

CLIMATE-RESILIENT HIMALAYAN PLANTS AS NATURAL BIOCONTROL AGENTS AGAINST EMERGING CROP PATHOGENS WITH TRANSLATIONAL POTENTIAL IN BIOMEDICAL AND HEALTH APPLICATIONS.

Conceptual mechanistic synthesis of stress-adapted phytochemistry in Himalayan medicinal plants.

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Introduction and Aim

Climate Pressure and Control Failure

- The rate of vectors and pathogens adaptation to varying environments in the crop world is accelerating with climate change.
- Additionally, the environmental regulations are severely dismantling traditional methods like chemical based pest control.
- The demand for biologically based solutions is increasing which may manage vectors in check over the long term.

Stress Physiology as a Biological Principle

- Plants within the high altitude Himalayas are always exposed to UV radiation, low oxygen levels, temperature changes, and a lack of nutrients. These abiotic stressors start stress signaling cascades and alter important metabolic pathways to make secondary metabolites that help the environment (Espinosa-Leal et al., 2022).

Physiological Basis of Bioactivity

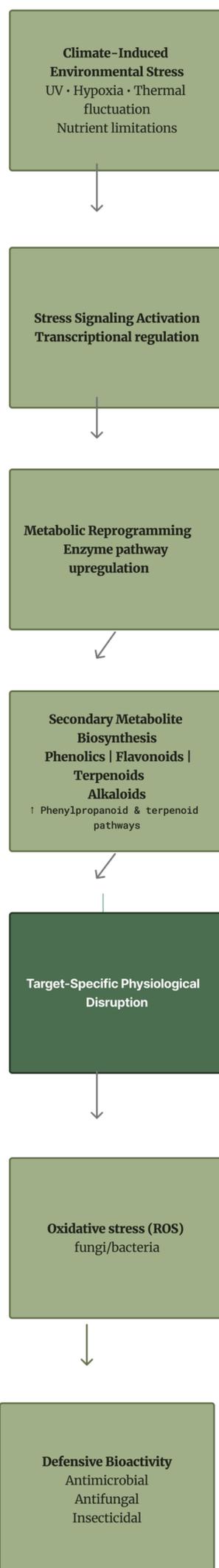
- Phytochemicals that adapt to stress are physiological defense agents.
- They act by disrupting membranes, producing ROS-related oxidative stress, preventing enzymes, and disturbing neurophysiology (Saleem et al., 2022).
- All these effects play a role in antimicrobial, antifungal, insecticidal and repellent effects.

Study Objective

- Stress-adapted phytochemicals act as physiological defense agents.
- Reported mechanisms include membrane destabilization, ROS mediated oxidative stress, enzyme inhibition, and neurophysiological disruption.
- These effects drive antimicrobial, antifungal, insecticidal, and repellent bioactivity.

Key References

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Phytochemical and Bioactivity Evidence from Target

Saussurea simpsoniana

- The plant contains high density in phenolics and terpenoids all associated to antimicrobial activity.
- It is said to be able to inhibit *Fusarium* spp. and other fungi in test tubes. It has demonstrated that it kills Gram-positive and Gram-negative Bacteria.
- Its anti-inflammatory compounds have given it a clue on possible application in regulating the immune system in a biomedical context (Hassan et al., 2020).

Hippophae rhamnoides (Sea buckthorn)

- Flavonoids, carotenoids, and alkaloids in high concentrations: the type of concentrations we would typically find in such plant samples.
- Insecticidal and repellent effects, which have been seen against storage pests and species of vectors.
- Antioxidant products and antimicrobial agents associated with inhibition of microbial growth that might potentially be applicable in food preservation. Anti-inflammatory and immunomodulatory activity, which is relevant in the case of vectors that carry diseases (Ahmad & Ali, 2013).

Mechanistic Evidence Synthesis

Metabolite Class	Target	Physiological Mechanism	Reported Outcome
Phenolics	Bacteria/Fungi	Cell membrane Destabilisation	Growth Inhibition
Terpenoids	Fungal Pathogens	ROS-mediated oxidative Stress	Antifungal Effect
Alkaloids	Insects/Vectors	Neurotransmission Interference	Insecticidal Activity
Flavonoids	Multiple	Enzyme Inhibition and Signalling Disruption	Suppressed Proliferation

Research Gaps and Experimental Priorities

- Limited field scale validation of insecticidal effects in actual field environments has been performed thus preventing the ability to ascertain whether the field could be similar to the lab.
- Lack of sufficient comparative metabolomic profiling to varying levels of stress, which hinders the easy detection of stress responses in plant metabolomic profiles.
- The lack of a standardized bioassay system for plant compounds creates inconsistencies in research findings
- A broader outlook demands greater integration of plant stress physiology with pest modeling of physiological responses.

Ecological and Conservation Constraints

- The Himalayan alpine ecosystem is very vulnerable to climate change and habitat fragmentation.
- Overexploitation of medicinal plants is a threat to sustainability. Phytochemical composition varies between cultivated and wild stressed plants (Sharma & Sharma, 2024).
- The phytochemical profiles may also vary with respect to the cultivated condition of the plants as opposed to their conditions subjected to wild stress.
- To generalize our findings, we can plant in an eco-friendly manner and conduct stress gradient metabolomics. Himalayan plants are constrained by ecological limitations and varying phytochemistries, but advancements require controlled plant growth and extraction protocols (Hasanuzzaman et al., 2020).