Impact of Abiotic Stressors on Selected Himalayan Medicinal Plant Germination and Seedling Development

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Abstract

The study emphasizes the effect of various abiotic stresses—drought, salt and cold—on the germination and early seedling growth of three economically important Himalayan medicinal plants viz., Valeriana jatamansi, Picrorhiza kurroa and Nardostachys jatamansi. The seeds were treated with stress in controlled conditions and germination percentage, mean germination time, seedling growth and chlorophyll content were noted. There was a significant decline in germination percentage and seedling growth in response to stress, and the strongest inhibitory impact was caused by drought and cold treatments. In addition, the chlorophyll content decreased markedly, suggesting that photosynthesis was not working efficiently. Picrorhiza kurroa of the species studied was relatively more tolerant to stress. The current results underscore the vulnerability of Himalayan medicinal plants to changing climate conditions and underline the need for continued research and conservation actions to protect these important species under modified climate scenarios.

Keywords: Abiotic stress, Germination, Seedling development, Himalayan medicinal plants, Drought, Salinity, Cold stress, Chlorophyll content, Valeriana jatamansi, Picrorhiza kurroa, Nardo Stachys jatamans.

1. INTRODUCTION

Medicinal plants of Himalayas are very important for traditional medicines as well as modern pharmacological medicines because of their huge variety and potential medicinal properties. Plants such as Valeriana jatamansi, Picrorhiza kurroa, and Nardostachys jatamansi are highly praised because of their medicinal attributes, which is mainly attributed to their anti-inflammatory, hepatoprotective, neuroprotective, and antioxidant actions. The plants have a great history in Ayurveda, Siddha, Unani, and Tibetan systems of medicine for more than two millennia and are gaining popularity worldwide in the preparation of herbal and alternative medicines. The majority of these species are distributed in high-altitude Himalayan landscapes, which are physiologically challenged and mostly extreme habitats. Yet the realization of their survival is at a greater risk than ever before due to climate change and the loss of natural resources.

Its continued existence is threatened by various abiotic stressors such as, drought, salinity, and low temperatures. These stress conditions can significantly influence the plant's life cycle, particularly during the early (and the most sensitive) stages of seed germination and seedling etiolation. Water stress due to drought results reduction in water potential leading to reduced seed imbibition and hormonal balance that are essential for germination. Ion imbalance, osmotic stress, and metabolic dysfunction are a result of increased salinity stress brought about by high salt concentrations in the soil. The slowing of the process Time to seed Germination depends on the high or low activation energy required in a substrate which can occur due to the cold stress and affect germination as well as growth due to a delayed or a stop in the germination and growth processes. These stresses together result in the establishment, productivity and survival of medicinal herbs, endangering biodiversity and their prospective usefulness for the future generations.

The germination process is a very important stage in the life of any plant that determines whether a seed will eventually generate a new individual. Early seedling growth also affects how well the plant can acclimate to and grow in its habitat. Thus, the analysis of the influence of abiotic stressors on these two important stages can provide valuable information regarding the plant behavior, stress tolerance and adaptation under stress conditions. Studies of this kind are especially crucial for the threatened and high value medicinal plants of the Himalaya, as the natural regeneration is low and habitat conditions are on a high rate of change.

Considering their ecological and economic values, there is very little information available on the physiological and developmental responses of these plants to environmental stresses. There are therefore few strategies for their conservation, multiplication and sustainable use. This is the gap which the present study is aimed to fill up by a comprehensive study to identify the impact of drought, salinity and cold stress on germination rate, mean germination time, seedling growth parameters (shoot and root length, number of leaves and fresh biomass) and chl a, chl b and carotenoids of Valeriana jatamansi, Picrorhiza kurroa and Nardostachys jatamansi. It will use drier and warmer conditions to induce stress to see how physiological traits are affected by stress and quantify the degree of stress-induced impact on physiological traits and determine which species are more resistant to stress.

The results could help in understanding the adaptive capability of Himalayan medicinal plants and provide guidelines for an efficient conservation management. They may also have practical implications for commercial cultivation under stress conditions, which will help farmers and herbal industries maintain high-quality medicinal raw material supply. Ultimately, this review aims to raise awareness on the vulnerability and resilience of Himalayan medicinal flora to abiotic adversities and call for an integrated approach towards plant conservation, sustainable collection and both in situ and ex situ climate adaptation strategies.

2. LITERATURE REVIEW

Pandey, Bhatt, and Nandi (2019) reiterated that Himalayan medicinal plants are increasingly endangered by an array of abiotic stresses including anthropogenic activities, temperature changes, degradation of soil, drought, altered precipitation patterns etc. Their review revealed a major research gap with respect to stress physiology, germplasm conservation, and climate change-resilient agriculture practices that requires long-term ecological and physiological investigation.

Rahman, Iqbal, and Husen (2023) reviewed the physiological and biochemical responses of medicinal plants exposed to abiotic stresses including drought, salinity, high/low temperature, and heavy metals. Their synthesized evidenced that stress conditions in many instances resulted in decreased photosynthetic efficiency, oxidative stress, and impaired nutrient uptake, which resulted in reduced plant productivity and medicinal quality. They also reported that adaptive mechanisms which include production of secondary metabolites and osmoprotectants were really important to respond to stress.

Pandey et al. (2022) reported on general environmental problems of Himalayan medicinal plants due to land use changes, soil erosion, various kinds of pollution, and changing climatic conditions. These stressors, they said, not only affect plants in terms of growth and reproduction but also drive habitat fragmentation and the erosion of genetic diversity. The authors supported integrative approaches including in situ conservation, stress-tolerant cultivar improvement and sustainable harvesting practices.

Sharma and Sharma (2020) examined the seed germination characteristics of Arnebia euchroma, threatened medicinal plant species endemic to the cold desert area of Spiti, Himachal Pradesh, India. The study indicated that the species germinates poorly under natural conditions because of dormancy and environmental challenges. Hence, they investigated the use of various germination enhancers on germination of this species including gibberellic acid (GA_3), sodium nitroprusside and proline. It was shown that these additives improved the germination percentage, shortened the mean germination time (MGT) and increased seedling vigour. They concluded that biochemical amendments have tremendous potential in conservation and propagation of threatened medicinal plant species in alpine environments.

Srivastava et al. (2023) examined the effects of temperature stress (both cold and heat) on a wide range of medicinal plants. Their findings described in the context of abiotic stress responses illustrated that high and low temperature extremes caused detrimental effects on plant physiology and growth and on secondary metabolite production. They said temperature stress affected enzymatic activities, stability of membranes (and the molecules within them), and their hormonal balance, all of which negatively affected the plants' productivity and medicinal attributes. The chapter also chronicled cold and heat adaptive responses in some species, and recommended the use of mitigation strategies and techniques to retain the medicinal value of medicinal flora impacted by climate change.

3. RESEARCH METHODOLOGY

3.1. Selection of Plant Materials

Three key Himalayan medicinal plants, Valeriana jatamansi, Picrorhiza kurroa and Nardostachys jatamansi were studied for the purpose. Seeds of those plants were obtained from reputable sources. Seeds were washed and disinfected in a light chemical substance before experiments to exclude all the detrimental micro-organisms. This served to insure that seeding germinated evenly and more uniformly.

3.2. Experimental Setup

The experiment was conducted under controlled conditions in a complete randomised design. The four treatments to which all plant species were exposed:

- Control – healthy condition, favourable conditions
- Drought stress – Imitated by the application of a particular substance (PEG) that limits water availability
- Salinity stress – With salt solution (100 mM NaCl)
- Cold stress – Imitated by exposing the seeds and seedlings to 5°C temperature in a chamber.

Each treatment was repeated three times for accuracy.

3.3. Germination Study

The For-seed germination analysis, seeds were similarly spread on wet filter paper in petri dishes. The paper was then soaked with either distilled water alone (control) or stress-causing solutions. Several glass Petri dishes of one species were exposed to either light or dark conditions for 15 days.

The germination seeds were counted every day. By the end of the competition, the germination rate and germination time were measured. An overview of the results has been published in the tables All these tables indicated that germination percentage was reduced under all stresses and germinating time was prolonged and the most severe stress was cold and drought stress.

3.4. Seedling Development Study

The surviving seedlings were moved to small pots of clean soil after germination. These seedlings were further allowed to grow in the same four treatments for 15 days.

The following vegetative parameters were determined at the time of the final sampling:

- Length of the shoot (stem)
- Length of the root
- Number of leaves
- Fresh weight of the plant

These observations were employed to evaluate the seedling performance. Results are presented in Table 1: Morphological Seedling Traits under Stress Conditions.

3.5. Measurement of Chlorophyll Content

To learn about plant health in response to the stress, feeding areas of the seedlings were sampled for the green pigment (chlorophyll) content from the leaves. "Chlorophyll is the heart of photosynthesis, and the decline of it shows stress in plants.

New leaves were crushed with a solution, and the liquid portion was tested with a machine called a spectrophotometer to take chlorophyll readings. Chlorophyll a, chlorophyll b and total chlorophyll were measured and values obtained.

3.6. Data Analysis

The results was recorded and analyzed. The means and SDs were calculated for each treatment. A series of statistical tests were performed to determine if the contrasts between control and stress treatments are significant. The data was organized and analyzed using the computer software SPSS and Excel.

The objective of this research was to determine the impact of drought, salinity and cold on germination and early seedling growth of three medicinal plant species from the Himalayas.

The study involved detailed seedling preparation, controlled stress exposure, monitoring on daily basis and correct execution of data-analysis. The findings shed light on how different plant species adapted to various types of environmental stress.

4. RESULT AND DISCUSSION

Table 1: Morphological Parameters of Seedlings Under Stress Conditions

Plant Species	Condition	Shoot Length (cm)	Root Length (cm)	No. of Leaves	Fresh Weight (g)
Valeriana jatamansi	Control	5.6	4.3	6	0.42
	Drought	3.1	2.2	3	0.18
	Salinity	3.4	2.7	4	0.21
	Cold	2.8	2.5	3	0.19
Picrorhiza kurroa	Control	6.1	5.2	7	0.45
	Drought	3.8	2.9	4	0.23
	Salinity	4.1	3.1	5	0.26
	Cold	3.0	2.7	3	0.20

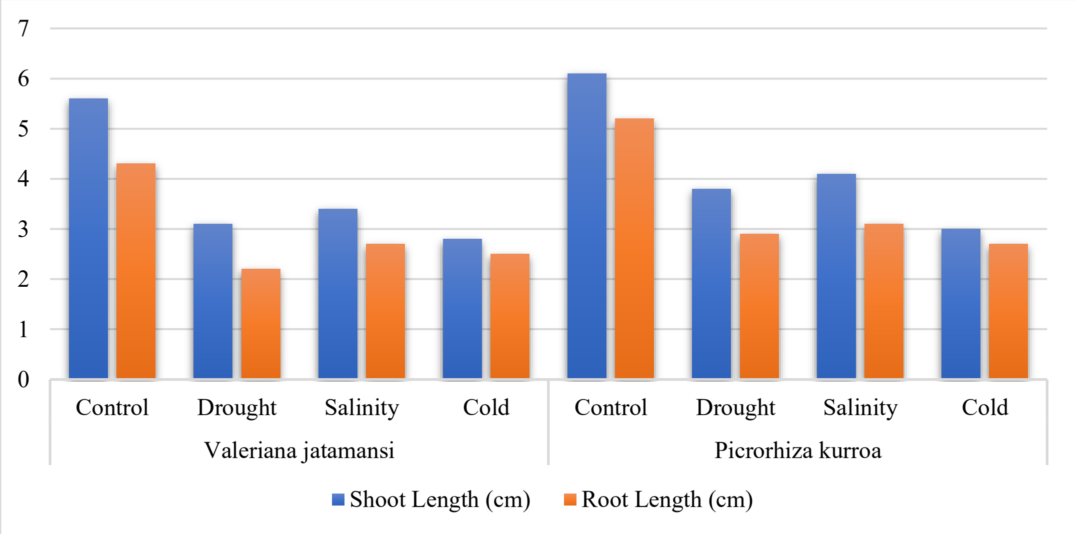

Figure 1: Morphological Parameters of Seedlings Under Stress Conditions

The data evidently show that the abiotic stress factors—drought, salinity and cold—had an inhibitory effect on the growth of seedlings of Valeriana jatamansi and Picrorhiza kurroa as compared to growth under control conditions. Drought and cold stress clearly elicited the most severe reductions of shoot and root lengths, number of leaves, and fresh biomass in both species, revealing a severe impact on water uptake, nutrient transport, and whole leaf metabolism. Moderate salinity, however, reduced growth traits compared to the control. Between the two plants, P. kurroa performed better under stress, i.e., salt, compared to S. jatamansi indicating relatively higher stress tolerance. These findings demonstrate that early seedling growth is extremely sensitive to environmental stress and can limit plant establishment and survival under natural and/or farming conditions.

Table 2: Chlorophyll Content (mg/g Fresh Weight) of Seedlings Under Stress

Plant Species	Condition	Chlorophyll a	Chlorophyll b	Total Chlorophyll
Valeriana jatamansi	Control	1.85	0.78	2.63
	Drought	1.21	0.49	1.70
	Salinity	1.36	0.53	1.89
	Cold	1.08	0.42	1.50
Picrorhiza kurroa	Control	1.92	0.84	2.76
	Drought	1.35	0.58	1.93
	Salinity	1.42	0.61	2.03
	Cold	1.18	0.51	1.69

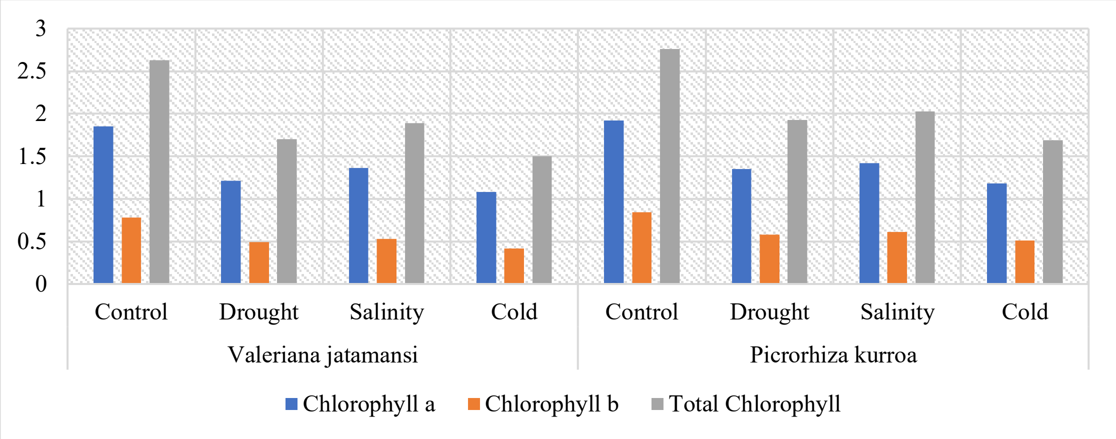

Figure 2: Chlorophyll Content (mg/g Fresh Weight) of Seedlings Under Stress

The chlorophyll content indicate that the drought, salt and cold had a significantly adverse effect on the levels of chlorophyll a, b and total chlorophyll of the seedlings in both Valeriana jatamansi and Picrorhiza kurroa, in comparison to their corresponding control. Both species had the highest chlorophyll content under control condition showing optimum photosynthetic performance. A significant decrease was recorded under drought stress and Valeriana jatamansi from 1.85 to 1.21 mg/g in chlorophyll a and 2.63 to 1.70 mg/g for total chlorophyll reflecting the inhibition of chlorophyll biosynthesis leading to partial reduction in photosynthesis perhaps due to moist stress. Moderate decline in chlorophyll was observed by salinity stress with little higher retention of chlorophyll than drought. Cold stress resulted in the lowest chlorophyll concentrations in the two species, indicating that pigment synthesis or stability were severely affected by low temperature. Picrorhiza kurroa recorded significantly higher chlorophyll values under all stress conditions than those of Valeriana jatamansi, demonstrating relatively superior level of tolerance to stress. Generally, lower chlorophyll content at stress indicates reduced photosynthesis, which could negatively interfere with plant growth and survival.

Table 3: Germination Percentage Under Different Abiotic Stress Conditions

Plant Species	Control (%)	Drought Stress (PEG -0.5 MPa)	Salinity Stress (100 mM NaCl)	Cold Stress (5°C)
Valeriana jatamansi	88	52	47	39
Picrorhiza kurroa	84	59	53	42
Nardostachys jatamansi	91	63	55	44

The percentage of germination data indicates that all the three Himalayan medicinal plants; i.e., Valeriana jatamansi, Picrorhiza kurroa, and Nardostachys jatamansi, showed a significant reduction in the seed germination under abiotic stress as compared to the control. In normal conditions, the germination rates for all species were high, varying from 84% to 91%. However, drought stress (PEG simulated) had significantly decreased germination, where the lowest percentage (52%) was belonged to V. jatamansi suggesting the relative sensitivity of its seed to water deficit. Germination percentages for seedlings under salinity stress were also lower (between 47 and 55%), but lower than drought stress. Cold stress caused the most pronounced reduction, with at least 39% germination observed in Valeriana jatamansi, indicating that low temperatures are predominantly restrictive to seedling emergence and development. Among the species, higher tolerance was observed for Nardostachys jatamansi with the highest germination in all stress environments. In general, the findings suggest that abiotic factors greatly inhibit seed germination, which may in turn threaten the natural regeneration and cultivation success of these two medicinally important plants.

Table 4: Mean Germination Time (MGT) Under Stress Conditions

Plant Species	Control (days)	Drought Stress	Salinity Stress	Cold Stress
Valeriana jatamansi	4.2	7.8	6.9	9.1
Picrorhiza kurroa	3.9	6.3	5.8	8.5
Nardostachys jatamansi	4.5	6.7	5.9	8.2

The data on Mean Germination Time (MGT) showed that the germination process in all three Himalayan medicinal plants was delayed significantly under abiotic stresses, being drought, salt and cold as compared to control. Under optimal conditions, germination was relatively fast which occurred between 3.9 and 4.5 days for the species (MGT). The longest extension of germination occurred under drought stress, Valeriana jatamansi showing the highest extension of germination time from 4.2 to 7.8 days, indicating a decrease in the absorption and metabolic activity when moisture was limited. Salinity stress also induced longer germination time although there was less with drought, meanwhile under cold stress, longest delay occurred across all tested species, with mean germination time of 9.1 days for Valeriana jatamansi. Picrorhiza kurroa had the minimum tMGT under stress, indicating more adaptability towards stress among species. In general, a delayed germination time under stress can be interpreted as an indication that abiotic factors are disadvantageous to seed metabolism and embryo development which might affect plant establishment in natural environments.

5. CONCLUSION

The study clearly evidenced by the abiotic stress factors like drought, salinity, cold, play a major effect on the germination and early seedling growth of the selected valuable Himalayan medicinal plants (Valeriana jatamansi, Picrorhiza kurroa and Nardostachys jatamansi). Germination percentages decreased significantly under stress conditions, with the lowest percentages in response to cold and drought stress. The mean germination time increased under all the stress conditions representing a decrease and delay in seed vigor. The growth parameters of the seedlings, including shoot length, root length, leaf number, and fresh weight, were also significantly inhibited, with the most marked decreases occurring under drought and cold conditions. In addition, all stressed seedlings also had significantly lower amounts of chlorophyll content, a good measure for plant health, suggesting that photosynthetic functions were lessened. In the three plant species, P. kurroa showed better tolerance to maintain higher germination percentage and chlorophyll under stress and could be considered as stress tolerant species. PERSPECTIVE The results thus provide evidence on the stress susceptibility of medicinal plants in Himalayas, emphasizing on the need of conservation and cultivation practices in stress susceptibility way for the survival of these plants and nondecreasing use of these plants from the region.

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