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Phenology and Morphological Changes of *Origanum vulgare* L. during Introduction in the Precarpathian Region

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Abstract
This study examines the ontogenetic development of *Origanum vulgare* L. during its introduction in the Precarpathian region to evaluate the acclimatization of the species to new growth conditions. The research established that the pre-generative period includes seedling, juvenile, and immature stages, with the latter being the shortest (15 days). The young generative stage was identified as the longest developmental phase, lasting 78 days. During the middle-aged generative stage, plants reached peak productivity, attaining heights of 30.0–42.0 cm and forming 12–32 inflorescences. A significant phenological shift was observed: the active flowering period extended until mid-September, and the transition to the subsenile period occurred only in October. This extension is attributed to regional climatic warming, with October temperatures ranging from 12 to 20°C, which delayed winter dormancy. The successful completion of all life-cycle stages and the observed phenotypic plasticity confirm the high adaptive potential of *Origanum vulgare* L. in the region. The results support the feasibility of broader introduction using various cultivation methods, including seedling-based establishment.

Keywords: *Origanum vulgare* L., plant introduction, Precarpathian region, adaptation, phenology, acclimatization.

1. INTRODUCTION

Plant introduction constitutes the purposeful translocation of species from their centers of natural origin to new ecological niches for acclimatization and cultivation (Khan 2017). The scientific significance of this process is multifaceted; it serves not only as a fundamental method in experimental botany for investigating adaptive mechanisms outside the natural range but also as a critical component of agricultural science, specifically in expanding the genetic base for plant breeding (Khan 2017). This process utilizes various forms of germplasm, including seeds, vegetative organs, and seedlings, to establish viable ex situ populations (Khan 2017).

The focal object of this study is *Origanum vulgare* L., a perennial herbaceous species within the Lamiaceae family. The selection of this crop is predicated on its high commercial and therapeutic value, driven by a specialized biochemical profile characterized by the accumulation of essential oils and bioactive secondary metabolites (Machado et al. 2023; Lukas et al. 2013; Carmo et al. 2008).

The research investigates the introduction of *O. vulgare L.* into the specific agro-climatic conditions of the Precarpathian region (Ivano-Frankivsk), utilizing the experimental grounds of the "Druzhba" Dendrological Park (Vasyl Stefanyk Carpathian National University). While the edaphic and climatic parameters of the Subcarpathian and Carpathian zones theoretically favor the distribution of this species, there is a critical paucity of systematic, up-to-date empirical data regarding its specific adaptive potential and growth dynamics in this area.

The successful development of introduction protocols for *Origanum vulgare* L. is essential for substantiating the feasibility of its transition to industrial-scale cultivation. This has significant implications for regional economic diversification and the development of the agribusiness sector. Furthermore, this research carries practical importance for enriching the collections of medicinal and aromatic crops in botanical gardens and arboretums of the Precarpathian region in Ivano-Frankivsk, as well as enhancing the biodiversity of local recreational zones.

2. METHODS AND MATERIALS

Measurements were carried out in field conditions on specimens of *Origanum vulgare* L., which were introduced to the territory of Ivano-Frankivsk (Precarpathian region), namely the dendrological park "Druzhba" of the Vasyl Stefanyk Carpathian National University (Fig.1) and grown from seeds.

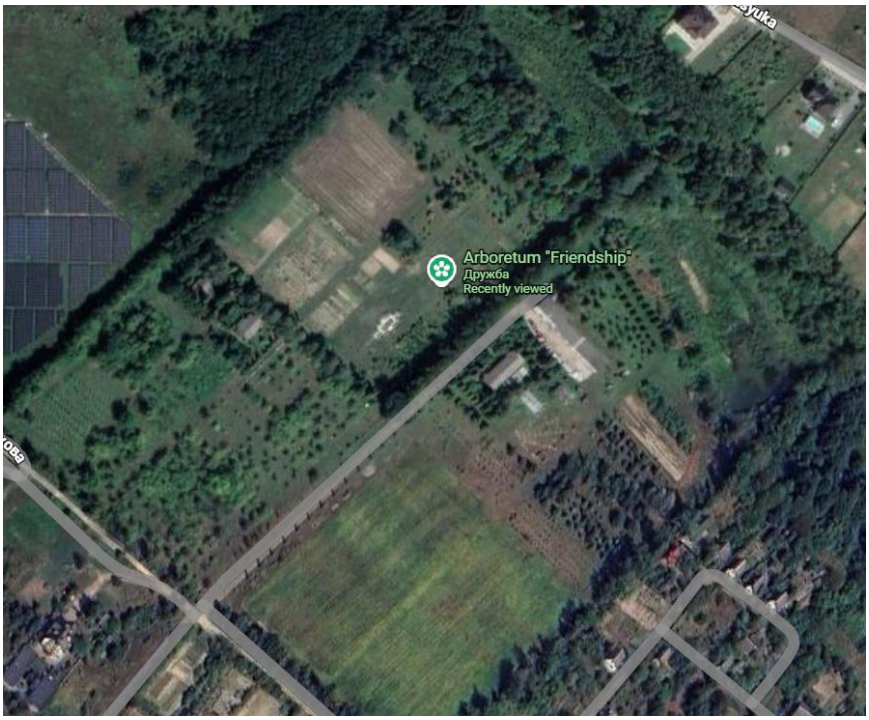

Fig.1. Dendrological Park 'Druzhba' at coordinates: 48.951869, 24.669828

Observations were carried out on annual plants in the period from April to September 2025, to study the growth, development, and morphological features of the species under conditions of introduction.

3. RESULTS AND DISCUSSION

Within the 'Druzhba' arboretum territory, the introduced specimens of *Origanum vulgare* L. were cultivated in a designated experimental plot located on flat terrain (Fig. 2). The site is characterized by an open landscape with full solar exposure and a complete lack of shading.

The plants were grown in well-drained, dark gray podzolized soil with a light loamy texture, which provided favorable edaphic conditions for the species. This plot is situated near other medicinal plant collections, including *Melissa* and *Rosmarinus*.

Furthermore, an apiary is located nearby, ensuring efficient entomophilous pollination of Origanum vulgare by honeybees during the flowering period. To maintain optimal growth conditions, regular weeding was performed to prevent the suppression of the introduced specimens by invasive or competing weed species.

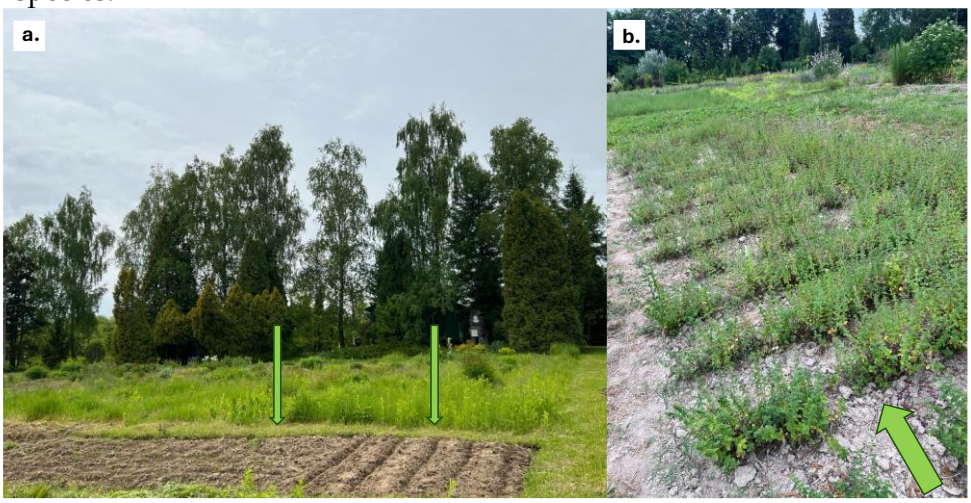

Fig 2. Site of *Origanum vulgare* L. introduction within the park territory: a – the experimental plot used for planting; b – plants in the stage of active vegetation

The ontogeny of *Origanum vulgare* L. comprises nine stages: seedlings, juvenile, immature, virginal, young generative plants, middle-aged generative, old generative, subsenile, and senile (Fig. 3).

The pre-generative period of *Origanum vulgare* L. represents a significant phase of vegetative development, comprising the seedling, juvenile, and immature stages. During this time, the plant focuses on biomass accumulation prior to reproduction. The cycle begins after the latent period concludes, where favorable conditions stimulate the transition to the seedling stage.

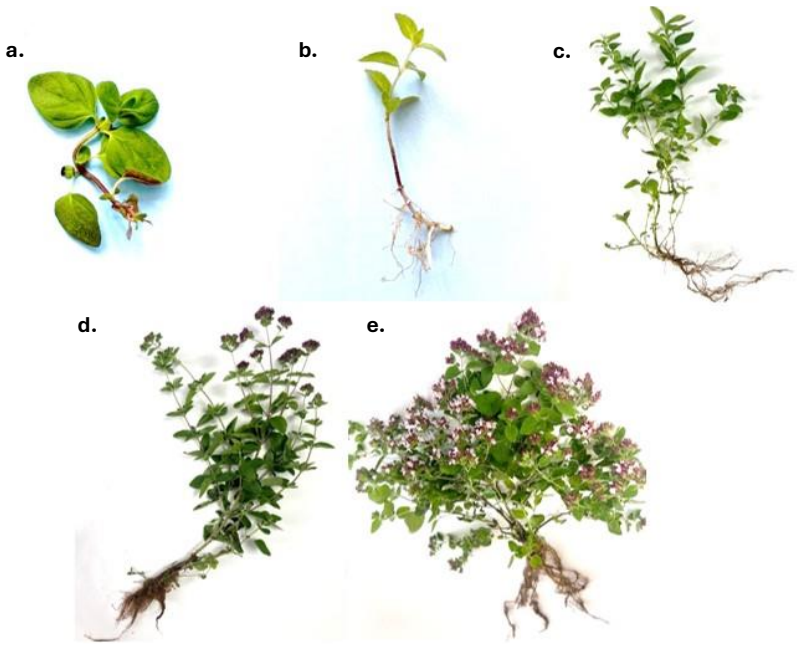

Fig. 3. The ontogeny of *Origanum vulgare* L.: a - juvenile stage; b - immature stage; c – virginal stage; d – young generative plants; e – middle-aged generative plants.

During the juvenile stage, the plant reaches a height of 2.00–5.00 cm. The aerial part comprises eight leaves measuring 0.50–1.00 cm in length and 0.30 to 0.70 cm in width, while the underground part forms a thin, thread-like root.

During the immature stage, the individual increases in height without a change in leaf number. However, leaf dimensions increase, ranging from 0.50 to 1.00 cm in width and 1.00 to 1.50 cm in length. The internode length is 1.00 cm. The root system develops, forming a visible main root with additional thread-like roots. Plant height ranges from 5.00 to 13.0 cm.

The virginal stage represents the final phase of the pre-generative period. During this stage, the individual accumulates significant vegetative mass and develops adult morphological traits. The shoot system becomes complex due to active branching, and the leaves acquire their definitive shape and size. Although the plant achieves the dimensions typical of a mature individual, reproductive organs remain absent.

The virginal plant *Origanum vulgare* L. is characterized by adult morphology but lacks flowering or fruiting. Leaf count increases to 24–30, with dimensions ranging from 1.50 to 2.00 cm in length and 1.00 to 1.70 cm in width. Branching (tillering) occurs, forming 2–7 lateral shoots with opposite leaf arrangement. Internode length varies from 1.00 to 2.00 cm. Basal shoots, 5.00–6.00 cm in length, emerge from the lower part of the plant. During this stage, the root system transitions to a fibrous type, lacking a visible main root. Plant height reaches 15.0–25.0 cm.

The generative period of young individuals of *Origanum vulgare* L. is divided into three states: young generative (formation of inflorescences, not flowering), middle-aged generative (active flowering), and old generative individuals (end of flowering, formation of seeds).

Young generative plants exceed virginal individuals in height, reaching 25.0–34.0 cm. Each shoot terminates in 1 to 5 inflorescences arranged in a parallel, corymb-like structure, containing 6–23 flowers each. Leaf dimensions increase to 1.50–2.00 cm in width and 2.00 to 3.00 cm in length, with the total leaf count rising to 30–46. Internode length ranges from 1.00 to 4.00 cm, exhibiting an acropetal gradient (shortest at the base, longest at the apex).

The root system is fibrous, consisting of tightly intertwined thread-like roots, making individual separation difficult. Vegetative growth continues during this phase; notably, purely vegetative shoots (without inflorescences) were observed alongside generative ones on the same individual.

Middle-aged generative plants represent the peak of ontogenetic development, distinguished by the highest viability and prolific flowering. During this phase, individuals achieve their maximum vegetative architecture.

The number of inflorescences ranges from 12 to 32, supported by a fully developed shoot system. Foliage density increases significantly, with leaf counts reaching 30–68. Leaf dimensions range from 2.50 to 4.00 cm in length and 2.00 to 2.50 cm in width. Plant height reaches 30.0–42.0 cm. The root system undergoes significant lignification and expansion. The rhizome is massive and fibrous, measuring 10.0–23.0 cm in length. It penetrates deeper soil horizons and forms a dense network, tightly intertwined with the roots of adjacent individuals, which enhances the plant's competitive ability. Internode length remains stable at 2.00–4.00 cm.

Old generative individuals represent the transitional phase toward senescence (Fig. 4). This stage is characterized by a marked decline in reproductive potential, specifically a decrease in flower number, as the plant prioritizes seed formation (fructification). A general reduction in physiological vitality is observed in both generative and vegetative organs. Consequently, the aerial part (shoot system) decreases in overall size and biomass compared to middle-aged individuals.

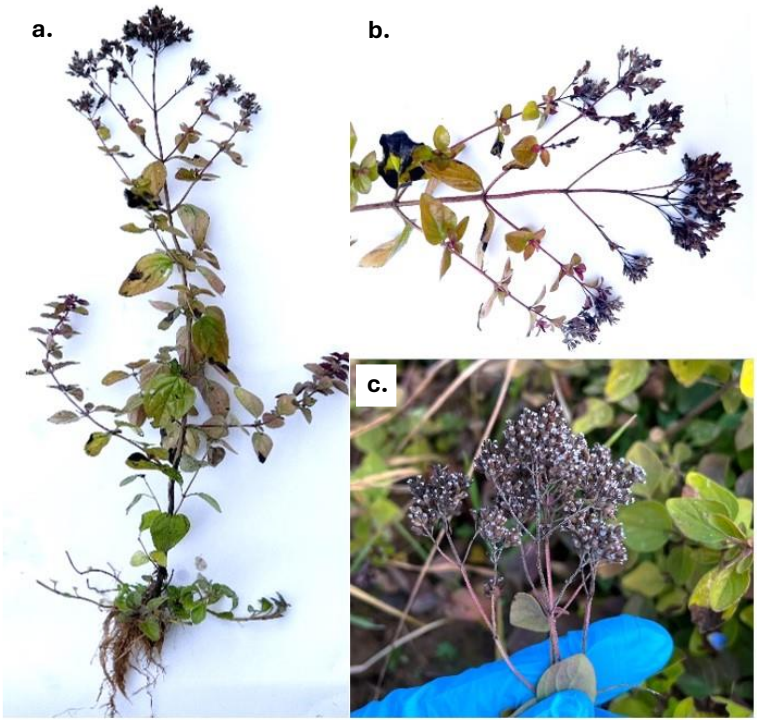

Fig. 4. Old generative plants of *Origanum vulgare* L. a - the specimen loses its ability to flower, leaves turn yellow, and the shoot weakens; b - inflorescence *Origanum vulgare* L., end of flowering; c - beginning of seed formation (photo taken under field conditions).

During this stage, foliage density declines to 25–30 leaves per individual. Conversely, internode elongation occurs, with the distance between nodes increasing to 6.00 cm. The lower leaves exhibit

chlorosis (yellowing) and subsequent necrosis. This process is indicative of nutrient remobilization, where essential resources are translocated from senescing aerial tissues to the underground organs.

The rhizome becomes robust, characterized by increased compaction and extensive lignification. These structural changes are critical for accumulating carbohydrate reserves required for winter survival and spring regrowth. The maximum plant height reaches 45.0 cm.

The post-reproductive period (Fig. 5) marks the cessation of the active life cycle. It is characterized by the termination of flowering and the completion of seed dispersal (dissemination). Following widespread leaf chlorosis and abscission, total dieback of the aerial biomass occurs. Only the rhizome persists for overwintering, ensuring the renewal of the life cycle in the following season, consistent with the perennial nature of *Origanum vulgare* L.

Notably, the active flowering period extended until mid-September, surpassing the anticipated cessation date of late August. The transition to the subsenile period occurred in October, marked by the complete termination of flowering and yellowing of basal leaves.

By early November, the plants entered the senile period. Given the thermophilic nature of *Origanum vulgare* L., this observed timeline indicates a notably prolonged vegetative season for these individuals.

Fig. 5. Post-reproductive period of *Origanum vulgare* L. a - mature seeds on the specimen; b - mass yellowing and senescence of leaves within the population.

This prolonged vegetative activity is likely a response to the elevated thermal regime associated with significant warming. Meteorological data for the Precarpathian region indicate that October temperatures fluctuated between 12 and 20°C. Notably, even in early November, daytime temperatures remained within the 9–15°C range, maintaining physiological processes above the threshold for cold-induced dormancy.

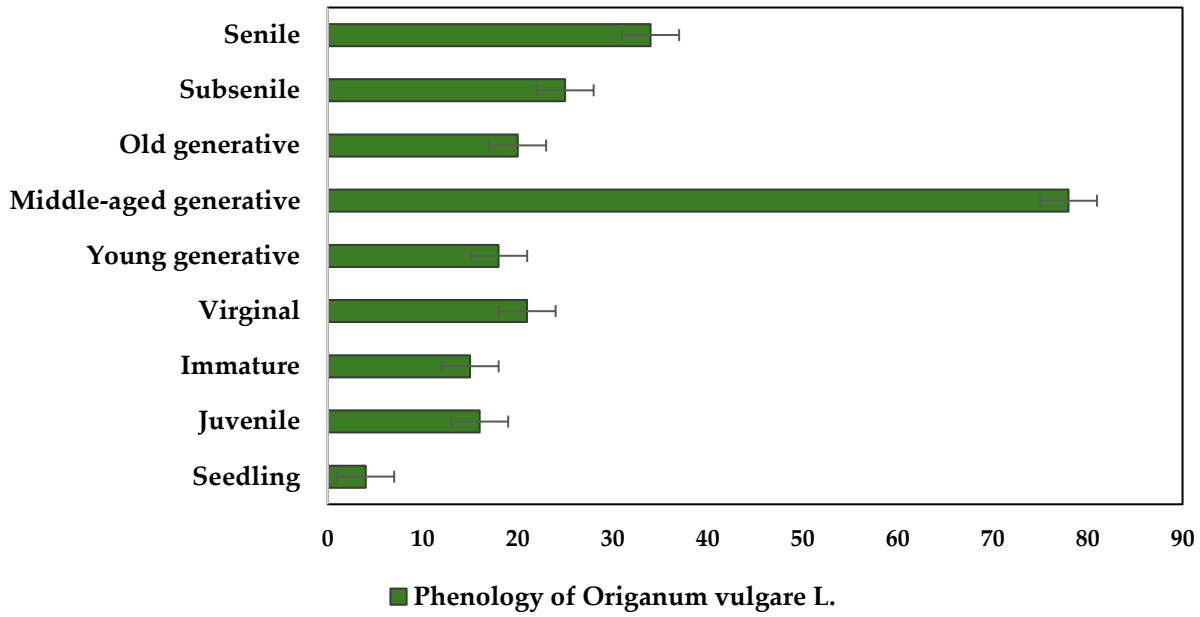

Fig. 6. Phenology of *Origanum vulgare* L. (duration in days).

A comprehensive summary of the developmental timelines for Origanum vulgare L. is illustrated in Figure 6. The data reveals a significant disparity in the duration of individual stages: the young generative stage reached its maximum duration at 78 days, reflecting a period of intense physiological preparation for flowering. Conversely, the immature stage was characterized by rapid transition, lasting only 15 days, which marks the shortest phase in the plant's pre-reproductive development.

4. CONCLUSIONS

Observations of the ontogenetic development of Origanum vulgare L. demonstrate the species' successful adaptation to new growth conditions, confirming the viability of its introduction in the Precarpathian region. The high adaptive capacity of the species provides favorable prospects for further research into introduction methodologies, including the evaluation of seedling-based establishment techniques. The ontogenesis of *Origanum vulgare* L. proceeded through consistent morphological transitions. Key developmental markers included a progressive increase in leaf number and dimensions, as well as the steady elongation of internodes. Essential life-cycle milestones, such as tillering, inflorescence differentiation, anthesis, and seed maturation, were clearly documented. Notably, the period between shoot senescence and the onset of winter dormancy was significantly prolonged. This extension is attributed to contemporary regional climate shifts, specifically the trend toward increased thermal indices in autumn, which delays the transition to physiological dormancy.

Author contributions. Conceptualization: SH, NR. Methodology, data collection, figures, tables, and referencing: SH, NR. Writing – original draft preparation: SH. Writing – review and editing: NR.

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Data availability. The data presented in this study are available on request from the corresponding author.

Declarations

Conflict of interest. The authors have no competing interests to declare relevant to this article's content.

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Світлана Гаріджук, Надія Різничук Фенологія та морфологічні зміни *Origanum vulgare* L. в умовах інтродукції на Прикарпатті *Журнал Прикарпатського національного університету імені Василя Стефаника. Біологія* 12. 141-148.

Анотація

У дослідженні проаналізовано особливості онтогенетичного розвитку *Origanum vulgare* L. в умовах інтродукції у Передкарпатті для оцінки пристосування виду до нових умов. Встановлено, що прегенеративний період включає стадії проростка, ювенільну та іматурну стадії, причому остання є найкоротшою (15 днів). Молода генеративна стадія визначена як найтриваліша фаза розвитку, що триває 78 днів. У середньовіковому генеративному стані рослини досягали піку продуктивності, маючи висоту 30,0–42,0 см та формуючи від 12 до 32 суцвіть. Виявлено значне фенологічне зміщення: період активного цвітіння тривав до середини вересня, а перехід до субсенільного періоду відбувався лише у жовтні. Таке подовження вегетації зумовлене регіональним потеплінням клімату (температури жовтня в межах 12–20°C), що затримало настання зимового спокою. Успішне проходження всіх етапів життєвого циклу та виявлена фенотипова пластичність підтверджують високий адаптивний потенціал *Origanum vulgare* L. у регіоні. Результати обгрунтовують доцільність ширшого впровадження культури з використанням різних методів вирощування, зокрема розсадного способу.

Ключові слова: *Origanum vulgare* L., інтродукція рослин, Прикарпаття, адаптація, фенологія, акліматизація.