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Primary Introduction and Cultivation Prospects of Medicinal Plants in Southern Kyrgyzstan

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ABSTRACT

Cultivation of medicinal plants in continental climates requires reliable evaluation of their introduction performance and cultivation prospects. The present study assessed the primary introduction of ten medicinal plant species cultivated in the Botanical Garden of Osh State University (southern Kyrgyzstan) during two growing seasons (2022–2024). Field observations included winter survival, aboveground biomass accumulation, seed productivity, thousand-seed weight, and germination capacity. Experimental trials were conducted under open-field conditions using a randomized block design with three replicated plots per species. A two-way analysis of variance (ANOVA) was applied to evaluate the effects of species and year on measured performance indicators. Significant interspecific variability was detected in winter survival, productivity traits, and reproductive parameters ($p < 0.05$). Perennial species generally demonstrated stable establishment and satisfactory overwintering, while annual and biennial species showed rapid generative development during the first growing season. *Origanum vulgare* exhibited moderate biomass accumulation but maintained consistently high winter survival and seed germination, indicating favorable cultivation prospects under the continental climatic conditions of southern Kyrgyzstan. Interannual differences in plant performance were associated

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with variations in minimum winter temperatures and spring precipitation. The results highlight the importance of multi-year introduction trials for evaluating cultivation potential of medicinal plants under variable mountain climate conditions. The study provides baseline information for ex situ conservation of medicinal plant genetic resources and supports the development of regionally adapted cultivation strategies for economically valuable species in Central Asia.

Keywords: *Origanum vulgare*; Medicinal Plants; Plant Introduction; Botanical Gardens; Ecological Adaptation; Kyrgyzstan

1. Introduction

Mountain regions of Central Asia represent important centers of floristic diversity characterized by pronounced altitudinal zonation, complex relief, and sharply continental climatic conditions. These environmental features create heterogeneous ecological niches that strongly influence plant distribution, growth performance, and reproductive success [1–3]. In such environments, the introduction and cultivation of economically valuable plant species, including medicinal plants, is associated with both scientific challenges and practical importance.

The flora of southern Kyrgyzstan, particularly the Alay region, includes numerous medicinal plant species traditionally used in folk medicine and increasingly recognized for their pharmacological and economic value [1,2]. At the same time, unsustainable harvesting of wild medicinal resources poses a potential threat to natural populations and ecosystem stability. Therefore, the development of cultivation technologies and the identification of species suitable for agricultural production are considered important components of biodiversity conservation and sustainable land use strategies [4,5].

Cultivation of medicinal plants in continental mountain climates requires careful evaluation of species performance under local environmental conditions. Southern Kyrgyzstan is characterized by cold winters, large annual temperature fluctuations, irregular precipitation patterns, and frequent spring weather anomalies. These factors may significantly affect plant establishment success, overwintering ability, and biomass accumulation. Moreover, traditional pastoral land use and grazing pressure contribute to changes in vegetation structure and productivity, influencing both natural and introduced plant populations [6–8].

Botanical gardens play a crucial role in experimental introduction programs aimed at evaluating cultivation potential of economically valuable plant species. Field trials conducted under open-ground conditions in botanical garden collections provide opportunities to assess survival rates, growth dynamics, reproductive traits, and general cultivation performance in environments that approximate regional agroecological conditions. Such studies contribute not only to the development of sustainable production systems but also to ex situ conservation of plant genetic resources and the maintenance of medicinal plant diversity [4,9].

Medicinal plant species differ considerably in life history strategies, phenological patterns, and ecological requirements. Annual, biennial, and perennial plants respond differently to abiotic stresses such as low winter temperatures, spring drought, soil moisture variability, and microrelief heterogeneity. These differences influence biomass productivity, timing of generative development, and seed formation success. Consequently, comparative evaluation of species representing different life forms is necessary to determine their suitability for cultivation in continental climates and to identify promising candidates for regional agricultural systems [10,11].

Plant responses to new climatic conditions are largely mediated by phenotypic plasticity and genetic adaptation mechanisms that determine survival and productivity under environmental stress [12–14]. In continental mountain regions, strong climatic variability may impose ecological limits on plastic responses and influence long-term acclimatization success of introduced populations [13].

Previous research in Central Asia has primarily focused on floristic inventories, ethnobotanical documentation, and pharmacological screening of medicinal plant species [1,12]. Although these studies have provided valuable baseline information, systematic introduction experiments involving multi-year field observations remain relatively limited. Reliable assessment of cultivation prospects requires repeated measurements across several vegetation seasons, as plant performance may vary substantially between years due to climatic variability and environmental fluctuations. In mountain ecosystems, extreme winter events or irregular precipitation patterns can significantly influence plant survival and productivity, highlighting the importance of long-term evaluation approaches [15,16].

Regional vegetation patterns and floristic diversity gradients also influence the ecological compatibility of introduced species and should be considered when evaluating cultivation prospects in Central Asian mountain systems [17].

The Botanical Garden of Osh State University serves as an important experimental platform for studying the introduction of medicinal plants under environmental conditions typical of southern Kyrgyzstan. Over recent years, several species of pharmacological and economic interest have been introduced from natural habitats and other introduction centers. Evaluation of their winter survival, biomass accumulation, reproductive characteristics, and seed quality parameters provides essential information for assessing their cultivation prospects and potential role in regional agricultural diversification.

The aim of the present study was to evaluate the primary introduction performance and cultivation prospects of selected medicinal plant species under continental climatic conditions of southern Kyrgyzstan. The specific objectives included: (1) assessment of winter survival and establishment success of introduced species; (2) comparison of growth and biomass productivity among species representing different life forms; (3) evaluation of reproductive traits and seed quality indicators; and (4) identification of species demonstrating relatively stable cultivation performance across years. The results are expected to contribute to the development of scientifically grounded recommendations for medicinal plant cultivation in mountain environments and to support strategies for sustainable use and conservation of plant genetic resources in Central Asia.

2. Materials and Methods

2.1. Study Area

The study was conducted in the Botanical Garden of Osh State University (40°32′ N, 72°48′ E; 870 m a.s.l.), located in southern Kyrgyzstan. The region is characterized by a sharply continental climate with cold winters, hot summers, and irregular precipitation distribution. Long-term climatic records indicate a mean annual temperature of approximately 12.5 °C and total annual precipitation ranging from 350 to 450 mm.

During the experimental period (2022–2024), climatic conditions differed markedly between years. The winter of 2022/2023 was relatively severe, with minimum air temperatures reaching −18 °C and unstable snow cover (5–8 cm). In contrast, winter 2023/2024 was milder (minimum temperature −12 °C) and characterized by more stable snow cover (10–15 cm). Spring precipitation in 2023 was below the long-term average, whereas increased rainfall was recorded during April–May 2024. Hydrothermal conditions during the growing season were evaluated using the Selyaninov hydrothermal coefficient [18].

2.2. Plant Material and Introduction Status

Ten medicinal plant species representing different life forms (annual, biennial, and perennial) were selected for primary introduction trials.

Plant material originated from natural populations in the Osh and Alai regions of southern Kyrgyzstan and partly from the seed collection of the Botanical Garden. Each species was represented by a single accession of known geographic origin, and therefore the experiment represents a primary introduction study focused on early stages of acclimatization under open-field cultivation conditions.

Perennial species were established in spring 2022 and evaluated mainly during their second vegetation year, when most individuals had entered the generative phase. Annual species were evaluated during their first growing season.

2.3. Experimental Design

Field trials were established in spring 2022 using a randomized block design. Each species was cultivated in an individual experimental plot of 10 m^2, with an accounting (harvest) area of 6 m^2. Plant density ranged from 8 to 10 individuals per m^2 depending on growth habit and morphological characteristics.

Each treatment consisted of three replicated plots, each containing approximately 40–60 individual plants depending on species density. Replicates were spatially randomized within the experimental field to minimize the effects of microrelief variation and soil heterogeneity.

Mean trait values were calculated at the plot level, and replicate plots were treated as experimental units in statistical analyses.

No artificial winter protection or mulching was applied in order to assess natural overwintering capacity under local climatic conditions.

2.4. Measured Traits

Adaptive performance was evaluated using the following indicators:

Winter Survival (%). Winter survival was assessed only for perennial species and calculated as the percentage of living plants recorded in spring relative to plant density measured in autumn before overwintering.

Biomass Yield (t ha^{-1}). Above-ground biomass was harvested at the full flowering stage from the accounting area of each plot. Fresh mass was measured and recalculated per square meter.

Seed Productivity (t ha^{-1}). Seed yield was determined at full maturity and recalculated per hectare.

1,000-Seed Weight (g). Measured by weighing four subsamples of 250 seeds and recalculating to the standard 1000-seed mass.

Germination Capacity (%). Laboratory germination tests were performed according to ISTA guidelines under controlled temperature (22 ± 2 °C). Final germination percentage was recorded on day 14.

2.5. Integrated Adaptive Assessment

To obtain a multidimensional evaluation of introduction success, an Integrated Adaptive Index (IAI) was calculated for each species based on normalized values of four indicators: winter survival, biomass productivity, seed productivity, and germination capacity.

The index was calculated as:

$$IAI = \frac{WSn + BYn + SPn + GCn}{4}$$

where WSn, BYn, SPn, and GCn represent normalized trait values ranging from 0 to 1.

This approach allowed comparison of overall adaptive performance among species without relying solely on vegetative productivity indicators.

2.6. Selective Identification of Promising Genotypes

Within the introduced population of *Origanum vulgare*, individual plants were evaluated across two consecutive growing seasons. Plants consistently belonging to the upper 20% for both biomass yield and seed productivity were identified as promising genotypes for further breeding and cultivation trials.

2.7. Statistical Analysis

All measurements were obtained from three replicated plots per species. Data are presented as mean ± standard deviation (SD).

A two-way analysis of variance (ANOVA) was applied to test the effects of species and year on winter survival, biomass productivity, and seed yield. When significant differences were detected ($p < 0.05$), Tukey's HSD test was used for post-hoc comparisons.

The coefficient of variation (CV%) was calculated to evaluate trait stability across years. Statistical analyses were performed using SPSS 26.0 software.

3. Results

3.1. Winter Survival of Introduced Medicinal Plants

Winter survival of introduced medicinal plant species varied both among species and between study years, reflecting interspecific differences in tolerance to continental climatic conditions. The highest overwintering success was recorded in *Artemisia absinthium, Origanum vulgare,* and *Salvia officinalis*, with mean survival values exceeding 82%. These species demonstrated stable establishment and effective recovery after winter stress. Moderate survival rates were observed in *Carum carvi, Matricaria chamomilla*, and Conium maculatum, while comparatively lower overwintering ability was recorded in *Glaucium fimbrilligerum* and *Codonopsis clematidea.*

A complete comparison of winter survival across species and years is presented in **Table 1**.

Table 1. Winter survival (%) of introduced medicinal plant species during two winter seasons

Species	Winter 2022/2023 (%)	Winter 2023/2024 (%)	Mean (%)
Origanum vulgare	82	87	84.5
Salvia officinalis	80	85	82.5
Artemisia absinthium	88	92	90
Carum carvi	75	80	77.5
Matricaria chamomilla	78	83	80.5
Conium maculatum	76	81	78.5
Delphinium confusum	70	75	72.5
Glaucium fimbrilligerum	65	70	67.5
Codonopsis clematidea	68	72	70

The perennial species *Dictamnus angustifolius* did not survive winter conditions and was therefore excluded from further productivity analysis. The observed variation in overwintering success indicates that winter hardiness represents one of the key limiting factors for successful introduction under continental climate conditions.

3.2. Biomass Productivity

Considerable interspecific variability was observed in biomass accumulation under field conditions. The highest biomass yield was recorded in Artemisia absinthium, which produced between 850 and 1,542 g m^{-2}, with a mean value of 1,196 g m^{-2} (11.96 t ha^{-1}). This species demonstrated vigorous vegetative growth and strong ecological plasticity.

Relatively high productivity was also observed in *Matricaria chamomilla* (mean 685 g m^{-2}) and *Conium maculatum* (mean 600 g m^{-2}). Intermediate productivity levels were characteristic of *Carum carvi* and *Delphinium confusum*, whereas lower biomass accumulation was recorded in *Salvia officinalis, Origanum vulgare, Glaucium fimbrilligerum,* and *Codonopsis clematidea*.

Detailed biomass productivity values are presented in **Table 2**, while the comparative distribution of biomass yield among species is illustrated in **Figure 1**.

3.3. Seed Productivity and Seed Quality

Seed productivity and seed quality characteristics differed among species and reflected variation in reproductive stability under introduction conditions. The highest seed yield was recorded in *Artemisia absinthium* (0.95 t ha^{-1}), followed by *Origanum vulgare* (0.85 t ha^{-1}) and *Conium maculatum* (0.80 t ha^{-1}).

High germination capacity (>85%) was observed in *Origanum vulgare, Carum carvi,* and *Artemisia absinthium*, indicating good seed viability and successful completion of reproductive cycles. Lower germination rates were recorded in *Glaucium fimbrilligerum* and *Codonopsis clematidea*, suggesting reduced reproductive performance.

A comparative overview of seed productivity, 1,000-seed weight, and germination capacity is provided in **Table 3**.

3.4. Productivity Grouping

Based on biomass productivity, the introduced medicinal plant species were grouped into three productivity categories. High-productivity species (>600 g m^{-2}) included *Artemisia absinthium, Matricaria chamomilla*, and *Conium maculatum*. Moderate productivity (300–600 g m^{-2}) was recorded in *Carum carvi* and *Delphinium confusum*, while low productivity (<300 g m^{-2}) was characteristic of *Salvia officinalis, Origanum vulgare, Glaucium fimbrilligerum*, and *Codonopsis clematidea*.

This classification reflects interspecific differences in growth strategy and ecological plasticity under continental climatic conditions. The grouping of species according to productivity levels is presented in **Figure 2**.

3.5. Integrated Adaptive Index

To obtain a comprehensive evaluation of adaptive performance, an integrated adaptive index (IAI) was calculated by normalizing four key indicators: winter survival, biomass yield, seed productivity, and germination capacity. This approach allowed comparison of overall adaptive performance among species rather than relying on single productivity traits.

The highest adaptive score was recorded in *Artemisia absinthium* (IAI = 1.00), confirming its strong ecological plasticity and suitability for cultivation under continental climatic conditions. High adaptive performance was also observed in *Conium maculatum* (IAI = 0.79), *Matricaria chamomilla* (IAI = 0.77), and *Carum carvi* (IAI = 0.77).

Notably, *Origanum vulgare* demonstrated a relatively high adaptive index (IAI = 0.75), reflecting stable overwintering, high germination capacity, and satisfactory reproductive performance despite moderate biomass accumulation. Intermediate adaptive performance was recorded in *Salvia officinalis* and *Delphinium confusum*, whereas the lowest adaptive scores were observed in *Glaucium fimbrilligerum* and *Codonopsis clematidea*.

Comparative adaptive performance based on the integrated index is illustrated in **Figure 3**.

Table 2. Biomass yield of introduced medicinal plant species.

Species	Biomass Yield Range (g/m^2)	Mean (g/m^2)
Artemisia absinthium	850–1,542	1,196
Matricaria chamomilla	540–830	685
Conium maculatum	500–700	600
Carum carvi	400–650	525
Delphinium confusum	280–450	365
Salvia officinalis	205	205
Origanum vulgare	180–220	200
Glaucium fimbrilligerum	100–250	175
Codonopsis clematidea	120–170	145

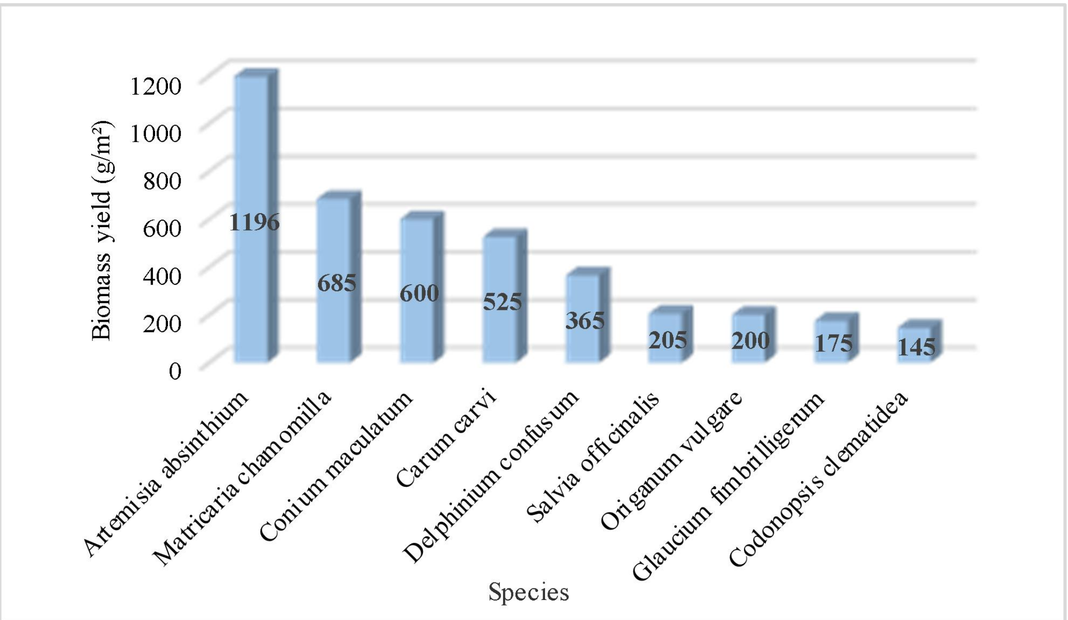

Figure 1. Biomass yield (g m^{-2}) of introduced medicinal plant species cultivated in the Botanical Garden of Osh State University

Table 3. Seed productivity and seed quality parameters of introduced medicinal plant species.

Species	Seed Productivity (t/ha)	1,000-Seed Weight (g)	Germination (%)
Origanum vulgare	0.85	0.18	86
Salvia officinalis	0.70	6.20	82
Artemisia absinthium	0.95	0.15	88

Table 3. *Cont.*

Species	Seed Productivity (t/ha)	1,000-Seed Weight (g)	Germination (%)
Carum carvi	0.75	3.40	85
Matricaria chamomilla	0.65	0.07	83
Conium maculatum	0.80	2.10	84
Delphinium confusum	0.60	2.50	78
Glaucium fimbrilligerum	0.50	0.90	76
Codonopsis clematidea	0.45	0.60	75

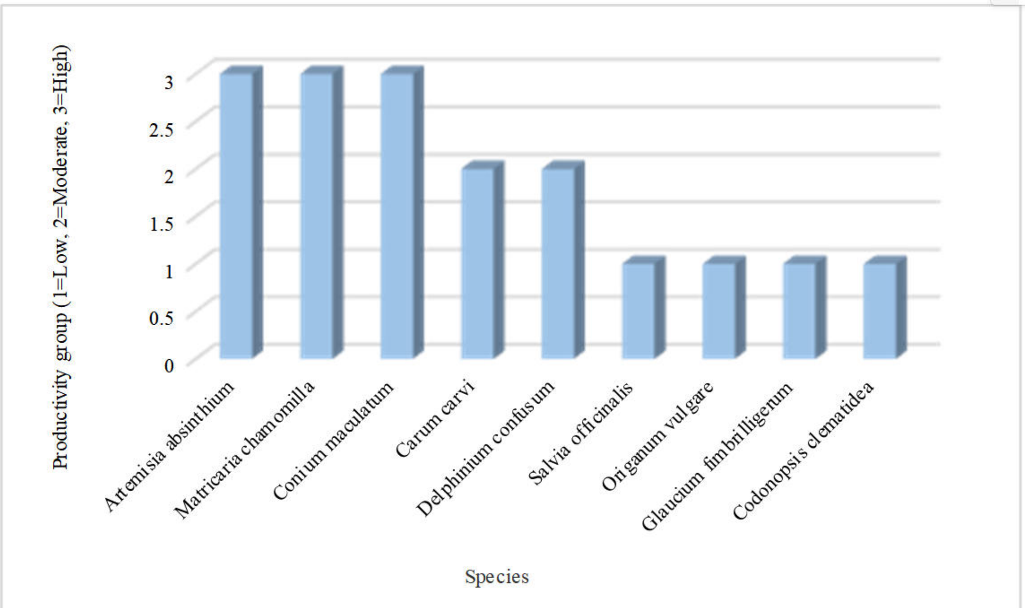

Figure 2. Productivity grouping of introduced medicinal plant species based on biomass yield levels.

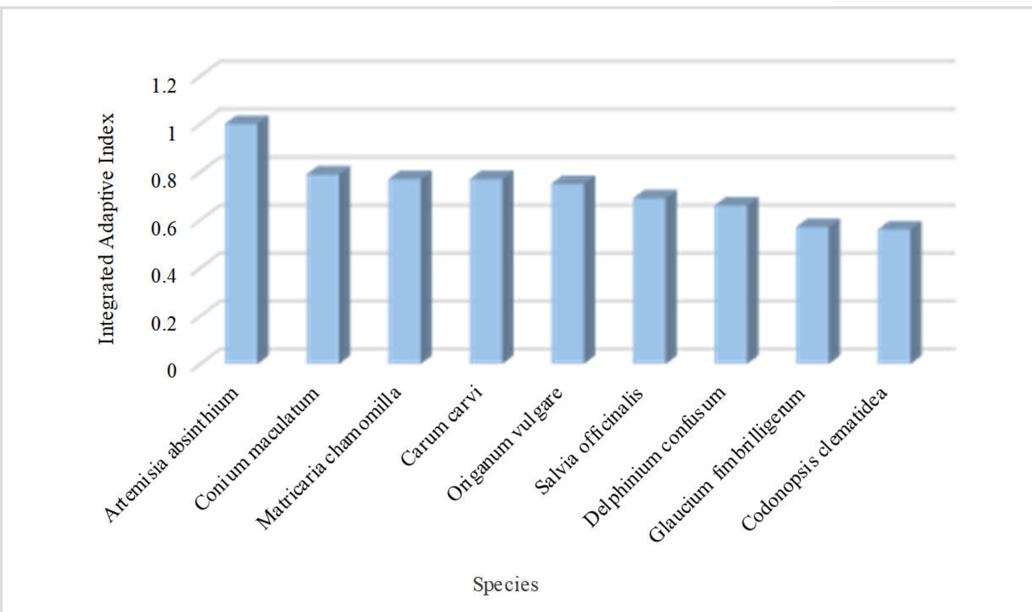

Figure 3. Integrated adaptive index (IAI) of introduced medicinal plant species.

4. Discussion

The introduction of medicinal plants into new environmental conditions represents a complex ecological and biological process that integrates species-specific traits, climatic constraints, and cultivation practices. Botanical gardens serve as important experimental platforms for evaluating the adaptive potential of plant species outside their natural habitats and contribute significantly to ex situ conservation strategies and sustainable utilization of plant resources [1].

Similar variability in introduction success has been documented in experimental cultivation of Central Asian herbaceous species in botanical gardens, where differences in survival and productivity were associated with climatic constraints and soil conditions [19,20].

Botanical gardens are increasingly recognized as global centers for plant conservation, introduction biology, and testing of climate resilience strategies for economically important taxa [21,22].

The results of the present study revealed pronounced interspecific variability in survival, biomass accumulation, and reproductive performance among the introduced medicinal plants cultivated under the continental climatic conditions of southern Kyrgyzstan. Such variability is characteristic of primary introduction trials and reflects differences in ecological plasticity, growth strategies, and physiological tolerance to environmental stress [6]. Importantly, adaptive performance cannot be interpreted solely on the basis of biomass productivity, since interspecific differences in vegetative growth often reflect inherent biological characteristics rather than true ecological adaptation.

To address this limitation, the present study applied an integrated adaptive assessment that combined winter survival, biomass productivity, seed productivity, and germination capacity. This multidimensional approach provides a more ecologically meaningful evaluation of introduction success compared with simple productivity ranking. The integrated analysis demonstrated that species such as *Artemisia absinthium, Matricaria chamomilla,* and *Conium maculatum* exhibited high adaptive potential due to the combination of stable overwintering, substantial biomass formation, and consistent reproductive performance. These findings are consistent with previous studies indicating high ecological plasticity of drought-tolerant and fast-growing medicinal species in continental climates [19].

Moderate adaptive performance observed in *Carum carvi* and *Delphinium confusum* suggests partial ecological compatibility with the environmental conditions of the experimental site. Caraway is known to demonstrate stable growth in temperate agroecosystems, whereas species of the genus Delphinium are often associated with cooler mountain habitats, which may explain their intermediate productivity under foothill conditions. Such results highlight the importance of matching ecological requirements of introduced species with local environmental gradients.

Lower biomass productivity recorded in *Salvia officinalis* and *Origanum vulgare* should not be interpreted as evidence of poor adaptation. In perennial aromatic species, moderate vegetative productivity may be associated with resource allocation to secondary metabolite synthesis and reproductive stability rather than rapid biomass accumulation. In the case of *Origanum vulgare*, relatively high winter survival and strong seed germination capacity indicate successful ecological establishment despite moderate biomass yield. Previous research has demonstrated considerable ecological amplitude and phytochemical diversity of oregano populations across Eurasia, supporting its potential for cultivation under varied climatic conditions.

Oregano species are known to exhibit high phytochemical variability and ecological amplitude across Eurasian habitats, which may contribute to their adaptive potential under contrasting environmental conditions [23–25]. Cultivation studies have also emphasized the importance of agronomic optimization and selection of locally adapted genotypes for improving productivity of aromatic crops [26].

Selective identification of high-performing individuals within the introduced population of *Origanum vulgare* revealed the presence of genotypes combining stable survival with relatively higher productivity. Such intra-population variability represents an important resource for future breeding programs aimed at developing locally adapted cultivation forms. In introductory biology, the early stages of acclimatization are often characterized by moderate productivity followed by gradual improvement under continued selection and agronomic optimization.

The lowest adaptive performance was observed in

Codonopsis clematidea and *Glaucium fimbrilligerum*, which demonstrated limited biomass formation and weaker reproductive indicators. These species are typically associated with specific ecological niches and may require particular soil or microclimatic conditions that were not fully reproduced at the experimental site. Failure of *Dictamnus angustifolius* to establish successfully further emphasizes that not all medicinal taxa possess sufficient ecological plasticity for cultivation outside their natural habitats. Identification of such limitations is an important outcome of primary introduction studies, as it allows researchers to refine species selection for sustainable cultivation programs.

Overall, the findings highlight the necessity of species-specific and multidimensional evaluation in medicinal plant introduction research. Adaptive success under continental climatic conditions depends not only on vegetative growth but also on the stability of survival and reproductive processes over multiple seasons. Long-term monitoring of introduced populations, including assessment of seed quality, phenological stability, and phytochemical characteristics, is therefore essential for reliable evaluation of cultivation prospects.

Integration of regional floristic research and experimental introduction trials contributes to a better understanding of medicinal plant resource potential in Central Asia and supports evidence-based strategies for sustainable utilization [27–29].

The present study contributes to the development of evidence-based strategies for medicinal plant introduction in Central Asia and demonstrates that several economically valuable species possess sufficient ecological plasticity to be cultivated successfully in southern Kyrgyzstan. Botanical gardens thus play a crucial role in linking biodiversity conservation with sustainable agricultural utilization of plant genetic resources.

5. Conclusions

The present study provides a comprehensive evaluation of the primary introduction and cultivation prospects of ten medicinal plant species under the sharply continental climatic conditions of southern Kyrgyzstan. The results demonstrate substantial interspecific variability in survival, vegetative productivity, and reproductive performance during the early stages of acclimatization. Such variability reflects differences in ecological plasticity and physiological tolerance to temperature fluctuations, moisture deficit, and winter stress typical of mountain foothill environments. These findings should also be considered in the context of ongoing climate change trends that may alter species distribution patterns, cultivation suitability, and long-term resilience of introduced plant populations in mountain regions [30].

A key methodological contribution of the study is the application of an integrated adaptive assessment combining winter survival, biomass productivity, seed productivity, and germination capacity. This multidimensional approach allows a more reliable evaluation of introduction success compared with single-trait indicators and provides a practical framework for future introduction biology studies in continental regions.

Among the studied taxa, *Artemisia absinthium, Matricaria chamomilla,* and *Conium maculatum* demonstrated the highest adaptive potential, characterized by stable overwintering, significant biomass formation, and consistent reproductive performance. These species can be considered promising candidates for further cultivation trials and potential agricultural utilization in southern Kyrgyzstan. Moderate adaptive performance observed in *Carum carvi* and *Delphinium confusum* suggests partial ecological compatibility with local environmental conditions and indicates the need for continued multi-year monitoring.

Despite moderate biomass productivity, *Origanum vulgare* exhibited stable establishment, high winter survival, and strong seed germination capacity, confirming its ecological suitability for cultivation under continental climatic conditions. The identification of high-performing individuals within the introduced population highlights the importance of intra-population variability as a resource for adaptive selection and breeding of locally adapted genotypes. These findings provide a scientific basis for the gradual domestication and sustainable cultivation of oregano in the region.

In contrast, limited adaptive performance recorded in *Codonopsis clematidea* and *Glaucium fimbrilligerum*, as well as the unsuccessful establishment of *Dictamnus angustifolius*, indicates that not all medicinal species possess sufficient ecological plasticity for introduction into foothill agroecosystems. Recognition of such constraints is essential for optimizing species selection and minimizing risks associated with cultivation attempts outside natural habitats.

Overall, the study confirms that botanical gardens represent effective experimental platforms for evaluating introduction success, conserving plant genetic resources, and developing regionally adapted cultivation technologies. The findings contribute to introduction biology, sustainable utilization of medicinal plant resources, and biodiversity conservation strategies in Central Asia.

Future research should focus on long-term monitoring of introduced populations, evaluation of phenological stability and phytochemical composition, and refinement of integrated adaptive indices. Such investigations will enhance the scientific basis for the cultivation, breeding, and sustainable management of medicinal plants under continental climate conditions.

Author Contributions

Conceptualization, Z.A.; methodology, G.D. and M.T.; resources, M.K. and O.K.; data curation, M.K. and O.K.; writing—original draft preparation, M.T.; writing—review and editing, A.D. and A.B.; supervision, B.K. and Z.A.; project administration, B.K. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The study was conducted at the educational and scientific laboratory "Biodiversity of Plants" of Osh State University. Experimental materials and plant samples were maintained at the experimental field of the Botanical Garden of Osh State University. Data supporting the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

All the authors also declare that there is no conflict of interest in relation to the research, authorship, and publication of this study.

AI Use Statement

The authors declare that no artificial intelligence (AI) tools were used in the preparation of this manuscript.

References

[1] Krishnan, S., Novy, A., 2016. The role of botanic gardens in the twenty-first century. CABI Reviews. 11(23), 1–10. DOI: https://doi.org/10.1079/PAVSNNR201611023

[2] Huang, H., Liao, J., 2022. On China's national botanical gardens: Building a comprehensive system of ex situ conservation of national botanical gardens with task oriented disciplines. Biodiversity Science. 30(6), 22220. DOI: https://doi.org/10.17520/biods.2022220 (in Chinese)

[3] Chen, G.S., 2012. Exploring methods to strengthen multi-function of medicinal botanical gardens. Advanced Materials Research. 524–527, 2122–2126. DOI: https://doi.org/10.4028/www.scientific.net/AMR.524-527.2122

[4] Minyazeva, Y.M., 2023. Medicinal plants of the Far East in the Botanical Garden of VILAR. Problems of Botany of South Siberia and Mongolia. 22(1), 225–229.

[5] Heywood, V.H., 2017. Plant conservation in the Anthropocene—Challenges and future prospects. Plant Diversity. 39(6), 314–330. DOI: https://doi.org/10.1016/j.pld.2017.10.004

[6] Tsitsilin, A.N., 2021. Introduction of medicinal and essential oil plants in botanical gardens (Current state,

prospects, problems). Plant Biology and Horticulture: Theory, Innovations. 4(161), 86–92.

[7] Vasfilova, E.S., Sushentsov, O.E., Zainullina, K.S., et al., 2013. Regularities of medicinal plant introduction based on vitality analysis. Vestnik Perm University. Biology. 2, 4–10.

[8] Lazkov, G.A., Sultanova, B.A., 2014. Checklist of Vascular Plants of Kyrgyzstan. Botanical Research Institute Press: Bishkek, Kyrgyzstan.

[9] Nicotra, A.B., Atkin, O.K., Bonser, S.P., et al., 2010. Plant phenotypic plasticity in a changing climate. Trends in Plant Science. 15(12), 684–692. DOI: https://doi.org/10.1016/j.tplants.2010.09.008

[10] Jump, A.S., Peñuelas, J., 2005. Running to stand still: Adaptation and climate change. Ecology Letters. 8(9), 1010–1020. DOI: https://doi.org/10.1111/j.1461-0248.2005.00796.x

[11] Parmesan, C., 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution, and Systematics. 37, 637–669.

[12] Sultan, S.E., 2000. Phenotypic plasticity for plant development, function and life history. Trends in Plant Science. 5(12), 537–542.

[13] Valladares, F., Gianoli, E., Gómez, J.M., 2007. Ecological limits to plant phenotypic plasticity. New Phytologist. 176(4), 749–763.

[14] Franks, S.J., Hoffmann, A.A., 2012. Genetics of climate change adaptation. Annual Review of Genetics. 46, 185–208.

[15] Teixeira, B., Marques, A., Ramos, C., et al., 2013. Chemical composition and bioactivity of different oregano (Origanum vulgare) extracts and essential oil. Journal of the Science of Food and Agriculture. 93, 2707–2714.

[16] Intergovernmental Panel on Climate Change (IPCC), 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability. IPCC: Geneva, Switzerland. Available from: https://www.ipcc.ch/report/ar6/wg2/

[17] Polechońska, L., Gleńsk, M., Klink, A., et al., 2020. Allelopathic potential of invasive wetland plant *Veronica peregrina*. Plant Biosystems. 154(4), 481–487. DOI: https://doi.org/10.1080/11263504.2019.1635225

[18] Selyaninov, G.T., 1928. About climate agricultural estimation. Proceedings on Agricultural Meteorology. 20, 165–177.

[19] Khrynova, T.R., Khrynova, A.N., 2023. Cultivation of Herbaceous Plants of Central Asia in Different Open Ground Exposures of the Botanical Garden of IBBM NNGU. Problems of Botany of South Siberia and Mongolia. 22(1), 400–404.

[20] Ivashchenko, A.A., Grudzinskaya, L.M., Tursynbai, A., et al., 2023. Experience of primary introduction of Fritillaria karelinii in the main botanical garden of Almaty. Problems of Botany of South Siberia and Mongolia. 22(1), 166–172.

[21] Heywood, V.H., 2017. The Future of Plant Conservation and the Role of Botanic Gardens. Plant Diversity, 39(6), 309–313. DOI: https://doi.org/10.1016/j.pld.2017.12.002

[22] Mounce, R., Smith, P., Brockington, S., 2017. Ex situ conservation of plant diversity in the world's botanic gardens. Nature Plants. 3, 795–802. DOI: https://doi.org/10.1038/s41477-017-0019-3

[23] Lukas, B., Schmiderer, C., Novak, J., 2015. Phytochemical diversity of European Origanum vulgare L. (Lamiaceae). Phytochemistry. 109, 32–40.

[24] Leyva-López, N., Gutiérrez-Grijalva, E.P., Vazquez-Olivo, G., et al., 2017. Essential Oils of Oregano: Biological Activity beyond Their Antimicrobial Properties. Molecules. 22(6), 989. DOI: https://doi.org/10.3390/molecules22060989

[25] Vokou, D., Kokkini, S., Bessiere, J.M., 1993. Geographic variation of Greek oregano (*Origanum vulgare ssp. hirtum*) essential oils. Biochemical Systematics and Ecology. 21(2), 287–295.

[26] Skoufogianni, E., Solomou, A.D., Danalatos, N.G., 2019. Ecology, Cultivation and Utilization of the Aromatic Greek Oregano (Origanum vulgare L.): A Review. Notulae Botanicae Horti Agrobotanici Cluj-Napoca. 47(3), 545–552.

[27] Karimov, B., Dursunbaeva, A., Babekov, A., et al., 2024. Analysis of medicinal flora of the Kurshab River basin in Eastern Alay to preserve biodiversity. E3S Web of Conferences. 537, 05009. DOI: https://doi.org/10.1051/e3sconf/202453705009

[28] Arjjumend, H., 2023. Mountain Ecosystems and Resources Management. The Grassroots Institute: Rome, Italy. Available from: https://grassrootsinstitute.net/books-mountaina.html

[29] United Nations Environment Programme (UNEP), 2018. Assessment Report on Biodiversity & Ecosystem Services in Europe and Central Asia: A Primer. United Nations Environment Programme: Nairobi, Kenya. Available from: https://www.unep.org/resources/assessment/assessment-report-biodiversity-ecosystem-services-europe-and-central-asia

[30] Intergovernmental Panel on Climate Change (IPCC), 2023. The Intergovernmental Panel on Climate Change's Sixth Assessment Report (AR6), Working Group II-Climate Change 2023: Impacts, Adaptation, and Vulnerability. IPCC: Geneva, Switzerland.