



# Seasonal rhythm and altitudinal variation of the physio-biochemical adaptation in *Juniperus communis* under the alpine and subalpine zones of Western Himalaya

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## Abstract

Western Himalaya, known for its steep gradients and climatic variability, was selected to examine *Juniperus communis* adaptations across four elevations (2900–3550 m) and seasonal cycles. Physiological and biochemical traits were studied across elevations and seasons in Tungnath, Western Himalaya, revealing adaptive responses. Malondialdehyde was highest (34.06 nmol/g) during December at 3,550 m, while total phenolic content (53.99 mg/g FW) and total flavonoid content (41.74 mg/g FW) peaked in October across all sites. Chlorophyll a declined from 2.30 mg/g FW (June, 2,900 m) to 0.59 mg/g FW (April, 3,550 m), while carotenoids increased from 0.06 mg/g FW (April, 2,900 m) to 0.35 mg/g FW (June, 3,550 m). Enzyme activities also rose with altitude: Superoxide dismutase (13.67–31.33 U/g FW), Peroxidase (6.88–17.67 U/g FW), Catalase (17.12–33.90 U/g FW), Polyphenol oxidase (13.09–26.55 U/g FW), and proline (20.45–55.44 μmol/g FW). Findings indicate a significant ( $p < 0.001$ ) effect of altitude and season on *J. communis*, reflecting its adaptability to alpine stress.

**Keywords** Alpine and subalpine · Altitudinal gradient · Climate change · Ecophysiology · Seasonal changes · Tree line

## Introduction

Altitudinal gradients and changing weather patterns are considered natural trials to evaluate the ecological responses of vegetation to a changing environment, as they are typified by rapid fluctuations in biotic and abiotic variables (Körner 2007). Furthermore, meteorological variables such as air temperature, high light intensity, wind velocity, soil

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