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Ecological and Agronomic Applications of Wild Almond Species in Arid Mountain Ecosystems

Abstract

This study investigates the ecological and agronomic significance of wild almond species (*Prunus* spp.) native to the arid and mountainous regions of Southwest and Central Asia. Through rigorous field experiments and laboratory assessments, three principal findings emerge: (1) the presence of drought-resilient root microbiome associations in *P. scoparia* and *P. turcomanica*, (2) notable cold tolerance in *P. fenzliana*, and (3) the allelopathic potential of *P. spinosissima* that promotes beneficial soil microbial communities. These findings emphasize the suitability of wild almonds as resilient rootstocks for marginal landscapes and their role in sustainable agriculture, land rehabilitation and biodiversity conservation.

Keywords: *wild almond, drought tolerance, cold adaptation, soil microbiome, allelopathy, ecological restoration, rootstock resilience*

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Quraq dağlıq ekosistemlərdə yabanı badam növlərinin ekoloji və aqronomik tətbiqləri

Xülasə

Bu tədqiqat Cənubi-Qərbi və Mərkəzi Asiyanın quraq və dağlıq bölgələrinə məxsus yabanı badam növlərinin (Prunus spp.) ekoloji və aqronomik əhəmiyyətini araşdırır. Sahə tədqiqatları və laboratoriya analizləri əsasında üç əsas nəticə əldə edilmişdir: (1) *P. scoparia* və *P. turcomanica* növlərində quraqlığa davamlı kök mikrobiomu assosiasiyalarının mövcudluğu, (2) *P. fenzliana* növündə əhəmiyyətli dərəcədə soyuğa davamlılıq, və (3) *P. spinosissima* növünün allelopatik potensialı nəticəsində torpaq mikrobiotasının faydalı istiqamətdə formalaşması. Bu nəticələr yabanı badam növlərinin sərt iqlimli ərazilərdə davamlı calaqaltı materialı kimi istifadəyə yararlı olduğunu, eyni zamanda dayanıqlı kənd təsərrüfatı sistemlərinin qurulmasında, torpaqların bərpasında və biomüxtəlifliyin qorunmasında mühüm rol oynaya biləcəyini vurğulayır.

Açar sözlər: *yabanı badam, quraqlığa davamlılıq, soyuğa uyğunlaşma, torpaq mikrobiomu, allelopatiya, ekoloji bərpa, calaqaltı davamlılığı*

Introduction

Wild almond species are increasingly recognized for their vital role in ecological stability and agricultural resilience. These species thrive in harsh environments—steep rocky terrains, water-scarce valleys and high-altitude cliffs—developing traits that enable survival under extreme abiotic

stress. In this research, we focus on five wild almond species endemic to Southwest and Central Asia: *P. fenzliana*, *P. scoparia*, *P. turcomanica*, *P. spinosissima*, and *P. bucharica*.

Cultivation trials were conducted on the Absheron Peninsula in Azerbaijan (40.461354, 50.082178), characterized by sandy soils, mild winters, and arid summers. Seeds were collected from mountainous regions, including *P. fenzliana* from Nakhchivan, and underwent stratification before planting. Over a three-year period, traits related to drought tolerance, freezing resistance, rhizosphere interactions, and allelopathic influence were systematically evaluated.

Prior studies (Gharaghani & Eshghi, 2015; Sorkheh et al., 2021) identified traits such as early leaf drop, stem photosynthesis, and natural pest tolerance. This study builds upon that foundation by incorporating microbial ecology, stress physiology, and plant-soil interaction insights.

Research

Additional research has highlighted the adaptability of *Prunus* species under abiotic stress. For instance, Zohary and Hopf (2000) explored the early domestication and geographic spread of almonds, while Ercisli and colleagues (2014) documented wild almond diversity across Anatolia. These findings complement our observations and strengthen the case for conservation and utilization of wild almond germplasm.

2. Materials and Methods

2.1 Field Conditions

Experiments were conducted in two ecologically diverse zones of Azerbaijan: Absheron (low altitude, sandy soils) and Shamakhy (elevated terrain, loamy soils), ranging from 30 to 750 meters above sea level.

2.2 Microbiome and Root Studies

Thirty rhizosphere samples were subjected to 16S rRNA and ITS sequencing using protocols outlined by Compant et al. (2020) and Smith & Read (2008) to profile bacterial and fungal communities.

2.3 Cold Tolerance Testing

Electrolyte leakage assays and thermal analysis were used to estimate lethal temperatures (LT50), comparing wild almond species to *P. dulcis* cultivars.

2.4 Allelopathy Evaluation

High-performance liquid chromatography coupled with mass spectrometry (HPLC-MS) was used to assess the chemical profile of root exudates. Soil bioassays tested their effects on Fusarium suppression and microbial community shifts.

2.5 Seed Germination Treatment

P. scoparia seeds were coated in hydrogel films to evaluate water retention effects under simulated drought conditions.

3. Results

3.1 Drought Resilience via Root Microbiomes

P. turcomanica demonstrated strong colonization by arbuscular mycorrhizal fungi, particularly *Diversispora* spp., enhancing root water uptake efficiency. Microscopic analysis revealed deeper root penetration and morphological adaptations such as expanded cortex aerenchyma.

3.2 Cold Adaptation in *P. fenzliana*

In cold stress assays, *P. fenzliana* maintained membrane integrity at sub-zero temperatures better than control varieties, likely due to cryoprotective solutes and structural adaptations. These traits contributed to survival rates below –20°C.

3.3 Allelopathic Soil Improvement

Root exudates from *P. spinosissima* suppressed *Fusarium* spp. growth while enriching beneficial soil bacteria like *Pseudomonas*. In soil assays, nematode density declined and soil structure improved, indicating potential for natural disease suppression and enhanced soil health.

3.4 Habitat Versatility and Soil Suitability

Table 1.
Natural Habitats of Wild Almond Species in Southwest and Central Asia.

Species	Distribution	Habitat Type	Elevation (m)
P. scoparia	Iran, Turkmenistan	Volcanic slopes, riversides	600–2300+
P. turcomanica	Iran, Turkmenistan	Rocky cliffs, ravines	600–2200+
P. bucharica	Central Asia, Afghanistan	Clay slopes	500–1500
P. spinosissima	Central Asia, Afghanistan	Limestone hills	700–1900
P. fenzliana	Azerbaijan, Iran, Türkiye	Rocky outcrops	1400–2500+

4. Discussion

The results demonstrate that wild almonds possess valuable traits for agricultural adaptation under climate stress. *P. fenzliana* displays exceptional frost resistance, surpassing previous cold tolerance benchmarks in *Prunus*.

The mycorrhizal partnerships observed in *P. turcomanica* suggest scalable methods for enhancing water efficiency in drought-prone orchards. Grafting of *P. dulcis* onto wild almond rootstocks also shows promise for sustainable cultivation (Hartmann et al., 2010).

Allelopathic activity in *P. spinosissima* can be harnessed for low-input biological control, improving soil structure and health naturally (Rice, 2012; Haas & Défago, 2005).

Conclusion

Wild almond species are not merely relics of biodiversity—they are key tools for ecological restoration and climate-resilient agriculture. Their traits include:

- Robust drought adaptation via symbiotic root microbiota
- Cold hardiness through cellular protective mechanisms
- Soil enhancement through allelopathic and microbial activity

Integrating these species into modern agroecosystems contributes to sustainable farming, reforestation and biodiversity goals aligned with the UNCCD's Land Degradation Neutrality agenda.

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