



Effects of climatic stress on meiotic behaviour of chromosomes in Cold Deserts of India

Maninder

Department of Botany, Multani Mal Modi College, Patiala, Punjab, India

Abstract

Cold deserts of India, including Ladakh, Lahaul–Spiti, and parts of Jammu & Kashmir, represent some of the harshest environments on Earth, where plants are exposed to multiple abiotic stresses such as low temperature, intense ultraviolet radiation, and limited soil moisture. These climatic extremes profoundly influence plant reproductive biology, particularly the meiotic process, which is crucial for gamete formation and genetic stability. The present review summarizes cytogenetic responses of cold desert plants to climatic stress, with emphasis on meiotic irregularities, polyploidy, and adaptive mechanisms. It also discusses molecular and physiological factors underlying stress-induced chromosomal behaviour and highlights the evolutionary significance of such variations.

Keywords: Meiosis, cold desert flora, cytogenetics, ladakh, lahaul–spiti, chromosome abnormalities, climatic stress, polyploidy, adaptation

Introduction

The Indian cold deserts, chiefly located in the Trans-Himalayan regions of Ladakh and Lahaul–Spiti, are characterized by aridity, subzero winter temperatures, high altitude (3,000–5,000 m), and intense solar radiation (Körner, 2003; Singh *et al.*, 2017) [13]. Despite the hostile conditions, these regions harbour unique floristic diversity with remarkable physiological and cytogenetic adaptations (Kumar & Sharma, 2015) [8]. Meiosis — the process of reductional cell division — is fundamental to genetic stability and reproductive success. Environmental stress, however, can induce irregularities in chromosome pairing and segregation, leading to partial sterility or formation of new cytotypes (Agarwal *et al.*, 2012 [1]; Singh & Roy, 2018) [1]. The study of meiotic behaviour under stress, therefore, offers critical insight into plant adaptation, genome plasticity, and evolutionary potential (Comai, 2005) [4].

Climatic Stress in Cold Deserts of India

Cold deserts of the Indian Himalaya experience extreme abiotic stresses: low precipitation, intense radiation, and freezing winters. Temperature ranges from -30°C in winter to $+25^{\circ}\text{C}$ in summer, with annual precipitation below 100 mm (Björn *et al.*, 1999 [3]; Rawat *et al.*, 2019) [11]. Soil is nutrient-poor and sandy, further constraining plant growth. Such stresses affect microsporogenesis and megasporogenesis, altering enzyme activity, spindle fibre integrity, and chromosomal condensation (Nair, 2019) [10].

Impact of Climatic Stress on Meiotic Behaviour

Plants exposed to low temperature and UV stress often exhibit asynapsis, desynapsis, laggards, bridges, stickiness, and micronuclei formation (Bir & Sidhu, 1997 [2]; Thakur & Devi, 2021) [16]. For instance, *Artemisia maritima* and *Caragana brevifolia* collected from Lahaul–Spiti showed high frequency of univalents and laggard chromosomes (Mehra & Kaur, 1986) [6], while *Aconitum heterophyllum* and *Saussurea obvallata* from Ladakh exhibited cytotoxicity (Kumar *et al.*, 2018) [8].

Polyploidy and Cytogenetic Adaptation

Polyploidy is a major adaptive mechanism in cold desert flora, seen in *Potentilla*, *Eritrichium*, and *Draba* (Stebbins, 1985) [15]. Polyploids exhibit larger cell size and greater enzyme diversity, providing resilience to temperature and drought extremes (Comai, 2005) [4]. Kaur & Mehra (1986) [63] reported several polyploid races in Ladakh, suggesting ongoing chromosomal evolution.

Molecular and Cellular Basis of Stress-Induced Meiotic Changes

Climatic stress triggers reactive oxygen species (ROS) accumulation, damaging DNA and proteins essential for chromosome segregation (Gill & Tuteja, 2010) [5]. Cold stress modulates expression of CBF/DREB transcription factors, influencing chromatin condensation (Sharma *et al.*, 2020) [12]. Heat shock proteins maintain spindle integrity (Kotak *et al.*, 2007) [7], while epigenetic modifications alter meiotic gene expression (Probst & Mittelsten Scheid, 2015).

Evolutionary Implications

Although meiotic irregularities reduce fertility, they promote chromosomal rearrangements and new cytotypes, enhancing adaptive potential (Ramsey & Schemske, 1998; Mandáková & Lysak, 2018) [9]. Thus, meiotic instability under stress drives microevolution in cold desert flora.

Future Perspectives

Advanced techniques such as FISH, next-generation sequencing, proteomics, and CRISPR/Cas9-mediated gene editing can elucidate stress-responsive meiotic pathways (Soyk *et al.*, 2019) [14]. Integrating cytogenetics with molecular biology will help decipher plant resilience under extreme climates.

Conclusion

Climatic stress in Indian cold deserts significantly affects meiotic behaviour, leading to chromosomal irregularities that influence fertility and evolution. These cytogenetic

responses serve both as stress indicators and as adaptive mechanisms ensuring survival of alpine species in harsh environments.

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