enzymes that help plants defend themselves by creating poisonous substances or preventing insects from absorbing nutrients. These enzymes are involved in lignification, somatic embryogenesis, and wound healing, all of which help plants defend themselves against herbivorous animals. Plant defence tactics also heavily rely on indirect defences like the emission of HIPVs, or herbivore-induced plant volatiles. These volatile substances have the ability to draw in herbivores' natural enemies, thereby forming a network of defence for the plant. However, since certain HIPVs may also draw in unwanted insect pests, it is crucial to take into account any possible ecological effects.

Protective proteins in plants

According to ecology, the link between the two in an insect-plant interaction is crucial for both species' existence. Insects are continually on the lookout for a genuine, robust host plant that can provide them enough nutrition, be used for oviposition and mating, and also supply food for the progeny. Because insects have comparable nutritional needs to other animals, any imbalance in how well they digest and use plant proteins would have a significant impact on their physiology. Changes in protein quality and quantity caused by altered gene expression during stress conditions, such as an insect assault, are crucial for oxidative defence and signal transmission. A significant portion of the plant proteins consumed by insects are stable, stay intact in the midgut, and even pass the gut wall into the hemolymph. The function of a protein is affected by changes to its amino acid composition or sequence. The injection of protease inhibitors (PIs), which stop the toxic proteins from degrading and enable them to perform their defence role, may also enhance the anti-insect action of a hazardous protein that is proteolysis vulnerable. Predicting the toxicity and mechanism of plant resistance proteins (PRPs) might be made easier with a better knowledge of protein structure and post-translational changes that contribute to stability in the herbivore gut. Recent developments in proteomic and microarray methods have shown that a large range of PRPs are involved in plant defence against herbivores. Arthropod-inducible proteins are regulated by a number of signalling pathways, including ethylene (ET), jasmonic acid (JA), and/or other fatty acids due to the different feeding strategies of arthropods.

Against homopteran, lepidopteran, and coleopteran insects, lectins have been proven to be effective. characteristics that repel insects in Galanthus nivalis L. The first plant lectin to be shown to be effective against hemipteran insects was agglutinin (GNA). The effectiveness of plant lectins that bind carbohydrates, such as GNA, Phaseolus haemagglutinin, and wheat germ agglutinin, against a variety of insect pests has been well investigated. Because of their interaction with a particular carbohydrate residue in the cell membrane, mannose-binding lectins have been shown to be efficient against sucking insects. Many plants, including GNA, PSA, and WGA, have been developed to express lectin-coding genes and to have insect defence [3], [4].

The mannose-specific lectin GNA has been shown to bind to the luminal surface of the midgut epithelial cells of brown planthoppers (*Nilaparvata lugens* (Stal.) in rice through recognition of the cell surface carbohydrate moieties of glycoproteins and/or other glycoconjugates in the gut, according to studies on the mechanism of action against these pests. The presence of GNA in the fat bodies, ovarioles, and hemolymph was detected using an immunolabeling GNA test, demonstrating that it may get through the midgut epithelial barrier and into the insect's circulatory system to cause systemic toxicity. In transgenic plants that express the snowdrop lectin in wheat, rice, and tobacco, partial resistance to homopteran insect pests has been shown.

DISCUSSION

Plant lectins are produced as a result of different stressors and are stimulated by elicitors. In tobacco leaves, JA increased NICTABA lectin expression. the invasion of herbivores, particularly S., that cause NICTABA. sexta Manduca littoralis L. and tobacco plants have been shown to have *Tetranychus urticae* Koch. Hessian fly, *Mayetiola destructor* (Say) response protein (HFR1), two chimerolectin-like proteins known as HFR2 and HFR3, and a mannose-binding jacalin-like lectin known as HFR1 have all been found to be expressed by Hessian fly, M. larvae. Wheat has a destroyer. Insects that eat differently express distinct lectins, such as the larvae of the autumn armyworm, S. While the phloem-feeding bird cherry-oat aphid, *Rhopalosiphum padi* Koch, caused HFR3 and HFR2 expression, the latter was expressed significantly later (12 d) than the former. Frugiperda induced HFR2, but not HFR3 expression. Monocot plants including rice, barley, wheat, rye, and maize all express a number of jasmonate-inducible lectins in their leaf tissues. The possibility for using these entomotoxic lectins in crop protection via genetic engineering depends on our knowledge of how plant lectins are produced in response to diverse stressors, including herbivory, and their involvement in plant defence. Despite the fact that introducing lectin genes into plants seems to be highly appealing and efficient, caution is required due to the potential toxicity of certain lectins to non-target creatures, such as mammals.

Anti-proteinase drugs

One of the most prevalent kinds of protective proteins in plants is known as a proteinase inhibitor (PI). A higher concentration of PIs is found in storage organs like seeds and tubers, and 1 to 10% of their total proteins are made up of PIs, which inhibit a variety of enzymes and are crucial for plant defence against insect herbivory 74,75. PIs bind to the digestive enzymes in the insect gut and inhibit their activity, which reduces protein digestion and leaves the insects with insufficient amino acids, which can slow down their development or cause them to starve.

Plants produce several different kinds of PIs in response to stressors. Serine PIs (SPIs), also known as Kunitz proteinase inhibitors (KPIs), are among the defence genes in plants that are most significantly activated in response to injury or herbivore feeding. The Solanum nigrum L. SPIs. has been discovered to negatively impact a variety of insect pests. The development of genome sequencing has led to the discovery of several proteinase inhibitors and other defence mechanisms that plants produce in response to herbivore damage. The majority of plant KPIs are elevated in response to insect herbivory, although the extent of this upregulation differs depending on the insect-plant interaction. Through the provision of a genetic repository of various PIs, various KPIs enable plants to contend with successive generations of insects. Some insects, however, react to PIs by producing naturally occurring or artificially generated PI-insensitive proteases or by inactivating ingested PIs, preventing them from binding to sensitive proteases. Such an insect feeding reaction has a detrimental impact on PI activity and may cause much more harm to the plants. Understanding the methods by which insects combat the PI-based plant defence is necessary to overcome this significant obstacle to manipulating and using PIs for a longer-lasting plant defence [5], [6].

Enzymes

The interruption of an insect's feeding is one of the key components of HPR's effectiveness against insects. Peroxidases, polyphenol oxidases, ascorbate peroxidases, and other peroxidases oxidise mono-or dihydroxyphenols to form reactive o-quinones, which in turn polymerize or form covalent adducts with the nucleophilic groups of proteins due to their electrophilic nature (for example, -SH or e-NH2 of Lys). These electrophiles interfere with the uptake of nutrients by insects. As well as lipoxygenases, phenylalanine ammonia lyase, and superoxide dismutase, there are other significant antioxidant enzymes. Recent years have seen a lot of interest in how herbivory affects the induction of antioxidative enzymes in plants.

POD, or peroxidases

Insect HPR has been linked to the oxidative status of the host plants, which produces ROS that are subsequently removed by antioxidative enzymes. One such family of enzymes that scavenges ROS in addition to playing other protective activities is POD. PODs play a significant role in plants' initial reaction to insect attack. PODs, which are monomeric hemoproteins that are extensively present in plants and comprise many isozymes whose expression is influenced by tissue, developmental stage, and environmental factors, are distributed as soluble, membrane-bound, and cell wall-bound inside the cells. PODs control a multitude of processes, including as lignification, suberization, somatic embryogenesis, auxin metabolism, and wound healing, which play direct or indirect roles in plant defence. PODs' role in enhancing plant defences against insect pests has been investigated in a number of plant systems. Insect eating is directly discouraged by the PODs' production of phenoxy and other oxidative radicals in conjunction with phenols, and/or these PODs create toxins that lessen plant digestibility, which in turn causes nutritional deficiencies in insects that have a significant impact on their growth and development. PODs may also be directly hazardous to herbivores' stomachs, according to reports. From numerous plants where they were generated in response to insect assault, PODs have been purified and characterised.

Polyphenol oxidases (PPOs) are crucial enzymes in plants that control insect pests' eating, growth, and development. They also play a crucial part in plants' defence mechanisms against biotic and abiotic challenges. PPOs may work in the methods described below: Quinones produced by PPO may alkylate important amino acids, reducing the nutritional value of plants; they may also cause oxidative stress in the gastrointestinal lumen via redox cycling; and they may be ingested by herbivores and have harmful consequences. The PPOs are metallo-enzymes that catalyse the oxidation of monophenols and o-diphenols to quinones. Quinones are highly reactive intermediate compounds that easily polymerize, react with nucleophilic side chains of amino acids, and crosslink proteins, reducing the availability of such proteins and affecting the nutritional value of the food. Quinones react with cellular nucleophiles in basic settings whereas quinines make semiquinone radicals in acidic conditions that in turn produce ROS. Compared to the original phenols, quinines are more poisonous to plant herbivores. The production of melanin by PPOs boosts the cell wall resilience to diseases and insects in addition to their contribution to the digestibility and palatability of plant tissues.80 PPO serves as a key instrument in plant resistance to a variety of challenges due to its ability to be activated by both biotic and abiotic stresses as well as by treatment with substances connected to the octadecanoid pathway. Different signalling molecules, injuries brought on by wounds, pathogens, or insect infestations variably trigger the PPO genes. In several plants, including tomato and lettuce, a correlation has been shown between the induction of PPO activity and insect fitness. Although PPOs build up in the plants' leaves, roots, stems, and flowers, immature tissues that are more susceptible to insect assault show more induction [7], [8].

Lipoxygenases

Through the octadecanoid route, lipoxygenases (LOXs), a different class of anti-oxidative enzymes, help plants defend themselves against a variety of stressors. Fatty acid hydroperoxides are produced as a consequence of the catalysed hydroperoxidation of polyunsaturated fatty acids. The latter are converted by enzymes and/or chemical reactions into extremely unstable and reactive aldehydes, -ketols, epoxides, and ROS such hydroxyl radicals, singlet oxygen, superoxide ion, peroxyl, acyl, and carbon-centered radicals. The amino acid absorption is impacted by protein-protein crosslinking and amino acid damage caused by the unstable reactive products' interactions with proteins. Additionally, the byproducts of lipid peroxidation are harmful to insects (antibiosis) and function as antixenosis or insect repellents. Linoleic and linolenic acids are the main substrates of LOX in plants. The oxidation of linolenic acid in the JA signalling pathway, which in turn plays a key role in activating plant defence both directly by producing oxidative enzymes and protease inhibitors, as well as indirectly through the production of volatile organic compounds (VOC) that attract the natural enemies of insect pests, is one of the most crucial aspects of LOX in plant defence. It has been shown that LOX catalyses the oxygenation of polyunsaturated fatty acids, which generates hydroperoxides that are metabolised to substances like JA and traumatin.

Induction of LOX activity in response to herbivory has been studied in many plants such as soybean in response to two-spotted spider mite, *T. urticeae*, in tomato in response to aphids, *Macrosiphium euphorbiae* Thom., and *M. persicae*, in *N. attenuata* following infestation by *Myzus nicotianae* Black. and in wheat following *Sitobion avenae* (F.) infestation. Compared to the plants whose LOX3-mediated defence decreased larval development, food intake, and frass generation, the LOX-deficient *N. attenuata* plants are more susceptible to attack by *M. sexta*, which also attracts additional herbivores including *Empoasca spp.* Upregulation of LOX transcripts and an increase in free phenolics (14-fold) in maize plants transformed with the wheat oxalate oxidase gene were positively correlated with resistance to the European corn borer, *O. nubilalis*.

Direct defences

A crucial part of defending plants from herbivore assault is the defensive reaction in plants that attracts natural enemies of herbivores. As a consequence of the combined impact of mechanical injury and elicitors from the attacking herbivore, indirect defences may be constitutive or induced. The secretion of extra floral nectar (EFN) and the production of volatiles facilitate interactions between plants and their natural predators or parasitoids, which actively lower the population of herbivorous animals that feed on them. The study of induced indirect defences at the genetic, biochemical, physiological, and ecological levels has lately attracted more interest.

HIPVs (herbivore-induced plant volatiles)

Plants release a mixture of volatile and non-volatile chemicals as a kind of cover against herbivore grazing. HIPVs, or herbivore-induced plant volatiles, play a significant part in plant defence by either luring in the herbivores' natural enemies or serving as a deterrent to eating and/or oviposition. In reaction to a herbivore assault, plants emit HIPVs, which are lipophilic chemicals with greater vapour pressure, into the atmosphere via their leaves, flowers, and fruits as well as into the soil through their roots. The types of plants and herbivores, their developmental stages, and the health of the plants and herbivores all affect the HIPVs that are generated. Normally, plants release the ideal amount of volatile compounds into the atmosphere, whereas in response to herbivory, a different mixture of volatiles is produced.8 The volatile mixture released by plants in response to insect attack is particular to a given insect-plant system, including natural enemies and nearby plants. The HIPVs mediate interactions between plants and arthropods, microbes, unharmed nearby plants, or intraplant signalling that alerts unharmed areas within the plant. Depending on the feeding strategies of insect pests, various defence signalling pathways are activated, which leads to the production of particular volatile compounds [9], [10].

Terpenes, green leafy volatiles (GLVs), ethylene, methyl salicylate, and other VOCs are among the HIPVs. The GLVs are the well-researched metabolites of stress-inducible chemicals produced by the hydroperoxide lyase (HPL) branch of the oxylipin-pathway. GLVs are reactive electrophile entities that participate in signals of stress and defence. The C6-aldehydes ((Z)-3-hexenal, n-hexanal) and their related derivatives ((Z)-3-hexenol, (Z)-3-hexen-1-yl acetate, and the equivalent E-isomers) make up GLVs. The GLVs levels have been adjusted either by the application of elicitors or by genetically modifying the expression of HPL in plants in order to comprehend the function of C6-aldehydes and their corresponding derivatives in plant defence. Plant volatiles such as methyl salicylates and the C16- homoterpene, 12- trimethyl-1, 3(E), 7(E), and 11- tridecatetraene [(E, E)-TMTT] have been found to attract the predatory mites.3,7,8,96 Methyl salicylate (MeSA), the most common component of the HIPVs, has been reported in the headspace of many insect-infested plants, including lim The reduction of cabbage moth Mamestra brassicae L. oviposition. by MeSA emitted during infection, indicating that the herbivorous predators can also detect MeSA. Additionally discovered from insect-infested plants is methyl benzoate (MeBA), which structurally mimics mesosanilic acid (MeSA). When frugiperda infests rice, roughly 30 volatiles are released, including MeSA and MeBA, which are very attractive to S's natural enemies. frugiperda, like the Creston's Cotesia marginiventris. However, employing HIPVs to build natural enemies has an environmental cost since they have the ability to attract agricultural pests. For instance, Leptinotarsa decemlineata (Say), a Colorado potato beetle, is drawn to a mixture of volatiles that includes cis-3-hexenyl acetate, linalool, and MeSA.

A number of chemicals, including ester methyl salicylate (MeSA), the monoterpenes myrcene and ocimene, homoterpene (E, E)-4, 8, 12-trimethyltrideca-1, 3, 7, 11-tetraene (TMTT), and sesquiterpene (E, E)-farnesene, are released hours after an infestation. This is one of the herbivore responses that has been most thoroughly researched. The HIPVs defend the plants either directly by repelling, discouraging, and making the herbivore poisonous, or indirectly by luring the assailants' natural foes and preventing further harm to the plants. Terpenoids, products of the terpenoid system, and metabolites of the lipoxygenase and shikimic acid pathways all contribute significantly to plant defence, both directly and indirectly. Numerous plants, including leaves of lima beans attacked by S., have been shown to emit period-specific volatiles. Forest tent caterpillar, L. littoralis,103 infected leaves of hybrid poplar (*Populus trichocarpa Torr.* and A. Grey X deltoides). Dispar released a mixture of volatiles that included mono-, sesqui-, and homoterpenes as well as (E)-ocimene. When exposed to (Z)-3- hexanol, maize plants emit a volatile mixture that often attracts natural enemies and is discharged after a caterpillar infestation.

Numerous plants have demonstrated volatile emission signal priming. It has been said that applying GLV compounds to maize seedlings, such as (Z) -3- hexanal, (Z) -3- hexen-1-ol, and (Z) -3- hexenyl acetate, separately and in combination, allowed the seedlings to react to injury and S. beetroot armyworm. Contrary to the control plants, the exigua caterpillar regurgitated and caused a buildup of JA and sesquiterpenes. Similar findings were noted N. responds attenuata to *M. sexta* infection, where plants prepared with volatiles produced by cut sagebrush showed modest damage. Priming, which is the incomplete activation of defense-related processes to minimise biochemical investments prior to the start of the real assault, therefore plays a significant part in plant defence. However, according to a few observations, volatile emissions from infected plants also attracted certain non-target insect pests, increasing the insect assault on the plant. It has been shown that predatory mite *P. persimilis* is drawn to transgenic Arabidopsis that overexpresses strawberry nerolidol synthase, a terpene synthase (TPS) that produces sesquiterpene alcohol (3S)-(E)-nerolidol. *Cotesia marginiventris* (Cresson), a parasitic wasp, was drawn to the lepidopteran larvae infesting transgenic maize plants with overexpression of the corn TPS10 gene, which produces (E)-farnesene, (E)-bergamotene, and other herbivore-induced sesquiterpene hydrocarbons.109

Roots have also been found to release a variety of volatile plant compounds that protect plants from belowground insect pests by acting as antimicrobial and antiherbivore substances as well as by attracting the natural enemies of the insect pests that feed on the roots. This is in addition to the volatile plant substances released from aerial parts of the plant. *Diuraphis noxia* (Mord.), a root-feeding insect, releases 1, 8-cineole, a volatile monoterpene that is poisonous and repulsive to certain insects. The nematode H is drawn to the sesquiterpene (E)-caryophyllene generated by maize roots in response to the larvae of *Diabrotica virgifera* LeConte feeding on them. Root-emitted volatiles, such as 1,8-cineole, however, hinder the growth of Brassica campestris seedlings because they prevent cell proliferation more severely than cell elongation, which is necessary for root growth, as well as because they interfere with nuclear and organelle DNA synthesis in the root apical meristem and change the composition of the root's phospholipids and sterols.

CONCLUSION

In conclusion, protective proteins are critical in the intricate interactions between plants and insects. They shape the dynamics of these interactions and have an impact on the fitness and survival of both species. The ecological relevance of these interactions emphasises how crucial it is to comprehend how plants use different defensive systems to ward off herbivorous insects and how insects evolve to circumvent these defences. In conclusion, research on defensive proteins in plants demonstrates how complex and dynamic insect-plant interactions are. By reducing the influence of herbivores on crop yields while conserving the delicate balance of ecosystems, we may create more efficient solutions for pest control and sustainable agriculture as our knowledge of these processes grows. To sum up, protective proteins are crucial elements of the complex dance between plants and insects in ecological systems. Understanding their functions, modes of action, and possibilities for genetic engineering may help develop crop protection and insect pest control systems that are more efficient and long-lasting. However, care must be taken to prevent unintentional damage to non-target creatures caused by such tactics.

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CHAPTER 7

EXPLORING THE VOLATILE ORGANIC COMPOUNDS AND INDUCED DEFENCE

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ABSTRACT:

The complicated phenomena of insect herbivory causes a variety of metabolic changes in plants that result in the creation of defence mechanisms, reactive oxygen species, hydroxy radicals, and higher phenol concentrations. The silver leaf whitefly *Bemisia argentifolii*, *Scirpophaga incertulas*, *Cnaphalocrosis medinalis*, and *Nilaparvata lugens*, among other herbivores, have been shown to cause biochemical reactions in their host plants, including the activation of enzymes like peroxidase, catalase, chitinase, and phenolic acids. Additionally, various insect species cause various plant defence responses, suggesting a complex interaction between specialised and generalist eaters. In addition to using direct defences, plants sometimes use indirect defences by releasing volatile organic compounds (VOCs), which attract parasitoids and herbivore predators. Through their role as chemical messengers that interact with higher trophic levels, these VOCs have created an intriguing universe of indirect defences. Over 30,000 naturally occurring terpenes and terpenoids have been found to far, and they play a crucial part in this chemical communication among other groups of VOCs. Tritrophic associations, in which parasitoids and predators are attracted to plants producing certain VOCs caused by herbivore infestation, have been revealed as a result of our growing understanding of the function of VOCs in plant-insect interactions. Additionally, plants respond to herbivory systemically, producing induced volatiles both locally and systemically throughout the plant. These reactions may affect parasitoids' and predators' behaviour, which increases the efficiency of the natural enemy in biological pest management.

KEYWORDS:

Defence, Herbivore, Organic, Plant, Volatile Organic Compound (VOC).

INTRODUCTION

Recent years have seen a rise in interest in the study of induced plant defences against herbivores and the chemical signals involved in host plant localization. In India, however, where crop protection measures may greatly benefit from a greater understanding of plant-insect interactions, this study is still in its infancy. Insights for pest management and plant breeding programmes may be gained by examining the secondary metabolites linked to both static and induced defences in brinjal plants (*Solanum melongena*) against the shoot and fruit borer (*Leucinodes orbonalis*). In the end, such study may result in the creation of crop kinds immune to insects and lessen the need for chemical pesticides. Even while this profession has made great strides, more study is still needed, especially in places like India where such studies are not as common. We may learn more about the complex dance of nature and create fresh approaches to sustainable agriculture by continuing to investigate the chemical and biological reactions of plants to herbivore assaults.

Insect herbivory causes a variety of changes in the metabolism of the plants it feeds on, including the creation of compounds used by plants to defend themselves, the production of reactive oxygen species, the hydroxy radical, and a rise in the concentration of phenols. It is known that these oxidative enzymes and reactive oxygen species build up in response to injury and herbivory. According to earlier research, the silver leaf whitefly *Bemisia argentifolii* has been found to stimulate chitinase while it feeds. tomatoes contain ß-1, 3-glucanase and peroxidase. According to recent reports, *Scirpophaga incertulas, Cnaphalocrosis medinalis,* and *Nilaparvata lugens* feeding caused rice plants to produce biochemicals like proteins, phenols, and carbohydrates as well as the protective enzyme activities of peroxidase, catalase, chitinase, and phenolic acids. A study concluded that castor plants' increased enzymatic activity was connected to their defence mechanisms, which varied depending on the kind of insect that attacked them. In castor plants, a clear distinction between specialised and generalist leaf feeders was discovered in the alteration of phenolic acids. Solanum plant species are attacked by shoot and fruit borer, which have various eating activities that affect the level of damage. It is highly interesting to quantify direct induced defence in these plant species [1], [2].

One of the first things that are seen in attacked host cells during virtually all plant-herbivore interactions is the buildup of protective compounds and enhanced enzyme activity. There aren't many reports on direct defence in brinjal plants. For instance, Mandal showed that elicitors such chitosan, salicylic acid, methyl salicylate, and methyl jasmonate caused the induction of phenolics, lignin, and important defence enzymes in aubergine roots. There haven't been any instances, yet, of aubergine developing an induced defence against *L. orbonalis*. In this work, we tried to investigate several facets of S's triggered defence. Regarding the biochemical and enzyme alterations brought on the feeding by fruit and shoot borer on melongana. This is S's major annoyance. Melongana causes the most crop damage. The modifications in S are explained by this research.

Plants defend themselves using a variety of defence strategies in addition to direct defence. In response to herbivory, plants produce a variety of substances that have an impact on how well insects function. However, they may also release intricate mixtures of volatiles that attract parasitoids and/or herbivore predators, which is a kind of communication between plants and the third trophic level. Because the plant produces volatile molecules in response to a herbivore infestation, which do not directly impact the herbivore but instead serve to alert higher trophic levels that the plant is home to herbivores, this sort of defence is known as a "induced indirect defence." The supply of shelter, food, and chemical information, either alone or in combination, may all fall under this category of defence. Volatile molecules generated by plants may be so instructive that they aid natural enemies in locating a herbivore-attacked plant and determining which type of herbivore is eating on it. Due to their host/prey specificity, carnivores find this to be crucial and significant. 'That enemy of your enemy is your friend' is the guiding philosophy behind it.

Volatile organic compounds are organic substances that readily produce vapours at standard pressure and temperature and have a high vapour pressure. Hydrocarbons, oxygenated hydrocarbons, and organic molecules containing nitrogen or sulphur are examples of volatile organic compounds. Since the previous three decades, there has been a lot of study done to identify these chemicals. Alcohols, aldehydes, aromatics, esters, ketones, pyrazines, terpenes, and terpenoids are some of the categories in which these substances fall. Terpenes are the only pure hydrocarbons, whereas terpenoids are oxygenated molecules made from isoprene units.

volatile substances that plants generate after a pest meal. Plants communicate through volatile compounds. Typically, people find the aroma of new flowers, flavorful coffee, or great wine to be alluring. However, plants do not normally use important energy creating these compounds only to appease people; instead, the majority of these volatiles serve other essential purposes for the benefit of plants. Dicke showed that the induction of plant volatiles was a typical response of plants to herbivory for more than 23 plant species from 13 families. Malvaceae, Rosaceae, Cucurbitaceae, Solanaceae, Poaceae, Fabaceae, Brassicaceae, and Asteraceae are a few of the significant plant families that were examined [3], [4]. One of the greatest categories of natural products is isoprenoid derivatives. There are already more than 30,000 naturally occurring terpenes and terpenoids known, and this figure is rapidly increasing. Monoterpenes are well-known examples of the hydrocarbon emissions from plants that give off the scents of pine, lemon, and eucalyptus.

DISCUSSION

The insect and mite species that plant volatiles attract are from 27 species and 13 families. These herbivores include fruit and stem borers as well as leaf miners. In fact, plants have been shown to produce volatiles in reaction to an herbivore's oviposition. The chemicals produced by plants demonstrate a lag between the beginning of feeding and the production of volatiles. Additionally, the production of these triggered chemicals has a diurnal cycle that persists even after herbivore feeding has ceased. For maize and rice, it was shown the significance of the diurnal cycle for the volatile emission of induced chemicals. One may distinguish between local induced compounds, which are produced at the site of harm, and systemic induced compounds, which are produced later on. There are two sorts of plant responses to herbivory in terms of induced volatiles.

1. The plant produces substantial, unique compounds in reaction to herbivory that are not generated in response to mechanical harm.
2. The plant reacts to herbivory by producing more and compounds that remain longer than those released in response to mechanical harm.

Identification of plant volatiles caused by herbivores. Plants, herbivores, parasitoids, and carnivores all interact with one another in tritrophic situations. Plants release a mixture of volatile substances in response to insect eating. Insect parasitoids that prey on their herbivorous host insects are drawn to these substances. These volatile substances may be seen as elements of an indirect defence mechanism in plants since they cause a decrease in plant feeding. Insects may directly detect these chemical signals released by plants via touch chemoreception or by diffusion using air or water as a transport medium. According to Metcalf, the insect antennae's olfactory chemoreceptors preferentially detect volatile compounds, which then cause behavioural reactions such as host identification and oviposition. According to some reports, the volatiles that plants instantly release after receiving a new meal are identical to the volatiles that plants intentionally injured with a razor blade emit.

Through the lipoxygenase, isoprenoid, and shikimic acid pathways, the main volatiles released by plants, including fatty acid derivatives, terpenoids, and phenols, are created. Green leaf volatiles, volatiles produced by lipoxygenase, and other constitutive chemicals unique to individual plants were released during the early phases of plant degradation. According to reports, if herbivore damage persisted after a few hours or the next day, plants would begin to emit these substances for as least three days [5], [6].

The biggest and most diversified chemical category in plants is comprised of terpenoid molecules. They may also be created through the 1-deoxy-D-xylulose-5 phosphate or the mevalonic acid pathways, according to reports. Numerous of them are infamous for harming herbivores. The plants treated with herbivore elicitors produced the most prevalent homoterpenoids, 4,8-dimethyl-1,3, 7-nonatriene and 4,8,12- trimethyl-1,3 7, 11-tridecatetraene. Indole and methyl salicylate are two phenolics released by plants with herbivore stimulation. Indole is a crucial step in the production of tryptophan, which is essential for plants' direct defence mechanisms such indole glucosinolates. As opposed to this, methyl salicylate is the volatile methyl ester of the plant hormone salicylic acid, which has been found in a variety of plant species, including lima beans, apples, and pears. Anthocorid predators exhibit an aggregative reaction when exposed to methyl salicylate and -a-farnesene, two volatile chemicals associated with Psylla infestation in pear trees. Given that these substances are derived from plants, it is reasonable to assume that Psylla damage causes them to be produced.

Produced volatiles are beneficial to plants. The term "mutualism" for the parasitoid-plant interaction in a tritrophic system of *Arabidopsis thaliana* Heynh., *Pieris rapae*, and *Cotesia rubecula* is justified because both parasitoids that attract parasitic plants and parasitoids that react to herbivore-induced plant volatiles will both experience selective advantages. The ability of parasitic wasps to recognise and react to certain scents connected to their hosts is a natural process. Because of their capacity for learning, parasitoids can discriminate between the aromas of plants that have had various kinds of damage, allowing them to concentrate on those that have been harmed by prospective hosts. Therefore, chemical reactions elicited in plants by herbivorous hosts may be crucial in parasitoids choosing their host environment. Further research is necessary to determine whether or not the induced volatiles are likewise trustworthy indicators of the identification of the herbivore to the predator and parasite. The three components of plant signals that appear to be most pertinent to the debate over whether or not herbivore-damaged plants actively entice their predators are described.

1. The signal has to be audible and distinct from background noise for the insects to be able to comprehend it.
2. A sufficient host or prey must be present, and the signal must be precise enough to dependably convey this.
3. The signal will need to be sent out while the natural enemies are out foraging.

However, attracting herbivores' natural enemies may provide an extra benefit to the plants, sustaining selection pressures that favour the synthesis of these compounds in large amounts. There have been investigations into many tritrophic systems. It has been reported that induced indirect defence mechanism in the tritrophic relationships comprising of maize plants, beetroot armyworms, *Spodoptera exigua*, and parasitic wasps, *Cotesia marginiventris*. The compound found in the oral secretion of the larvae that causes the generation of beetroot armyworm-induced volatiles in artificially injured leaves has been identified as N--L-glutamine. As a consequence, parasitoids find the regurgitate-treated plants to be particularly alluring. This elicitor, known as volicitin, is made up of a lipid moiety connected to glutamine by an amide connection. Volicitin or other comparable components have been found in the regurgitate of Spodoptera and *Manduca sexta* tobacco hornworm larvae [7], [8].

Green leaf volatiles are released and ethylene and jasmonic acid are induced by feeding by Spodoptera larvae. These phytohormones cause the release of terpenoids, indole, and other chemicals. Corn plants harmed by Spodoptera larvae are attracted to the Cotesia parasitoid wasp. It's interesting to note that mechanically injured plants release a different mixture of volatiles than those released by afflicted plants. Trans-2-hexenal, cis-3-hexenal, and hexanal concentrations in undamaged tomato plant leaves are rather modest, according to Buttery and Ling, but if the leaves are crushed or otherwise injured, the quantities of these aldehydes rise considerably. The concentrations of C6 volatiles in damaged leaves were at least ten times greater than those in undamaged leaves.

The parasitoid *Anagrus nilaparvatae* is drawn to the volatile emissions of the plant caused by the herbivory of the rice brown plant hopper, *Nilaparvata lugens,* according to extensive research on the rice ecosystem. A variety of volatile defence signals that the maize plant emits are very alluring to the females of several parasitic wasp species. a terpene synthase TPSIO that converts farnesyl diphosphate into farnesene, bergamotene, and other herbivore-induced sesquiterpene hydrocarbons. Volatile emissions from peanut plants that were concurrently harmed by insects and a fungus were observed and identified. It has been reported on the physiological reactions of Chinese cabbage caused by herbivory and fungus infection. Both Baldwin and his colleagues as well as Dicke and his colleagues have reported on the majority of the research on plant defence systems.

Induced reactions to injury may be systemic, meaning that a signal generated at the injured place travels throughout the plant and has an impact on locations far from the source of the harm. A few hours after caterpillar damage to maize seedlings begins, many volatiles that are extremely appealing to parasitic wasps begin to be released. For instance, the parasitic insect *T. Chilonis* react well to the leaf-surface compounds produced by the *Achaea janata L.*-infested castor plant. after five hours of eating. The reaction is widespread because harmed plants' injured leaves also release volatiles. According to several studies, systemic reactions brought on by herbivore feeding occur in a variety of plant species and influence the behaviour of parasitoids and predators. According to a recent paper, the yellow stem borer, *Scirpophaga incertulas* Walker, infected rice plants emit stem volatiles that stimulate oviposition and elicit arrestment responses in the egg parasitoid, *Trichogramma japonicum* ashmead.

There are no reports on S's systemic reaction available as of yet. melongena plant as a result of L. shoot and fruit borer feasting on it. orbonalis. The egg parasitoid T. rex was tested for behaviour in lab settings. As a biological sensor, chilonis was utilised to ascertain the dynamics of the S. defence reaction brought on by the melongena plant. Additionally, we identified the volatiles released by induced S using GC and GC-MS. *Melongene plants* [9], [10]. In India, aubergine, also known as brinjal, is a significant and popular vegetable crop that is cultivated all year round. Brinjal is mostly grown on tiny family farms and provides resource-poor farmers with a source of financial income. The insect brinjal fruit and shoot borer severely damages this major vegetable crop, with losses in South Asia ranging from 30 to 80 percent. In Tamil Nadu, Andhra Pradesh, Gujarat, and Himachal Pradesh, the pest has been documented to cause losses ranging from 20.7 to 60.0%, while it causes losses of 70% in Gujarat and 41% in Andhra Pradesh. Due to the pest's strong reproductive capacity, quick generational turnover, and extensive cultivation of brinjal throughout both the wet and dry seasons of the year, a major issue exists.

An attempt has been undertaken to research the defence mechanism in S, taking into account the material that is currently accessible on brinjal plants. the melongena plant. In this paper, we looked at the feeding, melongena plants have static defence mechanisms that have been induced. The potential use of these defences for efficient control of the main pest of the brinjal crop, the shoot and fruit borer, at the laboratory level. Many plants have chemical defences in place to stop insects and illnesses from attacking them. When the shoot and fruit borer, L. orbonalis, attacks the brinjal plant, it develops specific defence mechanisms to repel the intruder. Toxin production as a secondary metabolite and the emergence of quantitative and qualitative alterations in the plant are two examples of these. The parasitoid *Trichogramma sp.* can detect particular volatile compounds released by the brinjal plants when they are under pest assault. By luring them to the plants with pest infestations, these volatile kairomones may improve the parasitoids' capacity for biocontrol. They help the parasitoids behave more accurately by giving them indications about the position of the host.

Understanding plant resistance mechanisms to insect herbivores may be aided by research into volatile plant defences. The creation, enhancement, and use of host-plant resistance and other management strategies for insect and disease pests would benefit tremendously from the discovery of particular herbivore-induced plant volatiles. The role of certain volatile organic chemicals engaged in tritrophic interactions seems to be well studied in the herbivore-induced volatile organic chemical blends. The integration of the many facets of our understanding of induced plant defences against various adversaries has recently attracted a great deal of attention. Plant defences are well known to be very complicated and poorly understood. Additionally, it was noted that a plant's reaction to a biotic assault may include the allocation of resources to support regrowth and attack tolerance.

The usage of primary and secondary metabolites that have been extracted and identified from a particular plant source may be investigated further against various insect pests of the same or other crops for their potential function in either direct or indirect defence. In the current research, it is suggested that secondary metabolites present as static and induced defence in *S. melongena* plants be isolated, identified, and evaluated for use against specific pests of stored goods and agriculture. The findings of the current study will provide light on the chemical, biochemical, and enzymatic responses of the model plant to pest assault and how these defence mechanisms might be used to control insect pests effectively. The research will significantly improve our knowledge of the fundamental processes behind plant-insect interactions and the impact of certain biochemical signals in a plant. These investigations may potentially result in the creation of agricultural plants with improved insect resistance as an applied aim. The study will provide fresh information that may be used to improve plant breeding techniques and comprehend how plants respond to pests and parasitoids that are related to those pests. By using plant breeding or genetic engineering, new crop types that are more appealing to the natural foes of their insect predators may be created. The use of chemical pesticides will naturally decrease as a result of the initiatives.

The bulk of the studies in this field of study were completed recently. However, much of the study has been done in industrialised nations where there are contemporary equipment for analysing chemicals and insect behaviours. So yet, only a small number of volatile substances involved in host plant location and acceptance have been identified. The focus of major labs worldwide is the use of semiochemicals in pest control activities. But scientists are now paying a lot of attention to the trophic interactions and chemical communication of insects, which have previously received little attention. Despite the fact that these types of research provide the foundation for the creation of more modern and risk-free pest control techniques, study on insect plant interactions and analytical assessment of chemicals involved in the process of host plant location is almost nonexistent in India.

Numerous plants have chemical defences against insects and illnesses. When the shoot and fruit borer, *L. orbonalis*, attacks the brinjal plant (*S. melongena*), it develops specific defence mechanisms to repel the intruder. Toxin production as a secondary metabolite and the emergence of quantitative and qualitative alterations in the plant are two examples of these. The parasitoid *Trichogramma sp.* can detect particular volatile compounds released by the brinjal plants when they are under pest assault. By luring them to the plants with pest infestations, these volatile kairomones may improve the parasitoids' capacity for biocontrol. They help the parasitoids behave more accurately by giving them indications about the position of the host.

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CONCLUSION

The incredible complexity of the natural world is shown by the complex and diverse interactions between plants, herbivores, and their natural enemies. Plants' reactions to insect herbivory include the synthesis of protective chemicals, the emission of volatile organic compounds, and enzyme modifications. These reactions have ramifications for agriculture and pest management in addition to being intriguing from a scientific standpoint. In recent years, there has been a lot of interest in the research of induced plant defences, notably the involvement of volatile organic compounds. These substances work as chemical signals that attract herbivores' natural enemies, resulting in a sustainable and organic method of pest management. The study covered in this article demonstrates the possibility of using these plant defences to better protect crops and lessen the need for chemical pesticides. The research also highlights the need of understanding the particular chemical compositions and processes involved in plant-herbivore interactions. With the use of this understanding, crop types might be created that are more able to communicate with their natural adversaries and withstand herbivore attack. This would increase agricultural output while minimising environmental effect.

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CHAPTER 8

UNDERSTANDING INSECT ORAL SECRETIONS AND PHYTOHORMONE-MEDIATED RESPONSES BY PLANT DEFENSE ELICITORS

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ABSTRACT:

Plants' transcriptomes, proteomes, and metabolomes dynamically change in response to physical and chemical stimuli brought on by herbivores. Herbivore oral secretions (OS), which are crucial in establishing insect-induced plant defences, are mostly responsible for this reaction. Insect OS contains a variety of elicitors, each of which may start a different kind of defence mechanism. For instance, fatty acid-amino acid conjugates (FACs), which include substances like volicitin and N-(17-hydroxylinolenoyl)-L-glutamine (volicitin), are important parts of insect OS and induce certain plant responses. These reactions often entail the activation of vital signalling channels that regulate numerous plant defence mechanisms, including the mitogen-activated protein kinase (MAPK), salicylic acid (SA), and jasmonic acid (JA) pathways. Plant defence mechanisms against herbivores are mostly orchestrated by phytohormones, such as ethylene, JA, and SA. The creation of protective chemicals such protease inhibitors, volatile organic compounds (VOCs), alkaloids, and trichomes is started by JA, which is a fundamental regulator of plant defences. Another crucial phytohormone, SA, stimulates the formation of Reactive Oxygen Species (ROS), which defends plants against a variety of pests and activates defence against piercing and sucking insects. Ethylene supports both direct and indirect plant defences, often collaborating with JA or acting alone to strengthen resistance to herbivores.

KEYWORDS:

Insect, Herbivores, Mitogen-Activated Protein Kinase (MAPK), Oral Secretions (OS), Reactive Oxygen Species (ROS), Volatile Organic Compounds (VOCs).

INTRODUCTION

With a significant rise in cytosolic Ca^{2+} levels after a herbivore assault, calcium ions (Ca^{2+}) are essential signalling components in plant defence responses. Proteins like as calmodulin and calcium-dependent protein kinases (CDPKs) are activated by Ca^{2+}, and they in turn cause phosphorylation and transcriptional modifications that are crucial for defence. Hydrogen peroxide (H_2O_2) and other reactive oxygen species (ROS) play a crucial role in plant defence. As a secondary messenger, H_2O_2 controls gene expression and starts up defence mechanisms. Additionally, millions of genes are up- or down-regulated in response to herbivore assault, which is a vital part of how plants defend themselves. Additionally, transgenerational immunity a phenomenon known as resistance produced via generations can be seen in plants. It has been discovered that maternally induced resistance in plants shields both the mother and her offspring against herbivore pests. Through processes including DNA methylation, siRNA signalling, and epigenetic control, this transgenerational immunity is controlled.

Jasmonic acid (JA), salicylic acid (SA), and ethylene are three phytohormones that are essential for coordinating plant defence responses to herbivore assaults. Depending on the kind of danger, these hormones may operate alone or in combination to control the expression of genes involved in defence. The synthesis of many defensive substances, including proteinase inhibitors, volatile organic compounds (VOCs), alkaloids, trichomes, and extrafloral nectar (EFN), depends heavily on JA. This is true for both direct and indirect plant defences. Reactive oxygen species (ROS) and calcium ions (Ca^{2+}) are crucial components of plant defence. Early in insect-plant interactions, Ca^{2+} signalling activates a number of proteins implicated in signalling pathways. ROS, particularly hydrogen peroxide (H_2O_2), function as secondary messengers that cause the activation of defence genes in plants and aid them in fending off attacks by herbivores. In response to herbivore assaults, thousands of genes are up- or down-regulated, which is a critical component of plant defence. The use of DNA microarrays and RNA sequencing as well as other advances in genomics and transcriptomics have shed light on how the interactions between plants and herbivores alter gene expression patterns [1], [2].

In response to physical and chemical signals caused by herbivores, such as chemicals in oviposition fluids and oral secretions (OS) of insects, plants experience a dynamic alteration in their transcriptomes, proteomes, and metabolomes. The widespread consensus is that herbivore oral secretions and regurgitates promote insect-induced plant responses. Depending on the kind of elicitor and the biological processes involved, different elicitors produce different types of defences. A possible trigger for plant volatiles produced by herbivores in *Pieris brassicae* L. regurgitate. The larvae of the parasitic wasp *Cotesia glomerata* (L.) have been identified as -glucosidase, which causes the emission of a volatile mixture from mechanically injured cabbage leaves.

In insects' oral secretions, fatty acid-amino acid conjugates (FACs) constitute the main substance. Volicition, N-(17-hydroxylinolenoyl)-L-glutamine (volicitin), which was found in the OS of beetroot armyworm larvae, S, was the first FAC elicitor to be discovered. exigua. applying Volicitin to *Zea mays* L. prompted the release of an elicitor, which attracted the larvae's natural enemies. N-linolenoylglu was isolated from tobacco hornworm regurgitation. It has been discovered that sexta may cause volatile emissions in tobacco plants. The mitogen-activated protein kinase (MAPK) pathway, which controls plant growth and development, has been reported to be triggered by the FACs in the OS of insects. This system is crucial for signalling transduction in responses to numerous stressors, including cold, heat, ROS, UV, drought, disease, and insect assault. FACs found in M.'s oral secretions. Sexta, when applied to the wounded leaves have been found to activate signalling processes that lead to the activation of MAPKs, salicylic acid-induced protein kinase (SIPK) and wound-induced protein kinase (WIPK), and bursts of jasmonic acid (JA), JA-isoleucine conjugate (JA-Ile), salicylic acid (SA), and ethylene.118,119 In wild rice, *Oryza minuta* Presl., expression of putative MAPK, OmMKKI, is induced by brown plant hopper, N. feeding of lugens. N-acyl Gln/Glu is one of several additional FAC elicitors that have been identified from the regurgitates of different lepidopteran species.

The buildup of 7-epi-jasmonic acid, a phytohormone generated from octadecanoid that is a powerful elicitor of transcripts of herbivore-responsive genes in tobacco plants, has also been found to be caused by the FACs. The FACs in lepidopteran OS cause certain reactions such proteinase inhibitors in N, nicotine induction, and transcriptome and proteomic changes. attenuate. In addition to FACs, inceptins and caeliferins have also been shown to act as elicitors in insect oral secretions. In contrast to caeliferins, which are sulfated fatty acids, inceptins are disulfide-bonded peptides created by the proteolytic fragmentation of plastidic ATP synthase, -subunit, in the oral secretion of *S. americana* (Stal.), as well as other types of grasshoppers [3], [4]. The lipase activity of grasshopper oral secretions caused an immediate and rapid buildup of several oxylipins in Arabidopsis, including OPDA, JA, and jasmonic acidisoleucine, 13-hydroperoxy octadecatrienoic acid, and JA. On treatment with grasshopper oral secretions, there was also a rise in cytosolic calcium, ethylene emission, and MAPK activity.

DISCUSSION

The part phytohormones play in causing plant resistance. Numerous signal transduction pathways that are mediated by a network of phytohormones are involved in plant defence against herbivore assault. Plant hormones are essential for controlling a plant's development, growth, and defence systems. In plants harmed by herbivores, a variety of plant hormones have been linked to intra- and inter-plant communication. The majority of a plant's insect defence reactions are triggered by signal-transduction pathways that are mediated by JA, SA, and ethylene. These pathways during injury or insect feeding activate certain sets of defense-related genes. Depending on the aggressor, each of these hormones may operate alone, synergistically, or antagonistically.

The expression of both direct and indirect defences is activated by JA, the most significant phytohormone connected to plant defence against herbivores despite the fact that several phytohormones are involved in plant defence against herbivores. JA is derived from linolenic acid through octadecanoid pathway and accumulates upon wounding and herbivory in plant tissues. Chewing of plant parts by insects causes the dioxygenation of linoleic acid (18:2) and linolenic acid (18:3) by specific LOXs at C9 or C13 to form (9S)- or (13S)-hydroperoxy-octadecadi(tri)enoic acids, which are converted into 12-oxophytodienoic acid (12-OPDA) by allene oxide synthase and allene oxide cyclase. OPDA is moved to the peroxisome, where OPDA reductase 3 (OPR3) reduces it and converts it to JA. Linolenic acid is changed into phytoprostanes, which are signal transduction pathways, by the oxidative burst, which generates ROS. Jasmonates cause a wide range of defensive reactions, such as the synthesis of antioxidative enzymes, PIs, VOCs, alkaloid, trichome, and EFN.

JA controls a large number of genes involved in herbivore defence. Jasmonates cause concentrations of indole glucosinolate, an essential defensive molecule. In addition to its function in JA synthesis, OPDA also signals each defence pathway separately. For instance, OPDA signalling controls transcription that is CORONATIN-INSENSITIVE 1 (COI1) dependent and independent, modifies intracellular calcium levels, and affects the redox state of the cell. Jasmonates have been found to interact with the COI1 unit of an E3 ubiquitin ligase complex called SCFCOI1 (Skip/Cullin/F-box-COI1), which facilitates the binding of the COI1-unit to JAZ (jasmonate ZIM-domain) proteins, resulting in the degradation of JAZ proteins, which would otherwise suppress JA-inducible gene expression. With 34 members in Arabidopsis, calcium-dependent protein kinases (CDPKs) are a large family of serine/threonine kinases in plants and play a significant role in plant defence against a variety of biotic and abiotic stresses through signal transduction.129 In addition to the role played by JA in direct resistance against insect pests through the induction of various defensive components, JA has also been reported to affect CDPK transcript, and activity, in potato plants. Additionally, JA activates defence enzymes as POD,4,5,125 and PPO.

Benzoic acid derivative salicylic acid (SA) is a crucial phytohormone that controls plant defence. It is a significant endogenous plant growth regulator that, in addition to having an effect on plant growth and development, causes a variety of metabolic and physiological responses in plants that are involved in defence. A controlling protein known as Non-Expressor of Pathogenesis-Related Genes (NPR1) is necessary for responses to SA. The SA buildup activates the NPR gene via redox pathways, causing it to go to the nucleus; however, it does not bind to DNA directly and instead functions through transcription factors. Greater defence is induced by SA against piercing and sucking insect pests than chewing ones. The SA signalling molecule participates in both local defence and the development of systemic resistance. It has been suggested that the SA pathway's production of ROS might make plants resistant to insect pests, such as H. armigera. Because H2O2 actively harms insects' digestive systems and prevents them from growing and developing, it protects plants against a variety of insect pests. Additionally, SA signals the production of plant volatiles that attract the natural enemies of insect pests, for instance, spider mite-infested tomato and lima bean plants draw these pests' natural enemies. However, it has been claimed that SA and JA work in opposition to one another, with SA inhibiting JA's activity and vice versa. MeSA acts as a volatile signal to initiate induced defences in plants, such as HIPV emission, and it attracts a variety of predaceous arthropods in natural settings [5], [6].

Ethylene

Ethylene is a crucial phytohormone that actively contributes to plant defence against a variety of insects. The ethylene signalling pathway is crucial for both direct and indirect plant defence against herbivores and pathogens, though there are few studies on its contribution to indirect defence via the release of HIPVs. With JA, the ET signalling system either cooperates or competes to generate plant defence responses against diseases and herbivorous insects. According to reports, ET and JA collaborate to express PI in tomato. invasion caused by A. Alni caused *Alnus glutinosa* L. to produce different valatiles and emit ethylene. besides mono-, sesqui-, and homoterpenes, leaves also include. It has been noted that the ET precursor 1-aminocyclopropane-1-carboxylic acid increases the volatile emission from the detached leaves treated with JA. In maize, ethanol further stimulated the release of volatiles brought on by volicitin, JA, or (Z)-3-hexenol.

Calcium ions' (Ca^{2+}) function in plant defence

Different signal transduction pathways are used by plant defence elicitors that are produced in response to herbivory. Herbivore-induced signals quickly spread across the leaf and cause a strong Ca^{2+}-dependent transmembrane potential (Vm) depolarization in the damage zone. This is followed by a transient Vm hyperpolarization in the surrounding area, and a constant depolarization at distances greater than 6-7 mm. Ca^{2+} signalling is one of the early events in insect-plant interaction. When compared to the cytosol (100 and 200 nM), the Ca^{2+} content in organelles and apoplastic fluid is often greater (by roughly 104 to 105 times). However, when an insect attacks, the cytosolic Ca^{2+} level rises. This causes the calcium-sensing proteins calmodulin, calmodulin-binding proteins, and calcium-dependent protein kinases (CDPKs) to become active, which in turn promotes signalling processes including phosphorylation and transcriptional change. However, CDPKs, which form Ca^{2+} sensors and comprise a protein kinase domain and a calmodulin-like domain (containing an EF-hand calcium-binding site) in a single polypeptide, are the crucial proteins against biotic and abiotic stressors. In tobacco, NtCDPK2 controls the activation of MAP kinases brought on by stress. Two Arabidopsis CPKs (CPK3 and CPK13) have been shown to participate in the herbivory-induced signalling network in tobacco via the control of the defense-related transcriptional machinery by HsfB2a. caused by S. larvae of the littoralis on Phaseolus lunatus L. Ca^{2+} was raised not only in cells close to the feeding location but also all throughout the leaf. Wheat harmed by D showed a substantial increase in the expression of calmodulin binding proteins involved in plant defence signalling. *Arabidopsis* and Noxia by *M. persicae*.

Responsive oxygen species' (ROS) function in plant defence

Plants use their oxidative state as a crucial defence mechanism against a variety of stressors. Due to oxidative stress brought on by biotic and abiotic causes, plants often experience rapid and transitory formation of ROS. ROS may directly act as poisons and perform a variety of signalling roles that mediate various responses. It is still controversial whether biotic stress leads to the generation of ROS35, which includes partly reduced forms of oxygen such superoxide (O^-), hydrogen peroxide (H_2O_2), and hydroxyl radicals (HO^-). Different kinds of ROS, notably those involving MAPKs, activate distinct signalling pathways. Following insect assault, ROS collect in apoplastic and symplastic areas, in addition to their major concentration in exocellular matrix, peroxisomes/mitochondria, and plasma membrane. This is known as a "oxidative burst," which is a rapid rise in ROS content under stress circumstances. The apoplastic burst of ROS serves as a first line of defence against ensuing attacks from pathogens and herbivores. Because ROS are so reactive, they may interact with and/or harm proteins, lipids, and nucleic acids. However, plant cells have evolved ROS scavenging mechanisms for eliminating the surplus ROS to maintain a relatively low and consistent ROS concentration. This prevents the self-toxicity of ROS [7], [8].

High stability and readily diffusible H_2O_2 is a key element of the triggered defence response in plants to various stressors among all ROS. Although there are other methods to create H_2O_2, the activation of the membrane-bound NADPH complex is thought to be the mechanism by which the oxidative burst takes place. Superoxide dismutase (SOD) converts superoxide anion from NADPH oxidase to H_2O_2 at the plasma membrane or in the apoplast extracellularly. In addition to having a direct impact on infections and herbivores, H_2O_2 also triggers a series of chemical processes that cause the development of defence genes in plants, protecting them against further assault by diseases and herbivores. Numerous genes are up- and downregulated in Arabidopsis after H2O2 administration, indicating that ROS function as secondary messengers to regulate gene expression. The activation of several genes associated to defences and the mediating function of ROS in the peroxidase-mediated cross-linking of cell wall components are both significant. After an insect assault, plants undergo oxidative changes that result in oxidative damage to insects' midguts, which is mostly caused by H_2O_2 buildup. H_2O_2 stimulates a variety of physiological and molecular responses in plants that protect them against insect assault, and its levels stay high as long as the herbivore attack continues. Oat, wheat, barley, and groundnut have all been examined in relation to the reported increase of H_2O_2 in S-infested barley. graminum after 20 minutes of infestation, suggesting that H_2O_2 may be the start of a series of physiological and molecular processes that cause the synthesis of additional protective components and prevent plants from further harm. By controlling transcription and/or interacting with other signalling elements like phosphorylation in plant systems in response to a range of stressors, ROS influence the defence gene activation and generate additional defences.

Gene expression is a fundamental component of plant defence. In response to herbivory, plants undergo extensive gene expression changes, up- or down-regulating thousands, if not hundreds of thousands, of genes. The availability of whole-genome sequencing data, expressed sequence tags (ESTs), and microarrays, among other developments in genomics and transcriptomics, have improved knowledge of the changes in gene-expression patterns in response to insect assault. DNA microarrays have proved to be great instruments for concurrently monitoring the expression of thousands of genes because they provide a more detailed and comprehensive picture of gene-expression patterns and signalling responses mediated by insect elicitors and plant signals. However, it is projected that microarrays may soon be replaced by various new and revolutionary methods, such as RNA-sequencing, RAD-sequencing, reduced representation sequencing, etc., for directly assessing gene expression. This is due to the development of next-generation sequencing (NGS) technologies. Gene expression has undergone a revolution thanks to the discovery of expression quantitative trait loci (eQTL) mapping. Research on inducible defences in *Arabidopsis* against *P. rapae* and *Brassica oleracea var capitata* L. The benefit of eQTL mapping is that it can deal with thousands of features at once. and *Brassica nigra* L., against the aphid *Brevicoryne brassicae* L. or the caterpillar *P. rapae*. Numerous studies have been conducted on the responses to *Diuraphis noxia* (Mord.), *S. Graham*, *M. Nicholas*, *M. peri* and *S. avenae* on the leaves of *Apium graveolens* L., *Arabidopsis*, celery, and sorghum. Wheat, tobacco, and cereal plants have a strong presence.

Following herbivory, changes in gene expression patterns have shown a significant reallocation of plant resources to defence. Analysis of the variations in transcriptional profiles of several genotypes within a plant species has also been done using gene expression levels. In comparison to caterpillars, the aphid Persicae expresses a huge number of genes. While aphids control the expression of genes involved in cell wall modifications, oxidative stress, calcium-dependent signalling, and glucosinolate synthesis, lepidopterans typically cause changes in the expression of genes involved in glucosinolate metabolism in Brassicaceae, detoxification, cell survival, and signal transduction. Based on the feeding behaviour and the plant being attacked, various assailants cause diverse reactions in plants; for example, transcriptional alterations in Arabidopsis thaliana in response to aphid feeding. distinct plants react differently to the same herbivore, for instance, two varieties of white cabbage have quite distinct gene expression patterns in response to eating. Our understanding of the molecular mechanisms underlying plant defence against insect herbivores will increase as a result of the integration of several technologies, including genetic, genomic tools like microarrays, deep sequencing, and transcriptional profiling tools, and proteomics through mass spectrometry [9], [10].

Herbivore resistance that is induced through generations. It has been discovered that biotic and abiotic stressors in plants cause resistance to develop in both the mother and progeny plants. In addition to generating healthy seeds and seedlings, it has been shown that this maternally induced resistance (transgenerational immunity) shields the offspring of plants subjected to herbivory against insect pests. There are, however, a few accounts of plants' transgenerational immunity to insect pests. JA-damaged or JA-treated wild radish plants, Raphanus raphanistrum, give rise to progeny with high levels of induced resistance to this insect. Stresses including cold, heat, and flood on Arabidopsis plants led to enhanced homologous recombination frequency and genome methylation, which in turn produced stress tolerance in the offspring. Seeds from maternal plants with low to moderate herbivore damage may be more robust, and seedlings from these plants may be more resistant to insect pests. To fully comprehend the genetic and molecular pathways behind such signalling relationships, further research is necessary. Because a significant body of evidence has been demonstrated for mobile siRNA signals and inheritance of DNA methylation based changes in gene expression, research on plant-insect interactions should also be focused on the epigenetic regulation of plant defence pathways and insect responses. In-depth research is desperately needed on this topic in order to use the maternal ecology for pest control. Understanding transgenerational induced resistance may provide complex solutions to issues relating to plants' capacity to survive herbivore harm.

CONCLUSION

In conclusion, for the development of efficient strategies for plant defence against herbivores and the advancement of pest control techniques in agricultural systems, it is essential to comprehend the complex interactions between insect oral secretions, phytohormone-mediated responses, gene expression changes, and transgenerational immunity. In conclusion, research on defence elicitors, notably oral secretions of insects, has shown that plants and herbivores interact in a complex and dynamic manner. These elicitors cause a series of reactions in plants that activate a number of defence systems. Among the essential substances present in insect oral secretions that are crucial in the beginning stages of plant defences are fatty acid-amino acid conjugates (FACs), inceptins, and caeliferins. Furthermore, plants may show transgenerational immunity, wherein exposure to herbivores in the maternal generation can provide the offspring resistance. This phenomena calls for further research and offers fascinating potentials for pest management techniques. In conclusion, the complex network of interactions between plants and herbivores, which is mediated by defense-eliciting substances, phytohormones, calcium ions, reactive oxygen species, and gene expression, emphasises the amazing flexibility and resilience of plants in defending themselves against herbivore threats. For the purpose of creating long-term solutions to safeguard crops and natural ecosystems against herbivore harm, it is essential to comprehend these processes.

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CHAPTER 9

PROTECTING NUTRITION AND RESOURCES AGAINST INVADERS: A REVIEW STUDY

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ABSTRACT:

Providing a major source of nourishment and a wide range of necessary non-food substances, plants are crucial to maintaining life on Earth. But they are constantly threatened by a wide range of organisms, including bacteria, fungus, protists, insects, and vertebrates, who are all trying to take advantage of these precious resources. Amazingly, despite lacking an immune system similar to that of mammals, plants have developed a wide variety of structural, chemical, and protein-based defences to identify and fend off invaders. This also looks at the complex surveillance mechanisms that plants have developed, such basal resistance and the hypersensitive response, to quickly identify and react to pathogens. The use of plant activators to strengthen plant defences and systemic acquired resistance (SAR) are also covered, providing environmentally friendly alternatives to traditional chemical treatments. This also looks at the structural barriers found in plant tissues, emphasising how crucial the cell wall, lignin, cutin, suberin, and waxes are for protecting plants from infections and herbivores. It examines idioblasts, specialised cells that store poisons or crystals to dissuade herbivores, as well as the function of trichomes, thorns, and spines as physical defences. This thorough analysis has shown the sophisticated and varied defence mechanisms that plants use to ensure their survival and maintain life on our planet by fending off a variety of dangers. Understanding these defence systems is essential for managing diseases, using plants to combat illness, and improving agricultural practises.

KEYWORDS:

Cell, Defence, Food, Insect, Plant.

INTRODUCTION

In order to secure our food supply and develop plant species that are resistant to illness, this article presents an overview of plant defence systems and their function in defending against viruses and herbivores. We introduce plant diseases, both biotic (caused by living things) and abiotic (induced by environmental causes), and we discuss common defence systems in higher plants. The subject includes plant anatomy as well as the ecological connections that underlie disease resistance and plant defence. The process by which necessary products like wood, dyes, textiles, medicines, and industrial chemicals are made from compounds generated by plants during defence responses is given special consideration. In-depth discussion of plant diseases is provided, along with an explanation of the differences in interactions between pathogens and host plants that are compatible (disease-causing) and incompatible (disease-resistant). It discusses a variety of pathogens, such as biotrophs, necrotrophs, and hemibiotrophs, as well as the idea of host range, placing emphasis on the specificity of pathogen-host interactions. The function of RNA silencing in viral defence is discussed, along with methods for identifying and discouraging insect herbivores. The article explains how mechanical damage caused by insects may cause plant reactions, such as the emission of volatile organic compounds (VOCs) to ward off pests or draw in advantageous predators.

Numerous creatures, including bacteria, fungus, protists, insects, and vertebrates, rely on plants as a rich supply of nutrition. Plants have evolved a remarkable variety of structural, chemical, and protein-based defences intended to identify invading invaders and kill them before they can do significant harm, despite lacking an immune system equivalent to that of mammals. In addition to providing a variety of essential non-food items including wood, dyes, textiles, medications, cosmetics, soaps, rubber, plastics, inks, and industrial chemicals, plants are the source of virtually all of the food that humans consume. In order to safeguard our food supply and create plant species that are very disease-resistant, it is crucial to understand how plants protect themselves against viruses and herbivores. The notion of plant disease is introduced in this article, along with an outline of several typical defence mechanisms in higher plants. The presentation includes a detailed look at plant anatomy as well as some of the ecological connections that support plant defence and disease resistance. The illustration of how items needed in daily life are obtained from chemicals generated by plants during defence reactions has been given special consideration [1], [2].

Resistance and Plant Disease

A plant has a disease when there is any physiological aberration or severe disturbance to its "normal" health. Living (biotic) agents, such as fungus and bacteria, as well as environmental (abiotic) elements including nutritional shortages, droughts, low oxygen levels, high temperatures, UV radiation, and pollution may all contribute to disease. Plants have evolved a diverse range of constitutive and inducible defences to defend themselves from harm. Numerous built-in defences, including cell walls, waxy epidermal cuticles, and bark, are examples of constitutive (continuous) defences. These elements offer the plant strength and stiffness in addition to shielding it from intruders. Virtually all live plant cells have the capacity to recognise invading pathogens and react with induced defences, such as the creation of poisonous compounds, pathogen-degrading enzymes, and intentional cell suicide, in addition to prefabricated barriers. Due to the high energy expenditures and food needs involved with their synthesis and maintenance, plants often wait until infections are discovered before generating poisonous compounds or defense-related proteins.

Numerous plant pathogens behave like "silent thieves" trying to take cash from a bank vault. These burglars use specialised instruments to secretly access the bank's vault while disabling the security system. Similar to this, many viruses develop close relationships with their hosts to weaken plant defences and encourage nutrient release. Biotrophs are pathogens that consume living plant tissue while maintaining the health of their host. The fungus *Blumeria graminis* that causes powdery mildew and the bacterial rice disease *Xanthomonas oryzae* are two examples of biotrophic pathogens. Other diseases use raw force, much like burglars who use explosives to break into a bank vault. These diseases often emit poisons or enzymes that break down tissue, which overwhelm plant defences and encourage the rapid release of nutrients. Necrotrophs, as these pathogens are sometimes known, include the bacterial soft-rot pathogen *Erwinia carotovora* and the grey mould fungus *Botrytis cinerea*. Some pathogens exhibit biotrophic behaviour in the first stages of infection but switch to necrotrophic behaviour as the illness progresses. One of these infections, known as a hemibiotroph, is the fungus *Magnaporthe grisea*, which is the primary cause of rice blast disease.

Because each host-pathogen relationship calls for a somewhat distinct collection of specialised genes and molecular processes, the majority of biotrophic and hemibiotrophic diseases can only infect a limited number of host plants. The plant species on which a pathogen is able to spread illness are referred to as the pathogen's host range. Brome mosaic virus (BMV), for instance, affects grasses like barley but not legumes. A plant species is referred to be a non-host plant species if it does not exhibit illness when infected with a particular pathogen. Non-pathogens are defined as organisms that do not infect any plant species with disease, such as the saprophytic bacterium species Pseudomonas putida.

There are two potential results when a pathogen may infect a certain host species and cause disease: An interaction that causes illness is known as a compatible reaction, while an interaction that causes little or no disease is known as an incompatible response. Even if a certain plant species may be a vulnerable host for a specific disease, some individuals may possess genes that aid in spotting the pathogen's presence and triggering defences. When exposed to the bacterial pathogen *Pseudomonas syringae*, certain tomato cultivars exhibit illness (a compatible reaction), whereas others, like cultivar Rio Grande, are capable of identifying the germs and preventing disease via resistance (an incompatible response). illness resistance may range from immunity, which has no illness symptoms at all, through strong resistance, which has minor disease symptoms, to very susceptibility, which has severe disease symptoms [3], [4].

In order to detect potentially deadly diseases and act quickly before such organisms have a chance to seriously harm the plant, plants have evolved numerous layers of sophisticated surveillance systems. Specific pre-programmed defence reactions are connected to these monitoring systems. The initial layer of built-in and induced defences that shield plants against whole families of diseases is known as basal resistance, also known as innate immunity. When plant cells identify MAMPs, which include certain proteins, lipopolysaccharides, and typically encountered microbial cell wall components, basal resistance may be induced. As a consequence, live plant cells become more resistant to infiltration. Due to the extensive presence of these molecular components in plants' cells, both pathogens and non-pathogens may cause basal resistance.

DISCUSSION

In several plant species, pathogens have created defence mechanisms that may reduce basal resistance. The hypersensitive response (HR) is a second line of defence that plants might use in response to pathogens that can reduce basal defence. At the infection site, the HR is characterised by intentional plant cell death. The HR may restrict pathogen access to water and nutrients by sparing a few cells in order to protect the remainder of the plant, even though this is more extreme than baseline resistance. The HR is often activated when gene products in the plant cell recognise the presence of certain disease-causing effector molecules delivered into the host by the pathogen. The HR is generally more pathogen-specific than basal resistance. Plants may develop the HR due to bacteria, fungus, viruses, and tiny worms called nematodes.

Plant tissues may become extremely resistant to a variety of diseases for a lengthy period of time after the hypersensitive response has been initiated. The term "systemic acquired resistance" (SAR) refers to a condition where plant resources are heightenedly prepared in case of further attacks. By spraying plants with substances referred to as plant activators, researchers have figured out how to consciously activate SAR. Because they are less harmful to people and animals than fungicides or antibiotics, and because their protective benefits may last considerably longer, these compounds are becoming more and more popular in the agricultural sector.

Plants may protect themselves against viruses via a range of mechanisms, including the hypersensitive response and the highly developed genetic defence system known as RNA silencing. When a virus replicates in a host cell, many of them create double-stranded RNA or DNA. Plants have the ability to detect these alien molecules, and in response, they break down the genetic strands into ineffective bits to stop the infection. Chlorosis and mottling are common indications of viral infection in plants, but if RNA silencing is effective, illness symptoms may gradually go away, a process known as recovery. Additionally, a template of the digested genetic strand may still be present in the plant, which might be utilised to mimic the memory of vertebrate immune systems to promptly react to similar viral attacks in the future [2], [5].

Finding Insect Herbivores

Even while plants have evolved surveillance systems that allow them to identify insect pests and react with certain defence mechanisms, mechanical damage brought on by insects is not often regarded to be a "true" plant disease. Because chewing insects' saliva contains elicitors, plants can tell when an insect is eating and just generally harming them. Volatile organic compounds (VOCs), such as monoterpenoids, sesquiterpenoids, and homoterpenoids, may be released by plants as a result. These substances might deter pests that cause damage or draw in beneficial predators that feed on the pests. For instance, aphid-infested wheat seedlings may release VOCs that deter additional aphids. When spider mites harm lima beans, apple trees release compounds that attract predatory mites, and when moth larvae damage cotton plants, they release volatiles that draw predatory wasps. In healthy plant tissues, feeding on one area of the plant might cause the systemic synthesis of these molecules. Once released, these chemicals may function as signals to other plants to start manufacturing comparable substances. Because the host plant incurs a considerable metabolic cost in producing these substances, many of them are not generated in significant amounts until after insects have started to eat.

All plant tissues have built-in structural barriers that prevent the adhesion, invasion, and infection of pathogens. A crucial barrier against bacterial and fungal infections is the cell wall. When the cell recognises the presence of potential pathogens, it quickly activates a broad range of chemical defences in addition to a superb structural barrier. Most plant cells also create a secondary cell wall that forms within the original cell wall after the cell finishes developing. All plant cells have a primary cell wall, which provides structural support and is crucial for turgor pressure. Cellulose, a complex polysaccharide made up of hundreds of glucose monomers joined together to form lengthy polymer chains, makes up the majority of the main cell wall. The wall's strength and flexibility are provided by microfibrils, which are composed of these chains in bundles. Cross-linking glycans and pectins are two more kinds of branching polysaccharides that may be present in the cell wall. Hemicellulose fibres, which crosslink with cellulose to provide the wall strength, are among the cross-linking glycans. Pectins create hydrated gels that control the water content of the wall and "cement" adjacent cells together. Anyone who has seen fruits or vegetables become brown and "mushy" has witnessed these infections in action. Soft-rot pathogens often target pectins for digestion utilising specialised enzymes that cause cells to break apart.

Lignin, a heterogeneous polymer made of phenolic chemicals that gives cells their stiffness, is another component of many cell walls. Wood's main constituent, lignin, is what makes it so highly impenetrable to diseases and difficult for tiny insects to chew. Cell walls that become "lignified" are a result of this process. Cutin, suberin, and waxes are fatty compounds that may accumulate in the exterior protective tissues of the plant body, including the bark, as well as primary or secondary cell walls (or both). Proteins and enzymes found in cell walls actively remodel the wall during cell expansion while thickening and bolstering the wall during induced defence. Enzymes catalyse an oxidative burst that creates highly reactive oxygen molecules capable of harming the cells of invading organisms when a plant cell recognises the presence of a possible pathogen. By catalysing cross-linkages between cell wall polymers, reactive oxygen molecules also contribute to the cell wall's strength and alert nearby cells to an impending assault. In response to microbial invasion, plant cells also produce and deposit callose in close proximity to the invading pathogen between the cell wall and cell membrane. As part of the induced basal defence response, callose deposits, also known as papillae, are polysaccharide polymers that prevent cellular penetration at the site of infection [6], [7].

For plant defence, certain plant cells are extremely specialised. Idioblasts, often known as "crazy cells," aid in defending plants from herbivory by containing poisonous substances or pointed crystals that sever the mouthparts of insects and animals while they eat. Idioblasts may be categorised into a wide range of groups, such as pigmented cells, sclereids, crystalliferous cells, and silica cells. Plant components with pigmented cells are unsuitable as a food source because they often contain tannins with a bitter taste. Young red wines often have significant tannin content, which gives the wine a strong, biting flavour. The rough texture of pear fruit (Pyrus spp.) is created by hundreds of sclereid stone cells, which may abrasively wear down the teeth of eating animals. Sclereids are unruly cells with thick secondary walls that are tough to chew. The stinging cells produced by stinging nettles (Urtica dioica) resemble hypodermic needles and break off when disturbed, releasing poisons that are very irritating to herbivore tissues. Prostaglandins, hormones that activate pain receptors in vertebrate animals and heighten pain perception, are present in certain stinging cells. Crystals of calcium oxalate found in crystalliferous cells have the potential to irritate the mouthparts of herbivores when chewed and to be poisonous if consumed. Philodendron and Dieffenbachia species are typical tropical indoor plants that have significant numbers of these cells. Chewing the leaves of these plants may cause a burning feeling in the mouth and throat that is often followed by swelling, coughing, and the inability to speak for both people and animals. Dieffenbachia species are referred to as "dumb cane" for these reasons. Rows of silica cells are found in sedges and grasses' epidermal layers, which provide their leaf blades strength and stiffness as they develop and prevent insects from gnawing on them for food.

Up until they undergo significant secondary development, the epidermis of plants' leaves, floral components, fruits, seeds, stems, and roots serves as the outermost protective tissue system. It is made up of both specialised and non-specialized cells and serves as the body's initial line of defence against invasive infections. with aerial plant parts, the epidermal cells are often coated with a waxy cuticle that inhibits infection by preventing microbial pathogens from getting into direct touch with the epidermal cells while also preventing water loss from the plant. Aquatic plants have comparatively thin cuticles, but cactus have fairly thick cuticles. A significant defence against many fungal infections, which need standing water on the leaf surface for spore germination, is provided by the hydrophobic characteristic of the cuticle. The cuticle is broken down by certain fungal diseases, such as *Fusarium solani*, and this enables the fungus to enter the epidermis. Guard cells, which control gas exchange via tiny pores known as stomata, are scattered amid the epidermis' many unspecialized cells. These holes prevent the plant from losing too much water while allowing carbon dioxide to enter the leaf for use in photosynthesis. Plants have a strong control over stomatal pore size, and guard cells may take part in defence by shutting when MAMPs are present.

Trichomes (also known as "leaf hairs") are specialised epidermal cells that are located on aerial plant parts and may provide both chemical and physical defence against insect pests. Senecio cineraria, a plant, has hundreds of tiny trichomes covering its surface, giving it a velvety texture. Soybeans (*Glycine max*) have trichomes on their surface that prevent insect eggs from reaching the epidermis, which causes the larvae to starve after hatching. Snap bean (*Phaseolis vulgaris*) trichomes have a hook-like morphology that impales caterpillars as they travel over the leaf surface, while potato and tomato trichomes have glandular structures that release oils that deter aphids. On stems and roots of woody plants, the periderm takes the role of the epidermis. Outer bark (phellem), which includes significant quantities of water-resistant suberin and keeps many diseases and insects from invading the live cells below, is a great example of a prepared structural barrier. The honey locust tree (*Gleditsia triacanthos*) is one plant that has thorns, which are modified branches that defend plants from grazing animals. Like the barrel cactus (*Ferocactus spp.*), many cacti develop spines, which seem like thorns but are really modified leaves or portions of leaves (like stipules) that have similar functions. According to botany, the "thorns" on the stem of rose plants (Rosa spp.) are really prickles, which are epidermal growths that are neither genuine thorns nor spines [8], [9].

Primary metabolites and secondary metabolites are the two broad groups into which plant compounds may be separated. All plant cells generate primary metabolites, which have a direct role in growth, development, or reproduction. Proteins, carbohydrates, amino acids, and nucleic acids are a few examples. Although secondary metabolites are often engaged in plant defence, they are not directly involved in growth or reproduction. Terpenoids, phenolics, and alkaloids are the three main chemical classifications that these substances often fall under. With approximately 22,000 chemicals known, terpenoids (terpenes), which are found in all plants, are the biggest class of secondary metabolites. The simplest terpenoid is the hydrocarbon isoprene (C_5H_8), a volatile gas produced in huge amounts by plants during photosynthesis that may shield cell membranes from harm brought on by extreme heat or light. The amount of isoprene units utilised to build terpenoids determines their classification. For instance, monoterpenoids have two isoprene units, whereas sesquiterpenoids have three, diterpenoids have four, and triterpenoids have six.

The main components of essential oils, which are highly volatile substances that contribute to the fragrance (essence) of plants that generate them, are monoterpenoids and sesquiterpenoids. Many essential oils serve as insect poisons and many defend against bacterial or fungal assault. The monoterpenoids menthol and menthone, which are synthesised and stored in glandular trichomes on the epidermis, are highly produced by mint plants (*Mentha spp.*). Pyrethrins are monoterpenoid esters that chrysanthemum plants make that serve as neurotoxins on insects. Permethrin and cypermethrin are two examples of the several commercially available insecticides that are truly pyrethroids, which are synthetic mimics of pyrethrins. The monoterpenoids alpha- and beta-pinene, which are strong insect repellents and give the organic solvent turpentine its distinctive harsh smell, are abundant in pine tree resin. Insecticides are not the only use for monoterpenoids. Essential oils are used to create a variety of spices, flavours, condiments, and fragrances. These oils serve as plant-based insect poisons, but are generally safe for people to consume. Examples include menthol (*Mentha species*), peppermint and spearmint (*Mentha species*), basil (*Ocimum species*), oregano (*Origanum species*), sage (*Salvia species*), savoury (*Satureja species*), thyme (*Thymus species*), black pepper (*Piper species*), cinnamon (*Cinnamomum species*), and bay leaf (*Laurus species*).

Gossypol, a terpenoid generated by cotton (*Gossypium hirsutum*), is one of the diterpenoids and possesses potent antifungal and antibacterial activities. Triterpenoids have structural similarities with both plant and animal sterols as well as steroid hormones. Phytoectysones are hormones that imitate the moulting of insects. They interfere with larval development and increase insect mortality when generated by plants like spinach (*Spinacia oleracea*). The limonoids, a group of triterpenoids that give lemon and orange peels their fresh aroma, are responsible. Some insects are repulsed by concentrations as low as a few parts per million of azadirachtin, an extremely potent limonoid isolated from neem trees (*Azadirachta indica*). Because of its low toxicity to humans and biodegradable qualities, citronella, an essential oil extracted from lemon grass (*Cymbopogon citratus*), has grown in popularity as an insect repellent in the United States. It includes high quantities of limonoid.

Not just insects consume plants; there are other herbivores as well. Heart attacks may occur if large doses of terpenoids like cardiac glycosides are consumed by vertebrate herbivores like humans since they are so hazardous to them. The primary source of the cardiac glycosides digitoxin and digoxin, which are used medicinally in tiny doses to treat human heart disease, is foxglove (*Digitalis purpurea*). Some herbivores are able to avoid the harmful effects of cardiac glycosides and even gain from them. The milky latex of milkweed (*Asclepias spp.*), which contains significant levels of these poisons in its sap, is the primary food source for monarch butterfly caterpillars. When the caterpillars grow into adult butterflies, they are exceedingly toxic to the majority of raptors who consume them because they have securely stored these poisons inside their bodies.

Many plant species' cell membranes include glycosylated triterpenoids, or triterpenoids with linked sugar groups, known as saponins. These chemicals break the cell membranes of invasive fungal infections and exhibit detergent-like (soap-like) characteristics. Those oats that contain avenacins, a group of triterpenoid saponins, are resistant to infection by the wheat disease *Gaeumannomyces graminis*. *Botrytis cinerea, Fusarium oxysporum,* and *Septoria lycopersici* are all capable of degrading saponins and inflicting illness on vulnerable saponin-producing plants. However, certain fungal diseases have created countermeasures to these plant defences [10], [11].

Phenolics

Another huge class of secondary metabolites that plants make to protect themselves against infections is called phenols. They are generally produced by plants through the shikimic acid and malonic acid pathways, and they include a number of molecules that are involved in defence, including as flavonoids, anthocyanins, phytoalexins, tannins, lignin, and furanocoumarins. One of the major classes of phenolics is flavonoids. Anthocyanins are vibrant, water-soluble flavonoids that plants make to shield leaves from UV radiation's harmful effects. The vibrant hues of many plants are a result of anthocyanins, which are abundant in the autumn flowers, fruits, and leaves of deciduous plants. Phytoalexins are isoflavonoids that are formed in response to pathogen infection and have antibiotic and antifungal effects. These hazardous chemicals alter the cellular or metabolic processes of pathogens, yet they often only cause harm to that particular pathogen. Alfalfa (*Medicago sativa*) produces medicarpin, tomatoes and potatoes (all members of the Solanaceae family) generate rishitin, and Arabidopsis thaliana produces camalexin.

CONCLUSION

The extraordinary adaptations and tactics that plants have developed over millions of years are highlighted by this thorough investigation of plant defence systems against numerous dangers. Plants have evolved a wide range of structural, chemical, and protein-based defences to defend themselves against bacteria, fungus, protists, insects, and vertebrates since they lack an immune system similar to that of mammals. These defences not only assist plants in surviving, but also provide people with access to vital nutrients. In conclusion, plants have developed an amazing variety of defence systems to fend off a variety of dangers. Understanding these pathways has uses in horticulture, agriculture, and medicine in addition to advancing our understanding of plant biology. We can create more resilient and sustainable farming practises and improve our capacity to access the resources offered by these amazing creatures by learning how plants defend themselves.

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CHAPTER 10

BOTANICAL ARMORY: PLANTS' INGENIOUS DEFENSES AGAINST HERBIVORES

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ABSTRACT:

The foundation of life on Earth, plants, have coexisted alongside a wide variety of animal species, many of which use plants as their main source of nutrition. Although well-known herbivores like deer and cattle catch our attention, the terrain of plant-herbivore interactions is dominated by a vast array of insect species and related arthropods. This essay goes into great detail on how plants have developed a remarkable array of defence mechanisms in response to the persistent attack by these herbivorous critters. This thorough investigation starts by clarifying the evolutionary tactics used by plants to fend off herbivores' ravenous appetites. Plants use a variety of defence strategies, from physical deterrents like thorns and spikes to the synthesis of poisonous substances like caffeine and alkaloids. For plants, the decision to devote energy and resources to defence is a trade-off between costs and benefits; this fine balance often depends on the existence of herbivores in the ecosystem. The paper also describes the numerous signalling processes used by plants to identify the presence of herbivores and describes how defence mechanisms are then put into action. Important elements of plant-herbivore interactions include the detection of eating damage and the triggering of defensive responses by insect oral secretions. It is emphasised how elicitors, such as inceptins and fatty acid-amino acid conjugates (FACs), work to activate plant defences.

KEYWORDS: Botanical Armory, Defenses, Herbivores, Ingenious Defenses, Insect, Plant.

INTRODUCTION

The extensive network of plant defences is discussed in detail, ranging from constitutive defences that are always active to inducible defences that become active in response to herbivore assaults. These defences are used by plants to ward off herbivores and safeguard their precious resources. A sophisticated molecular reaction to herbivores is orchestrated through signalling pathways, notably the jasmonic acid system. This is a key regulator of induced plant defences. The intriguing world of plant chemistry is uncovered in this research, showing how substances like tannins, lignin, furanocoumarins, and alkaloids act as strong repellents and even poisons to herbivorous insects and animals. It is also shown how the eating habits of herbivores have influenced the development of plant defences by examining the complex dance of coevolution between plants and herbivores.

In order to prevent herbivores from consuming and digesting plant tissues, plants also create a range of proteins, including defensins, lectins, and digestive enzyme inhibitors. Because they use a significant amount of the plant's resources and energy, these protective proteins are often only generated in reaction to an assault. The jasmonic acid pathway is a key player in triggering defence responses in the very complicated signalling networks in plants that detect herbivore assaults. In addition to mechanical injury, plants are able to sense the presence of insect oral secretions, which cause more potent volatile responses. Different feeding techniques and specialised defences have developed as a consequence of the coevolutionary connection between plants and herbivores. While some herbivores have adapted to feed on particular host plants, others are generalists that can eat a variety of plant species. The balance between defending the plant and preserving resources for growth and development must be struck by plant defences [1], [2].

There are plants everywhere. Earth as we know it would not be possible without them. Yet an astounding variety of animal species consume plants. Some of them are well known, such as big grazing animals like deer or cattle. However, the thousands of different insect species and allied arthropods make up the majority. Plants have a wide range of defence mechanisms at their disposal. The evolution of plants to survive the assault of creatures that would eat them as food is discussed on this page. There are many different types of plant defences. Plant barriers. Thorns on a rose, ants that kill herbivores consuming plant nectar, caffeine-rich tea leaves that are poisonous to insects, and the tiny silica serrated edge of a grass leaf are seen from left to right. Animals utilise a variety of strategies to avoid predators. Running away is one behavioural reaction that is highly significant. Plants, on the other hand, are "sessile," which means they are immobile. Plants can't escape since their roots firmly attach them to the ground. As a result, they have evolved chemical and physical defences to defend themselves against herbivores, or animals that feed only on plant material. For many plants, physical defences serve as their initial line of defence. Herbivores find it challenging to consume plants because of their defences. Physical barriers include things like the thorns on flowers and the spikes on trees like hawthorn. These bodily barriers prevent herbivores from consuming the stems or leaves of plants by injuring them.

Grasses like wheat, rice and maize (corn) absorb silicon from the soil. The grass leaves are abrasive due to hard silicon particles. This defence functions by reducing the strength of grasshopper mandibles and the teeth of big grazing animals. Some plants have tiny structures called trichomes that give their leaves a fuzzy texture when touched. These little leaf surface protrusions might be quite numerous. It is more difficult for insects or mites to get to plant leaf cells because of this "forest" of trichomes. Additionally, plants use a wide variety of compounds to deter herbivores. Numerous of these substances are poisonous and deter or even kill grazing animals. Other times, these defences only have a tangential effect. As an example, several plants generate nectar that attracts ants. The plant produces nourishing nectar, which the ants consume. In exchange, the ants protect the plant against insects that eat the plant's leaves, known as herbivorous insects.

Energy is required by plants to produce chemical and physical defences. Plants have to divert energy away from development when they protect themselves. Therefore, self-defense has a cost. Because of this, many plants only activate their defences when they are being eaten by herbivores. Numerous herbivores may be found year-round in certain habitats, such as tropical woods. If a developing plant doesn't protect itself, it will be eaten. Some tropical plant species usually have high concentrations of hazardous substances. Constitutive defences in plants are ones that are always active. In contrast, cold winters in temperate zones control herbivore numbers. However, they may have extremely huge numbers throughout the growth season. In certain areas, the weather patterns that favour herbivores might change from one year to the next. In these environments, plants continue to use constitutive defences. However, they may also step up their defences if a herbivore attacks.

The plant's resources are held back by these "induced" defences until they are absolutely necessary. For instance, freshly emerging leaves may sometimes produce more trichomes. When a plant is consumed, many other plants increase the production of certain chemicals. Within minutes to hours, plants detect animals that are harming them. They may switch genes on and off in response, producing enzymes and other proteins to fend off the assault. When herbivores consume plant tissues or liquids, they physically harm the plants. Chemicals in the plant at feeding locations are activated when harmed. Even the saliva of a herbivore sometimes causes chemical reactions in plants [3], [4]. Plants create chemicals like hydrogen peroxide, which serves as an insect repellent, in response to these signals. Plants also create a vital substance called jasmonic acid (JA) when they are assaulted. The "master regulator" of induced plant defences is this molecule. The JA system may activate tens of thousands of genes within 24 hours of a herbivore assault. These genes produce proteins that affect herbivores in a variety of ways. Some harm herbivores' digestive systems. Others interfere with cellular processes vital to the development, maintenance, or procreation of herbivores.

DISCUSSION

Plants generate tannins, which are water-soluble flavonoid polymers that are kept in vacuoles. Tannins trigger the inactivation of proteins by binding to salivary proteins and digestive enzymes like trypsin and chymotrypsin, which makes them poisonous to insects. High tannin intake prevents weight increase in insect herbivores, which may lead to ultimate death. Red wine's astringent flavour is brought on by grape tannins' binding to salivary proteins, which causes protein coagulation in the mouth. Although primary walls may also get lignified, lignin is a highly branching heterogeneous polymer mostly found in the secondary cell walls of plants. It is a major constituent of wood and is made up of hundreds or thousands of phenolic monomers. Lignin makes a great physical barrier against pathogen assault because it is insoluble, stiff, and practically indigestible.

Many different types of plants create furanocoumarins, which are phenolic chemicals, in response to pathogen or herbivore assault. Due to their incorporation into DNA and potential for significant toxicity to certain vertebrate and invertebrate herbivores, they are triggered by UV light. They also contribute to fast cell death. In actuality, furanocoumarins, which dramatically enhance the absorption of certain medications into the circulation from the intestines, are present in minute amounts in grapefruit juice. Some medications have warning labels that inform users to refrain from consuming grapefruit juice while taking the medication to prevent an unintentional overdose.

Caffeine, cocaine, morphine, and nicotine are just a few of the numerous bitter-tasting nitrogenous chemicals known as alkaloids that are present in many vascular plants. Many of these compounds, which are produced from the amino acids aspartate, lysine, tyrosine, and tryptophan, have significant physiological effects on animals. Coffee (*Coffea arabica*), tea (*Camellia sinensis*), and chocolate (*Theobroma cacao*) all contain caffeine, an alkaloid. Both fungus and insects are poisoned by it. In fact, a process known as allelopathy occurs when excessive quantities of caffeine released by coffee seedlings can prevent other seeds from germinating nearby. Allelopathy enables a species of plant to "defend" itself against rival plants that could compete with it for nutrients and growth space.

Numerous significant alkaloid substances are produced by members of the nightshade family (Solanaceae). Tobacco plants (*Nicotiana tabacum*) create the alkaloid nicotine in their roots, which is then transferred to the leaves where it is stored in vacuoles. When herbivores feed on the leaves and tear opens the vacuoles, it is released. The deadly nightshade plant, Atropa belladonna, produces atropine, a neurotoxic and heart stimulant. Humans have used it medicinally in small doses as a pupil dilater and antidote for various nerve gas poisonings even though it is poisonous in big doses. The primary ingredients in chilli peppers are capsaicin and related capsaicinoids, which give hot, spicy meals their distinctive burning sensation. Capsaicin and related capsaicinoids are generated by species of the genus Capsicum [5], [6].

Hydrogen cyanide (HCN), a deadly toxin that stops cellular respiration in aerobic organisms, is produced through the breakdown of the especially hazardous family of nitrogenous chemicals known as cyanogenic glycosides. The enzymes that turn cyanogenic glycosides into hydrogen cyanide, such as glycosidases and hydroxynitrile lyases, are also produced by cyanogenic glycoside-producing plants, but they are stored in different parts of the plant or tissues. When herbivores consume these tissues, the enzymes and substrates combine to form lethal hydrogen cyanide. Members of the mustard family (Brassicaceae) generate sulfur-containing chemicals known as glucosinolates, commonly referred to as mustard oil glycosides, which, when broken down by thioglucosidases enzymes, release cyanide gas.

Enzymes and Proteins

Numerous plants and seeds include proteins that selectively inhibit disease and pest enzymes by assembling into complexes that obstruct the active sites of the enzymes or change their conformations, hence decreasing enzyme performance. These proteins tend to be tiny and high in cysteine, an amino acid. Defensins, amylase inhibitors, lectins, and proteinase inhibitors are a few of them. Proteins take a lot of plant resources and energy to generate, unlike simple compounds like terpenoids, phenolics, and alkaloids; as a result, many defensive proteins are only produced in considerable amounts after a disease or insect has attacked the plant. However, once active, protective enzymes and proteins efficiently suppress nematodes, bacteria, fungus, and insect herbivores.

Defensins were initially discovered in the endosperm of wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*), which are tiny, cysteine-rich proteins with wide anti-microbial action. They are extensively dispersed and might be found in the majority of plants. Although defensins are mostly found in seeds, they are also present in almost every other kind of plant tissue, including as leaves, pods, tubers, fruit, roots, bark, and floral tissues. They have a broad variety of biological behaviours that prevent the development of several fungus and bacteria. Some defensins prevent herbivores from producing digesting proteins. Plant defensins seem to operate on molecular targets in the plasma membrane of pathogens, while the specific processes by which they inhibit fungus and bacteria are still being characterised. These defensins may block already-existing ion channels or create brand-new membrane holes that upset the equilibrium of ions inside cells.

Digestive enzyme inhibitors are proteins that prevent vertebrate and invertebrate herbivores from properly digesting and absorbing nutrition. Proteins called alpha-amylase inhibitors are often present in legumes and bind to amylase enzymes to prevent the breakdown of starch. Lectins are non-enzymatic proteins and glycoproteins that bind to carbohydrates and have a variety of functions, such as preventing insects from properly digesting food and causing vertebrates to clump their blood cells together. Castor beans (*Ricinus communis*) are a source of the potent toxin ricin. It incorporates an N-glycoside hydrolase and lectin molecule that penetrates animal cells and prevents protein production. Ricin is a very powerful toxin, with an average human fatal dosage of about 0.2 milligrammes [7], [8].

Trypsin and chymotrypsin are two digestive enzymes that are often inhibited by protease inhibitors, which are typically generated in response to herbivore assault. They are broadly distributed in nature but have been extensively researched in grasses, solanaceous plants, and legumes. When a herbivore feeds, a number of molecular signalling processes are often set off, causing systemic synthesis of these substances in distant tissues. These chemicals help protect unharmed plant portions against repeated attacks by a variety of herbivore pests.

Some plants respond to infections by producing hydrolytic enzymes, which often gather in extracellular areas and break down the cell walls of pathogenic fungus. Chitin, a polymer with a backbone resembling cellulose and found in the cell walls of real fungi, is degraded by chitinases, enzymes. The destruction of glycosidic bonds in glucans, a family of polymers related to cellulose found in the cell walls of many oomycetes (water moulds), is catalysed by the enzymes known as glucanases. The anti-fungal effects of these substances have been shown in vitro, and transgenic plants expressing high amounts of these enzymes show improved resistance to a variety of foliar and root diseases. Lysozymes are hydrolytic enzymes that may break down the cell walls of bacteria.

Over 400 million years have passed since land plants and insects first coexisted. They have created sophisticated interactions that have an impact on organisms at all levels, from the most fundamental biochemistry to the level of population genetics. While some of these interactions, like pollination, are advantageous to both parties, the majority involve insect predation on plants and plant defence against herbivorous insects. In reality, practically every plant species is consumed by at least one insect species due to the prevalence of the predator-host interaction. This has led to the development of the co-evolutionary hypothesis, which contends that the increase in species variety among herbivores and hosts alike may be attributed to insect feeding on plants.

Evolution of plant types and insect feeding techniques: Due to interactions between plants and insects, new kinds of plants are demonstrated to have evolved along with novel feeding techniques. The numbers at the top represent the quantity of feeding techniques available. Lemnaceae, which are minuscule duckweeds, are just a few millimetres in size, whereas Sequoia sempervirens, an immense Californian redwood tree, is over 100 metres tall. Some plants have short life cycles that span just a few weeks, but others may survive for thousands of years. It follows that there is a wide range in the tactics used by plants to protect themselves against insect herbivores. Insect choice is influenced by some species' qualities, such as host plant preference and feeding habits, whereas performance is influenced by other species' traits, such as growth rate and development. These characteristics include the development of chemicals for chemical defence as well as morphological characteristics for physical defence.

Historically, insect herbivores have been classified as either specialists (monophagous and oligophagous), who graze on one or a small number of plant species from the same family, or generalists (polyphagous), which feed on a variety of hosts from various plant families. While most plants have a variety of defences that the generalists can withstand, they cannot feed on certain plants that have more unusual defences. On the other side, experts utilise a particular group of host plants that release defence chemicals that may also serve as feeding stimulants and ovipositioning signals. This viewpoint, however, has lately come under attack since it only considers the extremes, although in fact the distribution of insects feeding on a single plant to many is a continuum. The paradigm is further predicated on the difficult to establish idea that feeding generalists and specialists will cause distinct responses in plants. It is advised that such tests include at least four species from two taxonomic pairings, all of which belong to the same feeding guild. However, no such experiment has been documented to date.

Plants' herbivory defences may either be expressed naturally or can be generated and developed solely in response to an assault. Given that plant defence systems are costly, this is an issue of benefit against cost. Plants continuously struggle to balance growth, development, and defence. This is an issue, particularly if resources that restrict fitness, like nitrogen, are used or if the substances generated are poisonous to the plant itself as well as to herbivores [9], [10].

This study makes an effort to describe every step in the chain of defence against insect herbivores, from identifying a feeding insect to producing defence chemicals or using physical defences to the insect rejecting the plant as food. First, interactions at the plant/insect contact are defined as the first events that trigger the defence responses. The complicated intracellular signalling pathways are then discussed, with the jasmonate route receiving special attention. The various defence reactions are finally described. Only 21 root-feeding species of insect herbivores are known, while the bulk of insect herbivores feed on tissues above ground. This review will thus primarily concentrate on plant defence against above-ground insect herbivory, drawing comparisons to below-ground herbivory wherever feasible. Other infections may infect the plant as a result of insect eating. Although it is beyond the purview of this analysis and has been updated elsewhere, the defence against diseases and the defence against insect assaults share a number of characteristics.

Early Signalling is Induced by Plant/Insect Interactions

A variety of defence signals are triggered as soon as an insect herbivore begins to feed on a plant, resulting in various defence reactions. However, it is crucial to note that the plant can detect the eating of an insect herbivore before going on to describe the signalling process. Plants are able to recognise ovipositioning as well as mechanical damage from hail and wind in addition to herbivory. Since the development and release of defensive responses only helps plants that are herbivore-challenged, this characteristic is necessary to prevent the waste of costly defence resources. More than a million distinct types of herbivorous insects have been identified, and their varied eating habits result in varying degrees of mechanical damage to plant tissue. Leaf-eating beetles (Coleoptera) and caterpillars (Lepidoptera), which inflict damage with mouthparts developed for gnawing, snipping, or ripping, make up two thirds of all known herbivores. While piercing-sucking herbivores like spiders and trips employ a tube-like mechanism to suck the liquid content from lateral cells, leaf miners feed on the soft tissue in between the epidermal cell layers. Aphids, whiteflies, and other Hemiptera that feed off of phloem have specialised stylets that are inserted between the cells and into the phloem. Although root-chewers make up the bulk of root-eating insect herbivores, a few root borers/piercers have also been documented. The feeding guilds of these insects are less extensively studied than those of above ground herbivores.

Plants have been specifically investigated utilising caterpillars for their ability to assess the kind and extent of leaf tissue damage. When eating, caterpillars remove similar-sized bits of leaf tissue in a highly coordinated and predictable rhythm. *Phaseolus lunatus* (lima bean) was mechanically wounded to simulate recurrent caterpillar wounding, and the outcome was the production of volatiles that were qualitatively comparable to those produced during a real caterpillar assault.

Insect oral secretions include chemicals that plants can identify because they cause more potent volatile reactions than just mechanical harm. Fatty acid-amino acid conjugates (FACs) are created by the conjugation of precursors obtained from plants and herbivores. N-17-hydroxylinolenoyl-l-glutamine, one of numerous FACs often found in the oral secretions of Lepidopteran larvae, including *Pieris brassicae* (caterpillar of the giant cabbage white butterfly), was initially discovered in *Spodoptera exigua* (beetroot armyworm) oral secretions. Volicitin is specifically attached to the plasma membrane, which raises the possibility that there is a FAC receptor. Volicitin causes *Zea mays* (maize) to produce reactive free indoles from indole-3-glycerol by activating an enzyme called indole-3-glycerol phosphatase lyase (IGL). Some plants, such as *Vigna unguiculata* (cowpea), *Gossypium hirsutum* (Mexican cotton), *P. lunatus*, and *Arabidopsis thaliana* (thale cress), do not react to exogenously applied FACs.

Other elicitors have been identified, including inceptins, which are disulfide-bonded peptides created by proteolytic fragments of chloroplastic ATP synthase -subunit in the intestine of the autumn armyworm *Spodoptera frugiperda*. Inceptin is effective against *A. thaliana*, *Solanum melongena* (eggplant), *Glycine max* (soybean), and *Nicotiana tabacum* (cultivated tobacco), but not against *Phaseolus vulgaris* (common bean), *V. unguiculata*, and *Z. mays*. Inceptins don't yet have any known receptors.

CONCLUSION

In conclusion, this thorough investigation of plant defences against herbivores offers a profound insight of the intricate interactions between these two biotic groups. It illuminates the complex processes that have developed over millions of years in this continuous evolutionary conflict, shedding insight on the astounding flexibility and endurance of plants in the face of unrelenting herbivore pressure. In conclusion, there has been a complex dance between plants and herbivores for more than 400 million years, especially among insects. Different defence systems in plants have been developed as a result of this coevolutionary conflict to stop herbivores from eating them. Due of their immobility, plants have been forced to depend on physical defences, chemical compounds, and specialised proteins. As the initial line of defence against herbivores, physical defences like thorns, trichomes, and silica-rich leaves make it difficult for them to feast on plant tissues. Alkaloids, tannins, and cyanogenic glycosides are important chemical defences that may discourage or even kill herbivores. Animals exposed to these substances may have severe physiological consequences, including changes in digestion and food absorption. In conclusion, research on plant defences against insect herbivores shows an intriguing interaction of physical, chemical, and molecular systems that have developed over millions of years. The variety and coping mechanisms of both groups have been influenced by this constant conflict between plants and herbivores, which has eventually contributed to the complex web of life on Earth.

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CHAPTER 11

PLANT DEFENSE STRATEGIES: EXPLORING FROM STRUCTURAL BARRIERS TO BIOCHEMICAL WARFARE

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ABSTRACT:

Two separate forms of structural defences occur in the field of plant defence mechanisms against pathogens: pre-existing defence structures and defence structures created in response to pathogen assaults. Wax mixtures that are deposited on cuticular surfaces as part of pre-existing defences serve to resist water, obstruct pathogen germination, and prevent pathogen proliferation. The cuticle's fatty acids help create the negative surface charges that keep germs away. In addition, the cuticle's thickness is crucial in preventing pathogen access and departure. With lignin and silicic acid impacting resistance, epidermal cells with thick outer walls may directly block pathogen entrance or make penetration difficult. Depending on their size and internal makeup, natural holes like stomata and lenticels may either help or prevent pathogen entrance. Nectaries, which generate nectar with a high osmolarity, may act as a defence mechanism. In nectaries, an abundance of hairs may improve resistance. The existence of vascular bundles or sclerenchyma cells that prevent pathogen transmission, as well as the thickening and hardness of cell walls in response to environmental variables, are examples of internal defence structures. Following pathogen invasion, host plants create a range of defence mechanisms and structures to prevent future infection. Included in these are cytoplasmic defence reactions, cell wall alterations, tissue-specific defence structures, and finally necrosis, which results in the death of invading cells.

KEYWORDS:

Biochemical Welfare, Cell Defenes, Infection, Pathogen, Structural Barrier.

INTRODUCTION

The pathogen's mycelium is destroyed by cytoplasmic defences, which enclose the pathogen's hyphae within the cytoplasm of the host cell. Thickening, the production of fibrillar chemicals, and the development of callose papillae are all examples of cell wall defence mechanisms. In order to stop the spread of the disease, tissues adapt to infections by forming gum deposits, absorptive layers, tyloses, and stacking layers. The host cell's nucleus rapidly disintegrates as part of necrosis or hypersensitive defence systems, causing the cell to die and containing the infection within necrotic cells. To combat pathogen assaults and harmful consequences, biochemical defence systems produce a variety of compounds, such as phenolic substances, phytoalexins, enzyme inhibitors, and detoxifying agents. Additionally, hosts plants may make chemicals that inhibit pathogen enzymes and toxins or cause changes in their metabolism that are damaging to pathogens.

Physical defences such as wax deposits on cuticular surfaces, thick and hard outer walls of epidermal cells, and differences in cell wall resistance are examples of pre-existing structural defences. Pathogens trying to get past the plant's exterior defences face severe barriers as a result of these defences. Furthermore, it is possible to modify natural openings like stomata and lenticels to prevent pathogen invasion. Additionally, plants have internal defence mechanisms including thicker cell walls and vascular bundles that act as barriers to the spread of pathogens within the plant. Invading infections may be efficiently stopped by these structures. Plants launch post-infection defence mechanisms after pathogens get beyond these built-in defences. To stop the spread of infections, these mechanisms include cytoplasmic defence reactions, morphological changes to cell walls, and the deposition of callose papillae. In order to confine infections and stop their spread, tissues may also form gum deposits, absorptive layers, tyloses, and stacking layers. Necrosis, also known as the hypersensitive reaction, is the last line of defence, causing the infected cells to die and the infection to be contained. Another essential component of plant defence is biochemical defence, which involves the creation of different chemicals including phytoalexins, phenolic substances, enzyme inhibitors, and detoxifying agents that fend off pathogen assaults and harmful effects. In order to advance plant science and agriculture, it is essential to comprehend these many defence systems. By using this information, solutions to increase plant resistance to diseases and boost crop protection may be developed. It is clear from the interaction between pre-existing biochemical defences after infection and pre-existing structural defences that plants are remarkably adaptable and resilient in their continual conflict with pathogens [1], [2].

In plants, certain defence mechanisms are already in place to fight off an assault, but in other organisms, the host defence mechanisms emerge only after an infection. In this sense, structural defence may be divided into;

(A) Defence structures that already existed and

(B) Defence structures that were produced in response to the pathogen assault.

Some plants deposit wax-mixtures of long-chain aliphatic chemicals on their cuticular surfaces. Wax buildup on the cuticular surface is assumed to have a protective purpose by creating a hydrophobic surface that repels water. The pathogen thus does not get enough water to germinate or grow. Fatty acids, which make up the majority of the cuticle, also contribute to the development of a negative charge on the surface of leaves. Numerous infections are prevented or less likely to infect by the negative charge. For those that attempt to enter the host via the leaf surface, the cuticle's thickness is crucial. The thickness of the cuticle blocks the route of the infection. A thick cuticle also prevents the pathogen from leaving the host and lowers the risk of secondary infection.

Epidermal cells' tough and thick outer walls may directly prohibit the infection from entering at all or make penetration challenging. Variations in the cell walls' resistance to the pathogen's penetration may be seen depending on the presence or lack of lignin and silicic acid. The blast illness of the rice pathogen seldom penetrates the majority of the lignified outer walls of the epidermal cells of rice plants. The epidermal cells of potato tubers that are resistant to *Pythium debaryanum* have a greater concentration of fibre than those of susceptible types. The design of natural openings like stomata and lenticels, among others, affects whether a pathogen will enter. Citrus of the Szincum type have short, very narrow stomata that are encircled by broad-lipped elevated structures that block the passage of water droplets bearing the citrus canker bacteria. The size and internal makeup of lenticels may also act as a defence mechanism against infections. Apple fruit varieties with tiny lenticels hinder the admission of the infection, whereas those with big apertures make it simple for the disease to enter.

Nectaries create perforations in the epidermis and, given the high osmotic concentration of the nectar, may serve as a defence mechanism. The abundance of hairs in the nectaries of resistant apple types serves as a defence mechanism, while vulnerable kinds lack numerous hairs. Internal Defence Structures: The plant already has a large number of internal defence structures that inhibit pathogen access outside of them. Environmental factors cause the cell walls of particular tissues of some plants to thicken and harden, which makes it more challenging for pathogens to spread. Vascular bundles or extensive patches of sclerenchyma cells in cereal crop stems inhibit the spread of the rust infection. Pathogens like the angular leaf spot pathogen are effectively stopped in their tracks by leaf veins.

After the pathogen has defeated the host's natural defences, the host's cells and tissues are invaded. This is when the host's defence structures are formed. The host plants create certain structures or mechanisms to prevent further pathogen invasion. These mechanisms may include defence responses in the cytoplasm, defence structures in the cell wall, defence structures in the tissues, and eventually, necrosis, the death of the invaded cell. Here, they will be briefly discussed [3], [4].

The pathogen's hyphae are encircled by the cytoplasm of the invading cell, and the host cell's nucleus is stretched until it splits in half. The cytoplasm and nucleus of the infected cells increase in certain host cells. The cytoplasm generates granular particles and becomes granular and dense. These cause the pathogen's mycelium to disintegrate, stopping the invasion. Some mycorrhizal fungi and weak pathogens like Annillaria have these cytoplasmic defence systems. The host receives little assistance from cell wall defence mechanisms. These include modifications to the host's cell wall's morphology. Cell wall defence structures typically come in three different types:

1. In reaction to the infection, cell walls thicken by manufacturing cellulose material, obstructing the pathogen's entrance.
2. When the parenchyma cells' outer layer of cell walls come into touch with invading bacterial cells, they release an amorphous fibrillar substance that traps the bacteria and stops them from growing.
3. The penetration of fungal infections results in the deposition of callose papillae on the inner layers of cell walls.

In unprocessed situations, callose material that subsequently becomes infused with phenolics forms a sheath around the hyphal ends of the infecting fungal pathogen after they penetrate the cell wall and expand into the cell lumen. Defence Structures Developed by the Tissues. Following penetration, the tissues undergo the following four developments:

Deposit of Gum:

As a consequence of infection, plants create a range of gooey substances surrounding lesions or areas. These gooey substances stop the infection from spreading. Stone fruits often create the sticky stuff.

Absorptive Layers:

In order to remove the mature fruits and old leaves from the plant, abscission layers are often generated. However, in certain stone fruit trees, similar layers appear in the young leaves in response to a fungus, bacterial, or viral infection. A gap that develops between two circular layers of cells around the infection spot is known as an abscission layer. One or two layers of the middle lamella and one or two layers of cells around the infected loci dissolve, causing a gap to form. As a consequence, the infected locus is no longer supported, shrivels, dies, and falls down with the pathogen. The development of abscission layers defends healthy leaf tissue from pathogen assault. After infection, several defensive structures emerged.

Tyloses:

Tyloses are protoplast outgrowths from nearby living parenchyma cells that protrude into xylem arteries via pits when under stress or in reaction to vascular pathogen assault. Their growth obstructs the Xylem vessels, preventing water flow and causing the onset of wilt symptoms. However, some resistant plants develop tyloses before to infection, shielding the plant from harm.

Stacking of Layers:

In response to infection, various pathogens, including some bacteria, some fungi, some viruses, and even some nematodes, cause the host to produce multilayered cork cells as a consequence of the pathogen's secreted chemicals stimulating the host's cells. These layers prevent the infection from invading farther and stop the flow of poisonous compounds that the pathogen secretes. Additionally, cork layers restrict the host's nutrition supply, depriving the infection of resources. Soft not of potatoes produced by Rhizopus species, potato tuber disease caused by Rhizoctonia species, potato scab caused by Streptomyces scabies, and necrotic lesions on tobacco induced by tobacco mosaic virus are a few examples of cork layer production as a consequence of infection.

DISCUSSION

Necrosis or hypersensitive type of defence: Some pathogens, such as *Synchytrium endobioticum*, which causes potato wart disease, *Phytophthora infestans*, which causes potato late blight disease, *Pyricularia oryzae*, which causes rice blast, etc., also use this defence strategy. When the pathogen gets into touch with the host's protoplasm in such disorders, the host nucleus travels in the direction of the infection. Brown granules that first gather around the pathogen before scattering throughout the host cytoplasm are formed when the nucleus quickly breaks down. The cell eventually explodes and dies once the membrane starts to enlarge. These make the cytoplasm of the pathogen thick and the pathogen nucleus dissolve into a uniform mass. This prevents the infection from spreading beyond the necrotic or dead cells and stops its further development.

Biochemical Protection:

Despite the fact that structural defence systems do stop pathogen attacks, the defence mechanism also involves the chemicals produced in plant cells either before or after the infection. The importance of metabolic defence mechanisms above structural defence mechanisms has now been demonstrated. The fact that many viruses invading non-host plants naturally or intentionally fail to induce infections in the absence of any structural barriers has complemented this. This does imply that plants' resistance to certain infections is the result of chemical defence mechanisms rather than structural ones.

During the Prepenetration Stage, Inhibitors are Released:

Plants often release organic material from their roots and phyllosphere, or above-ground sections. Certain diseases are known to be inhibited by certain of the chemicals generated by various plants during the prepenetration stage. For instance, fungistatic substances generated by sugar beetroot and tomato stop Botrytis and Cercospora from germinating. Conidia of *Colletotrichum circinans* do not germinate on the surface of red onions when phenolic compounds like protocatechuic acid and catechol are present. High quantities of inhibitors found in plant cells also play a crucial part in plant defence. Young fruits, leaves, and seeds are resistant to Botrytis because they contain a variety of phenolic compounds, tannins, and certain fatty acid-like substances, such as dienes. In comparison to susceptible vars, the tubers of potato that are resistant to potato scab disease have larger quantities of chlorogenic acid surrounding the lenticels and tubers. Numerous additional substances, like the tomato chemical tomatin and the oat compound avinacin, have antifungal properties. Pathogens' cell wall components may be destroyed by certain enzymes like glucanases and chitinases found in the cells of various plants [5], [6].

Another pre-existing biochemical defence mechanism is the absence of nutrients that the virus needs to survive. Plant species or variations that don't generate any of the compounds necessary for a pathogen's development may serve as resistant variants. For instance, a chemical found in Rhizoctonia-prone seedling types triggers the production of hyphae cushions from which the fungus shoots penetration hyphae within the host plants. In the absence of this material, hyphal cushions do not develop and the infection is prevented.

Absence of Common Antigen in Host Plant: It is now known that the appearance of a disease in the host is influenced by the presence of a certain protein (antigen) in both the pathogen and the host. However, the host becomes resistant to the pathogen if the antigen is present in the host but lacking in the host or vice versa. For instance, linseed types that share an antigen with their pathogen are more prone to the *Melampsora lini* caused disease rust of linseed. In contrast, linseed cultivars without the antigen but with the antigen present in the pathogen are resistant to the disease. Another example is the cotton leaf spot disease brought on by *Xanthomonas campestris pv. malvacearum*. Post-Infection Biochemical Defence Mechanism: Plant cells and tissues synthesise several compounds that prevent the development of the causative organism in order to prevent infections brought on by pathogens or damage brought on by other sources. These compounds are often created close to the area of an illness or damage with the primary goal of resolving the issue. The following list of significant compounds is provided:

Phenolic Substances:

These are the substances that plants most often create in reaction to harm or sickness. Either the "acetic acid pathway" or the "shikimic acid pathway" is used to synthesise phenolic chemicals. Chlorogenic acid, caffeic acid, and ferulic acid are examples of typical phenolic chemicals that are poisonous to pathogens. The production of these phenolic chemicals occurs considerably more quickly in resistant cultivars than in susceptible variants. Most likely, the combined impact of all the phenolics present is what prevents the illness from spreading.

Phytoalexins:

Toxic antimicrobial compounds known as phytoalexins are created "*de novo*" by plants in reaction to damage, pathogenic organisms or their byproducts, and physiological cues. The two phytopathologists Muller and Borger coined the word "phytoalexin" in 1940 to describe the fungi-static substances that plants create in response to infection or mechanical or chemical harm. The discovery of phytoalexins, which are all lipophilic substances, came about as a result of research on the *Phytophthora infestans*-induced late blight of potatoes. Although it is thought that live cells are where phytoalexins are produced, necrosis shockingly occurs quite soon.

According to Bill (1981), necrosis nearly usually occurs at the same time as phytoalexin concentration peaks. Although the precise process by which phytoalexin is produced is not fully understood, it is generally accepted that a host plant metabolite interacts with a particular receptor on the pathogen's membrane to release a substance called a "*phytoalexin elicitor*" that then enters the cells of the host plant and stimulates the synthesis of phytoalexin. By changing the plasma membrane and preventing oxidative phosphorylation, phytoalexins are thought to halt the proliferation of infections. Numerous kinds of plants, including soyabean, potato, sweet potato, barley, carrot, and cotton, have been shown to contain phytoalexins, which are now being studied. Ipomeamarone, Orchinol, Pistatin, Phaseolin, Medicarpin, Rishitin, Isocoumarin, 'Gossypol' Cicerin, Glyceolin, Capisidiol, and others are examples of frequent phytoalexins [7], [8].

Chemicals Produced by the Host to Neutralise Pathogen-Produced Enzymes:

Some hosts create chemicals that counteract the pathogen-produced enzymes, protecting the host. As a result, these chemicals assist plants in fending off disease attacks. Rhizoctonia solani infection results in necrosis in bean plants. When pathogens invade resistant bean cultivars, the methyl group separates from methylated pectic compounds and creates polyvalent cations of calcium-containing pectic salts. Both the infected and the nearby healthy tissues store calcium ions, which prevents the pathogen's polygalacturonase enzymes from dissolving the intermediate lamella. In sensitive kinds, they are known to disintegrate the central lamella of healthy tissue.

Deactivation of Pathogen Toxins and Enzymes:

In certain instances, plants create compounds that render the infections' toxins inactive. As an example, the rice blast disease-causing *Pyricularia oryzae* generates the poisons picolinic acid and pyricularin. The sensitive kinds are still harmed by these poisons even while resistant varieties may change them into N-methyl picolininic acid and pyrecularin. Similar to tomato and cotton wilts, resistant variants of the pathogen transform the poisonous N-methyl-fusaric acid amide into a non-toxic form. The harmful enzymes generated by the pathogen are inactivated by phenolic compounds or their oxidation products, much as when toxins are detoxified. Some types of cider apples are resistant to the *Sclereotinia fructigena*-caused brown not disease. It could be as a result of the resistant types creating pheolic oxidation products that render the pathogen's pectinolytic enzymes inactive [9], [10].

Biochemical Changes:

It has been noted that when a pathogen infects a host, the host undergoes metabolic changes that may be toxic to the pathogenic microorganisms and result in disease resistance. Certain new enzymes are produced, and larger concentrations of other substances are synthesised. By being harmful to pathogenic microbes, this may also increase the plant's resilience.

CONCLUSION

In conclusion, plants use a multifaceted defence strategy to defend themselves against a variety of infections. This method includes both pre-existing structural defences and post-infection biochemical defences. To create efficient plant disease control and crop protection methods, it is essential to comprehend these processes. In conclusion, plants use a variety of intricate and complicated defence mechanisms to fend off infections, which may be generally divided into pre-existing structural defences and post-infection biochemical defences. These defence systems enable plants to ward off possible threats from a variety of diseases, which makes them crucial for their survival and wellbeing.

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CHAPTER 12

PATHOGEN-PLANT INTERACTIONS: FROM SUBSTRATE NEEDS TO DEFENSIVE STRATEGIES

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ABSTRACT:

With an emphasis on the distinction between necrotrophs and biotrophs based on their substrate needs and an in-depth examination of the intricate processes governing these interactions, this comprehensive abstract investigates the intriguing realm of plant-pathogen interactions. Necrotrophs, which kill plant cells before parasitizing them, are compared to "thugs" since this causes an unfavourable cellular contact between the parasite and the host. The appropriate transport and sensitivity to these poisons influence the host's resistance, which is a key factor in necrotrophic illnesses. Toxin specificity separates host-specific necrotrophs from those that are widespread, resulting in pathogenic races within species. Contrarily, biotrophs are obligatory parasites that feed only on living plant cells and need a sufficient cellular link with their hosts in order to function. Their infections may advance before the plant activates its defence systems because they establish this relationship by piercing host cell walls, often between cells. The host range of biotrophs is often limited, and their pathogenic race structure is well characterised. A variety of small-scale cellular interactions result in variable degrees of plant resistance or susceptibility to diseases. From a cellular standpoint, this range of resistance is not always visible, therefore interactions are often categorised as "resistant" or "susceptible" for ease of use. Different genes in plants may hinder pathogen development at different phases, such as limiting colony growth and reproduction or preventing propagule germination and penetration.

KEYWORDS:

Defence systems, Necrotrophs, Plant Interaction, Resistance, Susceptible.

INTRODUCTION

Necrotrophs and biotrophs, two major categories of pathogens, by their differing substrate needs. In because they murder plant cells before parasitizing them, necrophages are like "thugs." Cells of the host and the parasite cannot live in peace. Therefore, the development of a disease depends on an incompatible cellular interaction between the parasite and the host. Host cells won't die if the toxins employed to kill them are not delivered at the proper time, location, or concentration, or if a certain host genotype is resistant to the toxin. The plant will be resistant and the necrotroph will be unable to colonise or reproduce. Necrotrophic diseases fall into two categories: those with broad host ranges including several plant species, and (ii) those has a host range restricted to a few plant species or even cultivars within a species. The specificity of the toxin(s) generated is the primary distinction between these two kinds of necrotrophs. Wide-ranging necrotrophs release toxins that affect metabolic targets shared by a variety of plants. In contrast, the gene that encodes the capacity to make the toxin and a gene in susceptible cultivars of the host that encodes sensitivity to that toxin condition the pathogenic potential of necrotrophs that release host-specific toxins. A pathogenic race or pathotype structure is often formed by host-specific necrotrophs, where certain races are able to attack select cultivars of a species but not others. A cultivar will be resistant to the illness brought on by a particular pathogen if that cultivar lacks the gene that controls susceptibility to a certain host-specific toxin.

On the other hand, biotrophs are obligatory parasites that feed off of live cells. As a result, they must create a suitable cellular connection with their hosts. 'Sneaks' are biotrophs. They generally spread disease via unnatural holes or by piercing the surface of their host. In order to generate food-absorbing haustoria, they generally continue to develop between the cells of their host, only penetrating host cell walls (but not host cell membranes). The infection either grows without triggering the host's defensive mechanisms or spreads before the plant can mobilise its defence mechanisms. Because of the amount of specialisation needed to develop this kind of connection, biotrophs often have a narrow host range and a well-defined pathogenic race structure. The plant will be resistant if host cells of a biotrophic pathogen die before invasion because the pathogen is unable to form a parasitic connection [1], [2].

The way the challenged plant reacts is a second aspect that determines whether a parasitic connection will develop. Individual pathogen propagule interactions with plant cells may result in effective pathogen establishment in some cases but not in others. It will become clear that a plant's overall resistance or susceptibility is the result of several small-scale cellular interactions. The vast majority of individual pathogen propagules that attack resistant plants are restricted or delayed in their growth and reproduction. In this respect, resistance is quantitative; in resistant hosts, a larger percentage of pathogen propagules are prevented or delayed from developing and reproducing than in susceptible animals. Although from a cellular viewpoint this difference is not always evident, the response of a plant to pathogen inoculation is often classified as either "resistant" or "susceptible" for the purposes of plant breeding. It is more appropriate to think of resistance and susceptibility as the extremes of a continuum, on which most host-parasite interactions lie. Inhibiting propagule germination and penetration, eliminating pathogens before to establishment, and restricting or delaying colony growth and reproduction after the pathogen has already taken hold are just a few examples of how resistance may manifest itself. For instance, different genes in wheat that prevent stem rust function at various phases of the host-parasite relationship. Others permit initial infection but stop haustorial development and starve the pathogen, while the 'slow-rusting' genes permit parasitism and pathogen reproduction, but at a much slower rate than in susceptible cultivars. Some of these genes cause the pathogen to quickly perish after an attempt at penetration. For plant breeders, each kind of interaction offers beneficial resistance since they all postpone the start of epidemics and lower output losses.

The first stages of the development of a host-pathogen association are fragile and highly susceptible to environmental variables, such as the presence of other microorganisms. A complicated signal exchange mediates the connection between the host, parasite, and environment. When a pathogen attacks, plants defend themselves by creating a complex network of molecular, cellular, and tissue-based defensive barriers. These defences can be activated by all plants. They won't be able to stop the infection if they are triggered too early, too late, or in the incorrect spot, leaving the plant vulnerable. In response, pathogens either circumvent, inhibit, or render ineffective plant defence mechanisms, such as plant antibiotics, by detoxifying them.

If environmental factors support infection, there are five potential results from the interplay of the pathogen's nutritional needs and the host's reactions. When the pathogen and the plant ignore one another, no connection is made. For instance, a fungal spore may germinate, but the resultant hypha is unable to penetrate or form a parasitic relationship because the host does not supply the necessary conditions for pathogen growth. When the fungus runs out of energy, it perishes. The plant exhibits no reaction and is by nature resistant. It is not a host.

There are five probable connections between potential pathogens and plants [3], [4]. When a plant releases substances into its surroundings that limit the growth of the disease, it is said to be hostile to the pathogen. For instance, certain brassicas' stubble releases 'biofumigants' into the soil that stop nematode eggs from developing and stop some fungus from growing that may infect roots. When interplanted with nematode-susceptible plants like tomato, asparagus and marigolds (*Tagetes spp.*) exude chemicals into the rhizosphere that are harmful to worms and provide excellent protection against nematodes. Many plants produce phenolic substances onto the surfaces of their leaves that deter herbivore eating and prevent a wide range of microorganisms, including potential diseases. In this interaction, the pathogen is unable to grow and has no discernible impact on the host plant's metabolism.

DISCUSSION

Plant antagonists may only momentarily prevent pathogen growth in specific circumstances, such as when *Colletotrichum gloeosportoides* infects ripening avocado fruit. The growth of the appressoria, which are formed when spores germinate, is halted by fungistatic compounds in the peel. These materials are enzymatically broken down after harvest, and the appressorium then germinates to produce infection hyphae. Anthracnose lesions eventually appear. The stem end rot diseases of avocado and mango. When the pathogen secretes substances that harm the plant, it becomes hostile to the plant. *Periconia circinata*, for instance, infects the roots of sorghum, but only strains of the fungus that generate the host-specific toxin, periconin, cause symptoms of milo disease, and only in cultivars that are susceptible to this toxin. Similar to this, certain strains emit poisons that are particular to their hosts and damage cells of those species and cultivars. For instance, a pathogenic strain of the fungus on tomatoes releases AAl-toxin, to which tomatoes have a special sensitivity. AAM-producing strains target apples, AAK-producing strains harm Japanese pears, AAC-producing strains harm citrus, and so on. Citrus is not pathogenic to the tomato, apple, or Japanese pear strains because citrus is exclusively susceptible to the AAC-toxin. On vulnerable oat cultivars, generates the toxin victorin, which causes severe seedling blight; however, it has little impact on resistant cultivars or other plant species. Insensitivity to the poison the infection produces leads to resistance. A plant species is referred to be a non-host if this insensitivity is present in all cultivars.

Both the host tissue and the pathogen are inhibited or killed as a consequence of the antagonistic interactions between the plant and the pathogen. For instance, both host and pathogen cells perish as a result of an unfavourable interaction between the stem rust pathogen Puccinia gramtnis and resistant wheat varieties. A compatible cellular interaction between the host and pathogen results from mutual adjustment. Mutually beneficial interactions include those between nitrogen-fixing prokaryotes and plant roots as well as between mycorrhizal fungi and plant roots. In plant tissue, endophytic fungi and bacteria colonise the intercellular gaps, ostensibly without harming their host cells. Before they infect fruits, several stem end rot pathogens undergo an endophytic phase in leaves and twigs. On live host tissue, biotrophic diseases like rusts and mildews thrive and proliferate. Even while host cells are not harmed, the host's development is negatively impacted by the diverted resources to the invader's disease [3], [5].

The sequence in which pathogens often attack plant defence system. In general, passive defence mechanisms are those that exist before coming into touch with the pathogen, while active defence mechanisms are only triggered when the pathogen has been identified. Since many pre-existing defences are altered by infection, this difference is not always evident in practise.

Passive protection

Pathogens must first get past the natural barriers put up by healthy plants in order to access the nutrients or replication machinery located inside the host cell. These barriers might be chemical (inhibitory substances or the lack of stimulatory compounds required for pathogen growth) or physical (the cuticle, cell wall, stomatal opening, or lenticel). Saprophytes are unable to cross these organic barriers.

Physical obstacles

The dependency of many infections on adherence and the subsequent release of 17 has shown the significance of the cuticle as a barrier to penetration. Pathogen defences in plants at the moment of penetration, cutin-degrading enzymes were present. Although many saprophytic fungi and bacteria also release cutin-degrading enzymes, these organisms' main function is to provide access to the cellulose found in plant cell walls as a food source. Pathogens pierce the cell wall via a variety of cutin-degrading enzymes. Since the aggressiveness of isolates of *Fusarium solani f. sp. pisi* is directly correlated with the activity of this kind of cutinolytic enzyme, pathogens unable to dissolve the cuticle at the site of penetration are rejected.

Resistance to certain diseases may be influenced by cuticle and cell wall thickness. Some varieties of "adult plant resistance" may have stronger, more durable cell walls, which may limit disease entry. The germ tubes originating from basidiospores on mature leaves cannot penetrate the thicker cuticles of certain diseases, such as *Puccinia graminis*, which only infects young barberr plants with thin cuticles. Similar to this, it has been suggested that the difficulty of germ tubes to get through the thicker cuticles of older leaves is the reason why Taphrina dejorrnans exclusively infects young, freshly unfolded leaves. Secondary cell walls in sclerenchyma, xylem, or older plant tissue often slow the growth of pathogens, resulting, for instance, in angular leaf patches where the pathogen's ability to spread is constrained by the leaf veins. Thick cuticles may actually stop sporophores from erupting and spores from dispersing. The majority of experimental data, however, indicates that hardened cell walls and cuticles are just one of several elements that contribute to resistance.

The development of moisture films on leaf surfaces may be prevented by waxy cuticles and vertically orientated leaves. Pathogens including bacteria, nematodes, and fungal zoospores that need a coating of water for movement may infect dry leaf surfaces and cause disease. Due to the fact that the majority of fungus spores need moisture to germinate, they may also be hindered. This has to be contrasted with the fact that 268 Dauid is vertically orientated. In comparison to those who are horizontally oriented, Guest and John Brown are more vulnerable to impaction by wind-borne pathogen propagules and are more likely to experience greater inoculum levels.

Many diseases enter via wounds, holes in the environment, or are spread by vectors. It is challenging to understand how natural defences like the cuticle and cell wall may contribute to resistance in these circumstances. Some researchers have hypothesised that plants may be more resistant to pathogen attack if their stomatal apertures are the wrong shape or size for pathogen infection structures to enter or if they close at the time of day when pathogen spores typically germinate. *Phgtophthora palmiuora*, the pathogen responsible for black pods, penetrates cocoa pods via stomata. Lesions are less likely to develop in cocoa genotypes that generate pods with fewer, comparatively smaller stomata than those that produce more, bigger stomata. It should come as no surprise that there is no connection between resistance to black pod and cuticle thickness or pod case hardness given that the pathogen penetrates via stomatal holes. *Xanthomonqs campestris*, the bacterium that causes citrus canker, enters grapefruit via open stomata [6], [7].

Mandarins are resistant because the bacteria can't enter via their tiny stomata. Similar to this, infections like *Streptomyces scabies*, which is the cause of common potato scab, may be physically excluded by lenticels that suberise quickly enough to induce a reduction in their size.

Chemical defences

Pathogen development may be stimulated or inhibited by substances found in plant cells or exudates on the surfaces of plants. Plants may resist infection in certain cases because they do not provide the pathogen with the necessary nutrients. The germination or hatching of dormant spores of pathogens like Spongospora subterranea (powdery scab of potatoes), *Urocgstls agropgri* (flag or leaf smut of wheat), *Plasmodtophora brassicae* (club root of crucifers), and eggs of the potato cyst nematode, *Globodera rostochiensis*, depends on the presence of particular chemicals. These are offered in various plants' secretions, including those of prospective hosts. By default, plants that don't release these stimulators are resistant. The pathogen's pre-penetration development may simply not be supported by other plant secretions. In one experiment, the development of certain fruit-rotting bacteria is inhibited by reducing the availability of iron using binding agents (siderophores). Pathogens may be deprived of vital nutrients by host cultivars that release lower than usual quantities of iron onto their surface, which would stunt their development. Similar to this, microbes that bind accessible iron to leaf surfaces have the potential to act as biocontrol agents.

Occasionally, during normal growth, plants secrete substances that prevent the spread of diseases. Phytoanticipins may collect in dead cells, be secreted in vacuoles in an inactive state, or be expelled into the environment (such as the rhizosphere or phylloplane). The quinones catechol and protocatechuic acid, which are present in the dead cells of brown onion skins, prevent the development of the spores of the pathogens that cause neck rot and smudging, respectively. White onions are smudge-prone despite not producing these chemicals. These inhibitors are ineffective against *Aspergillus niger*, which affects both white and brown onions. Borbinol, an antibacterial phenolic substance, is secreted into the rhizosphere by avocado rootstocks that are resistant to *Phgtophthora cannamomr* root rot. Asparagus and marigold roots are surrounded by rhizospheres that contain nematode-inhibiting compounds, as was previously described. Only mature fruit displays the symptoms of avocado anthracnose, which is brought on by *Colletotrichum gloeosporiordes*. Unripe avocado fruit's peel contains antifungal lipids called dienes that stop the germination. *Quiescent appressoria* germinate as a result of these dienes' progressive metabolism into less poisonous substances during fruit ripening, which also improves anthracnose sensitivity. Diene breakdown is prevented in anthracnose-resistant cultivars after infection, prolonging the duration of antifungal levels. The amount of the phenolic chemicals chlorogenic acid, phloridzin, arbutin, and iso-chlorogenic acid in the outer layers of the fruit is correlated with the resistance of young apples and pears to scab, which is brought on by *Venturia inaequalis* and *V. pirina*, respectively. Unripe apples and pears also have a harsh taste from these substances, and as the fruit ripens and becomes sweeter, it also becomes more prone to scab [8], [9].

The saponins are a subclass of phytoanticipins that have surfactant (wetting agent) characteristics. In pathogen cell membranes, saponins bind sterols, impairing membrane function and integrity. In this manner, saponins are poisonous to species (such as plants and fungi, but not Oomycota) whose membranes contain sterols. The vacuoles of undamaged plant cells seem to retain inactive saponin precursor molecules, but hydrolase enzymes released after injury or infection transform these precursors into active, antimicrobial forms.

Saponins may have a role in determining host range and disease resistance, according to a number of lines of research. The capacity of certain pathogens to detoxify particular saponins seems to correspond to their host range. For instance, the pathogen *Gaeumannomaces graminis var. auenae*, which affects oats, wheat, and barley, secretes the enzyme avenacinase. The triterpenoid saponin known as avenacin, which is present in the epidermal cells of oat plant roots, is detoxified by avenacinase. Mutants with the avenacinase gene deleted are sensitive to avenacin in vitro and do not cause disease on oats, but they do cause disease on wheat and barley.

Because it lacks avenacinase, *Gaeumannomaces graminisvar. tritict* only attacks wheat and barley and avoids avenacin-containing oat species. *Gaeumannomaces graminis var. tritici* may infect *Auena Longiglumis*, an oat species that doesn't generate avenacin. Tomatine, another saponin, aids in the tomato leaves' defence against Botrytis cinerea. Additionally, several plant peptides prevent the growth of insects, viruses, bacteria, and fungus. They function as lectins, ribosome inhibitors, proteinase and polygalacturonase inhibitors. These inhibitors prevent nutrients from reaching the pathogens and prevent them from growing, which increases disease resistance. They are known as plant defensins because of their resemblance to peptides called defensins that are present in insects and mammals. A crucial line of protection against viruses that dampen off is provided by secreted defensins. Defensin makes up 30% of the proteins produced by germinating seeds, although making up just 0.50% of the total protein in ungerminated radish seeds. It offers the budding radicle an antibacterial microenvironment. Up to 10% of the total proteins in cereal, legume, and solanaceous seeds may be accounted for by Defensins. Defensins have been shown in similar research to be present in the outer cell layers of other plant tissues such flowers, leaves, and tubers. While many defensins build up naturally as plants grow, others are triggered or their buildup is accelerated after injury. Defensins provide a protection against viruses spread by insects due to their anti-feeding effect towards insects.

Recognising pathogens

The fact that plants may react when prospective diseases confront them suggests that they detect these pathogens as "non-self." Plants perceive a wide variety of signals emanating from microorganisms and the environment to generate defensive responses, in contrast to mammals that employ antigen-antibody interactions to recognise non-self. Numerous signals of both abiotic and biotic origin trigger defensive reactions in a variety of cultivars and host species that have nothing in common with the host ranges of pathogens. The quantity of elicitor present affects how big of a reaction is given. Abiotic elicitors may trigger physiological stress responses, some of which can lead to resistance. Examples include heavy metal ions, light, and certain metabolic inhibitors. They often have a vague and transient impact. Abiotic elicitors are seldom present at the infection court, making it difficult to always understand their role in host-parasite interactions. However, exposure to solar UV radiation may cause stress reactions in exposed plant tissues, acting as an additional defence against pathogen invasion. However, environmental stress often makes plants more vulnerable to necrotrophic diseases.

Plants have defensive mechanisms in response to bacteria and fungi that leak pieces of their cell walls. *Phgtophthora megasperrna f. sp.* glgcinea cell wall fragments are effective inducers of defensive reactions in soybeans. Heptabetaglucan, which has seven glucose units, is the smallest active fragment and is present in the cell walls of several pathogenic and non-pathogenic oomycetes races and species. Recently, it was shown that soybean cell plasma membranes have a receptor. This, together with its effectiveness, raises the possibility that heptabetaglucan and similar oligosaccharides play a role in pathogen identification [10], [11].

Plant cell wall fragments that trigger defensive reactions are released by hydrolytic enzymes of either pathogen or plant origin. For instance, the middle lamella of plant tissues is dissolved by the polygalacturonase enzymes produced by fungus and bacteria that cause fruit deterioration. While doing so promotes pathogen colonisation, it also results in the production of pectic fragments, which are effective elicitors made up of oligosaccharides made up of nine to thirteen polygalacturonate units. From culture filtrates of bacterial and fungal pathogens, a variety of peptides and glycoproteins have been identified that induce defensive responses in plants.

An effective elicitor is a 46 kD glycoprotein isolated from tobacco plants infected with the black shank pathogen *Phgtopttthoranicotianae var. ntcottanqe* and culture filtrates of this pathogen. Ppn 468, a 46 kD glycoprotein, may also elicit by releasing pieces of cell walls, according to some indications that it contains endoxylanase activity. From *Phgtophthora megasperma f. sp. gtgcinea*, a 42 kD glycoprotein with glucanase activity has been identified. A thirteen-amino acid peptide that interacts to a receptor on the host plasma membrane is the glycoprotein's active portion. The fact that these elicitors are present in both virulent and non-virulent isolates suggests that resistance is not based on how they operate.

Elicitins are a class of lOkD peptides that have been identified from the culture filtrates of several oomycetes and *Phgtophthora species*. There are two types of elicitins: acidic A-elicitins, like parasiticein and capsicein produced by *P. ntcottanae var. parasitica* and *P. capstci,* and basic B-elicitins, like cryptogein and melonin produced by *P. cryptogea* and cinnamomin by *P. cryptogea*. In tobacco, all cause systemic necrosis. When sprayed to the plant, elicitins are translocated, although they have not yet been discovered at the infection court. The fungi that make them are not known to use them in any metabolic processes. Highly aggressive *P. nicotianae var. nicotianae* isolates do not emit an elicitin and do not trigger host defence mechanisms against pathogens. Less aggressive isolates as well as isolates from hosts outside tobacco, however, release parasiticein. This data suggests that the host range of certain oomycetes may be constrained by elicitin release. In the early stages of infection, the black shank pathogen is a biotroph, and through co-evolution with its host, tobacco, aggressive mutants with low elicitin levels may have been chosen.

Slices of potatoes react defensively when exposed to polyunsaturated fatty acids from *Phgtophthora infestans* cell membranes, such as arachidonic and eicosapentaenoic acid. When used in combination, these fatty acids improve the elicitor activity of glucans, while having lesser elicitor activity in other plants when used alone. This and other data suggest that certain infected plants' complicated responses could be dependent on the identification of a number of elicitors. Gene-specific elicitors are those that have been preconditioned by the pathogen's avirulence genes. Their behaviour closely resembles the gene-for-gene theory. A few gene-specific elicitors have just lately been characterised thanks to the use of molecular methods, even though their existence has long been assumed. The avirulence genes of the biotrophic tomato pathogen *Fbtuia jutua* have produced a number of peptides that are race-specific. Following their first isolation from the intercellular fluids of infected leaves, these peptides have now been discovered around the infection site.

Only in cowpeas with the matching resistance gene can a heat labile exudate from sprouting basidiospores of incompatible races of cowpea rust (*Uromgces uignae*) elicit defensive responses. Similar to this, cultivars with the matching resistance gene particularly induce resistance to a 6.4 kD peptide from the pathogen that causes barley leaf scald, *Rhgnchosportum secalis*. These peptides' hosts have not yet been discovered. Although their gene products have not yet been fully described, a number of avirulence genes have been found in plant pathogenic bacteria. According to the gene-for-gene theory, avirulence (anr) genes control host range (species/pathovar and cultivar/race relationships). Qur genes, however, only seem to work when another gene cluster, the hrp (hypersensitive response and pathogenicity) gene cluster, is present, according to experiments using genetically altered bacteria. Numerous Gram-negative bacteria, both pathogenic and non-pathogenic, include Hrp genes. In the lack of the aur gene, they serve as pathogenicity genes, whereas in its presence, they serve as hypersensitive response-inducing genes. These hrp genes produce the heat-stable protein harpin, which is essential for membrane transport. A hole that permits the secretion of aur gene products seems to be lined by clusters of harpin subunits. The extracellular polysaccharides that prevent the pathogen from being recognised by the host are secreted by Hrp gene products, which contribute to both virulence and avirulence.

Factors that inhibit and promote compatibility. here have been two tiers of compatibility considerations mentioned. Every biotroph must develop a fundamental compatibility with its host. Additionally, virulent races may create particular compatibility characteristics that hinder, prevent, or completely eliminate detection by ordinarily resistant cultivars of a host plant. The co-inoculation of a host with compatible and incompatible strains of a pathogen enables the typically avirulent strain to infect, colonise, and reproduce, according to experiments utilising a variety of host-parasite interactions. These findings imply that the virulent isolate somehow inhibits the host's defence systems.

The host is resistant to both strains, however, if the virulent strain is administered a few hours after the avirulent strain, showing that suppressors are unable to turn off resistance responses after they have been triggered. On the surface of virulent isolates, but not avirulent ones, are water-soluble compounds. Slices of potato tuber are suppressed in their defensive reactions by *Phytophthora iryfestans*. *Ascochgta rabiei* and *Mgcosphaerella pisi* both create glycopeptides that inhibit the defensive mechanisms of their respective hosts, chickpea and pea, respectively. These interactions could occur often in nature.

CONCLUSION

Necrotrophs and biotrophs, two primary groups of pathogens, each with its own distinct methods and substrate demands, constitute the world of plant-pathogen interactions, which is complicated and intriguing. Necrotrophs, often called "thugs," damage plant cells prior to parasitizing them, resulting in an unfavourable cellular contact between the parasite and the host. Their host range is determined by the specificity of the toxins they generate; some impact a variety of plants, while others are host-specific. There is a continuum between resistance and susceptibility in plant-pathogen interactions, with different genes and processes at work. These interactions may hinder propagule germination, limit or postpone colony expansion, and prevent the establishment of pathogens. Utilising these relationships, plant breeders may create disease-resistant cultivars and lower disease outbreaks. The early phases of plant-pathogen relationships are controlled by a variety of signals and chemical defences generated by both the plant and the pathogen. Plant-pathogen partnerships are susceptible to environmental conditions. Chemical defences and physical barriers like the cuticle and cell wall may stop pathogen entry or impede their development. Defensins and other plant peptides are essential for preventing illnesses brought on by different bacteria.

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