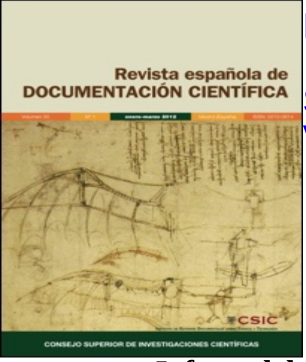

Revista Española de Documentación Científica,
ISSN :0210-0614 ; eISSN: 1988-4621
Spain
Volume 25-Issue1(2025)
https://doi.org/10.63386/610840

OPEN ACCESS

Conservation and Propagation of Pyrus L. Species in the Greater Caucasus: Integrating Biodiversity Strategies with Green Economy Principles

Check for updates

Jafarzadeh Sabina [1] (ORCID ID 0000-0002-1649-9542, sabina.cafarzadeh@mail.ru)
Bakhshaliyeva Konul[1-2] (ORCID ID 0000-0002-4876-5542, konul.baxsh@mail.ru).
Iskandar Elman[1] (ORCID ID 0009-0004-0790-2784,acae55@hotmail.com)
Mammadova Bahar[3] (ORCID ID 0009-0000-1103-3199, Bahar93@mail.ru).
Muradova Sevda[4] (ORCID ID 0000-0003-2836-4079, muradovasevda1961@gmail.com).
Muradov Panah[1] (ORCID ID 0000-0001-9660-1377, mpanah@mail.ru).

[1]Ministry of Science and Education of Azerbaijan Republic, Institute of Microbiology, A.Abbaszade , 115, AZ 1004, Baku, Azerbaijan.
[2]Institute of Fruit and Tea Cultivation of the Ministry of Agriculture of the Republic of Azerbaijan, Guba.
[3]Institute of Ecology of the National Aerospace Agency of the Ministry of Defense Industry of Azerbaijan Republic, Akhundov street 1, AZ 1115, Baku,Azerbaijan
[4]Azerbaijan State Pedagogical University, Baku

Correspondense author: sabina.cafarzadeh@mail.ru

ABSTRACT

This research examines various plant propagation techniques, focusing on horticultural crops and conservation strategies, with a particular emphasis on the genus *Pyrus* L. and its distribution in the Greater Caucasus region. The study incorporates a range of methods, including tissue culture, morphological analysis, and pollen fertility comparison, to explore the effectiveness of both in situ and ex situ conservation approaches. Materials used include plant samples from both wild and cultivated populations of *Pyrus* species, collected from various regions of Azerbaijan. The analysis integrates laboratory techniques for fungal pathogen identification and the study of abiotic factors influencing plant growth under controlled conditions. Additionally, the article explores the impact of anthropogenic activities on plant biodiversity, particularly focusing on rare tree species in Azerbaijan. Results indicate that tissue culture is an efficient tool for the production of horticultural crops, while the morphological differences among *Pyrus* species highlight the adaptive strategies of these plants to environmental stressors. Furthermore, the study reveals that *ex situ* conservation methods can complement traditional approaches, offering valuable insights for long-term plant preservation. The article concludes by emphasizing the importance of integrated conservation strategies to safeguard plant biodiversity in the face of ongoing climate change and human intervention. Perspectives for future research include refining propagation techniques, understanding genetic diversity, and enhancing the resilience of plants in changing environmental conditions.

Keywords: green economy, biodiversity, conservation, *Pyrus* L, ecological sustainability

INTRODUCTION

The authors critically examine the green economy narrative, suggesting that it often serves the interests of market-driven forces rather than genuinely addressing ecological sustainability. They argue that environmental issues are frequently reframed to maintain or even strengthen capitalist markets, instead of challenging the economic systems that contribute to environmental harm. Policies related to green growth and sustainable development are increasingly promoted as solutions to both environmental and economic challenges. However, the authors assert that such policies often protect existing market structures, allowing businesses and corporations to continue operating within capitalist systems while presenting themselves as environmentally responsible. In essence, the "greening" of the economy often becomes a means of preserving market capitalism, rather than transforming it into a more sustainable model. From a radical political economy viewpoint, the authors argue that genuine ecological sustainability demands systemic changes that go beyond market-based solutions. They contend that environmental issues should be addressed in ways that challenge the current economic framework, rather than reinforcing it [Kenis and Lievens, 2019].

This study investigates the differences in pollen morphology and fertility between *Pyrus L.* species cultivated in *in situ* and *ex situ* conditions in the Greater Caucasus region of Azerbaijan. The research seeks to better understand how environmental factors influence the reproductive traits of these species. By comparing pollen characteristics and fertility rates, the study offers valuable insights into effective cultivation and conservation strategies (Jafarzadeh and Iskender, 2024). This paper examines how species of the genus *Pyrus L.* from northern Greater Caucasus respond to various abiotic stressors under ex situ conditions. The study looks into the effects of environmental factors such as temperature, moisture, and soil composition on the growth and development of these species. Understanding the adaptability of these pear species to such conditions is vital for developing effective conservation and management approaches in non-natural environments (Jafarzadeh et al., 2023). The research also explores fungal pathogens affecting *Pyrus L.* species in the Greater Caucasus region, with a focus on the role of biotic factors in plant health. Fungal diseases pose a significant threat to pear species in both natural and cultivated environments. By identifying the types of fungal pathogens present, the study aims to improve disease management strategies for these important species (Jafarzadeh and Iskender, 2024).

Recent research on biodiversity conservation in protected areas (PAs) has focused on critical ecosystems and species that are rare or endangered, examining the status and changes of these conservation priorities (Wang et al., 2022). Moreover, the effectiveness of PAs is often shaped by regional development, with these areas potentially having both positive and negative effects on local social and economic progress (Naidoo et al., 2019). This work investigates the anthropogenic impacts on the Ajinohur arid forests in Azerbaijan, focusing on the environmental changes driven by human activities. The study examines deforestation, land-use changes, and pollution, and their effects on biodiversity and ecosystem services provided by these forests. The findings underline the critical need for sustainable forest management practices to mitigate the damage caused by human activities in this unique ecosystem (Togola, 2023). This research provides a comprehensive morphological description and taxonomy of *Pyrus L.* species in northeastern Greater Caucasus. The study aims to clarify the classification and identification of pear species in this biodiversity-rich region. By investigating key morphological traits, the research contributes to the understanding of the genetic diversity and evolutionary history of these species (Iskender et al., 2024).

The Kunming-Montreal Global Biodiversity Framework, established at the 15th Conference of the Parties (COP) to the Convention on Biological Diversity (CBD) in 2022, sets a target to protect and manage 30% of the Earth's terrestrial, inland water, coastal, and marine areas by 2030 (the 30×30 goal). Protected areas (PAs) are considered the most straightforward and impactful measure for safeguarding biodiversity [Maxwell et al., 2020]. From these studies, it is clear that emphasizing the conservation and management effectiveness of protected areas (PAs) is a crucial and positive step toward achieving the 30×30 target. Determining the most effective management strategies and maintaining a balance between biodiversity conservation and the sustainable development of PAs and their surrounding areas are essential for improving the overall success of these areas. In conclusion, these studies offer valuable insights that will enhance our understanding of biodiversity conservation and sustainable development both within PAs and in their neighboring regions [Wang et al., 2024]. The concept of green growth seeks to align economic growth with environmental sustainability. The author critically explores how policymakers and economists have embraced green growth as a solution to the interconnected challenges of environmental degradation and economic stagnation. The paper delves into the economic theory behind green growth, particularly the idea that economic growth can be achieved without causing environmental harm. It also examines the political discourse around green growth, highlighting its influence on environmental policy and international climate negotiations. While green growth presents a promising path to sustainable development, the author notes that its practical implementation often encounters significant obstacles. The economic assumptions underlying green growth models, such as reliance on technological innovation and market-based solutions to environmental issues, are also discussed. Additionally, the paper highlights the potential risks of green growth being co-opted by political elites to preserve the existing system, rather than addressing the fundamental causes of environmental and social problems [Jacobs, 2019]. This study employed a computational approach to assess the effectiveness of directing funding to regions at the greatest risk of biodiversity loss. The results indicate that more focused and timely funding could significantly reduce the most urgent threats to global biodiversity [Waldrons et al., 2019]. The paper reviews the strengths and weaknesses of the Advocacy Coalition Framework (ACF), offering insights into its practical application for analyzing environmental policy. It also suggests potential future directions for the framework's development within policy studies [Weible et al., 2009]

The UNEP (2021d) report explores whether post-COVID-19 economic recovery efforts are promoting inclusive and green development. It provides evidence from 2020 and outlines strategic pathways for recovery spending that address both environmental sustainability and social equity (UNEP, 2021d).The World Bank (2018) publication analyzes long-term global wealth trends, highlighting the crucial role of natural capital in sustainable development. It emphasizes the need to include produced, human, and natural capital in national wealth assessments to support informed policy decisions (World Bank, 2018).The World Economic Forum (2020a) report, *Nature Risk Rising*, examines the increasing risks associated with biodiversity loss and environmental degradation. It argues that the decline of nature poses significant threats to economic systems and business resilience (World Economic Forum, 2020a).The second installment, World Economic Forum (2020b), titled *The Future of Nature and Business*, identifies key transitions needed in various industries to promote nature-positive outcomes. It emphasizes that shifting toward sustainable practices can unlock economic opportunities while preserving ecosystems (World Economic Forum, 2020b).In its 2021 Global Risks Report, the World Economic Forum (2021) highlights environmental challenges—particularly biodiversity loss and climate change—as some of the most pressing risks facing the global community. The report integrates these risks into broader discussions about economic and geopolitical stability (World Economic Forum, 2021).

EXPERIMENTAL AND METHODS

This section focuses on the study of the biological properties of research materials in both *in situ* (natural habitat) and *ex situ* (controlled or artificial environment) conditions. It examines five species from the genus *Pyrus L.* found in the northeastern Greater Caucasus, a region notable for its ecological richness and high levels of endemism. The analysis includes a comparative study of morphological traits such as leaf structure, fruit size and shape, growth patterns, flowering time, and seed viability. These traits provide essential insights into the adaptive strategies of *Pyrus L.* species under varying environmental conditions. The study also considers physiological characteristics such as photosynthetic activity, transpiration rates, and reproductive success, which are vital indicators of plant health and environmental fitness. Under *in situ* conditions, the biological traits reflect the species' natural responses to local abiotic factors like soil composition, elevation, moisture levels, and temperature fluctuations. These native habitats allow researchers to assess how these species interact with their surrounding ecosystems, including pollinators, symbiotic fungi, and competitive vegetation.Conversely, ex situ conditions, such as botanical gardens or experimental plots, offer controlled environments to evaluate how these species cope with abiotic stressors like drought, poor soil nutrients, or temperature extremes. Monitoring these factors helps in understanding the ecological plasticity and resilience of each *Pyrus* species, which is crucial for conservation strategies and potential reintroduction into degraded or altered habitats. The section discusses the reproductive biology of these species, including pollen viability, germination rates, and cross-compatibility. These reproductive traits are particularly important for breeding programs aimed at developing climate-resilient cultivars, enhancing fruit production, and conserving genetic diversity.

By documenting and analyzing the biological traits of *Pyrus L.* under both natural and artificial conditions, this part of the study contributes to a deeper understanding of species adaptability and guides effective conservation, restoration, and sustainable utilization strategies. It also highlights the role of such foundational research in supporting the goals of the green economy, where biodiversity conservation is harmonized with agricultural development and ecological restoration.

The table below outlines the natural distribution areas of the *Pyrus* L. species investigated in the northeastern Greater Caucasus, including their GPS coordinates (Table 1).

Table 1. Geographic distribution and coordinates of the studied species (source: http://www.theplantlist.org).

№	**Latin name of the species**	**Common names of species**	**Distribution areas**	**Coordinates**	
1.	*Pyrus communis* L.	Common pear	Khizi r., Dizavar v. Gusar r., Yasab v. Gusar r., Hil v. Gusar r., Mujug v. Guba r., Digah v.	N40°48'10.10" N41°28'20.59" N41°26'19.06" N41°28'15.84" N41°24'26.28"	E49°7'41.50" E48°17'29.93" E48°20'2.59" E48°13'40.20" E48°29'39.00"
2.	*Pyrus caucasica* Fed.	Caucasus pear	Khizi r., Altiaghaj settl. Khizi r., Dizavar v. Guba r., Alpan k Guba r., Digah k Gusar r., Hazra v. Shabran rn, Pirabadil v. Gusar r., Mujug v.	N40°33'10.60" N40°47'56.56" N41°22'21.84" N41°22'53.27" N41°29'36.20" N41°12'18.04" N41°29'7.84"	E48°37'47.04" E49°8'7.65" E48°24'1.48" E48°27'57.86" E48°14'58.68" E48°48'30.39" E48°14'30.29"
3.	*Pyrus georgica* Kuth.	Georgian pear	Khizi r, Altiaghaj settl. Guba r., Ikinji Nughadi v. Guba r., Alpan v. Gusar r., Hazra v. Shabran r., Pirabadil v. Shabran r., Dagh Biliji v.	N40°55'38.82" N41°18'47.01" N41°23'47.26" N41°30'52.84" N41°12'5.65" N41°13'9.45"	E49°0'49.22" E48°35'47.97" E48°24'58.83" E48°16'11.06" E48°48'2.54" E48°50'46.84"

4.	*Pyrus vsevolodii* Heideman	Vsevolod pear	Khizi r, Altiaghaj settl. Siyazan r., Dagh Gushchu Siyazan r., Sadan v. Khachmaz, Hajialibay v.	N40°54'1.71" N40°59'46.09 N41°3'33.98" N41°24'29.49"	E48°57'58.75" E48°57'38.20" E49°1'54.63" E48°41'4.53"
5.	*Pyrus salicifolia* Pall.	Willowleaf pear	Khizi r, Altiaghaj settl. Guba r., Ikinji Nughadi v. Gusar r., Hil v. Khachmaz r., Hajialibay v Siyazan r., Sadan v.	N40°52'37.30" N41°18'48.65" N41°26'50.76" N41°24'14.43" N41°3'19.56"	E48°55'24.16" E48°35'47.58" E48°19'37.70" E48°41'47.20" E49°2'13.94"

This work examines various plant propagation techniques with a focus on horticultural crops and conservation strategies, particularly the genus *Pyrus* L. in the Greater Caucasus region. The study employs a combination of tissue culture, morphological assessment, and germination trials to evaluate the effectiveness of propagation under different conditions. Plant propagation involved sowing seeds collected from both natural habitats and introduced specimens in the Absheron region, specifically within the Central Botanical Garden (Akin et al., 2009; Bhumikaben et al., 2024).] Propagation was conducted in both open (field) and closed (greenhouse) environments during the autumn and spring seasons to determine how seasonal and environmental factors influence seed viability and germination success. The results show that tissue culture provides a reliable method for mass propagation, while environmental conditions significantly affect seed germination and seedling survival. *Ex situ* conservation methods were shown to effectively support species facing threats in natural habitats. The study concludes that integrated propagation strategies combining field and laboratory approaches are essential for conserving rare and economically important species. Future perspectives include the improvement of seed treatments, the use of biotechnology for genetic conservation, and the application of data to broader conservation planning under climate change scenarios.

Through systematic experimental work, the average germination rate of seeds from each *Pyrus* species was calculated. The findings revealed notable differences in germination performance among the species. *Pyrus salicifolia* Pall. demonstrated the highest germination rate under ex situ conditions, reaching 86%, indicating strong adaptability and reproductive potential outside its natural habitat (Figure 1). This suggests that *P. salicifolia* may be particularly well-suited for conservation efforts and reintroduction programs, especially in managed or restored environments. Additionally, variations in germination rates across different environments and seasons provided valuable insights into optimal propagation strategies for each species. These results support the importance of seasonally timed sowing and habitat-specific management in enhancing the success of *ex situ* conservation programs.

Figure 1. Seedlings of the studied plants grown in greenhouse conditions

The research findings indicated that the main difference in the morphological structure of the seedlings was influenced by whether the seeds were collected from *ex situ* or *in situ* conditions. During the germination period, minor but notable changes in the shape of vegetative organs—such as leaf length, stem thickness, and root structure—were observed in some species when compared to those grown under *in situ* conditions. These variations were primarily attributed to the distinct climatic and environmental factors present in the two growing environments, including differences in temperature, humidity, light exposure, and soil composition. While the studies revealed no significant overall difference in the fundamental morphological structure of the sprouts from seeds collected under *in situ* (natural) and *ex situ* (cultivated) conditions, the subtle variations in vegetative organ development highlight the influence of microclimatic differences. These findings suggest that even small environmental changes can affect early plant development, which is crucial information for designing effective *ex situ* conservation and propagation strategies. The implications of these results go beyond basic botanical interest. Understanding how *Pyrus* species respond morphologically in controlled versus natural conditions helps guide conservation practices and supports the principles of the green economy. Specifically, these insights contribute to more sustainable agricultural practices, where native species can be cultivated in managed environments without compromising their natural characteristics or ecological integrity. This approach aligns with goals of biodiversity conservation, sustainable land use, and climate resilience.

The study assessed the conservation status of rare pear species found in the northeastern Greater Caucasus using the IUCN (2001) classification system. The analysis revealed that two of the four rare species—*Pyrus vsevolodii* and *Pyrus salicifolia*—were classified as Vulnerable (VU), indicating a high risk of extinction in the wild if current threats persist. The other two species, *Pyrus caucasica* and *Pyrus georgica*, were categorized as Near Threatened (NT), meaning they are close to qualifying as threatened in the near future. These results underscore the urgent need for targeted conservation actions, such as habitat protection, seed banking, and sustainable cultivation programs, to safeguard these valuable genetic resources. Preserving these species not only contributes to regional biodiversity but also supports ecological balance and long-term sustainability within the framework of green development.

The green economy aims to promote sustainable development by balancing economic growth with environmental protection, with a focus on efficient resource use, biodiversity conservation, and reducing environmental degradation. Biodiversity is fundamental to the green economy, as it underpins ecosystem services that support sustainable economic development. The green economy seeks to stimulate economic growth while minimizing harm to the environment, with biodiversity playing a key role in maintaining ecosystem health, which in turn supports agriculture, forestry, fisheries, and other sectors.

RESULTS AND DISCUSSIONS

The growth and development traits of the studied plants under both in situ and ex situ conditions showed significant variations. Under *ex situ* conditions, *Pyrus salicifolia* Pall. was the tallest one-year-old plant, growing to a height of 28 cm over a period of 101 days. In contrast, *Pyrus georgica* Kuth. had the least growth, reaching only 22 cm in 90 days. In general, the height of the one-year-old plants ranged from 22 to 28 cm, while the two-year-old plants grew between 68 and 82 cm. Among the three-year-old plants, *Pyrus vsevolodii* Heideman showed the least growth at 57 cm, while *Pyrus salicifolia* Pall. demonstrated the most growth at 76 cm. The vegetation period for three-year-old seedlings varied from 112 to 121 days, depending on the species, while the vegetation period for perennial plants ranged from 42 to 61 days . The flowering and fruiting characteristics of the studied plants under both in situ and ex situ conditions revealed that the plants generally begin to flower at the age of 6-7 years in cultivated environments, while they bloom between 8-11 years in their natural habitats. The research indicated that flowering and fruiting occurred 2-4 years later in the studied species under in situ conditions compared to ex situ conditions, depending on the species.

The analysis showed that fruit storage capacity under ex situ conditions was lowest for *Pyrus communis* L. and *Pyrus caucasica* Fed., both having a storage capacity of 11%, while *Pyrus salicifolia* Pall. and *Pyrus georgica* Kuth. had the highest storage capacity at 14%. Conversely, under in situ conditions, the lowest fruit storage was observed in *Pyrus communis* L. and *Pyrus caucasica* Fed. (both at 14%), while *Pyrus salicifolia* Pall. had the highest storage capacity at 22% [Abbasova and Iskender, 2020]. Overall, it was found that plants grown under in situ conditions had 3-8% higher fruit retention compared to those grown under *ex situ* condition (Table 2).

Table 2. The fruiting characteristics of *Pyrus L.* species in the northeastern region of the Greater Caucasus were studied under both *ex situ* and *in situ* condition

№	**Species**	**The number of bloomed flowers per plant**	**The number of fruit**		**Fruit ripening time**	**The number of bloomed flowers per plant**	**The number of fruit**		**Fruit ripening time**
			piece	**%**			**piece**	**%**	
		ex situ				*in situ*			
1.	*Pyrus communis* L.	1331	141	11%	11.09	1350	186	14%	25.09
2.	*Pyrus caucasica* Fed.	1120	122	11%	25.09	1225	167	14%	12.10
3.	*Pyrus georgica* Kuth.	1296	143	14%	21.09	1571	235	15%	08.10
4.	*Pyrus vsevolodii* Heideman	1227	139	12%	20.09	1235	187	15%	06.10
4.	*Pyrus vsevolodii* Heideman	1227	139	12%	20.09	1235	187	15%	06.10
5.	*Pyrus salicifolia* Pall.	2122	297	14%	08.09	2225	511	22%	18.09

The results of this study highlight the critical intersection between biodiversity conservation and today's economic crisis. By integrating sustainable practices into the green economy, we can address both biodiversity loss and economic instability. Focusing on the protection of species like *Pyrus L.* serves as a model for how environmental conservation can contribute to economic resilience. Beyond species protection, the study underscores how biodiversity conservation strengthens ecological systems that underpin economic activities. Healthy ecosystems provide essential services—such as pollination, water purification, soil fertility, and climate regulation—that support a wide range of sectors, particularly agriculture and forestry. In the case of *Pyrus L.* species, preserving genetic diversity ensures the adaptability of crops to changing environmental conditions, supporting food security and agricultural innovation. The research also reveals that green economy approaches—such as eco-agriculture, sustainable land management, and ecosystem restoration—offer scalable solutions for preserving biodiversity while stimulating local economies. These nature-based solutions not only help mitigate the effects of climate change but also create green jobs in conservation, agroforestry, and ecological monitoring. Furthermore, by valuing biodiversity as a natural asset, the green economy promotes investment in conservation infrastructure and ecological research. For example, ex situ conservation programs for *Pyrus L.* in botanical gardens or gene banks contribute to species survival while offering educational and ecotourism opportunities that benefit regional economies.

The findings emphasize that a green economy not only preserves natural resources but also creates sustainable jobs and long-term economic opportunities. It promotes a systemic shift where economic development aligns with ecological health, offering a viable path forward amidst the current environmental and economic challenges. This alignment is particularly urgent in biodiversity hotspots like the Greater Caucasus, where rich ecosystems are under increasing pressure from human activity and climate change.

CONCLUSION

This study underscores the vital importance of integrating biodiversity conservation into the framework of the green economy, using *Pyrus L.* species from the northeastern Greater Caucasus as a case study. The biological, ecological, and reproductive assessments conducted under both *in situ* and *ex situ* conditions provide valuable insights into the adaptive potential, morphological plasticity, and conservation needs of these rare and regionally significant pear species.The findings clearly demonstrate that environmental conditions have a measurable impact on seed germination, seedling morphology, flowering and fruiting cycles, and storage capacities. Notably, *Pyrus salicifolia Pall.* showed superior germination rates and reproductive performance under *ex situ* conditions, marking it as a strong candidate for cultivation, restoration, and genetic preservation initiatives. The observed variations in vegetative and reproductive traits between growing environments emphasize the importance of tailored conservation strategies that consider both natural habitats and managed cultivation sites. From a conservation policy perspective, the classification of *Pyrus vsevolodii* and *Pyrus salicifolia* as Vulnerable (VU), and *Pyrus caucasica* and *Pyrus georgica* as Near Threatened (NT), highlights the urgency of protective measures. These include habitat protection, sustainable propagation techniques, seed banking, and the development of climate-resilient cultivars to safeguard against further biodiversity loss. Beyond the ecological implications, the research affirms the broader socio-economic benefits of conserving genetic diversity and ecosystem services. By aligning species conservation with green economy principles—such as sustainable agriculture, ecosystem restoration, and green job creation—this study presents a compelling model for how biodiversity conservation can also drive economic resilience and sustainable development.

In conclusion, protecting endangered plant species like *Pyrus L.* contributes not only to the preservation of biodiversity but also to the transformation of economic systems toward more inclusive, resilient, and ecologically sound futures. The study reinforces the notion that a thriving green economy must be built on a foundation of healthy ecosystems, long-term resource stewardship, and science-based policy action, particularly in biodiversity hotspots like the Greater Caucasus.

ACKNOWLEDGMENTS: We would like to express our heartfelt gratitude to the Institute of Microbiology for its invaluable support and guidance throughout this work. The institution's profound expertise and continuous encouragement have played a pivotal role in the successful completion of this work.

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