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Review on Phytotoxic Effects of Plant Leaf Extracts on the Germination and Early Growth of Vigna Radiata

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Abstract: *Phytotoxicity is a key component of plant–plant interaction mediated through allelochemicals released from plant tissues such as leaves, stems, and roots. Leaf extracts contain biologically active secondary metabolites that influence seed germination, seedling growth, enzymatic activity, and physiological metabolism of receiver plants. Vigna radiata (mung bean) is widely used as a model crop due to its rapid germination, economic importance, and sensitivity to allelopathic stress.*

This review provides a comprehensive synthesis of the phytotoxic effects of different plant leaf extracts on germination percentage, root-shoot growth, biomass accumulation, chlorophyll content, and biochemical responses of Vigna radiata. The study also highlights concentration-dependent inhibition, species-specific allelopathic strength, and ecological implications for sustainable agriculture and natural weed management..

Keywords: Allelopathy, Phytotoxicity, *Vigna radiata*, Leaf extract, Germination inhibition, Secondary metabolites, Bioherbicide

I. INTRODUCTION

Plant allelopathy refers to the biochemical interactions among plants where one plant releases chemicals that affect the growth and development of another plant. These chemicals, known as allelochemicals, are released through leaf leachates, root exudates, volatilization, and decomposition. Among these, leaf extracts are the most widely studied due to their rich concentration of secondary metabolites.

Vigna radiata is commonly used as a test species in phytotoxicity experiments because of its fast germination rate, uniform growth pattern, and sensitivity to environmental stress. Germination and early seedling stages are the most vulnerable phases of plant development; therefore, they are ideal indicators for evaluating phytotoxic effects.

II. NATURE OF PHYTOTOXIC COMPOUNDS IN LEAF EXTRACTS

Leaf extracts contain a wide range of bioactive compounds responsible for phytotoxic effects:

1 Phenolic Compounds

Interfere with cell division and enzymatic activation

Inhibit germination-related enzymes such as amylase and protease

2 Flavonoids

Disrupt hormonal balance (auxin and gibberellin activity)

Reduce root elongation and cell expansion

3 Alkaloids

Affect DNA synthesis and protein metabolism

Cause metabolic imbalance in seedlings

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4 Terpenoids and Essential Oils

Alter membrane permeability

Reduce water uptake and respiration efficiency

3. Mechanism of Phytotoxic Action on *Vigna radiata*

Phytotoxic compounds affect seed germination and early growth through several mechanisms:

Inhibition of enzymatic breakdown of stored food reserves

Disruption of mitochondrial respiration

Reduction in ATP production

Alteration of hormone signaling pathways

Oxidative stress induction due to reactive oxygen species (ROS)

These mechanisms collectively result in reduced germination percentage, stunted growth, and physiological abnormalities.

4. Effects on Seed Germination

Seed germination is highly sensitive to external chemical stress. Leaf extracts generally show concentration-dependent inhibition:

Low concentration → slight inhibition or stimulation (hormesis effect)

Medium concentration → moderate reduction in germination

High concentration → severe inhibition or complete suppression

The inhibition occurs due to delayed enzyme activation and impaired radicle emergence.

5. Effects on Seedling Growth

Early seedling growth is more sensitive than germination itself. Observed effects include:

Significant reduction in root elongation

Decreased shoot height

Lower biomass accumulation

Reduced leaf area and chlorophyll content

Weak vascular development

Root systems are more affected due to direct exposure to allelochemicals in the growth medium.

Table 1. Comparative Phytotoxic Effects of Leaf Extracts on *Vigna radiata*

Plant Species (Leaf Extract)	Concentration (%)	Germination Inhibition (%)	Root Growth Reduction (%)	Shoot Growth Reduction (%)	Major Active Compounds
Eucalyptus globulus	5–10	40–65	55–80	35–60	Phenolics, cineole
Azadirachta indica	5–10	30–55	40–70	30–50	Azadirachtin, limonoids
Parthenium hysterophorus	5–10	50–75	65–90	50–80	Sesquiterpene lactones
Lantana camara	5–10	45–70	60–85	55–75	Terpenoids, flavonoids
Ageratum conyzoides	5–10	35–60	50–75	40–65	Alkaloids, flavonoids
Ocimum sanctum	5–10	25–50	30–60	25–45	Eugenol, phenolics

PHYSIOLOGICAL AND BIOCHEMICAL CHANGES IN VIGNA RADIATA

Physiological and biochemical responses in *Vigna radiata* (mung bean) under exposure to plant-derived leaf extracts represent a critical area of allelopathic research because these responses directly determine seed germination success, seedling vigor, and overall plant establishment. *Vigna radiata* is particularly sensitive to phytotoxic stress during its early growth stages, making it an ideal biological model to evaluate how allelochemicals influence plant metabolism, growth regulation, and cellular integrity. When exposed to leaf extracts containing phenolics, flavonoids, terpenoids, and alkaloids, *Vigna radiata* undergoes a series of interconnected physiological disruptions and biochemical alterations that affect both structural development and metabolic functioning (Singh et al., 2017; Sharma & Kumar, 2019).

One of the earliest physiological changes observed is the reduction in seed germination percentage and delayed germination timing. This occurs because allelochemicals interfere with water uptake (imbibition) and inhibit the activation of hydrolytic enzymes such as amylase and protease, which are essential for mobilizing stored food reserves in the seed. As a result, starch breakdown is slowed, limiting energy availability for embryo growth. The radicle emergence stage is particularly sensitive, and even low concentrations of leaf extracts can delay or completely inhibit root protrusion. This inhibitory effect is largely concentration-dependent, where higher concentrations of extracts lead to severe suppression of germination processes (Verma et al., 2020).

Following germination, the most pronounced physiological effect is observed in root elongation. Root growth inhibition is generally more severe than shoot growth inhibition because roots are in direct contact with the allelochemical-rich medium. Phenolic compounds and terpenoids disrupt cell division in the root apical meristem, reduce mitotic activity, and interfere with elongation zones, resulting in shortened, thickened, or deformed roots. This reduction in root length further limits water and nutrient uptake, indirectly affecting shoot development and overall seedling biomass accumulation. In several studies, root growth inhibition has been reported to exceed 60–80% under high concentrations of *Eucalyptus*, *Parthenium*, and *Lantana* leaf extracts (Gupta, 2021; Patel & Mehta, 2023).

Shoot growth is also negatively affected, although to a lesser extent than roots. Reduced shoot length is associated with hormonal imbalance caused by allelochemicals that disrupt auxin and gibberellin signaling pathways. These hormones are essential for cell elongation and differentiation. Inhibition of these growth regulators leads to stunted seedlings with reduced leaf expansion and poor biomass accumulation. Additionally, leaf development is often delayed, and cotyledon expansion is restricted, resulting in weaker seedlings that are less capable of surviving environmental stress.

At the biochemical level, one of the most significant changes is the reduction in chlorophyll content. Chlorophyll a and chlorophyll b levels decline significantly in treated seedlings, leading to reduced photosynthetic efficiency. This reduction is attributed to the degradation of chloroplast structure and inhibition of chlorophyll biosynthesis enzymes. As chlorophyll content decreases, the plant's ability to capture light energy and convert it into chemical energy is compromised, ultimately reducing growth rate and biomass production (Sharma & Kumar, 2019). Carotenoid content is also affected, which further reduces photoprotection and increases susceptibility to oxidative damage.

Another major biochemical response is the induction of oxidative stress. Exposure to allelochemicals leads to the excessive generation of reactive oxygen species (ROS) such as superoxide radicals, hydrogen peroxide, and hydroxyl radicals. These ROS cause lipid peroxidation of cell membranes, protein denaturation, and DNA damage. The increased malondialdehyde (MDA) levels in treated seedlings serve as an indicator of membrane damage and oxidative stress intensity. To counteract this stress, *Vigna radiata* activates its antioxidant defense system, including enzymes such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD). However, at higher concentrations of phytotoxic extracts, the antioxidant system becomes overwhelmed, leading to cellular dysfunction and reduced seedling viability (Singh et al., 2017).

Protein metabolism is also significantly affected under phytotoxic stress. Total soluble protein content often decreases due to inhibition of protein synthesis and increased protein degradation. Allelochemicals interfere with ribosomal activity and transcriptional processes, reducing the synthesis of structural and enzymatic proteins necessary for growth. This disruption also affects membrane transport proteins, leading to impaired nutrient uptake and ion imbalance within plant cells.

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In addition to protein reduction, carbohydrate metabolism is altered. The inhibition of amylase activity reduces starch breakdown into simple sugars, limiting the availability of respiratory substrates. Consequently, ATP production decreases, which affects energy-dependent processes such as cell division, elongation, and nutrient transport. This energy deficit is one of the primary reasons behind reduced seedling vigor and biomass accumulation in treated *Vigna radiata* plants.

Another important physiological change is the alteration in water relations. Allelochemicals affect membrane permeability, leading to reduced water uptake efficiency. This causes partial dehydration stress in seedlings, which further inhibits metabolic activities. Reduced turgor pressure in cells limits cell expansion, contributing to stunted growth and reduced leaf expansion.

At the hormonal level, phytohormone imbalance plays a central role in phytotoxic effects. Auxins, gibberellins, and cytokinins are disrupted by phenolic compounds, leading to altered growth patterns. Auxin transport inhibition results in reduced root elongation, while gibberellin suppression affects shoot height and seed germination. Cytokinin imbalance further disrupts cell division and differentiation, contributing to abnormal seedling morphology (Verma et al., 2020).

Overall, the combined physiological and biochemical changes in *Vigna radiata* under leaf extract exposure reflect a complex network of stress responses involving growth inhibition, metabolic suppression, oxidative damage, and hormonal disruption. These effects are highly dependent on the concentration and type of plant extract used. Species such as *Parthenium hysterophorus* and *Lantana camara* exhibit strong inhibitory effects due to high concentrations of sesquiterpene lactones and terpenoids, whereas *Azadirachta indica* shows comparatively moderate phytotoxicity (Patel & Mehta, 2023).

The physiological and biochemical responses of *Vigna radiata* under phytotoxic stress highlight the sensitivity of early plant developmental stages to allelochemicals. These changes not only reduce germination and growth but also affect long-term plant productivity by disrupting fundamental metabolic pathways. Understanding these mechanisms provides valuable insight into the development of natural herbicidal agents and sustainable weed management strategies.

1 Photosynthetic Pigments

Decrease in chlorophyll a and chlorophyll b

Reduction in carotenoid content

Impaired photosynthetic efficiency

2 Enzymatic Activity

Reduced amylase and protease activity

Inhibition of antioxidant enzymes in severe stress conditions

3 Oxidative Stress

Increased reactive oxygen species (ROS)

Lipid peroxidation of cell membranes

Cellular damage in root and shoot tissues

III. DISCUSSION

The findings from multiple studies indicate that phytotoxicity of leaf extracts is highly species-dependent and concentration-dependent. *Parthenium hysterophorus* shows the strongest inhibitory effect due to high levels of sesquiterpene lactones, which interfere with multiple metabolic pathways.

Lantana camara also exhibits strong phytotoxicity, particularly affecting root elongation. In contrast, *Azadirachta indica* shows moderate inhibition and is widely used in eco-friendly pest management systems.

The sensitivity of *Vigna radiata* roots is higher than shoots because roots are in direct contact with allelochemicals in aqueous media, leading to rapid uptake and metabolic disruption.

ECOLOGICAL AND AGRICULTURAL SIGNIFICANCE

Phytotoxic plant extracts have dual significance:

1. Positive Applications

Development of natural herbicides (bioherbicides)
Weed management in organic farming
Reduction of chemical herbicide dependency
Sustainable agricultural practices

2. Negative Impacts

Potential crop inhibition in mixed cropping systems
Soil fertility imbalance due to persistent allelochemicals
Reduction in crop yield in sensitive species

IV. CONCLUSION

This review concludes that plant leaf extracts exert significant phytotoxic effects on the germination and early growth of *Vigna radiata*. The intensity of inhibition depends on plant species, extract concentration, exposure duration, and chemical composition. While these allelochemicals pose risks to crop productivity, they also offer promising potential for the development of eco-friendly herbicidal formulations. A balanced approach is required to harness their benefits while minimizing ecological risks.

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