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2. Morphological Changes in Plants in Response to Insect Pests

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Abstract:

Insect pest pose a significant threat to global agriculture, causing substantial yield losses and economic damages. To combat these pests, plants have evolved a multitude of defense mechanisms, including various morphological changes. These changes encompass a wide range of adaptations, including alterations in leaf structure, the development of specialized structures, and changes in root morphology. These morphological adjustments are often accompanied by changes in plant physiology and biochemistry, collectively constituting an integrated defense strategy. Morphological changes occur in plants both above and below-ground level. Climate change can alter temperature, humidity, precipitation patterns, and distribution of pests, which in turn leads to various morphological changes in plants in relation to leaf thickness and texture, trichome density, altered flowering and seed production etc. Climate-driven adaptations can influence the interactions between plants and herbivores, potentially leading to shifts in the composition of plant and pest communities over time.

Keywords:

Morphology, Trichome, Root system, Climate change

2.1 Introduction:

Plants as sessile organisms have evolved intricate defense mechanisms to counteract the myriads of challenges presented by their dynamic environment. Among these challenges insect pests pose a significant threat to plant survival, exerting selective pressure that has driven the development of a diverse array of adaptive strategies (Skendžić et al., 2021). Insect pests ranging herbivorous to parasite represent one of the most potent selective pressures on plants. As herbivorous consume plant tissues for sustenance impose a constant threat to fitness of plants (Miller & Raman, 2018). The relationship between plants and insects represents a complex web of interactions, ranging from mutualistic to antagonistic, each employ an array of strategies to ensure its survival and reproductive success (Nepi et al., 2018). This dynamic interplay has driven the co-evolution of plants and insects, leading to an evolutionary arm race characterized by remarkable and counter adaptations. As plant develops defense mechanism to deter herbivory insects evolve counter strategies to overcome these barriers (War et al., 2012).

This escalation of adaptation is a driving force behind the remarkable changes observed in plants in response to insect pests. Morphological changes in plants as a response to insect pests are multifaceted and can encompass alterations at various organizational levels, from cellular structure to entire plant organs. These changes can be rapid, occurring within hours of herbivore attack, or may develop gradually as a part of a longer-term defense strategies. They often entail shift in plant growth patterns, resource allocations, and structural modifications, all aimed at deterring herbivores, mitigating damage, and ultimately enhancing plant survival and reproduction. These adaptations can be categorized into those occurring above the ground, below the ground, and even at the structural level. Structural modifications such as development of thornes, prickles and spines further discourage herviorous from feeding on plants. These hardened structures often arise from modified leaves or stems; create physical barriers that prevent formidable challenge to would be herbivore. Furthermore, plants have developed a sophisticated array of chemical defense that is deeply interwined with their morphological adaptations. This defense manifest as secondary metabolites such as alkaloids, terpenoids, and phenolic compounds, effectively deployed chemical weaponry that repel herbivores and or attack their natural predators thus creating a delicate ecological balance. Understanding the mechanisms that underlie these morphological changes require a comprehensive exploration of intricate signaling pathways, hormonal network and genetic factor that orchestrate the plants response. In this chapter we have discussed the diverse morphological adaptations that plant employ in response to pest pressure and also the role of abiotic factors in shaping plant morphology.

2.1.1 Morphological Adaptation of Plants above Ground:

Plants adapt to environmental stress by altering their metabolism, flowering, growth, and reproduction; and by migrating toward areas with more favorable climatic conditions. Climate change has significant effects on the morphological adaptation of plants above ground level. Here are some impacts:

A. **Increased leaf area**: Leaf morphological traits vary systematically along climatic gradients. Rising temperature and elevated carbon dioxide levels can stimulate photosynthesis in plants, leading to increased leaf area. This allows plants to capture and utilize more sunlight for energy production (Gamage et al., 2018). There are two mechanisms identified by which this happens: wall extensibility, which progressively alters the leaf over time and permanently enlarges it, or osmotic regulation, which has a transient effect that causes leaves to grow in size. The different leaf diameters of plants growing in the same habitat are anticipated to have unique thermal regulation capacities that affect leaf water loss and heat loss.
B. **Altered leaf shape and size**: The use of leaf morphological attributes for species identification dates back to long time and is frequently recognized as diagnostic of species. These traits include leaf colour, shape, orientation, and degree of marginal dissection. changes in temperature, moisture availability, and CO2 level can influence leaf morphology. For example, in response to higher temperature, plants may develop larger, thinner, leaves to enhance the heat dissipation through transpiration (Vicente-serrano et al., 2022). Different mechanisms have developed to control plastic, heterophyllous responses to changes in temperature and light quality as well as heteroblastic changes in leaf shape in response to photosynthesis.

C. **Shift in flowering and fruiting patterns:** Climate change can disrupt flowering and fruiting cycle of plants. In some case warming temperature can induce early flowering affecting pollination and seed production. This can also lead to desynchronization between plant and pollinator species (Freimuth et al., 2022). It has been noted that angiosperm flowering times advance with climate change, but it is unclear whether fruiting dates also vary as a result of moving flowering times, or whether they react to climate change differently or not at all.

D. **Change in Plant height:** As temperature increase, Plant may exhibit vertical growth to seek cooler and moisture rich environment (Reich et al., 2018). There are some significant elements influencing plant growth: Temperature: As the temperature rises, growth quickens. Light: A plant's physiological activities are influenced by the amount, type, and quality of light available. Water: A plant's ability to grow depends on water. The majority of plant issues are brought on by environmental stress, either directly or indirectly. In some circumstances, a plant is directly harmed by unfavourable environmental conditions (such not enough water). Other times, environmental stress weakens a plant, making it more prone to illness or insect assault.

E. **Trichome:** Trichomes are hair like structure found on the leaves, stems and other plant parts. They serve various functions including, protection against herbivores, reducing water loss and reflecting sunlight (Jolivet, 2023). Secondary metabolites, such as terpenoids, flavonoids, and others that can repel, damage, and catch insects and other pests, are secreted by glandular trichomes, providing a variety of plant defenses. They can be found alone or sporadically in groups. They come in a variety of shapes and sizes and can be unicellular or multicellular. They range from tiny protuberances of the epidermal cells to intricate multicellular formations that are branching or stellate. Hair cells could have lived or dead cells. The hairs commonly lose the protoplasm inside of their cells. Climate changes have both direct and indirect impact on trichome formation in plants and on the morphology of trichomes.

F. **Increased trichome density**: Higher temperature and increased UV radiations associated with climate change can stimulate the trichome formation in response to elevated stress levels. This can lead to an increase trichome density on plant surface (Punja et al., 2023). When stem water potential fell, the number of leaves trichomes rose, which increased the amount of visible light that the leaf reflected. Under water stress, cell and leaf growth were constrained, and epidermal cell size and trichome density showed negative relationships.

G. **Change in trichome shape, size and density**: Trichomes have consistently been shown to be a useful phenotypic characteristic for identifying species' evolutionary and taxonomic relationships. Trichome can produce chemical compounds that deter herbivores and pathogens. Morphology, density and dimensions relationships of subtypes of trichomes can be employed to find correlations between trichome characteristics with herbivore feeding intensity and behavior. In response to increased temperature, trichomes may become longer and more branched, maximizing their surface area to enhance cooling effects through increased transpiration (Wang et al., 2021).

H. **Leaf hardening and sclerification:** Climate change can lead to leaf hardening and sclerification in plants. Leaf hardening can refer to the process of leaves becoming tougher and more rigid, while sclerification refers the development of sclerenchyma cells, which are thick walled and provide additional support to the leaf structure. This process can be influenced by several factors related to climate change:

I. **Drought Stress**: increasing temperature and altered precipitation patterns associated with climate change can lead to more frequent and prolonged droughts (Jump et al., 2017). In response, plants may undergo leaf hardening and sclerification as mechanism to conserve water and reduce water loss through transpiration (Salleo & Nardini, 2000). Plant biomass output, quality, and energy are all hampered by drought stress, an unavoidable condition that occurs in many ecosystems with no clear bounds and warning. It is the most significant environmental stress brought on by changes in temperature, light intensity, and rainfall levels.

J. **Heat stress:** Higher temperature can cause heat stress in plants, leading to the development of thicker and tougher leaves (Lipiec et al., 2013). Leaf hardening help protect the underlying tissues from excessive heat and reduce water loss (Wahid et al., 2007). Extreme heat can cause oxidative stress, which damages plant cells and hinders their growth by generating reactive oxygen species (ROS); also, water stress is brought on by increased transpiration rates brought on by high temperatures, which reduce the quantity of water available to crops.

K. **Increased UV radiations**: Climate change can result in higher level of UV radiations reaching the earth surface. Plants and microbes are directly impacted by ultraviolet (UV) radiation, which also changes the way that different species interact with one another. Various effects of UV radiation's three separate bands, UV-A, UV-B, and UV-C, on plants and the microbes that live on them. While UV-A and UV-B primarily influence morphogenesis and phototropism, UV-B and UV-C significantly increase the formation of secondary metabolites.

L. **Cryptic coloration and mimicry:** Changing climate can have significant impact on cryptic colorations and mimicry in plants. These adaptations are crucial for plants to blend it with their surroundings, avoid predations or exploit mimicry to gain benefits (Niu et al., 2018). Climate change can lead to shifts in vegetation patterns and seasonal timing. As a result, plant populations may no longer match their current surroundings, diminishing the effectiveness of cryptic colorations (Delhey & Peters, 2017). E.g., if snow cover can reduce in snowy habitat, plants with white colorations will be less camouflaged. Many plant species have evolved to mimic the appearance of other organisms such as insects or flowers (Jürgens et al., 2015). Climate change can disrupt the synchronization between phenology of mimicking plants and their targets (Forrest, 2015).

2.1.1 Morphological Changes below the Ground:

Climate change can have significant impact on plant parts present below the ground including roots, tubers, rhizomes, and bulbs.

A. **Root system distribution:** Climate change particularly changes in temperature and rainfall pattern can alter soil moisture availability. This can influence root system development and distribution (St. Clair & Lynch, 2010). Plants may develop deeper and more extensive root system in search of moisture in drought-prone region, while in water logged areas, they may develop shallower roots to access oxygen (Ding et al., 2021).

B. **Root length and thickness:** Change in temperature and soil moisture can influence the growth and size of roots. In warmer and drier conditions, plants may develop longer and thinner roots as they search for water and nutrients in the deeper soil layers

(Montagnoli et al., 2012). Conversely, in cooler and wetter conditions, plants may develop shorter and thicker roots to maximize nutrient uptake in shallow soil layers (Montagnoli et al., 2023).

C. **Changes in root exudates composition:** Root exudates are organic compounds releasd by plant roots into the surrounding soil. They provide nutrient to surrounding soil. They provide nutrition to soil microorganisms, influence nutrient cycling, and interact with the rhizosphere (Lamichhane et al., 2023). Climate change particularly elevated CO2 level and altered soil moisture, can affect the composition of root exudates, potentially altering microbial communities and nutrient dynamics in soil (Raza et al., 2023).

D. **Altered root hair proliferations:** Root hairs are tiny, elongated outgrowths of root epidermal cells that increase the surface area for water and nutrient absorption (Adu et al., 2023). Tubular extensions known as root hairs grow from the epidermal cell layer in the differentiation zone. They are essential in increasing the root's surface area, which improves the root's ability to absorb water and nutrients from the soil. Climate change including change in temperature, precipitation, and change in soil moisture, can affect root hairs proliferation. In water stressed conditions plats may develop more hairs to increased water uptake.

2.2 Structural Modifications in Plants due to Climate Change:

Climate change can lead to various structural modifications in plants as they adapt to changing environmental conditions. Here are some examples:

A. **Change in plant height and architecture:** The organization of the plant body in three dimensions is referred to as plant architecture. This covers the branching pattern, as well as the size, shape, and location of leaves and flower organs, for the sections of the plant that are above ground. Rising temperature and changing precipitation patterns can alter plant growth patterns. In response pants may undergo structural modifications such as changes in height, branches, and overall architecture (Prisa & Fresco, 2023). For instance in drought prone areas, plants may become shorter and more compact to reduce water loss and increase water efficiency (Chen, 2023).

B. **Leaf modifications:** Climate change can influence leaf morphology and structure. Some plants may develop thicker leaves to withstand higher temperature and reduce water loss through transpirations (Yu et al., 2023). Additionally leaf size and shape may change to optimize energy capture and heat dissipation. In regions experiencing shifts in temperature and light availability, plants also exhibit change in leaf orientations or the presence of leaf hairs or trichomes on the leaf surfaces.

C. **Modifications in reproductive structure:** Climate change can affect the reproductive structure of plants, such as flowers, fruits, and seeds. Different reproductive techniques have evolved in plants to ensure the survival of their species. As opposed to animal species, which rely almost completely on sexual reproduction, some plant species reproduce sexually while others do so asexually. Pollinators are not necessary for asexual reproduction in plants, although sexual reproduction usually requires them. Flowers are typically the most lavish or potently scented part of plants. Because of their vivid colours, enticing smells, and distinctive shapes and sizes, flowers attract insects, birds, and other species for pollination. Other plants get pollinated via the wind or the water, while some plants self-pollinate.

2.2.1 Thrones, Prickles and Spines Modification in Plants due to Climate Change:

Climate change can also lead to modification in the thrones, prickles and spines in plants. These structures are often used by plants as a defense mechanism against herbivores and other threats (Belete, 2018). One possible modification is an increase in the density and length of the thrones, prickles and spines in plants (Benelli, 2015). Warmer temperatures and changing precipitation pattern can create more favorable conditions for herbivores such as insects or grazing animals (Koulelis et al., 2023). In response plants may develop more pronounced or larger thrones, prickles or spines in response as a way to deter herbivory and protect themselves (War et al., 2012). Additionally, climate change can also impact the chemical composition of these defensive structures. Certain compounds present in thrones, prickles, or spines can act as toxin or deterrent, making them less appealing for herbivores to feed on them (Halpern et al., 2007). Changes in temperature and other environmental factors can influence the production and concentration of these chemicals, potentially leading to modification in the level of plant defense.

2.3 Modification in Bark and Periderm:

Climate change can also lead to modification in the bark and periderm of plants. The periderm is the outer protective layer of the plants, including the cork cambium, cork cells, and phelloderm. These modifications occur due to the changing environmental conditions (Teixeira, 2022). As temperature rise and the drought conditions increase, plants may develop thicker bark to protect themselves from desiccation and excess heat (Marchin et al., 2022). Thicker bark provides insulation and reduces water loss through transpiration. Climate change can stimulate the cork cambium to produce more cork cells, leading to increase in the thickness of the periderm. This can enhance the plants resistance to environmental stress such as heat, fire and herbivory. Change in temperature and moisture level can cause variations in the composition of the periderm.

2.4 Conclusion:

Morphological changes in plants in response to insect pests represent a fascinating and intricate facet of plant-insect interactions. These changes, driven by a plant's natural defense mechanisms, have evolved over millions of years to help plant withstand the pressures of herbivory. From altering leaf structures and producing secondary metabolites to attracting beneficial insects and enhancing root defenses, plants have developed a diverse array of strategies to cope with insect pests. Understanding these morphological changes is crucial not only for advancing our knowledge of plant biology but also for developing sustainable pest management strategies in agriculture. Furthermore, ongoing research in this field continues to uncover the intricacies of plant-insect interactions, shedding light on the molecular and genetic mechanisms underlying these morphological changes.

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