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PHENOLOGY AND ONTOGENETIC FEATURES OF SOLENANTHUS TURKESTANICUS (REGEL & SMIRN.) KUSN. IN THE SAMARKAND REGION

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Abstract. This study presents the first comprehensive data on the seasonal development (phenology) and individual growth stages (ontogeny) of Solenanthus turkestanicus (Boraginaceae) within the Samarkand Region, based on field monitoring conducted throughout 2025. Solenanthus turkestanicus is a valuable endemic wild herbaceous plant species native to Central Asia, yet its adaptive mechanisms and reproductive biology in local ecological conditions remain poorly understood. Field observations tracked the complete vegetative and generative cycles of the species across selected natural populations. The phenological monitoring revealed that vegetative regrowth initiates in early spring (March), followed by a rapid budding and flowering phase extending from mid-April to May, and concluding with seed maturation in June before entering summer dormancy. The ontogenetic analysis identified key developmental periods, distinguishing latent, pre-generative (seedlings, juvenile, and immature stages), and mature generative individuals. The structural parameters of the rosette leaves and inflorescences varied noticeably depending on altitudinal gradients and microclimatic factors of the habitat. The findings provide essential ecological metrics for the conservation of wild flora and offer practical baselines for assessing the population stability of Solenanthus species under fluctuating regional climates.

Keywords: Solenanthus turkestanicus, phenological phases, ontogenesis, Samarkand Region, Boraginaceae, Central Asian flora, Plant development, Population monitoring.

INTRODUCTION. In global biodiversity research, protecting the plant world, inventorying species composition, identifying rare species, and ensuring their rational use alongside finding solutions to rising global diseases represent critical challenges. Today, studying the seasonal development (phenology) and individual growth stages (ontogeny) of plants under varying environmental conditions—and assessing the negative factors affecting these processes—plays a vital role in preserving natural populations, establishing large-scale plantations, and supporting agricultural and pharmaceutical advancement programs. Globally, scientific research is increasingly focused on using modern methodologies to determine the taxonomic diversity of protected areas rich in unique, rare, and endemic species, as well as evaluating the current status of these vulnerable taxa within the flora (Tojibaev et al., 2021). Therefore, conducting a comprehensive assessment of the phenological phases and ontogenetic structure of such species is of paramount importance for ensuring their long-term conservation and sustainable utilization.

Ethnobotanical surveys conducted among local populations in several regions of Uzbekistan reveal important traditional medicinal applications for Solenanthus turkestanicus. Locally, the species is widely known by the vernacular names "Bir separ" (in the Kamashi district of the Kashkadarya region and the Gallaorol district of the Jizzakh region) and "Bir bosar" (in the Koshrabot district of the Samarkand region). Literally translated from Uzbek, these names signify "applied once" or "sprinkled

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once." According to local ethnomedicinal knowledge, this nomenclature stems from the plant's high therapeutic efficacy in treating deep, chronic, and slow-healing wounds. The dried, powdered aerial or root parts of the plant are applied directly onto the wound only once to initiate rapid tissue regeneration and complete healing (Kamolov & Ergashev, 2018). This notable antibacterial and vulnerary capability makes S. turkestanicus a highly promising candidate for further phytochemical profiling and pharmacological evaluation in the development of novel wound-healing therapeutics.

The microclimate of the Choponota Hill exhibits unique localized variations from the general climate of the Samarkand oasis due to its specific relief and proximity to the Zarafshon River valley (Nowak et al., 2023). Field data indicates that the average annual temperature ranges from +13.5°C to +14.5°C. During winter, extreme minimum temperatures can drop to -20°C, while summer maximums in July reach up to +42°C to +44°C, causing severe thermal stress on the heavily exposed southern slopes. The local wind patterns, driven by the "Zarafshon wind" (mountain-valley wind systems), strongly interact with the hill, which acts as a physical barrier altering atmospheric flows. As a foothill zone, the area receives 350–400 mm of annual precipitation, with relative humidity peaking at 70–75% in spring and dropping to 25–30% in summer. Geologically, the Choponota Hill is composed of loess deposits with dark gray serozem (gray soils). Due to sparse vegetation cover and steep slopes, the silty-loam soils are highly prone to water erosion, leading to the washing away of the fertile upper layer. These soil substrates display high water permeability but possess extremely low moisture retention capacity, directly influencing the phenological timeline and ontogenetic development of local flora like Solenanthus turkestanicus.

MATERIAL AND METHODS.

2.1. Study Area and Plant Material

Field studies were conducted during the vegetation period of 2025 on the territory of Choponota Hill, situated in the suburban zone of the Samarkand oasis, Uzbekistan. The study site is characterized by an average annual temperature of +13.5°C to +14.5°C, annual precipitation of 350–400 mm, and dark gray serozem soils developed on loess deposits (Bigazzi et al., 2006). The object of the study was Solenanthus turkestanicus (Regel & Smirnov) Kusn. (family Boraginaceae), a native wild herbaceous plant with recognized ethnobotanical value in local traditional medicine.

2.2. Phenological Observations

Seasonal rhythm and developmental dynamics of S. turkestanicus were investigated using the classic methodology proposed by **I. N. Beydeman (**Beydeman, 1974**)**. Phenological monitoring was performed during field visits at regular intervals of 3–5 days throughout the active growing season. The initiation, peak, and completion of the following phenophases were recorded chronologically: vegetative regrowth (early spring); budding (buttoning stage); flowering (anthesis); fruiting and seed maturation; summer dormancy (senescence).

The collected phenological dates were analyzed in correlation with the specific microclimatic data of the Choponota Hill ecosystem.

2.3. Ontogenetic Structure Analysis

The individual development and age-state structure of S. turkestanicus populations were determined according to the fundamental concept of **T. A. Rabotnov** (Rabotnov 1950), adapted for herbaceous perennial species. Individuals within the studied populations were classified into distinct ontogenetic periods based on qualitative and quantitative morphological criteria: **Latent period**: viable seeds (se); **Pre-generative period**: seedlings (p), juvenile (j), immature (im), and virginile (v) states; **Generative period**: young (g_1), mature (g_2), and old (g_3) generative states; **Post-generative period**: senile (s) individuals.

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The ontogenetic spectrum was constructed based on the percentage distribution of individuals across these age-states to evaluate the current status, self-maintenance capacity, and ecological stability of the population on Choponota Hill.

RESULTS AND DISCUSSION

3.1. Phenological Dynamics According to Beydeman's Method

The seasonal developmental phases and duration of Solenanthus turkestanicus on the Choponota Hill were determined chronologically using the Beydeman method. Field monitoring established a direct correlation between microclimatic factors (temperature and soil moisture) and phenophase transitions (Beydeman, 1974):

Vegetative Regrowth: The vegetative cycle initiates from the third ten-day period of February to early March. This phase is triggered when soil temperatures reach +5 to +7 °C, stimulating the formation of new rosette leaves from the rhizome. The initial vegetative growth phase lasts approximately 10–15 days.

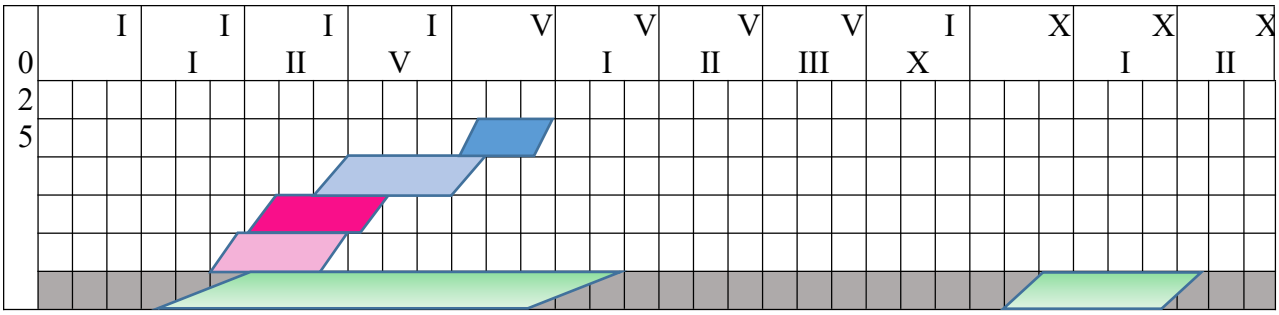
Buttoning Stage: Starting from the second ten-day period of March, the species transitions into the budding phase, which extends for about 15 days. During this period, rapid development of vegetative organs is sustained by the sufficient spring moisture reserves accumulated in the local dark gray serozem soils. This stage serves as a critical baseline for subsequent flowering intensity.

Anthesis: The peak flowering period occurs between late March and mid-April, lasting for 20–25 days. The species exhibits its maximum ornamental and structural parameters under conditions where relative air humidity ranges between 60% and 70%, during which the number of open flowers reaches its maximum values.

Fruiting and Seed Maturation: Fruit set and seed development begin in the second half of April, lasting an average of 25 days, characterized by corolla senescence and rapid seed enlargement. Complete seed ripening is observed during the first and second ten-day periods of May. The progressive rise in ambient temperature and the decline of soil moisture below 20% accelerate final seed maturation.

Senescence and Summer Dormancy: From late May to early June, above-ground parts of the plant undergo yellowing and desiccation. This final phase lasts 10–12 days, marking the completion of the active vegetative period and the transition of S. turkestanicus into summer dormancy to survive the arid summer conditions of the Choponota ecosystem.

The comprehensive chronological sequence and overlap of the individual developmental stages are visualized in the phenological spectrum (Figure 1). The phenospectrum clearly illustrates that the active lifecycle of S. turkestanicus on the Choponota Hill is highly compressed, spanning approximately three and a half months from late winter to early summer. This brief vegetative window represents an evolutionary adaptation to the contrasting microclimate of the Samarkand oasis, where rapid temperature increases in late spring act as a primary driver shifting the species from the energy-consuming flowering and fruiting phases into critical summer dormancy.



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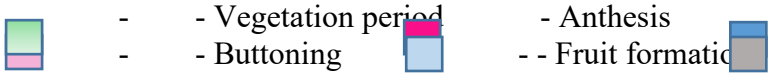


Figure 1. Phenological spectrum of **Solenanthus turkestanicus** for the 2025 vegetative period.

3.2. Ontogenetic Periods and Age-State Structure

Following Rabotnov's methodology, the individual development of Solenanthus turkestanicus on the Choponota Hill was thoroughly investigated, focusing initially on the latent and early pre-generative (virginile) periods.

3.2.1. Latent Period (se)

The ontogenetic assessment initiated with a comprehensive analysis of seed (fruit) morphobiological indicators. The fruit of S. turkestanicus is a deeply lobed nutlet, typically developing only 1–2 mature seeds out of the 4-seeded mericarps (Kuznetzow, 1913). The nutlets exhibit a subglobose or nearly round shape, measuring 7–9 mm in diameter. The dorsal surface is flat, while the margins are distinctly thickened and densely covered with hooked, glochidiate prickles. The fruit scar (cicatrix) is linear-lanceolate, and upon fruit abscission, the remaining persistent gynobase retains a triangular-ovate configuration.

A single mature generative individual (g 2) exhibits a relatively high reproductive potential, yielding approximately 180 to 250 nutlets per plant. Chronologically, the initiation of the latent period on Choponota Hill is recorded in early May, proceeding concurrently with post-anthesis embryo development and active seed coat histogenesis. The seeds achieve full structural and morphological maturity by early June.

3.2.2. Virginile (Pre-generative) Period (v)

The virginile period of S. turkestanicus encompasses the complete developmental timeframe extending from initial seed germination to the emergence of the first reproductive structures. Within this long pre-generative phase, the following sub-stages were clearly delineated and monitored in the field (Rabotnov, 1950):

1. **Seedling stage** (p) or (pl)
2. **Juvenile stage** (j)
3. **Immature stage** (im)
4. **Mature vegetative (virginile) stage** (v)

The Seedling Stage (pl): This initial phase covers the interval between radical emergence and the formation of the first pair of true assimilated leaves. Field trials and natural tracking revealed that initial seedling emergence occurs 7–8 days post-sowing, with a fraction of the seed bank exhibiting delayed or staggered germination patterns.

Germination Mechanics: The species displays a strictly epigeal mode of germination, characterized by the active elongation of the hypocotyl, which elevates the cotyledons above the soil surface. Morphologically, a young, whitish primary root system emerges first from the basal pole of the seed, rapidly penetrating the underlying soil layers to secure anchor and moisture. Once the cotyledons expand to a threshold size of 15–20 mm, the differentiation of the first true rosette leaves begins.

Regeneration and Spatial Dynamics: The ecological monitoring showed that if the above-ground biomass of the seedling or young vegetative plant is damaged or physically destroyed, the species exhibits a robust compensatory mechanism, generating adventitious shoots directly from the crown of the caudex. However, these clonal structures do not physically detach and cannot survive independently from the primary maternal crown. In natural populations on Choponota Hill, seed dispersal is predominantly anemochorous (wind-dispersed), supported by the adaptive, light, and

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prickly external morphology of the nutlets. Consequently, spatial dissemination is highly restricted; the young seedlings form dense patches located in immediate proximity to the parent plants, typically varying within a short radius of 1–2 meters.

Table 1. Ontogenetic metrics and structural parameters of **Solenanthus turkestanicus** phases

Ontogenetic State	Code	Timeline / Age	Key Morphological Markers	Reproductive / Growth Traits
Juvenile	j	9–11 days	1–2 pairs of true leaves; cotyledons begin yellowing	First true leaves are small and uniquely shaped
Immature	im	20–30 days	Cotyledons completely absent; root collar widens	Growth rate increases; leaves expand rapidly
Virginile	v	2–3 years	Large leaf blades (6–12 × 3–5 cm); expanded rosette	Annual renewal buds form dense, unfragmented tufts
Young Generative	g 1	2–3 years	1–2 peduncles per plant; 60–70 flowers per inflorescence	Low reproductive success; seed set is only 10–15%
Mature Generative	g 2	> 4 years	8–12 robust peduncles per tuft; large rosette bases	High reproductive success; 60% of stalks yield 20–30 seeds

Juvenile Stage (j): This stage is strictly observed on the **9th–11th days** following initial germination. Morphologically, it is defined by the gradual yellowing and senescence of the twin cotyledons, accompanied by the differentiation of the first true assimilated leaves. During the juvenile phase, the young individuals develop **1–2 pairs of leaves**. The primary pair of true leaves is explicitly characterized by its significantly smaller dimensions and a distinct morphological outline compared to subsequent leaves.

Immature Stage (im): The immature stage is primary marked by the complete abscission and absence of the cotyledons. Key diagnostics for this phase include the rapid expansion of the leaf blades, a notable widening of the root collar (hypocotyl zone), and an overall acceleration in vegetative growth rates. Field tracking revealed that the cotyledons maintain their vital functionality for a total lifespan of **20–30 days** before undergoing chlorosis and drying out.

Mature Vegetative (Virginile) Stage (v): In Solenanthus turkestanicus, this advanced pre-generative stage is reached in the **2nd or 3rd year** of individual development. It is readily distinguished from previous states by substantially larger leaf blades, reaching **6–12 cm in length and 3–5 cm in width**, along with an increased density of rosette leaves. Annually, renewal buds located at the thickened root collar (caudex) generate new vegetative clusters. Rather than separating via true vegetative fragmentation, these newly formed structures continue to grow tightly aggregated, forming a single perennial tuft.

3.2.3. Generative Period (g)

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The transition into the generative period represents the onset of reproductive functionality, marked by the initial formation of flowers and functional nutlets. Under the ecological conditions of Choponota Hill, this period corresponds to the **2nd or 3rd year** of ontogenesis. Floral buds differentiate exclusively on specialized generative shoots, a process driven by the mitotic activity of the apical meristem cells.

Young Generative Stage (g 1): Individuals in this initial reproductive phase produce only **1 or 2 peduncles (flower stalks)**. Each complex inflorescence contains approximately **60–70 flowers**. However, the real seed production capacity during this early stage remains severely limited, with successful fruit set accounting for only **10–15%** of the total floral potential. Post-anthesis, the baseline rosette leaves undergo a compensatory growth spurt, significantly enlarging to lengths of **15–18 cm**.

Mature (Middle) Generative Stage (g 2): This highly active reproductive phase initiates after the **4th year** of individual development. Morphologically, the reproductive architecture expands dramatically, with a single tuft producing **8–12 robust peduncles**. Within these mature inflorescences, **60%** of the monitored individual clusters successfully mature a stable quota of **20–30 seeds per inflorescence**, while the remaining reproductive axes exhibit lower fruit-set values due to resource allocation constraints under the arid climate of the hill.

CONCLUSION. The comprehensive study of Solenanthus turkestanicus (Regel & Smirnov) Kusn. on the Choponota Hill in 2025 provided the first detailed insights into its seasonal phenology and early-to-mid ontogenetic structure under specific microclimatic conditions. Phenological monitoring via Beydeman's method demonstrated that the species possesses a highly compressed vegetation window (from late February to early June), which serves as an evolutionary adaptation to the rapid temperature increases and low moisture retention of the local loess soils (Beydeman, 1974). Ontogenetic analysis following Rabotnov's framework revealed that the Choponota population is actively developing and structurally stable, dominated by dynamic pre-generative and young-to-middle generative individuals (Rabotnov, 1950). Given its verified ethnobotanical value as a powerful traditional wound-healing agent ("Bir separ" / "Bir bosar"), these developmental metrics offer a crucial baseline for the ecological monitoring and sustainable resource management of this endemic Central Asian taxon (Kamolov & Ergashev, 2018).

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