Design for Biosecurity

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Lecture 3

Understanding Novel Weapon Hypothesis and Innovative Measures to avoid Allelopathic Interferences

Welcome, everyone. In our last session, I introduced you to the concept of allelochemicals and concluded by classifying 14 distinct groups of allelochemicals that are currently recognized. One critical point I emphasized was the role these chemicals play in determining the success or failure of invasive species, as well as the impact on crops or other specific life forms. Essentially, the triumph or downfall of these entities often hinges on specific chemical interactions.

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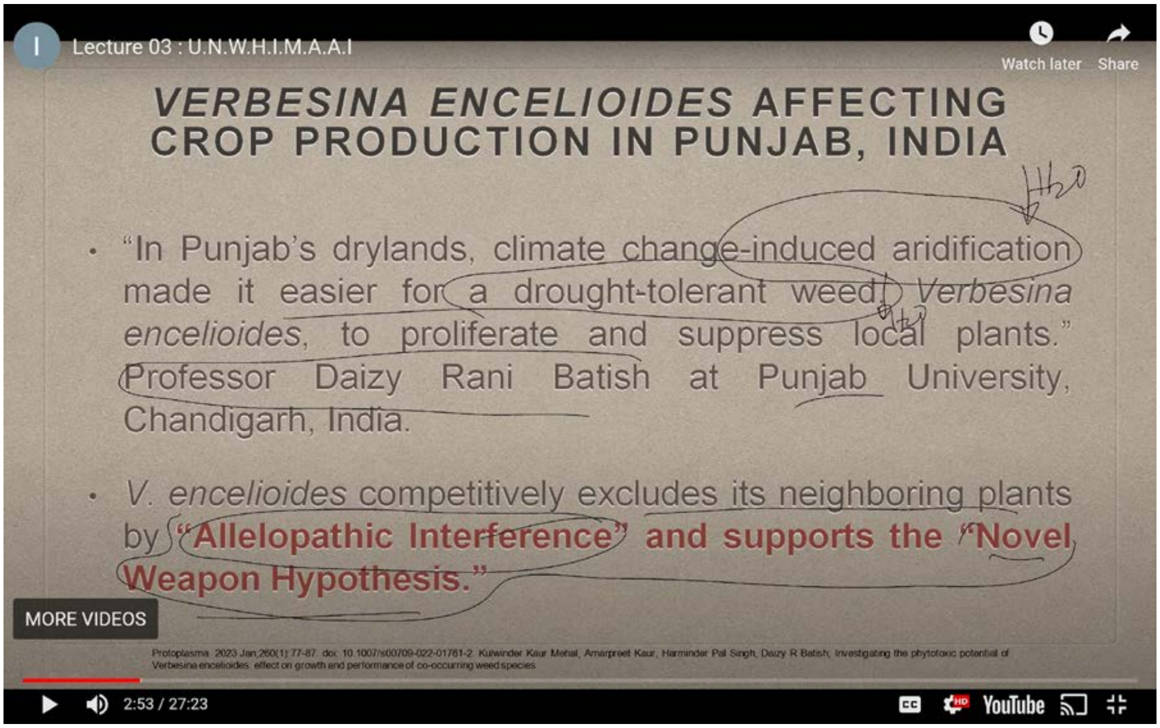

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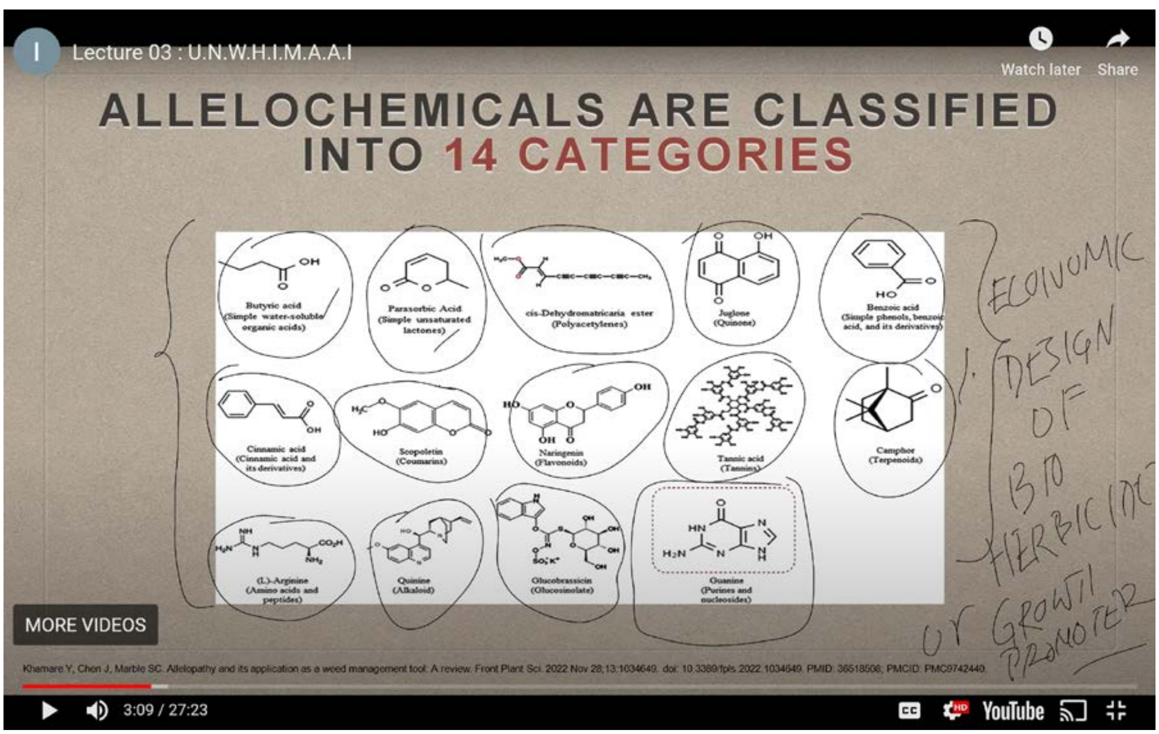

Today, we will delve into these chemical factors that contribute to the dominance of one species over another. Understanding these interactions is crucial as it allows us to devise strategies and develop sensory devices to counteract the pervasive threat of biological invasion.

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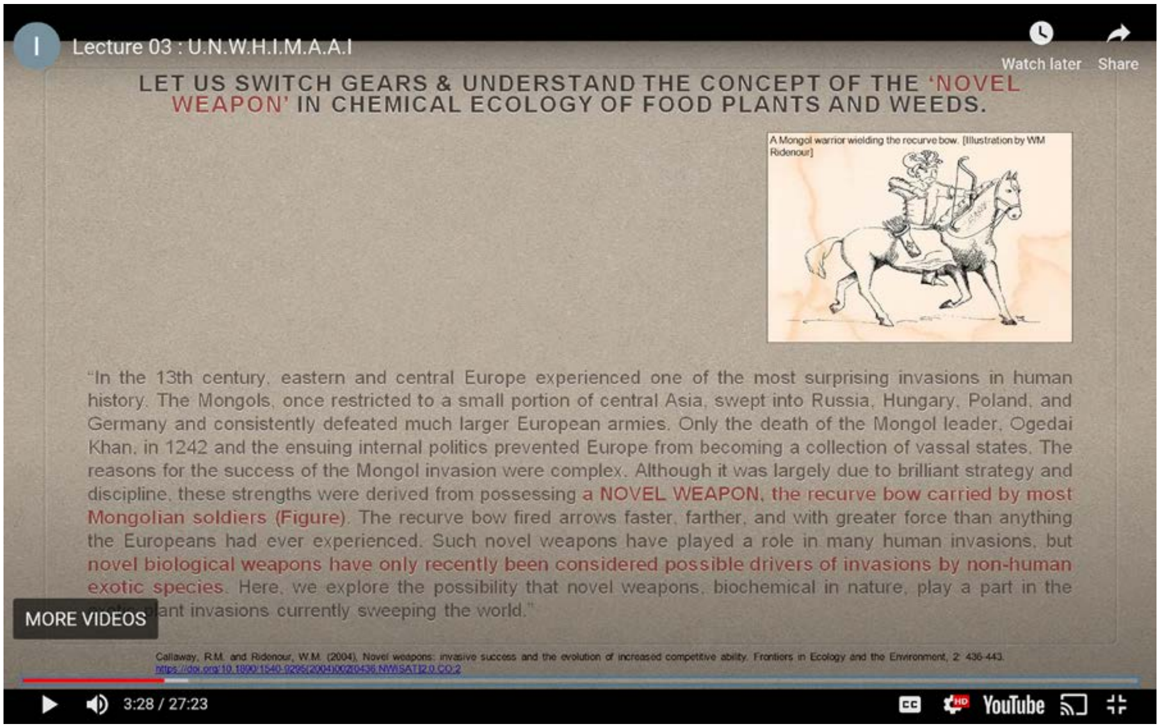

Let’s return to our slides. If you observe the slide depicting the global spread of Verbesina encelioides, you’ll notice something intriguing: the species appears to originate from a specific location, yet it has managed to spread across the globe. This raises an interesting question, how do a small number of seeds manage to proliferate so widely? For instance, consider a scenario where a limited quantity of seeds from Region A is introduced to Region B, either through animal activity, human intervention, or another means.

How do these few seeds manage to compete with an already established and significantly larger population? In invasion, it's not a vast army that arrives, but rather a small, seemingly insignificant force that ultimately overtakes. This phenomenon has puzzled evolutionary biologists, particularly those focused on invasion theories.

In this context, I previously introduced the novel weapon hypothesis, which we will revisit today. The key points, highlighted in red on the slide, include allelopathic interference, a concept we've already discussed, that supports the novel weapon hypothesis. This theory is rooted in Dr. Bhatish's earlier work. As we review the chemical interactions, remember the 14 chemical groups mentioned in our last session, with a particular emphasis on the guanine derivatives, which we will explore in greater detail today.

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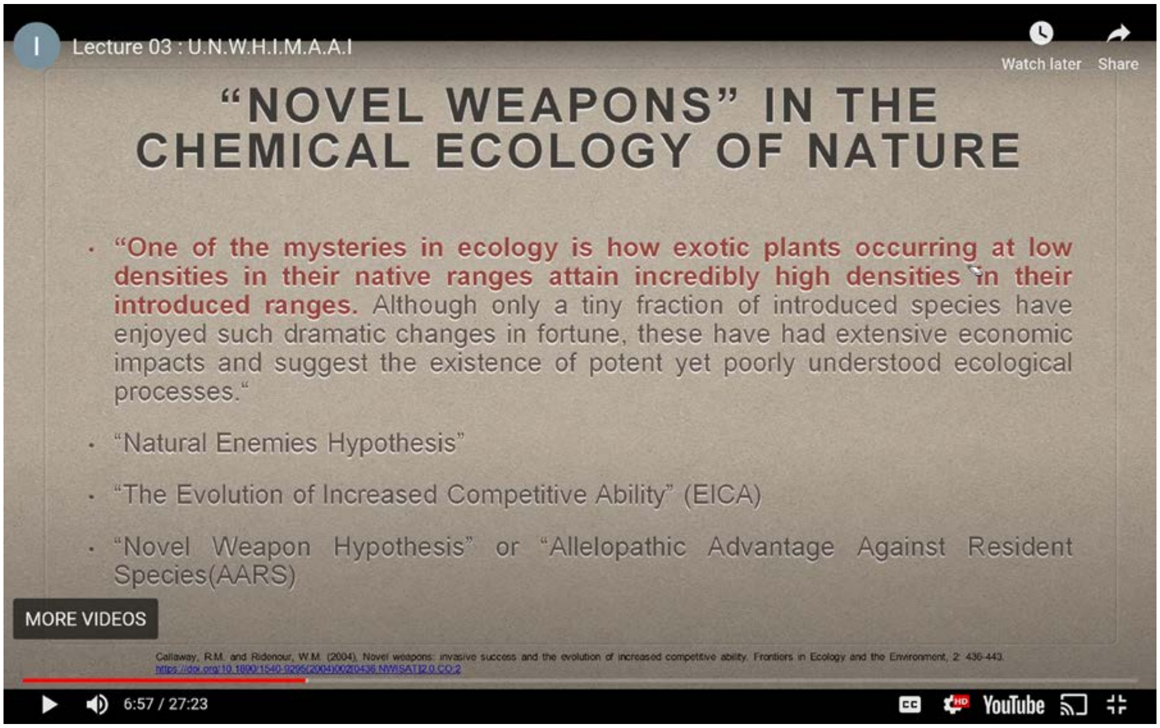

Let's delve into the concept of the novel weapon hypothesis. To illustrate this idea before we dive into the details on the slide, consider the following scenario: imagine a species moving into a new region. This migration could occur through various means, whether via animals, insects, natural processes, human activity, or even through intentional introduction.

Now, what are the possible outcomes for this species? One possibility is that it competes with the native population over an extended period, 10 years, 20 years, perhaps even a century, before eventually establishing itself, or it may fail to establish and perish.

Alternatively, the species might develop a unique strategy that allows it to outmaneuver the existing large population.

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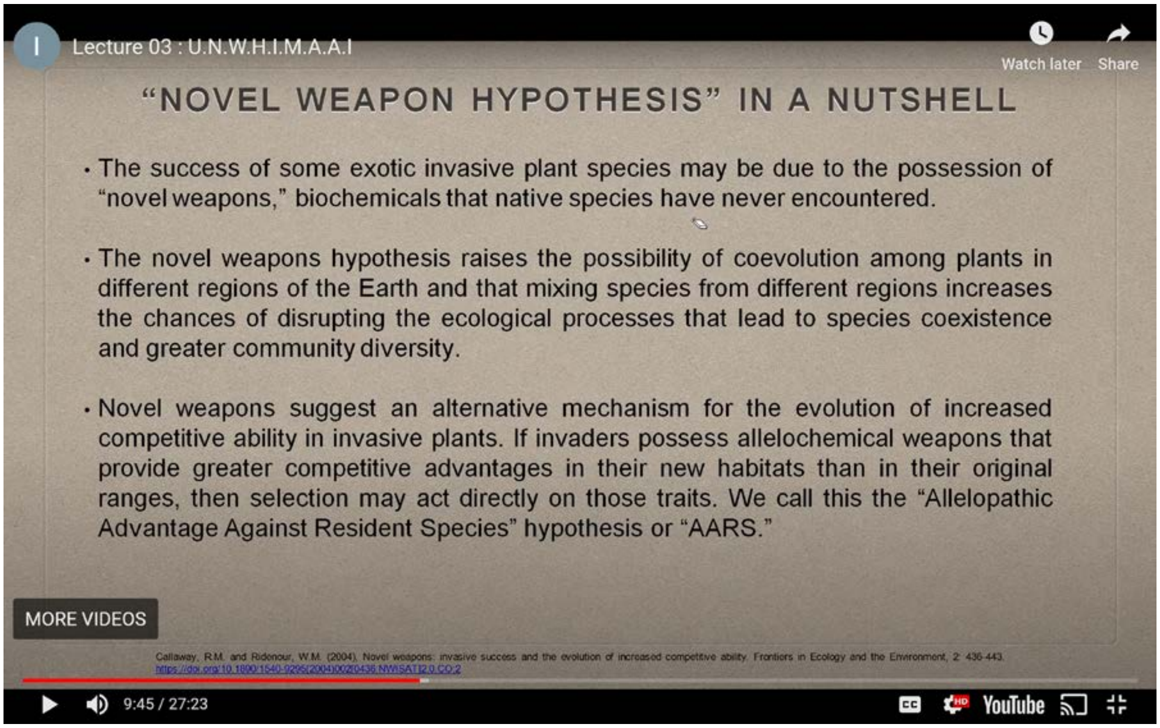

You could think of this scenario as a small army attempting to invade a vast country, but instead of relying on sheer numbers, this small force uses highly sophisticated instruments that the invaded country does not possess. In this metaphor, the small army of invaders has access to extraordinarily advanced weaponry, which gives them a distinct advantage.

To put this in a historical context, let's look at an example from the past. If you refer to the slide, you'll see a fascinating reference to the Mongol invasions of Europe during the 12th and 13th centuries. Despite being relatively small in number, the Mongols were extremely successful in their conquests. While it's true that the Mongols were exceptionally disciplined and skilled fighters, their success was also due to a specific piece of technology they possessed, the recurve bow.

At the time, the recurve bow was a revolutionary weapon. It allowed the Mongols to fire arrows faster, farther, and with greater force than anything the Europeans had ever encountered. This novel weapon gave them a significant advantage in battle. Throughout history, such innovative weapons have played crucial roles in human invasions, and it is now believed that novel biological weapons may similarly drive the invasion of non-human exotic species.

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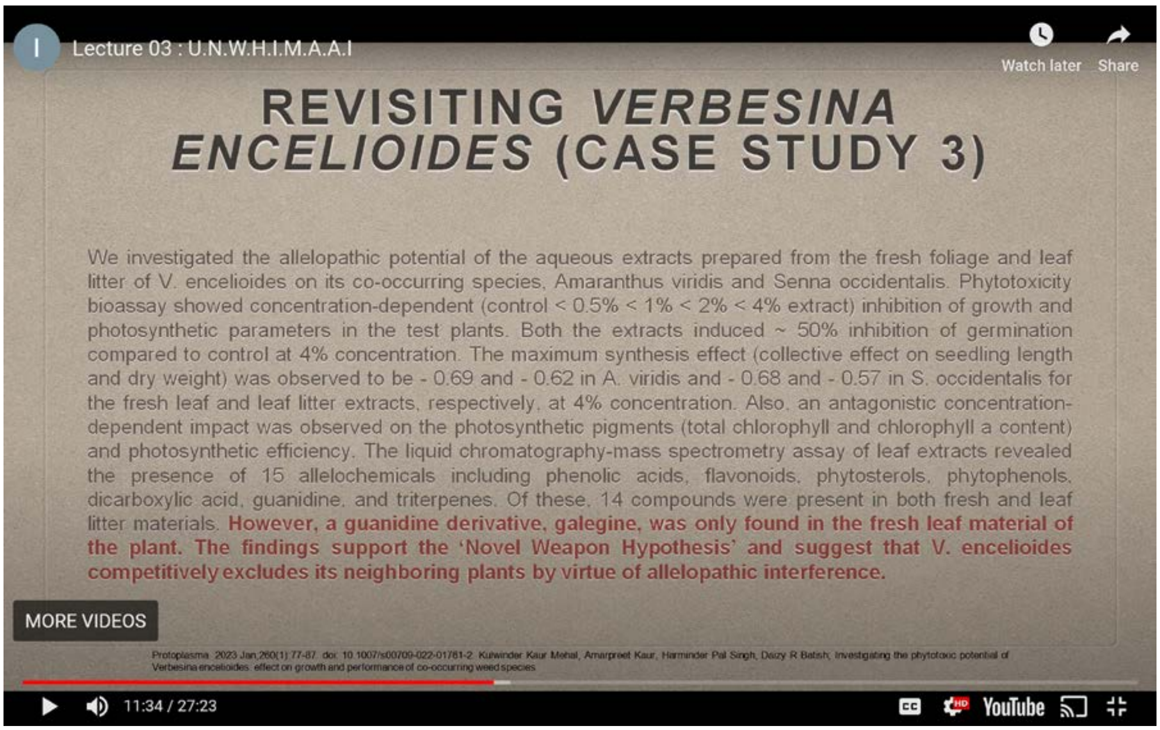

This brings us to the crux of the novel weapon hypothesis in evolutionary biology: the idea that possessing a novel weapon, in this case, a chemical one, can enable an invading species to outcompete native populations. But what exactly is this "novel weapon" in the context of chemical ecology?

As I mentioned earlier, one of the great mysteries in ecology is how exotic plants, which are often found in low densities in their native ranges, can suddenly achieve incredibly high densities when introduced to new regions. This phenomenon was highlighted when I showed you the global spread of a particular species. How can a small number of individuals spread so effectively and completely invade these ecosystems?

In trying to understand this, several hypotheses have been proposed, one of which is the natural enemy hypothesis.

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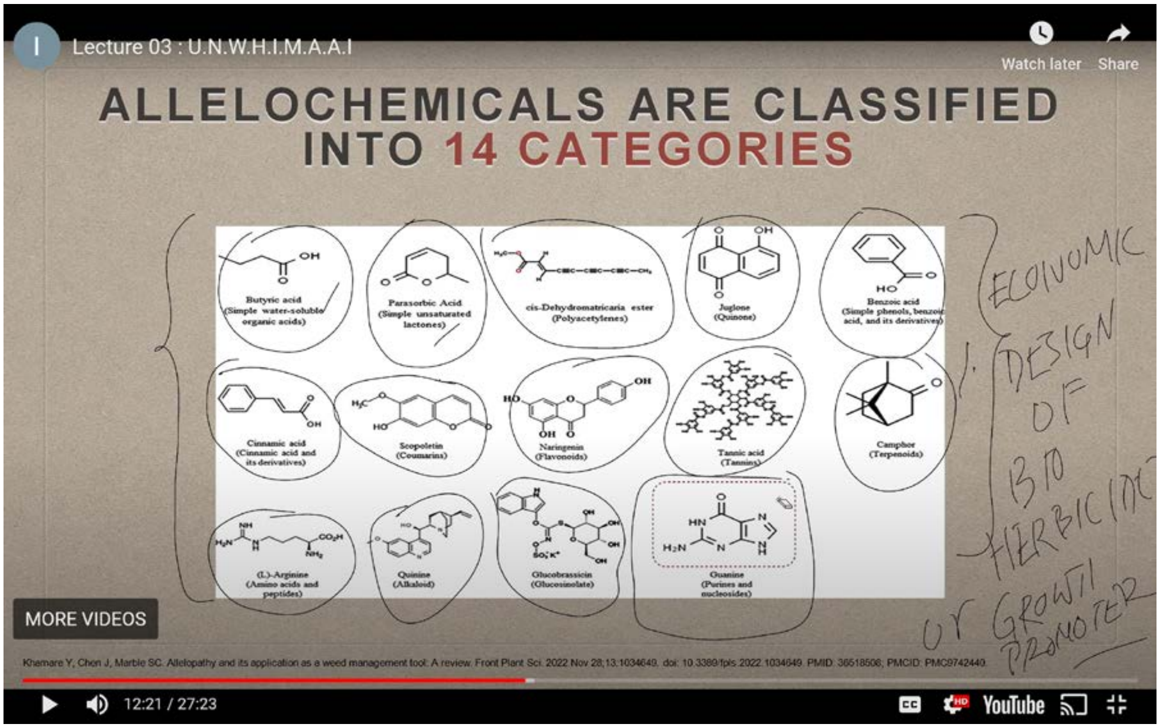

Let's delve into some fascinating concepts that are central to understanding plant invasions, starting with the notion of natural enemies. These are organisms that exist in a different biogeographic region but somehow become adversaries to plants from another area. This raises an intriguing question: how can a plant from one geographic region have natural enemies in another?

This leads us to another concept, the evolution of increased competitive ability. This idea suggests that some plants develop superior competitive abilities over time. However, whether we're discussing natural enemies or competitive ability, there must be a tangible, physical basis for these theories to hold true. Specifically, there must be a chemo-evolutionary advantage, some form of chemical cue that drives these interactions. Without this, it becomes challenging to substantiate such claims. This is precisely where our course aims to inspire you: to seek out the chemical signatures, the molecules that validate these hypotheses.

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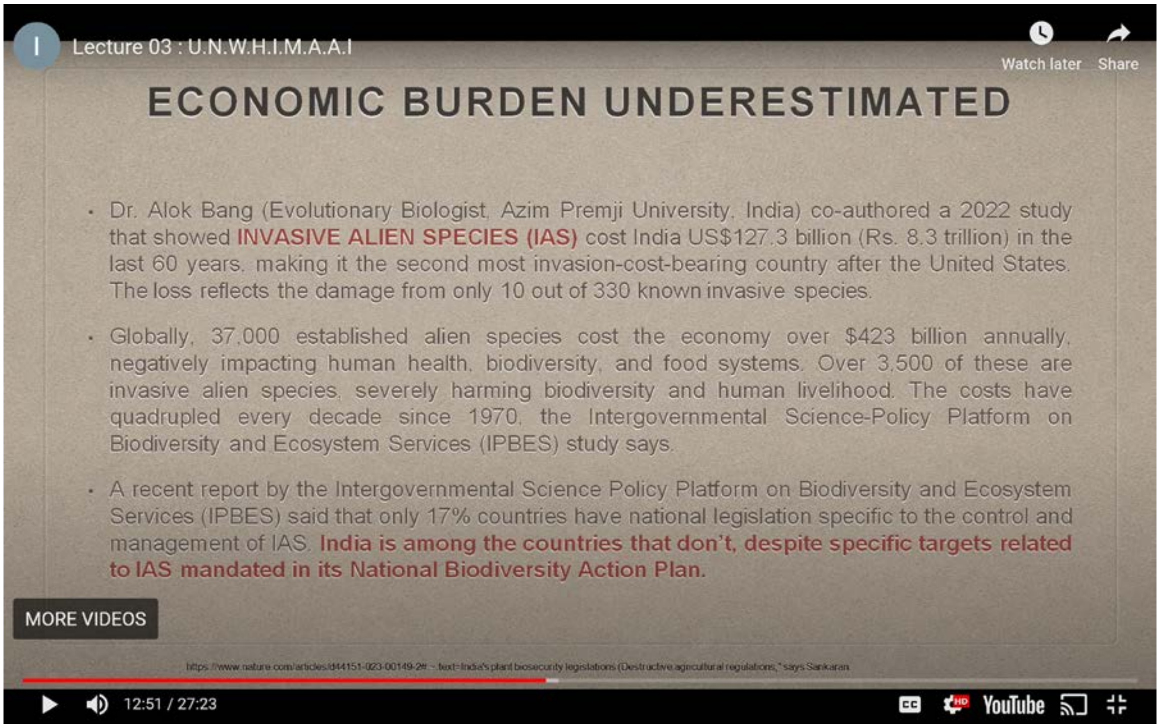

Now, let's turn our attention to the third concept: the novel weapon hypothesis, or allelopathic advantage against resident species (AARS). This hypothesis is particularly intriguing. Imagine an invasive plant species entering a new biogeographic region. This plant begins to secrete allelochemicals, compounds that the native plants in that region have never encountered. These allelochemicals can act as growth inhibitors or trigger inflammatory responses in the host plants. As a result, the invasive plant may stunt the growth or even cause the death of the surrounding native plants.

In essence, the novel weapon hypothesis suggests that the success of certain exotic invasive plant species may be attributed to their possession of these novel biochemical weapons, compounds that the native species have never been exposed to and therefore cannot defend against. This hypothesis also raises the possibility of co-evolution among plants from different regions of the world. Pay close attention to this idea: introducing species from one region into another can disrupt the ecological balance and the processes that once allowed for species coexistence and maintained high levels of community diversity.

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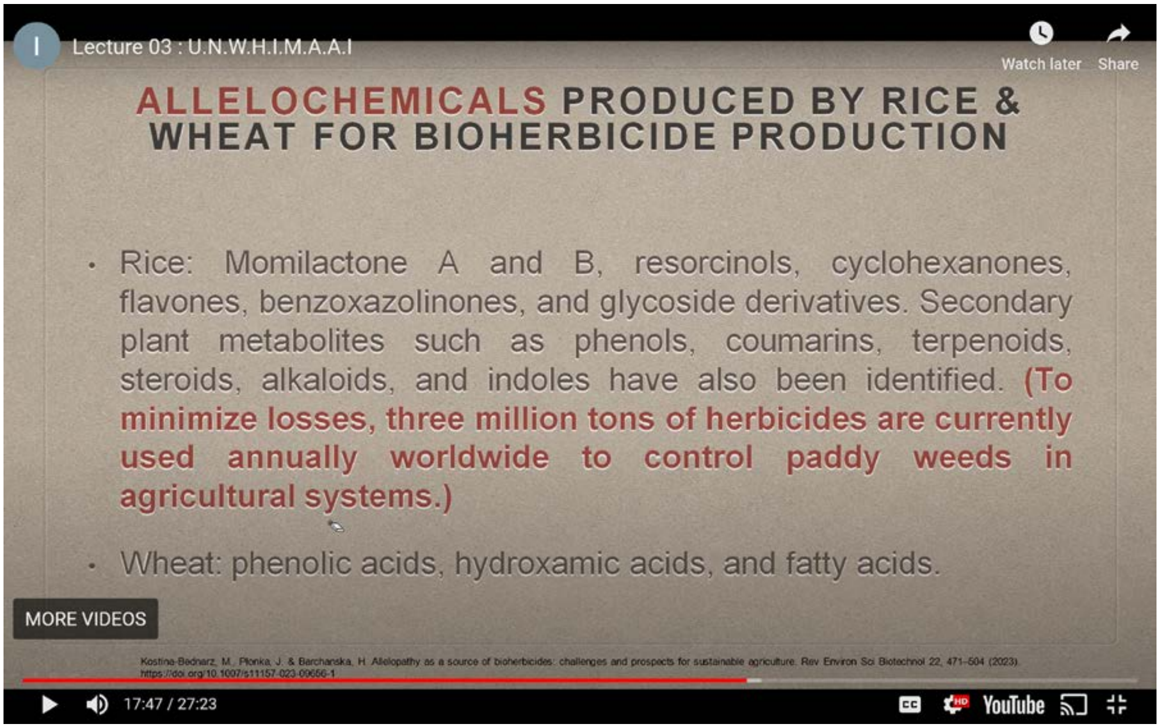

Moreover, the novel weapon hypothesis offers an alternative explanation for how invasive plants may develop increased competitive abilities. This concept challenges us to consider how these biochemical weapons not only enable invasive species to thrive but also alter the evolutionary dynamics within ecosystems.

If an invader possesses allelochemical weapons that grant it a greater competitive advantage in its new habitat than in its original range, then natural selection may favor those specific traits. This phenomenon is known as the Allelopathic Advantage Against Resident Species (AARS) hypothesis.

Let’s now revisit the groundbreaking work of Professor Desira Nibatish on Verbesina encelioides. In one of her seminal papers, she beautifully illustrated how this particular weed managed to spread across the Indian subcontinent and into Australia. Her research team uncovered that these plants secrete specific allelochemicals, which are crucial to understanding their invasive success. As highlighted in the red-marked sections of her study, a particular guanidine derivative, galagine, was identified, but only in the fresh leaf material of the plant.

These findings provide strong support for the novel weapon hypothesis, suggesting that Verbesina can outcompete and exclude neighboring plants through allelopathic interference. This underscores the significance of a single compound from the plant's chemical arsenal. Now, referring back to the slide where I had drawn attention to a boxed section, this particular guanidine derivative is of paramount concern.

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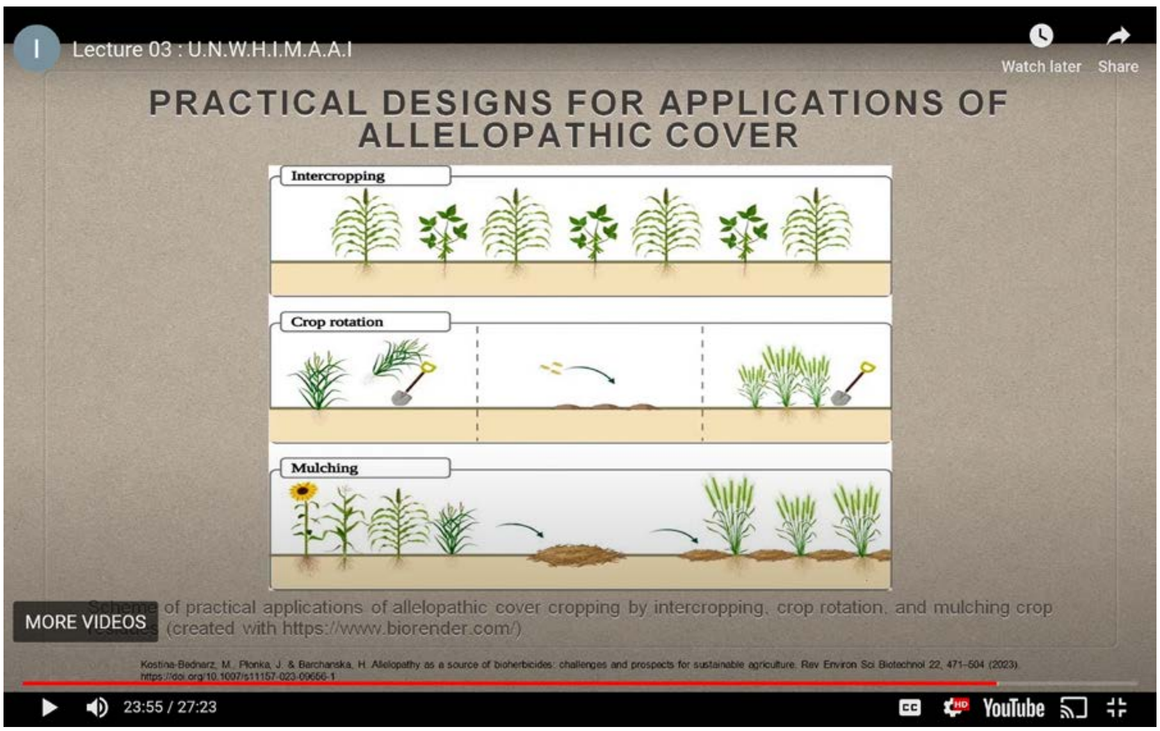

To develop an effective biochemical or biosensor, we must first understand the nature of these molecules and devise methods to detect them. Furthermore, if our goal is to control the spread of such invasive species, we need to explore ways to neutralize these allelochemicals through alternative means. We will discuss potential strategies for this as we progress.

Before diving further into the concept of allelochemicals, I want to highlight a related issue. If you now refer to the slide, you'll notice the underestimated economic burden caused by invasive species. A study conducted by Dr. Alok Bank, an evolutionary biologist from Azim Premji University, and co-authored in 2022, revealed that invasive alien species have cost India a staggering $127.3 billion over the past 60 years. This makes India the second-highest invasion cost-bearing country after the United States.

What’s particularly astonishing is that this figure represents the damage from only 10 out of the 330 known invasive species. We have yet to fully understand the impact of the remaining 320 species, which could lead to even more substantial economic losses. Globally, there are 37,000 established alien species, costing the global economy $423 billion annually, with devastating effects on human health, biodiversity, and food systems.

Consider a simple example: imagine mustard crops growing in a field. An invasive species with seeds that closely resemble mustard could mix with the crop, often inadvertently introduced by humans. This could compromise the quality of the mustard oil produced, introducing harmful chemicals into the oil that are detrimental to human health and consumption. The consequences of such invasions extend far beyond agriculture, affecting the entire ecosystem and economy.

This is one of the simplest examples I can provide. If you refer to the slide, you'll see that over 3,500 of these invasive alien species are causing severe harm to biodiversity and human livelihoods. The economic costs associated with these species have quadrupled every decade since 1970. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has been emphasizing this issue for decades.

In the specific case of India, the country lacks a strong legal framework to effectively prevent or mitigate the impact of invasive alien species, despite the specific targets mandated by the National Biodiversity Action Plan (NBAP). As a result, India does not have a robust platform to combat the spread of these invasive species, which include not only plants but possibly microbes and other organisms as well. These invaders are causing significant disruptions in our economy, with mostly detrimental effects.

This situation highlights the critical need to understand the fundamental concepts of biosecurity. Often, we overlook these factors when evaluating the productivity of crops and other agricultural products.

Now, let's shift gears back to the topic of allelochemicals. When discussing the novel weapon hypothesis, we often focus on the idea that alien species negatively impact native species by secreting unique chemicals. But the question arises: do native species also produce allelochemicals? Interestingly, the production of allelochemicals is not exclusive to weeds or alien species. Every plant has the capability to produce these compounds.

To illustrate, consider rice plants. They produce various allelochemicals, such as momilactone A and B, resorcinols, cyclohexanol, flavones, glycoside derivatives, and other secondary plant metabolites like phenols, coumarins, terpenoids, and steroids. These are all identified as allelochemicals. To minimize losses from weeds, approximately 3 million tons of chemical or synthetic herbicides are used annually worldwide in agricultural systems, particularly for paddy cultivation.

Now, imagine an alternative approach. If rice plants naturally produce these allelochemicals, could we harness them as natural herbicides? This is an invitation to think differently. Up until now, we've viewed allelochemicals as novel tools or weapons used by alien species to invade native populations. However, native species also have their own arsenal of allelochemicals, which serve as a natural defense mechanism.

Allow me to briefly digress from our main topic to touch on the history of herbicides, weedicides, and pesticides. This is a relatively recent development, primarily emerging in the 19th century. It was around the 1930s and 1940s that humankind began using these chemicals extensively in crop production.

Before the widespread use of synthetic chemical compounds, there was no such large-scale application of these substances in agriculture. This raises the question: how did plants defend themselves before these advancements? Weeds have existed since time immemorial, and plants had to find ways to survive.

In a scenario from, say, 100 years ago, before the advent of fertilizers, plants had to develop stronger immune profiles to secure nutrients from the soil. For instance, rice and wheat plants produced more allelochemicals as a defense mechanism against weeds growing around them. However, the Green Revolution, marked by the discovery of the Haber-Bosch process and the availability of nitrogen fertilizers, potash, and phosphorus, changed this dynamic. Plants began receiving nutrients readily from the soil, reducing their need to produce allelochemicals for defense. As a result, their natural ability to combat weeds diminished because they were no longer exposed to the same stressors as before the Green Revolution, or before the introduction of chemically synthesized herbicides, weedicides, and pesticides.

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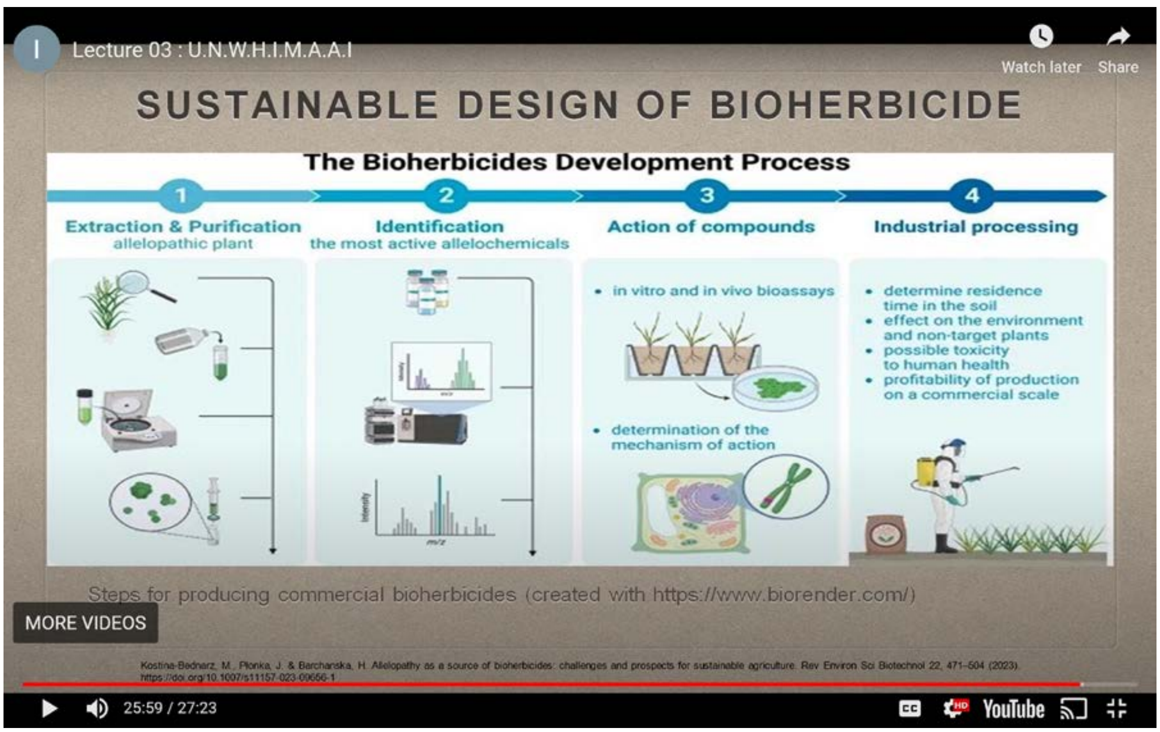

This leads to an intriguing thought: what if wild varieties of crops like rice, millet, and sorghum, when grown under harsher conditions without fertilizers, still possess higher levels of allelochemicals? These plants, untainted by the luxuries of modern agricultural practices, might retain their innate ability to fight off weeds, unlike their counterparts in the post-Green Revolution era, who have been fed an abundance of fertilizers.

This notion struck me while analyzing data on rice. If rice can produce such a significant amount of allelochemicals, and if we consider wheat, which produces phenolic acids, hydroxamic acids, and fatty acids, it suggests that each of these plants has a natural ability to generate herbicidal or weedicidal properties. These allelochemicals act as the plant's natural defense system.

Historically, before the development of chemical alternatives, we utilized non-chemical methods like intercropping. Intercropping involves planting two crops together, where one plant secretes substances that inhibit weed growth, thereby promoting the growth of the other plant, and vice versa. Another method is crop rotation, where you alternate between different crops, such as planting rice one season, followed by a short-term crop, then wheat, and so on. This practice continuously alters the soil's microbial environment, preventing weeds and invasive species from establishing themselves unless they are extremely adaptable. Essentially, crop rotation disrupts the soil microbiota, making it difficult for weeds to settle.

Mulching is another strategy where the soil surface is covered to prevent weed growth. These methods have been employed over the years to control weeds without chemicals.

Now, consider an opposite strategy. If we identify the specific chemicals causing harm to native plants and know that these native plants have the resilience to withstand them, we could explore new avenues for enhancing plant defense mechanisms.

If we could extract and purify these allelochemicals, we could then identify them using various techniques like mass spectrometry. Once identified, we could study their effects on different plants, and from there, move towards industrial processing. This approach would allow us to harness one of nature's most fundamental chemical tools to develop bioherbicides. In fact, even the allelochemicals produced by invasive species could be repurposed as bioherbicides in ecosystems where these invaders have caused destruction.

This concept demonstrates that substances with potentially detrimental effects can also be redirected towards positive applications. The key lies in how we manipulate the chemical properties of these compounds. But to do this effectively, we must first understand how nature has evolved its own survival strategies. By gaining this understanding, we can design sustainable strategies for creating bioherbicides.

In this discussion, we've covered two main concepts. First, we explored the novel weapon hypothesis, and then delved into the chemical nature of these novel weapons, specifically allelopathic chemicals, which can be classified into 14 different groups. We also examined a case study from Professor Desira Nibatish's work on a particular weed and the unique guanidine derivative it produces, another example of a novel weapon.

Additionally, we discussed the ability of crop plants like rice, wheat, sorghum, and millet to produce allelochemicals, and how we can capitalize on these compounds. We can even utilize the allelochemicals produced by invasive species to develop bioherbicides that naturally degrade and protect the soil from harmful effects. So, that is where we are closing this class. Thank you.