GERMINATION CAPACITY OF BLACK SAXAUL (*HALOXYLON APHYLLUM*) SEEDS IN SALINE AND ARID ENVIRONMENTS AND THE ECOPHYSIOLOGICAL IMPACT OF HALOTOLERANT MICROBIOME

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Abstract. Evaluating the germination capacity of *Haloxylon aphyllum*-growing in the dried seabed region of the Aral Sea-under high soil salinity conditions underscores the necessity of studying its associated microbiome and assessing key ecophysiological features of its survival mechanisms in adverse environments. In this article, the impact of biopreparations and the effect of NaCl salinity concentrations (0, 20, 60, and 100 mM) on *Haloxylon aphyllum* seeds were analyzed based on a literature review. It can be observed that higher salinity concentrations exert a greater negative impact on the germination percentage. Under such conditions, identifying promising halotolerant bacterial strains and studying their mechanisms of action on seed germination in highly saline climatic conditions is of paramount importance.

Keywords: *Haloxylon aphyllum*, seed germination, salinity, NaCl, halotolerant.

Introduction

The Aralkum region, formed as a result of the shrinkage of the Aral Sea, is characterized by high salinity, moisture deficiency, extreme temperature fluctuations, and dust-salt storms. Under these severe conditions, establishing vegetative cover is critical for ecological stability and mitigating wind erosion. Black saxaul (*Haloxylon aphyllum*) is one of the key ecologically significant species in this process; its ecosystem-forming role, sand-fixing capacity, and importance in restoring degraded

lands have been demonstrated in numerous studies (Shamsutdinov et al., 2016).

Seed germination represents one of the most sensitive stages of the plant life cycle to salinity. Seeds must possess sufficient water potential to imbibe water, activate embryo metabolism, and initiate radicle emergence. However, elevated salt levels impede water uptake by the seed, resulting in the accumulation of ions such as Na^+ and Cl^-, which can disrupt cellular metabolism. Temporarily halting germination under high salinity conditions and recovering germination once stress subsides is highlighted as a critical ecological strategy in halophyte seeds (Şekerci et al., 2026). The severity of biotic and abiotic stresses, particularly salinity, impairs crop cultivation prospects, serving as a primary environmental stress factor that negatively impacts seed germination.

Materials & Methods.

H. aphyllum is one of the essential habitat-forming plant species in the desert ecosystems of Central Asia. Research by Shamsutdinov revealed significant variations in air and soil moisture, temperature regimes, as well as soil humus and salt content within the phytogenic field of black saxaul. These findings demonstrate that *H. aphyllum* not only survives in arid and saline environments but also actively shapes the surrounding microecological conditions (Shamsutdinov et al., 2016).

Studies in the Aral region indicate that deep soil layers are also crucial for the subsequent survival of *H. aphyllum* seedlings. Matsui et al. determined that the physicochemical properties of deep soil layers significantly influence the survival and growth of *H. aphyllum* seedlings in the Aral Sea region. Areas with high seedling mortality were dominated by high clay and silt content alongside elevated salinity up to a depth of 100 cm, whereas areas with lower mortality were characterized by sandy, low-salinity soils (Matsui et al., 2019). Chang et al. evaluated the growth, biomass, and carbon sequestration of *H. aphyllum* plantations established in the Aralkum Desert of Kazakhstan. According to their results, the establishment of saxaul plantations

facilitated vegetation cover formation and carbon accumulation on the dried seabed (Chang et al., 2019). Under high salinity conditions, excessive accumulation of Na^+ and Cl^- ions can lead to impaired water uptake, nutrient imbalances, and metabolic disruptions in plants. This state manifests as a reduction in seedling biomass and overall growth parameters. Najafi et al. investigated *H. aphyllum* seedlings under 300 and 600 mM NaCl conditions and found that high salinity—especially 600 mM NaCl—caused a decline in seedling biomass and quality index. Concurrently, the application of halotolerant plant growth-promoting rhizobacteria (PGPR)—*Bacillus pumilus* HR and *Zhihengliuella halotolerans* SB—reduced Na^+ accumulation, enhanced mineral nutrient uptake, and improved the salinity tolerance of the seedlings (Najafi et al., 2022).

Oxidative Stress and Antioxidant Defense

High salinity exacerbates oxidative stress, increasing reactive oxygen species (ROS) production and membrane lipid peroxidation. A study by Najafi Zilaie et al. revealed that inoculating *H. aphyllum* seedlings with halotolerant *Bacillus pumilus* HR and *Zhihengliuella halotolerans* SB strains mitigated the negative impacts of salinity and dust stress. Bacterial inoculation altered malondialdehyde (MDA) levels, proline, phenolic compounds, and certain antioxidant response parameters, thereby improving plant nutrient status and seedling quality. The authors noted that halotolerant rhizobacteria enhance *H. aphyllum* resistance to salinity and dust stress by limiting ROS formation and protecting cell membranes (Najafi et al., 2022).

An early foundational study on the response of *H. aphyllum* seeds to salinity was conducted by Shahbazi. The research evaluated seed germination under NaCl concentrations ranging from 0 to 500 mM across various temperature regimes. Results demonstrated that increased salinity and temperature decreased both germination percentage and rate. Nevertheless, germination was recorded in some seeds even under 500 mM NaCl. Furthermore, germination recovered after transferring seeds from the

saline solution to distilled water. These findings highlight that *H. aphyllum* seeds possess a inherent tolerance to high salinity and maintain the potential to recover germination once salt stress is alleviated (Shahbazi et al., 2005).

Another study explored the application of moisture-retaining substances and growth biostimulants to enhance plant survival in desertification conditions, stimulate root development, and ensure efficient utilization of available soil moisture. In this context, biostimulants capable of sustaining plant growth and retaining soil moisture were investigated under desert conditions. Specifically, several moisture-retention techniques were analyzed in establishing *Haloxylon aphyllum* plantations in the Aral Sea region, alongside the biological and ecological indicators of saxaul growing on the dried seabed (Oripova va boshq 2026). The effect of NaCl salinity concentrations (60 mM and 100 mM) in combination with bacterial suspension dilutions (1:100, 1:500, 1:1000) on the seed germination of *H. aphyllum* was evaluated experimentally in Petri dishes.

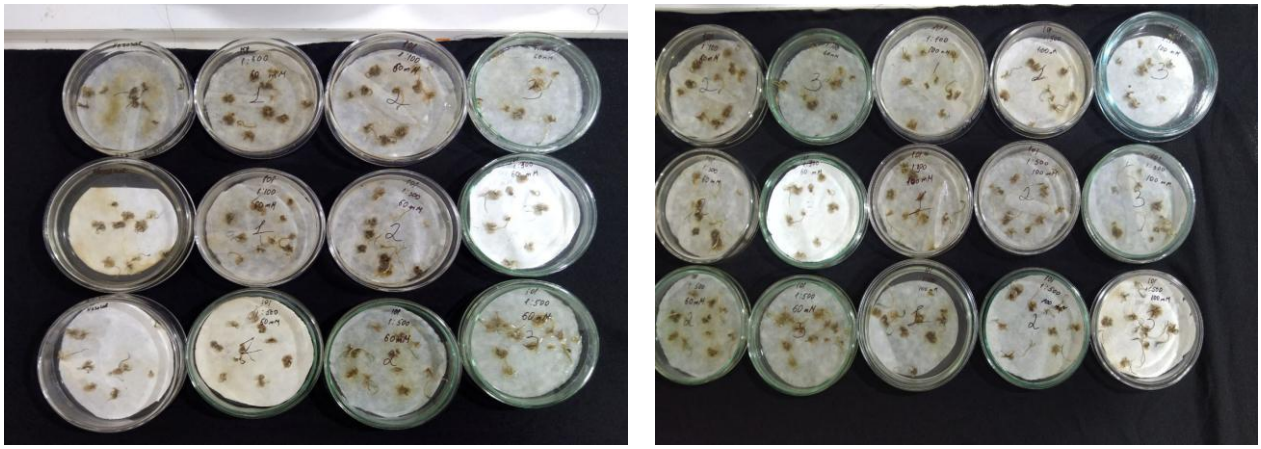


Figure 1. Effect of NaCl on the seed germination of *H. aphyllum*

The goal of this work was to demonstrate the negative impact of salinity on plant growth and highlight the potential of rhizobacterial strains to alleviate this effect during early seed germination. One biological solution to mitigate salinity stress is using halotolerant plant growth-promoting bacteria (PGPB), which can enhance plant growth and yield under stress conditions (Etesami et al., 2019).

Conclusion

The literature review demonstrates that salinity affects *H. aphyllum* seed germination primarily through osmotic restriction and ion stress. However, as a desert halophyte, black saxaul is adapted to high salinity environments, and its seeds retain the ability to recover germination after salinity stress declines. This underscores the importance of *H. aphyllum* in restoring Aral Sea ecosystems, highlights seedling growth limitations in saline soils, and indicates the potential for enhancing stress tolerance via halotolerant microorganisms. Nevertheless, modern, standardized experiments specifically targeting seed germination tailored to Aral region conditions remain insufficient. Therefore, comprehensively evaluating the combined effects of NaCl and Na_2SO_4 gradients, electrical conductivity (EC), temperature, recovery of germination, root-shoot length, and halotolerant PGPR represents a highly relevant and novel scientific research direction.

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