Impact of Plastic Pollution on Orchid-Mycorrhizal Interactions and Habitat Integrity in the Western Ghats of Wayanad

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Received:- 11 May 2025/ Revised:- 18 May 2025/ Accepted:- 27 May 2025/ Published: 05-06-2025

***Abstract*—** *Plastic pollution, though traditionally examined within aquatic and urban contexts, is now recognized as a rising terrestrial threat to sensitive forest ecosystems. In the biodiversity-rich montane forests of the Western Ghats, India, particularly Wayanad, plastic waste is disrupting ecological processes vital to the survival of endemic wild orchid species. This five-year field-based study explores the influence of accumulated plastic debris on orchid microhabitats, with an emphasis on its interference in orchid–mycorrhizal symbioses—critical relationships required for orchid seed germination, nutrient absorption, and long-term survival.*

Systematic sampling across orchid-dense forest zones revealed that discarded polybags, plastic wrappers, and synthetic packaging materials significantly altered substrate conditions. Soil analyses demonstrated reduced water percolation, compromised aeration, and chemical leachates from plastics that skewed soil pH. Most importantly, microbial assays revealed a marked decline in viable mycorrhizal spore density in plastic-contaminated plots, correlating with poor orchid seedling emergence and higher mortality rates.

Microscopic observation of orchid root systems showed weakened or absent mycorrhizal colonization in areas of plastic accumulation, suggesting a direct impact on symbiotic functionality. Orchids growing in plastic-free control zones showed stronger pseudobulb formation, better chlorophyll content, and a higher rate of root-fungal interaction. These disruptions are of particular concern as many orchid species in the Western Ghats exhibit narrow habitat specificity and obligate fungal dependence.

The study concludes that plastic waste, even in minimal quantities, can have cascading ecological consequences on fragile plant–fungus networks that underpin forest resilience. Given the ecological importance and conservation priority of orchids, the findings call for immediate intervention through habitat-specific plastic exclusion strategies, community-led waste clean-ups, and the incorporation of ***mycorrhizal inoculation protocols*** *in orchid restoration projects.*

By demonstrating a previously underexplored linkage between plastic pollution and subterranean symbiotic processes, this research highlights the urgent need to integrate plastic mitigation into broader biodiversity conservation frameworks in forest ecosystems.

Keywords*— *Plastic waste, epiphytic orchids, mycorrhizal fungi, soil health, habitat degradation, Western Ghats, Wayanad, orchid germination, forest pollution, biodiversity conservation.

I. INTRODUCTION

The Western Ghats, recognized as a UNESCO World Heritage Site and one of the world's top eight biodiversity hotspots, is a sanctuary for over 300 species of orchids, many of which are endemic, rare, and highly habitat-specific. These orchids, especially epiphytic and lithophytic types, are not only ecologically sensitive but also dependent on symbiotic associations with mycorrhizal fungi for their germination and early growth.

Mycorrhizal fungi play an indispensable role in facilitating nutrient exchange, moisture retention, and protection from pathogens, especially in nutrient-poor tropical soils. Orchid seeds, being dust-like and devoid of endosperm, require immediate fungal colonization to initiate germination—a process called *mycoheterotrophy*.

In the past decade, **plastic pollution has emerged as a silent but significant disruptor** in forest-edge ecosystems of Wayanad, Kerala. Due to increasing tourism, agricultural intensification, and unregulated waste disposal, plastic debris such as polybags, food wrappers, and multilayered packaging is frequently found in and around forest trails, riparian zones, and hill slopes. While the macro-level impacts of plastic on fauna and waterways have been widely reported, the **micro-ecological effects on orchid habitats and soil fungal networks remain under-investigated**.

According to research conducted over the past five years in Wayanad's tropical montane forests, plastic pollution is now recognized as a **contributing factor to the degradation of orchid-rich habitats**. Field observations and soil assessments have revealed that **plastic residues obstruct water percolation**, alter the moisture balance in orchid microhabitats, and **create localized soil compaction,** thereby impeding root respiration and microbial activity.

Moreover, chemical leachates from degraded plastics—especially phthalates and bisphenol compounds—are toxic to soil biota. These toxins compromise **mycorrhizal diversity and infectivity,** ultimately inhibiting orchid seed germination and survival. The **absence or decline of viable mycorrhizal partners** reduces reproductive success and limits natural regeneration in the wild.

TABLE 1
IMPACTS OF PLASTIC POLLUTION ON ORCHID–MYCORRHIZAL SYMBIOSIS

Pollution Factor	Direct Impact	Ecological Consequence
Polybags & multilayered plastic	Blocks water infiltration in soil	Reduces fungal growth and root colonization
Plastic leachates (phthalates, BPA)	Alters pH and kills beneficial microbes	Decline in mycorrhizal fungi and seed-fungal associations
Soil surface coverage	Inhibits leaf litter decomposition	Loss of organic matter and fungal substrate
Microplastic accumulation	Disrupts fine root-soil contact	Impairs nutrient uptake and seed germination

II. OBSERVATIONS AND FINDINGS

2.1 Soil and Plastic Interactions:

Plastic debris alters the physical and chemical composition of the soil in several ways:

- Prevents natural **water percolation**, leading to **surface runoff** and **desiccation** of upper soil layers.
- **Leaches additives and toxins** (e.g., phthalates, BPA) into the soil, affecting microbial health.
- Creates **anaerobic pockets** and changes soil porosity, suppressing the growth of beneficial fungal hyphae.

Long-term monitoring of orchid-rich microhabitats revealed that soils contaminated with visible or embedded plastic showed a **36% reduction in fungal spore density**, as compared to adjacent plastic-free zones. The **mycorrhizal colonization rate in orchid roots dropped by over 40%** in these sites.

2.2 Orchid Seed Germination and Establishment:

Orchid seeds sown ex situ in plastic-contaminated soil samples showed significantly **lower germination rates** (<15%) than those in natural or compost-enriched soils (>55%). Seedlings in contaminated samples also exhibited stunted growth and chlorosis, often failing to survive beyond 3–4 weeks.

Field plots with higher plastic litter also showed **limited recruitment of wild orchid seedlings**, especially among species such as *Habenaria digitata*, *Bulbophyllum fimbriatum*, and *Dendrobium herbaceum*—all of which are known to rely on specific mycorrhizal partners.

2.3 Microclimatic Impact and Forest Floor Integrity:

Plastic debris traps heat and disrupts **leaf litter decomposition**, thereby reducing the organic content and microbial activity in the soil. The **soil temperature under plastic mulch was found to be 2.4°C higher** than surrounding areas, while soil moisture content was reduced by nearly 30% during summer months.

Such thermal and hydrological alterations negatively affect both orchid roots and the fungal colonies they depend on.

TABLE 2
DATA SUMMARY TABLE

Parameter	Plastic-Contaminated Sites	Plastic-Free Control Sites	% Change
Mycorrhizal Spore Density (per gram soil)	620	970	↓ 36%
Orchid Seed Germination Rate	14.8%	56.3%	↓ 74%
Soil Moisture Content (avg. summer %)	18.5%	26.4%	↓ 29.9%
Soil Temperature (avg. surface °C)	33.1°C	30.7°C	↑ +2.4°C
Orchid Seedling Survival After 4 Weeks	22%	63%	↓ 65%

III. MATERIALS AND METHODS

3.1 Study Area:

This study was conducted in ecologically diverse forest patches of Wayanad district, Kerala (800–1400 m elevation), situated within the core zone of the Western Ghats biodiversity hotspot. Three major habitat types were represented: **moist deciduous forests, semi-evergreen tracts,** and **shola-grassland transition zones**. These microhabitats support a high density of epiphytic orchids and associated mycorrhizal fungi, which are sensitive to edaphic and anthropogenic changes. Forest edges and interior zones near popular trekking trails and settlements were chosen to capture a range of plastic contamination gradients.

3.2 Sampling Design:

Twenty naturally occurring orchid-bearing plots were selected and categorized into three levels of plastic contamination based on visible plastic waste density:

- **Low contamination**: <1 plastic item/m² (mostly interior undisturbed forest)
- **Moderate contamination**: 1–3 items/m² (edge zones)
- **High contamination**: >3 items/m² (disturbed tourist trails and forest-fringe zones)

At each plot, **paired sampling** was performed:

- **Target zone**: orchid root zone (epiphytic or lithophytic substrates)
- **Control zone**: 2 meters away from orchid presence, free from visible roots

Key orchid species monitored included *Rhynchostylis retusa*, *Dendrobium herbaceum*, and *Coelogyne nervosa*. Parameters measured included **germination success, root colonization**, and surrounding **soil quality.**

3.3 Laboratory Analyses:

Multiple analyses were carried out to assess the influence of plastic contamination on orchid-mycorrhizal dynamics:

- **Soil Parameters**: Soil pH, water-holding capacity, and organic matter content were analyzed using standard protocols.
- **Microplastic Residue**: Soil and substrate samples were screened for microplastic residues using **Fourier-Transform Infrared (FTIR) Spectroscopy**, which revealed the presence of polyethylene and polypropylene fragments.
- **Mycorrhizal Assessment**:
    - Fungal spore densities were quantified using wet sieving and decanting methods.
    - *In vitro* orchid seed germination trials were conducted with isolated native mycorrhizal fungi on semi-solid OMA (Orchid Mycorrhizal Agar).
    - Microscopic analysis of fine roots was used to quantify **mycorrhizal colonization percentage** in orchid root cortex cells.

TABLE 3
IMPACT OF PLASTIC LOAD ON ORCHID-MYCORRHIZAL ASSOCIATIONS

Contamination Level	Avg. Fungal Spore Density (/g)	Mycorrhizal Colonization (%)	Seed Germination Success (%)	Organic Matter (%)
Low (<1 item/m²)	210 ± 15	78.6 ± 4.2	65.3 ± 3.5	6.2 ± 0.4
Moderate (1–3 items/m²)	120 ± 12	42.7 ± 5.1	28.5 ± 2.8	4.1 ± 0.5
High (>3 items/m²)	45 ± 8	17.3 ± 2.3	9.6 ± 1.9	2.2 ± 0.3

IV. RESULTS

- Plastic-affected plots exhibited 35–50% lower organic matter content, likely due to physical blockage of litter decomposition and leaching of plastic-associated chemicals.
- Soil pH shifted towards acidic in high-contamination zones (pH 4.7–5.2), unfavorable for native orchid fungi.
- FTIR confirmed the presence of polyethylene and polystyrene microplastics in rhizosphere soils.
- Mycorrhizal colonization dropped by up to 62% in high-contamination areas, with corresponding reductions in orchid seedling survival.
- Co-culture experiments showed a 70% decrease in seed germination success when mycorrhizal fungi were sourced from plastic-contaminated soils.

TABLE 4
EFFECTS OF MICROPLASTIC CONTAMINATION ON SOIL AND ORCHID SYMBIOSIS

Contamination Level	Avg. Mycorrhizal Colonization (%)	Germination Rate (%)	Organic Matter (%)
Low	85	68	6.8
Moderate	51	38	4.3
High	32	20	2.6

V. DISCUSSION

The study demonstrates that plastic pollution is not merely a waste management issue, but a serious ecological stressor for fragile ecosystems such as the Western Ghats. The orchid-mycorrhizal relationship, which is critical to orchid biodiversity, is highly sensitive to changes in soil chemistry, temperature, and biological composition—all of which are disrupted by plastic accumulation.

Furthermore, microplastic particles, which result from the fragmentation of larger plastic waste, have been observed to bind with soil minerals, reducing nutrient exchange efficiency and altering fungal community structure. The long-term implication is a gradual collapse of below-ground biodiversity, which precedes the loss of visible plant life.

Orchid species, being slow-growing and microhabitat-specific, are unable to migrate or adapt rapidly. The result is a decline in natural recruitment and regeneration, pushing several native orchid populations toward local extinction.

VI. CONSERVATION IMPLICATIONS

To protect orchid-rich zones in Wayanad and the broader Western Ghats, a multi-pronged strategy is essential:

- Ban single-use plastics in eco-sensitive zones and forest-adjacent villages.
- Conduct forest-edge plastic clean-up drives involving local communities and tourists.
- Monitor soil health and mycorrhizal density through participatory citizen science programs.

- Promote orchid ex-situ conservation in plastic-free nurseries with fungal inoculation.
- Educate stakeholders—forest officials, farmers, trekkers—on the hidden ecological impacts of plastic.

VII. CONCLUSION

Plastic pollution is not only a visual or aquatic menace but also a critical ecological disruptor in sensitive terrestrial ecosystems. In Wayanad's orchid-rich forests, it undermines the very foundations of plant-fungal symbiosis and long-term habitat integrity.

Conservation strategies must now integrate plastic mitigation as a core ecological priority**.** Suggested interventions include:

- Establishing plastic exclusion zones around orchid-rich habitats
- Conducting mycorrhizal restoration using lab-grown inoculants
- Launching community awareness programs on plastic-free pilgrimage and trekking
- Promoting research on microplastic impacts on soil microbial networks

Protecting orchids is no longer just about preserving beauty—it's about safeguarding forest functionality against the creeping crisis of synthetic pollution.

ACKNOWLEDGEMENTS

We acknowledge the support of **Eunoia Orchid Garden, Ambalavayal**, for field assistance and access to ex situ propagation facilities and local community members for participating in habitat monitoring.

REFERENCES

[1] Arditti, J. (1992). *Fundamentals of Orchid Biology*. John Wiley & Sons.
[2] Batty, A. L., et al. (2002). Orchid conservation and mycorrhizal associations. *Selbyana*, 23(1), 64–70.
[3] Benzing, D. H. (1990). *Vascular Epiphytes: General Biology and Related Biota*. Cambridge University Press.
[4] Kannan, V., & Ramasamy, S. (2019). Water conservation mechanisms in epiphytic orchids. *Journal of Plant Physiology*, 231, 14–21.
[5] Kumar, A., & Joshi, R. (2016). Role of mycorrhizal fungi in drought tolerance of orchids. *Mycorrhiza*, 26(5), 403–410.
[6] Myint, T. L., et al. (2010). Environmental factors affecting orchid conservation. *Plant Ecology*, 206(1), 85–97.
[7] Pierce, S., et al. (2017). Plant strategies and climate change. *Ecology Letters*, 20(3), 310–320.
[8] Rasmussen, H. N., & Rasmussen, F. N. (2009). Orchid mycorrhiza: Implications of a mycophagous lifestyle. *Oikos*, 118(3), 334–345.
[9] Swarts, N. D., & Dixon, K. W. (2009). Terrestrial orchid conservation. *Annals of Botany*, 104(3), 543–556.