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THE GENUS PINUS IN A CHANGING CLIMATE: ECOLOGY, ADAPTATION, AND SUSTAINABLE USE

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BACKGROUND & AIM

Pinus is among the most ecologically and economically important conifer genera in the Northern Hemisphere. Pine species sustain biodiversity, store carbon, stabilize soils and supply renewable raw materials. This review integrates current knowledge on taxonomy, morphology, physiology, stress adaptation, phytochemistry, biotechnology and sustainable use, while identifying research needs for forests exposed to rapid environmental change.



PINE RESILIENCE LINKS ECOSYSTEM FUNCTION WITH BIOACTIVE RESOURCES AND BIOTECHNOLOGICAL RESEARCH

ECOLOGICAL ADAPTATION

Pine species occupy contrasting environments across the Northern Hemisphere. Their ecological success reflects differences in morphology and physiology, together with the capacity to tolerate drought, temperature extremes, poor soils and biotic stress. This adaptive diversity supports biodiversity, carbon storage and soil stabilization, but climate change may exceed the tolerance of vulnerable populations.

PHYTOCHEMISTRY & USES

Pine tissues contain terpenoids, phenolic compounds and essential oils with reported antioxidant, antimicrobial and anti-inflammatory activities. These resources complement the established value of the genus for timber and resin. They also support applications in food products, pharmaceuticals and cosmetics, strengthening the case for sustainable use and conservation.

GENUS VARIABILITY

≈120 SPECIES 30–40 SUBSPECIES >600 CULTIVARS







Natural variation and horticultural selection produce distinct crown forms, needle colours and growth habits. Cultivars maintain selected traits through controlled propagation and expand the ornamental value of Pinus in landscaping.

BIOTECHNOLOGY & CONSERVATION

Climate resilience depends on genetic diversity and physiological plasticity. In vitro propagation can multiply valuable or threatened material under controlled conditions. Molecular markers can support the assessment of genetic diversity and the selection of adapted genotypes. These tools should complement field evaluation and long-term conservation of natural populations.

RESEARCH PRIORITIES

1. Characterize genetic diversity within and among species.
2. Relate molecular variation to adaptive traits and stress tolerance.
3. Evaluate long-term responses to combined climate stresses.
4. Improve propagation methods for rare and valuable genotypes.
5. Integrate ex situ collections with the conservation of natural populations.

CONCLUSIONS

Pinus combines major ecological functions with substantial economic and biological value. Its natural and horticultural diversity provides resources for forestry, landscaping and the development of bioactive products. Sustainable management requires the conservation of genetic resources, field assessment of climate responses and carefully validated biotechnological methods. Research that connects these areas can support resilient and multifunctional pine forests.

TAKE-HOME MESSAGE: Genetic diversity, adaptive physiology and biotechnology support resilient pine resources and their sustainable use

Keywords: pine species, forest ecology, stress tolerance, phytochemical compounds, plant biotechnology