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Bioecological Features of *Plantago ovata* Forssk. in the Conditions of the Tashkent Oasis

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Abstract

Plantago ovata Forssk., an annual medicinal plant of the family Plantaginaceae, was investigated under laboratory and field conditions to evaluate its seed germination, ontogenetic development, and seasonal growth dynamics. Laboratory experiments examined the effects of temperature regimes and a 0.2% gibberellin solution on seed germination. Germination rates in distilled water were 100% at 15˚C, 96% at 20˚C, 100% at 25˚C, and 48% at 30˚C, whereas seeds treated with gibberellin exhibited germination rates of 100% at 15˚C, 20˚C, and 30˚C, and 92% at 25˚C. The most favorable and stable germination was observed within the temperature range of 20˚C - 25˚C. Field experiments evaluated the effects of different organic fertilizers on seed germination. The highest values were recorded in the cattle manure treatment, reaching 31% in 2025 and 70% in 2026, compared with 32% and 48% under sheep manure, 25% and 51% under poultry manure, and 15% and 50% in the control treatment, respectively. Seeds stored for one year exhibited a germination rate of 54.75%, whereas seeds stored for three years showed a germination rate of 25.75%, representing a difference of 29 percentage points (approximately 2.13-fold). However, because seed age may have been confounded with differences between growing seasons and seed lots, this difference cannot be attributed solely to storage duration. The ontogeny of *P. ovata* was characterized by five developmental stages: latent (se), seedling (p), juvenile (j), immature (im), and generative (g), and the morphological and biological features of each stage were described. The vegetation period lasted 88 days in 2025 and 77 days in 2026. The species exhibited active growth during the spring-summer season and demonstrated considerable tolerance to variations in temperature and moisture conditions. These findings provide valuable information

on the bioecological characteristics of *Plantago ovata* and its cultivation potential under the environmental conditions of the Tashkent Oasis.

Keywords

Plantago ovata Forssk., Seed Germination, Ontogeny, Seasonal Development, Bioecology, Organic Fertilizers, Gibberellin, Seed Material, Medicinal Plants

1. Introduction

Plantago ovata Forssk. is an annual medicinal herb belonging to the family Plantaginaceae. The species is characterized by a basal rosette of leaves and soft pubescence, reaching a height of 30 - 45 cm. Its leaves are narrow linear to lanceolate, measuring 7.5 - 23.0 cm in length and 0.5 - 1.0 cm in width. The root system is well developed and consists of a primary taproot with numerous fine lateral roots. Several flowering stalks emerge from the base of the plant. During the flowering stage, the spikes become reddish-brown, while the lower leaves dry out and the upper leaves gradually turn yellow. Flowering generally begins approximately 60 days after sowing. The flowers are small, numerous, and white, arranged in ovate to cylindrical spike-like inflorescences measuring 1.3 - 3.8 cm in length. The fruit is a pyxidium enclosed within a persistent calyx and contained in a dehiscent capsule that opens upon maturity. The seeds are hard, boat-shaped, light to dark brown in color, and up to 8 mm in length [1].

According to the studies conducted by Barfa (2010), *Plantago ovata* is characterized by a deep taproot system that penetrates the soil effectively and enables efficient water uptake, while lateral roots remain poorly developed. During the vegetative stage, the plant produces numerous leaves from the root crown. In the generative stage, a true stem, referred to as a floral axis or flowering stalk, develops and elongates. The stem is leafless. The leaves are elongated, narrow, and parallel-veined, forming a basal rosette. The number of leaves varies from 2 to 12 throughout the growing season. The flowers are small, whitish-green, and arranged in spike-like inflorescences. They are bisexual, and pollination occurs primarily through wind action. The seeds are small, ovate in shape, and rich in mucilage. The fruit is an elliptical capsule approximately 8 mm long, containing smooth, boat-shaped seeds measuring 2 - 3 mm in length and exhibiting a pinkish-white color. The inner surface of the seed is covered by a thin membrane that forms the seed coat. The seed epidermis consists of polygonal cells whose walls are thickened by secondary deposits, which serve as the primary source of mucilage production [2].

Plantago ovata is naturally distributed in the Mediterranean region, particularly in Southern Europe, North Africa, and Western Asia [3]. In the Xinjiang region of China, the species is utilized as both a food and medicinal plant. Previously,

Plantago ovata Forssk. was introduced into China from India, Pakistan, and several other countries. In recent years, it has also been successfully introduced and cultivated in the Hotan area of Xinjiang, where its adaptation and potential economic value have attracted increasing attention [4].

Medicinal plant cultivation using organic fertilizers enhances the biological and pharmacological quality of medicinal raw materials, increases seed productivity, and improves soil fertility. Organic fertilizers are of considerable importance for maintaining and enhancing the physical, chemical, and biological properties of soils. They provide essential macro- and micronutrients, including nitrogen, phosphorus, potassium, calcium, and magnesium, thereby promoting plant growth and development. In addition, organic matter improves soil structure, enhances water retention capacity, and stimulates soil microbial activity. Conversely, the excessive application of chemical fertilizers may lead to nitrate accumulation in plant tissues, changes in soil chemical and microbiological properties, nutrient leaching, and deterioration in the quality of medicinal plant raw materials.

Excessive use of chemical fertilizers has been reported to decrease earthworm activity as a result of elevated salt concentrations in the soil solution [5]. Beyond their nutritional value, organic amendments significantly influence soil properties, especially physical characteristics related to soil structure and fertility (Pedra *et al.*, 2006). Increased manure application reduces soil compaction and improves the soil environment by enhancing organic matter content. Furthermore, manure-treated soils exhibited higher mucilage content than other fertilization treatments, which may be attributed to improved potassium and phosphorus uptake by *Plantago ovata* Forssk., particularly in the seeds, thereby enhancing seed quality and yield [6].

Plantago ovata Forssk. is widely known under various vernacular names, including “Isabgol” (Isabgula) in India, “Esfarzeh” in Iran, “Karnıyarık otu” in Türkiye, “Psyllium” or “Blond psyllium” in Europe, “Psyllium husk” in the United States and Canada, and “Podorozhnik ovalnyy” in Russia. Owing to its medicinal and commercial value, the species is cultivated on a commercial scale in several European countries, as well as in Pakistan and India [7] [8].

Studies by Meena *et al.* [9] investigated the chemical composition and pharmaceutical importance of the seed husk of *Plantago ovata* Forssk. The authors reported that the outer seed coat contains 10% - 30% hydrocolloids, which are hydrolyzed into neutral and acidic polysaccharides. Furthermore, the husk is rich in biologically active compounds, including L-rhamnose, D-galactose, L-arabinose, D-xylose, D-galacturonic acid, tannins, the glycoside aucubin, sterols, sugars, lipids, and proteins. These bioactive constituents are largely responsible for the medicinal and pharmaceutical value of *P. ovata* seed husk.

Ghaderi-Far *et al.* [10] reported that the maximum germination percentage of Plantago ovata seeds (80%) was achieved when the seeds were sown on the soil surface. However, burial of the seeds at a depth of 3 cm resulted in complete inhibition of seed germination.

According to F. F. Ghaderi *et al.* (2012), the germination response of *Plantago ovata* seeds is strongly influenced by several environmental factors, including temperature, salinity, water potential, oxygen concentration, and pH. Among these factors, temperature plays a crucial role in determining seed germination and subsequent seedling development. In addition, water potential and salinity were identified as major determinants affecting germination performance and the successful establishment of seedlings [10].

Hashemi *et al.* [11] reported that a temperature of approximately 20˚C represents the optimal condition for *Plantago ovata* seed germination and provides the greatest tolerance to salinity stress. Increasing salinity levels significantly reduced all germination indices. These findings highlight the importance of temperature management in enhancing the cultivation of isabgol (*P. ovata*) in saline environments and provide valuable information for the development of effective cultivation strategies under salt-affected soil conditions.

Cowley *et al.* [12] reported that pre-harvest rainfall exposure significantly impairs the quality of *Plantago ovata* seeds. Moisture was found to cause partial degradation of the seed coat and mucilage layer, accompanied by noticeable changes in seed color. These effects are likely associated with pigment leaching and microbial growth under moist conditions. Furthermore, such deterioration adversely affects the appearance and quality of the extracted mucilage, ultimately reducing the pharmaceutical and commercial value of the seed material.

According to Roumani *et al.* (2019), foliar application of salicylic acid (SA) and the polyamine spermine (Spm) effectively reduced the negative impacts of water deficit stress in *Plantago ovata*, resulting in improved yield and yield-related traits. Application of these compounds at the flowering stage enhanced biological yield even when irrigation was withheld. The beneficial effects were associated with alleviation of drought-induced damage, including reduced plant stature and leaf abscission. Moreover, SA and Spm positively affected the photosynthetic machinery and stimulated the photochemical conversion of light energy, thereby increasing the plant's resilience to drought stress [13].

According to previous studies, *Plantago ovata* Forssk. seedlings exhibit marked phenotypic changes in response to selenium (Se) biofortification. High Se concentrations significantly reduced both root and shoot length, with roots showing greater sensitivity than shoots. In contrast, low Se concentrations (<50 μM) enhanced selenium accumulation without adversely affecting plant growth and promoted the synthesis of various polyphenolic compounds. These results indicate that selenium enrichment of *P. ovata* through phytoremediation is a feasible and effective strategy for improving its nutritional value and potential use in functional food and dietary products [14].

Seeds of *Plantago ovata* and their epidermis, commonly known as psyllium husk, have long been utilized in the traditional medicine systems of China, India, Pakistan, and several European countries as a safe and effective laxative agent [15]. Clinical and pharmacological investigations have further confirmed the efficacy

of psyllium preparations in the management of chronic constipation and the maintenance of normal intestinal function [16].

A detailed understanding of the seasonal development of *Plantago ovata* Forssk. under the climatic conditions of the Tashkent Oasis is essential for evaluating its adaptive potential and cultivation prospects. Investigations of its vegetation period, phenological phases, developmental stages, and responses to environmental factors, including temperature, moisture, and light, are crucial for improving cultivation technologies, supporting breeding programs, and expanding the species' medicinal raw material resources.

According to the morphological and ecological classification of I.G. Serebryakov, *P. ovata* is classified as a monocarpic species, completing its life cycle through a single flowering and fruiting event before senescence [17].

Under introduction conditions, the seasonal flowering dynamics of plants are evaluated through the assessment of flowering onset, peak flowering, and flowering completion, which are strongly influenced by environmental factors. Systematic monitoring of these phenological stages enables the assessment of the adaptive potential of introduced species. In particular, plant accessions exhibiting high seed productivity are regarded as well adapted to the new environmental conditions, reflecting successful establishment and reproductive performance under introduction conditions [18] [19].

Numerous studies have shown that flowering biology is a fundamental component of the reproductive cycle of plants, encompassing the maturation of male and female reproductive organs, pollination, and fertilization processes. R.Ye. Levina emphasized that flowering characteristics are strongly influenced by flower type, pollination strategy, and environmental conditions. Furthermore, the flowering process can be regarded as an important indicator of plant adaptation to novel habitats and introduction environments. In the present study, climatic data for the Tashkent region were obtained from the World Weather database and used to evaluate the influence of environmental factors on the growth, development, and phenological behavior of *Plantago ovata* Forssk. [20].

The quantitative characteristics of seed productivity are highly variable and are closely associated with the edaphic and climatic conditions of the species' habitat. Environmental factors such as soil fertility, temperature regime, and moisture availability play a crucial role in determining reproductive success and seed yield [21].

Seed productivity is a highly variable trait that is closely associated with the soil and climatic conditions of the environment in which a plant grows. Variations in environmental conditions can substantially influence reproductive performance and seed yield [22].

2. Materials and Methods

The present study focused on *Plantago ovata* Forssk., an annual medicinal herb of the family Plantaginaceae. The aboveground portion of the plant is composed of

a shortened rosette stem formed by basal leaves and one or more erect flowering stalks emerging from the root crown. Plants typically attain a height of 30 - 45 cm. The seeds are smooth, glossy, and boat-shaped to ellipsoid in form, with a length of approximately 2 - 3 mm (Figure 1).



(A) (B)

Figure 1. *Plantago ovata* Forssk.: (A) Seedling stage, (B) Immature stage.

Field experiments were conducted during 2025-2026 at the experimental plots of the Botanical Garden of Mirzo Ulugbek National University of Uzbekistan. The study area is characterized by a semi-arid climate with moderate temperatures during spring and summer, an average annual precipitation of 300 - 350 mm, and typical sierozem (gray desert) soils. Seeds of *Plantago ovata* Forssk., introduced from Hangzhou, Zhejiang Province, People's Republic of China, in 2024, were used as the plant material for the experiments. Field experiments were conducted under the conditions of the Tashkent Oasis to evaluate the effect of organic fertilizers on the growth, development, and seed productivity of Plantago ovata (Figure 2).



Figure 2. Experimental field site during the 2025-2026 growing seasons.

The experiment included four treatments: cattle manure, sheep manure, poultry manure, and an unfertilized control. For each fertilizer type, three application rates were tested: cattle manure at 2.0, 2.5, and 3.0 kg·m^{-2}; sheep manure at 1.5, 2.0, and 2.5 kg·m^{-2}; and poultry manure at 0.5, 0.7, and 1.0 kg·m^{-2}. The control treatment received no fertilizer. The experiment was established using a randomized plot design with three independent replicates for each treatment. Organic fertilizers were applied and incorporated into the topsoil (0 - 20 cm) before sowing. All plots received identical agronomic practices, including irrigation, weed control, and soil cultivation. Morphological observations were conducted on ten randomly selected plants from each replicate plot. Plant height, number of leaves, number of inflorescences, and other growth parameters were measured throughout the growing season. Seed yield was determined at full maturity by harvesting plants from a measured area of each plot. The collected seeds were cleaned, weighed, and expressed as grams per square meter (g·m^{-2}). The experimental design and fertilizer treatments are presented in Table 1.

Table 1. Amounts of organic fertilizers used in the experiment.

No.	Organic Fertilizer	Treatment I	Treatment II	Treatment III
1	Cattle manure	2 kg	2.5kg	3 kg
2	Sheep manure	1.5 kg	2 kg	2.5 kg
3	Poultry manure	0.5 kg	0.7 kg	1 kg
4	Control	-	-	-

A comparative assessment of the germination capacity of *Plantago ovata* seeds stored for one and three years was conducted. Seeds were sown in the first decade of April, and germination commenced on the fifth day after sowing. Maximum germination reached 32% in 2025 and 70% in 2026. The highest germination percentage (80%) was obtained in the treatment amended with 2.5 kg of cattle manure, followed by 53% in the 2.0 kg sheep manure treatment and 52% in the 0.5 kg poultry manure treatment. The control treatment showed a germination rate of 50%. Ontogenetic development was monitored through phenological observations, while biometric parameters, including plant height, leaf number, root penetration depth, and generative organ formation, were systematically evaluated.

Seed germination was assessed using the methods described by M.K. Firsova [23] and O.N. Granitova [24]. Seeds of *Plantago ovata* Forssk., imported from Hangzhou City, Zhejiang Province, People's Republic of China, were used in the study. Laboratory experiments were conducted to evaluate the effects of temperature regimes and gibberellin treatment (0.2%) on seed germination. Germination tests were conducted in Petri dishes lined with two layers of filter paper. Each experimental unit consisted of 25 seeds, with four independent replicates per treatment (100 seeds in total). To determine the influence of temperature on germination performance, seeds were incubated at four temperature levels: 15˚C,

20˚C, 25˚C, and 30˚C. A photoperiod of 12 h light and 12 h darkness was maintained throughout the experiment. Germination parameters were recorded at designated time intervals, and the obtained results were subjected to comparative analysis.

Plant ontogeny is understood as the process beginning with embryo development from the seed, followed by the completion of the vegetative growth period, seed production, and ultimately the death of the plant [25]. Observations were conducted at 2 - 3 day intervals throughout the vegetation period. The ontogenetic stages of the plants were studied according to the methodologies proposed by T.A. Rabotnov [26], I.G. Serebryakov [17] [27], A.A. Uranov [28] [29], and L.A. Zhukova [30]. At each developmental stage, morphological characteristics, growth rates, and phenological phases were recorded. Meteorological data, including daily air temperature and relative humidity, were obtained for Tashkent, Uzbekistan, from the World Weather database [31]. Weather records corresponding to the experimental period (April-July 2025 and April-July 2026) were used to characterize environmental conditions during plant growth and development. Monthly averages of temperature and relative humidity were analyzed to assess their association with the phenological development and flowering dynamics of Plantago ovata. Since soil moisture and nutrient availability were not directly measured, relationships between weather conditions and plant performance were interpreted as associations rather than causal effects.

The phenological developmental stages of the plants were monitored according to the methodologies developed by I.V. Borisova [32], Beideman [33], and G.N. Zaytsev [34]. During the study, seasonal developmental processes were recorded, including seed germination and mass emergence, plant growth during the vegetative stage, leaf appearance and size, and root development. During the generative stage, observations focused on spike inflorescence formation, budding, flowering, daily and seasonal flowering dynamics, fruit set, seed production, and seed productivity.

3. Results and Discussion

Under laboratory conditions, seeds of *Plantago ovata* Forssk. were subjected to germination in a thermostat at 15˚C, 20˚C, 25˚C, and 30˚C. The onset of seed germination was observed within 2 - 4 days of incubation (**Figure 3**; **Table 2**).

Table 2. Germination of *Plantago ovata* Forssk. seeds under laboratory conditions.

Culture medium		Temperature			
		15˚C	20˚C	25˚C	30˚C
Distilled water, % (seeds)	Day 2	84 (21)	96(24)	100 (25)	36 (9)
	Day 4	100 (25)	96(24)	100 (25)	48 (12)
Gibberellin solution (0.2%), % (seeds)	Day 2	92 (23)	100(25)	92 (23)	100 (25)
	Day 4	100 (25)	100(25)	92 (23)	100 (25)

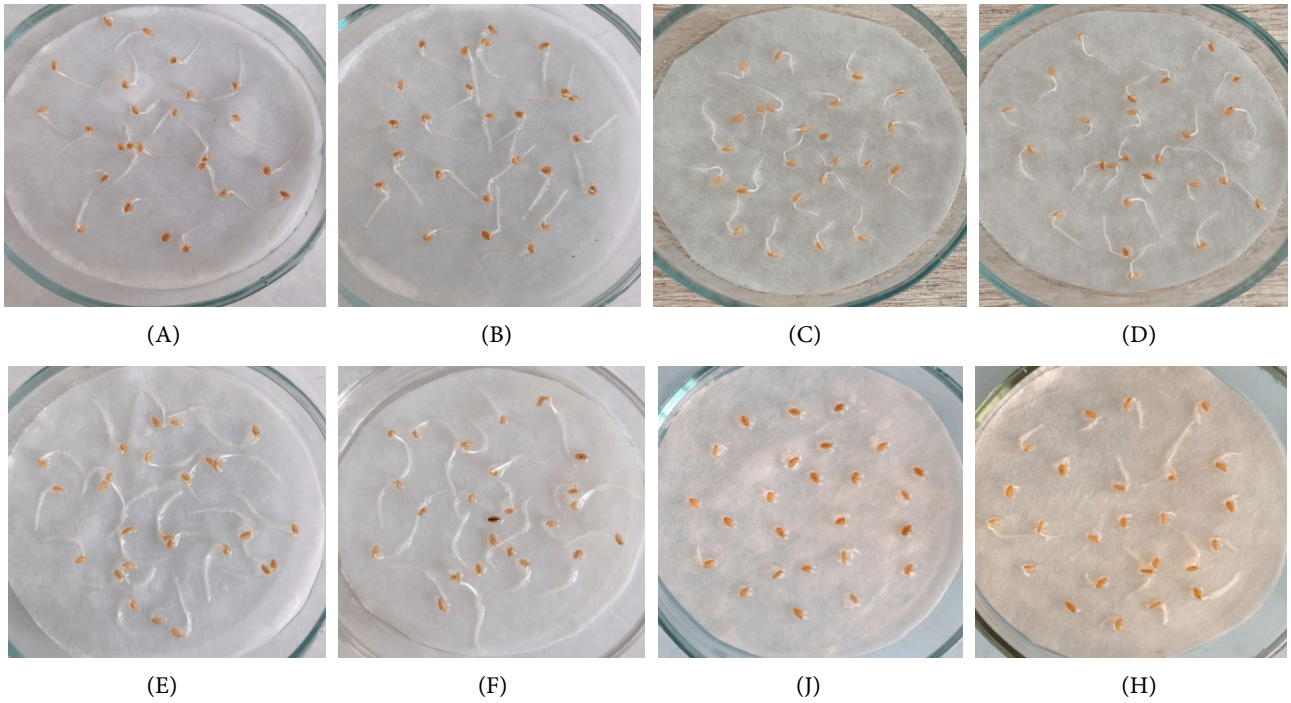


Figure 3. Seed germination of *Plantago ovata* Forssk. under laboratory conditions: (A) Distilled water at 15˚C; (B) Gibberellin solution (0.2%) at 15˚C; (C) Distilled water at 20˚C; (D) Gibberellin solution (0.2%) at 20˚C; (E) Distilled water at 25˚C; (F) Gibberellin solution (0.2%) at 25˚C; (G) Distilled water at 30˚C; and (H) Gibberellin solution (0.2%) at 30˚C.

As shown in Table 1, the highest germination rate in the distilled water treatment was observed at 25˚C, where 100% of seeds (25 seeds) germinated by the second day. Although final germination also reached 100% at 15˚C, germination occurred more slowly than at 25˚C. At 20˚C, final germination ranged from 84% to 96%, indicating favorable conditions for seed germination. In contrast, germination was markedly reduced at 30˚C, reaching only 36% on the second day and 48% on the fourth day. These findings suggest that 20˚C - 25˚C provides the most favorable conditions for rapid germination, while temperatures above 30˚C negatively affect germination performance. Therefore, the proposed optimum temperature range is based primarily on germination speed rather than final germination percentage.

Treatment with 0.2% gibberellin markedly improved seed germination. A germination rate of 100% was achieved on the second day at 20˚C and 30˚C. Similarly, germination at 15˚C increased from 92% to 100% following gibberellin application. However, at 25˚C, the germination percentage remained unchanged at 92%, indicating no apparent stimulatory effect of gibberellin under this temperature regime.

The experimental results demonstrated that the optimum temperature range for the germination of *P. ovata* seeds was 20˚C - 25˚C. Gibberellin treatment enhanced the physiological activity of the seeds and was particularly effective in improving germination under unfavorable temperature conditions. In the control treatment, seed germination decreased significantly at 30˚C, which may be at-

tributed to the adverse effects of high temperature on seed physiological processes. In contrast, the application of gibberellin mitigated the negative impact of high temperature, maintaining a high germination rate even at 30˚C. These findings suggest that gibberellin enhances seed tolerance to unfavorable environmental conditions.

Seed Germination under Field Conditions. Seeds of *Plantago ovata* were sown in the experimental field of the Botanical Garden of the Mirzo Ulugbek National University of Uzbekistan during the first decade of April in 2025-2026 (Figure 4).



Figure 4. Field plot used for the experiment.

The field experiment was conducted on plots measuring 1 × 1 m^2 and included three organic fertilizer treatments and a control treatment. A total of 100 seeds were sown in each plot at a depth of 1 cm, and seedling emergence began within 4 - 5 days after sowing. The seeds used in the 2025 experiment had been stored for three years, whereas one-year-old seeds were used in the 2026 experiment (Table 3).

Table 3. Seed germination characteristics of *Plantago ovata* Forssk. during 2025-2026.

Organic fertilizers	Initial seedling emergence	Mass emergence	Germination (%) 2025	Germination (%) 2026
Cattle manure	4 - 5 days	8 - 10 days	31	70
Sheep manure	4 - 5 days	8 - 10 days	32	48
Poultry manure	5 - 6 days	9 - 11 days	25	51
Control	6 - 7 days	11 - 12 days	15	50

The results of the field experiment indicated that the germination of *P. ovata* seeds depended on the type of organic fertilizer applied. Initial seedling emergence was observed within 4 - 7 days after sowing, whereas mass emergence occurred within 8 - 12 days. The highest germination percentage was recorded in the cattle manure treatment, reaching 31% in 2025 and 70% in 2026. This may be attributed to the beneficial effects of cattle manure on soil physical properties, including improved moisture retention and enhanced nutrient availability.

Early seedling emergence was also observed in the sheep manure treatment, with relatively high initial emergence rates. However, the overall germination percentage was lower than that recorded in the cattle manure treatment, reaching 32% in 2025 and 48% in 2026. This difference may be associated with the relatively slower mineralization rate of sheep manure, which can delay the release of nutrients required for seed germination and early seedling development.

In the poultry manure treatment, initial seed germination was observed within 5 - 6 days after sowing, with germination percentages of 25% in 2025 and 51% in 2026. The relatively high nitrogen content of poultry manure may have exerted a certain inhibitory effect on the germination process. In the control treatment, germination began within 6 - 7 days, and mass emergence continued until 11 - 12 days after sowing. The corresponding germination percentages were 15% and 50%, respectively, confirming the positive effect of organic fertilizers on the germination of *P. ovata* seeds.

Therefore, the results of the present study indicate that the use of *Plantago ovata* seeds stored for one to two years is more suitable for propagation purposes, whereas prolonged storage may lead to a decline in seed germination capacity. These findings suggest that seed age is an important factor affecting germination performance and should be taken into consideration when developing propagation strategies for *P. ovata*.

Overall, the results of the present study demonstrated that the application of organic fertilizers, particularly well-decomposed cattle manure, promotes early and enhanced germination of *P. ovata* seeds [35].

Our investigations revealed that the ontogenetic development of *Plantago ovata*, from seed germination to complete senescence, occurs within the period extending from early spring to late summer. Under the experimental conditions, the plant completed the following ontogenetic stages.

Latent Stage (se). The latent stage encompasses the period from seed maturation to seed germination. The seeds of *Plantago ovata* are light to dark brown in color, with a smooth and glossy surface. They are boat-shaped (elliptic-ovate), slightly concave on one side, and measure approximately 2 - 3 mm in length and 1 - 1.5 mm in width. The weight of 1000 seeds is approximately 1.8 g (**Figure 5**).

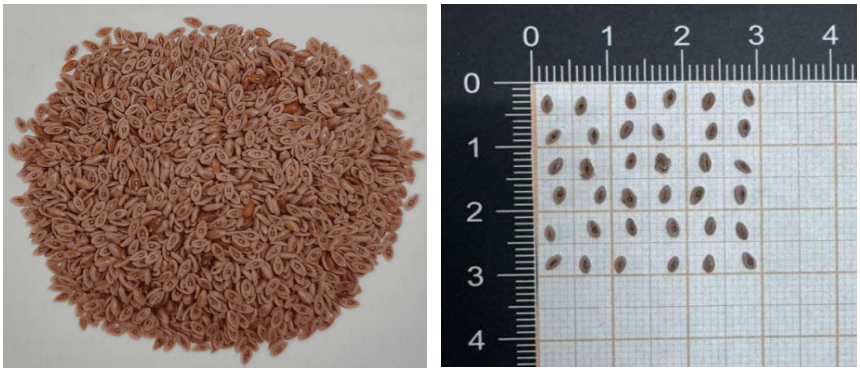


Figure 5. External morphology of *Plantago ovata* Forssk. seeds.

Virginile Stage (v). The virginile stage extends from seed germination until the initiation of bud formation and comprises the following developmental phases: p, seedling stage; j, juvenile stage; and im, immature stage.

Seedling Stage (p). Three-year-old seeds imported from China in 2024 and stored at room temperature until March 2025 were sown in a previously prepared field on 4 April 2025. Seedling emergence was first observed on 9 April. In 2026, one-year-old seeds were sown on 7 April. In both one-year-old and three-year-old seed lots, germination occurred within 4 - 6 days after sowing. The period of dormancy in the soil was 3 - 4 days for both seed age groups. However, under field conditions, the germination rate of one-year-old seeds sown in spring was found to be 4 - 5 times higher than that of the three-year-old seeds.

During the seedling stage, the cotyledons reached 3 - 4 cm in length and 1.0 - 1.5 mm in width. Plant height at this stage corresponded to the length of the cotyledons (3 - 4 cm), as the species lacks an aerial stem during vegetative growth and develops a flowering stalk only during the generative phase. The primary root measured 0.6 - 0.7 cm in length, and lateral roots had not yet developed. The seedling stage lasted for 8 - 9 days (Figure 6).



Figure 6. Seedling stage of *Plantago ovata* Forssk.

Juvenile Stage (j). This stage extends from the emergence of the first true leaves to the formation of a rosette of leaves. The first true leaves began to develop 14 - 15 days after sowing. Initially, the first pair of true leaves reached 2 - 3 cm in length and 0.6 - 0.7 cm in width. The third leaf appeared within 4 - 5 days, and the leaves gradually started to arrange in a rosette pattern.

During this stage, the primary root continued to elongate, while lateral roots began to develop. The primary root reached a length of 2 - 3 cm, whereas lateral roots attained a length of 1 - 3 mm. By the end of the juvenile period, the fourth true leaf had emerged. The first pair of leaves was noticeably larger than the subsequent leaves, with leaf blades measuring 4.0 - 4.5 cm in length and 1.5 - 2.0 cm in width. The leaves were sessile and covered with fine hairs.

The average plant height during the juvenile stage was 10 - 12 cm. The duration of the juvenile stage was recorded as 14 days (Figure 7).



Figure 7. Juvenile stage of *Plantago ovata* Forssk. under field conditions.

Immature Stage (im). The immature stage extends from the appearance of 8 - 9 leaves until the onset of budding. In *P. ovata*, this stage was observed approximately 23 days after seed germination, corresponding to the first decade of May. During this stage, the leaves reached 10 - 15 cm in length and 0.6 - 0.8 cm in width. The leaves were sessile and covered with trichomes (hairs). The root system was characterized by a taproot, with the main root reaching 5 - 6 cm in length, while lateral roots measured 0.8 - 1.2 cm. At the beginning of bud formation, the first-order branches bore two pairs of leaves. The overall plant height ranged from 12 to 15 cm. The immature stage lasted for 7 - 8 days (Figure 8).



Figure 8. Immature stage (im) of *Plantago ovata* Forssk.

Generative Stage. The generative stage was characterized by the growth of erect

flowering shoots bearing spike-like inflorescences. This stage began during the second decade of May. At the onset of flowering, plant height reached up to 17 cm. The main shoot bore 7 - 8 pairs of leaves. The leaves were arranged in a basal rosette, and new leaves and spikes developed in the axils of the lower leaves. The largest leaves measured 16 - 17 cm in length and 0.9 - 1.0 cm in width; they were sessile and covered with trichomes (hairs). The smallest leaves were 11 - 12 cm long and 0.5 - 0.6 cm wide.

The budding stage commenced in the second decade of May and continued until the end of the third decade of May. Spike formation began after the development of the seventh or eighth pair of leaves. Flowering also started in the second decade of May and continued until the third decade of June (**Figure 9**).



Figure 9. Generative stage of *Plantago ovata* Forssk.

Flowering of the buds within the spike-like inflorescences followed an acropetal pattern, with flowers opening sequentially from the base towards the apex. Flower opening began on 19 May. The flowers were small, whitish to pale yellowish-white in color, and actinomorphic. Each spike inflorescence contained 28 - 60 buds, with the lower buds being larger than the upper ones, reflecting the basipetal-to-apical sequence of flower opening. The average plant height ranged from 24 to 33 cm.

The cotyledons persisted throughout the vegetative growth period. Their yellowing was first observed at the beginning of the generative stage, coinciding with the onset of budding and flowering. By 15 June, seed maturation had commenced in all experimental treatments. At this stage, the leaves in the lower part of the plants began to turn yellow and senesce, eventually shedding as seed development progressed.

During this stage, a considerable increase in shoot height, as well as in the number of leaves and buds, was observed. The fruiting stage began in the second decade of June and continued until the end of the growing season. Seeds were harvested on 4 July 2025 and 30 June 2026. The cotyledons remained persistent

throughout the entire vegetation period and were retained until the completion of the plant life cycle. The generative stage lasted for 53 - 55 days. Furthermore, no senile stage was observed in *P. ovata* under the conditions of the present study.

Under the environmental conditions of the Tashkent oasis, *Plantago ovata* also exhibited the principal ontogenetic stages, including the latent, virginile (seedling, juvenile, and immature substages), and generative periods (Table 4).

Table 4. Ontogenetic stages of *Plantago ovata* Forssk. under the environmental conditions of the Tashkent oasis in 2025.

№	Ontogenetic Period	Ontogenetic Stage	Start Date	End Date	Duration
1	Latent	Seed	July 2024	April 2025	9 months
2	Virginal	Seedling	09 Apr 2025	17 Apr 2025	9 days
3		Juvenile	18 Apr 2025	01 May 2025	14 days
4		Immature	02 May 2025	09 May 2025	8 days
		Bud Formation	10 May 2025	29 May 2025	20 days
5	Generative	Flowering	19 May 2025	22 Jun 2025	35 days
		Fruiting	13 Jun 2025	04 Jul 2025	22 days

The latent period corresponds to the seed dormancy stage. The seedling stage (p) of the virginile period lasted from 9 April 2025 to 17 April 2025 (9 days). The juvenile stage (j) extended from 18 April 2025 to 1 May 2025 (14 days), whereas the immature stage (im) lasted from 2 May 2025 to 9 May 2025 (8 days). Within the generative period, the budding stage lasted from 10 May 2025 to 29 May 2025 (20 days), the flowering stage from 19 May 2025 to 22 June 2025 (35 days), and the fruiting stage from 13 June 2025 to 4 July 2025 (22 days) [36].

Table 5. Ontogenetic stages of *Plantago ovata* Forssk. under the environmental conditions of the Tashkent oasis in 2026.

No.	Ontogenetic Period	Ontogenetic Stage	Start Date	End Date	Duration
1	Latent	Seed	July 2025	April 2026	9 months
2	Virginal	Seedling	13 Apr 2026	20 Apr 2026	8 days
3		Juvenile	21 Apr 2026	30 Apr 2026	10 days
4		Immature	01 May 2026	05 May 2026	5 days
		Bud Formation	06 May 2026	25 May 2026	20 days
5	Generative	Flowering	15 May 2026	20 Jun 2026	35 days
		Fruiting	10 Jun 2026	30 Jun 2026	20 days

The latent period corresponds to the seed dormancy stage (Table 5). The seedling stage (p) of the virginile period lasted from 13 April 2026 to 20 April 2026 (8 days). The juvenile stage (j) extended from 21 April 2026 to 30 April 2026 (10

days), while the immature stage (im) lasted from 1 May 2026 to 5 May 2026 (5 days). Within the generative period, the budding stage lasted from 6 May 2026 to 25 May 2026 (20 days), the flowering stage from 15 May 2026 to 20 June 2026 (35 days), and the fruiting stage from 10 June 2026 to 30 June 2026 (20 days).

Subsequently, the plant clumps gradually completed their vegetative growth and entered the final phase of their life cycle. Since the fruiting period continued until the termination of vegetation, no distinct senile stage was observed during the phenological investigations.

During the study, the duration of the ontogenetic stages and the morphometric characteristics of *Plantago ovata* Forssk. were determined as follows: seed germination lasted 5 - 7 days; germination was optimal at temperatures of 18˚C - 22˚C, with the highest germination rates reaching 32% in 2025 and 80% in 2026. The juvenile stage, characterized by the formation of true leaves, lasted 10 - 14 days; during this period, root depth reached 2 - 3 cm, the number of leaves ranged from 6 to 7, and plant height was 7 - 9 cm. The immature stage lasted 5 - 8 days, during which the number of leaves increased to 8 - 12 and plant height reached 14 - 15 cm; the maximum growth rate was observed at temperatures of 25˚C - 28˚C. The generative stage lasted 53 - 55 days, with an average of 20 - 40 flowers per plant, while seed formation began on the 57th-63rd day of vegetation.

During field experiments conducted under the environmental conditions of the Tashkent oasis in 2025-2026, the seasonal developmental pattern of *Plantago ovata* was monitored. The obtained results demonstrated that the vegetative and reproductive processes of the species were closely associated with the prevailing climatic conditions of each growing season.

In 2025, seeds of *Plantago ovata* were sown on 4 April under environmental conditions of +27˚C and 24% relative humidity. Initial seedling emergence was observed on 9 April at +23˚C and 41% relative humidity, while mass emergence occurred on 14 April when the temperature was +26˚C and relative humidity was 37%. In 2026, seeds were sown on 7 April at +13˚C and 81% relative humidity. Initial seedling emergence was recorded on 13 April under conditions of +26˚C and 25% relative humidity, whereas mass emergence was observed on 18 April at +18˚C and 44% relative humidity (Table 6).

Table 6. Effect of temperature and relative humidity on the emergence of *Plantago ovata* under the environmental conditions of the Tashkent oasis (Botanical Garden of the National University of Uzbekistan).

Year	Sowing date	Initial seedling emergence	Mass emergence	Temperature at initial emergence (˚C)	Year	Sowing date	Initial seedling emergence
2025	4 April	9 April	14 April	23	41	26	37
2026	7 April	13 April	18 April	26	25	18	44

An analysis of the germination dynamics of *Plantago ovata* seeds over two growing seasons revealed that variations in temperature and relative air humidity

had a significant influence on seed emergence. In 2025, seeds were sown on 4 April under environmental conditions of +27˚C and 24% relative humidity, and initial seedling emergence was recorded on 9 April, indicating a germination period of 5 days. During this period, the combination of a temperature of +23˚C and relative humidity of 41% promoted rapid physiological activation of the seeds, resulting in accelerated germination. The occurrence of mass emergence on 14 April further suggests that *P. ovata* is capable of adapting rapidly to favorable environmental conditions within a specific ecological range.

Agroclimatic conditions observed in 2026 differed considerably from those recorded in the previous year. Although seeds were sown on April 7 under air temperature and relative humidity conditions of 13˚C and 81%, respectively, the low temperatures and frequent precipitation during the first ten days of April reduced soil temperature and limited soil aeration. The first seedlings emerged on April 13, when the air temperature reached 26˚C and relative humidity was 25%. The relatively low air temperature and high relative humidity at the time of sowing slightly delayed seed emergence. As a result, seed germination was extended to six days, indicating that these environmental conditions acted as factors limiting the rate of germination.

The results obtained over the two-year study period indicate that the optimal emergence time of *Plantago ovata* Forssk. depends not only on the sowing date but also on the combined effects of temperature and moisture conditions. The findings suggest that under optimal thermal and moisture regimes, water uptake by seeds, enzyme activity, and the mobilization of stored reserves are enhanced, resulting in more rapid germination and seedling emergence. In contrast, low temperatures or insufficient moisture reduce metabolic activity and delay the germination process. Therefore, when determining the sowing time for the introduction and cultivation of this species, consideration should be given not only to calendar dates but also to prevailing environmental and climatic conditions.

Overall, the observed differences not only reflect the ecological adaptability of *Plantago ovata* Forssk., but also highlight the need for a more comprehensive investigation of the effects of agroclimatic conditions on the timing and progression of phenological stages.

In 2025, the formation of the first true leaves lasted 4 - 5 days. At this stage, plant height and leaf length were 3 - 3.5 cm, leaf width was 0.1 - 0.2 mm, and the length of the primary root was approximately 1 - 1.5 cm. In 2026, the formation of the first true leaves proceeded somewhat more slowly, lasting 5 - 6 days; at this stage, plant height and leaf length reached 4 - 4.5 cm, leaf width 0.2 - 0.3 mm, and primary root length 1.5 - 2 cm. These differences are attributable to the temperature and humidity conditions prevailing in the respective years: during the cooler spring months vegetative development slowed somewhat, after which it accelerated (**Figure 10**, **Table 7**).

The juvenile stage of the plant began to form in 2025 during the second and third decades of April, under conditions of a mean daytime air temperature of +25˚C and a relative humidity of 31%. In 2026, this stage was observed during the

second half and third decade of April (+26˚C, 41% humidity). This indicates that a rise in temperature had a positive effect on the formation of the juvenile stage in plants (Figure 11).



Figure 10. Juvenile stage of *Plantago ovata* Forssk.

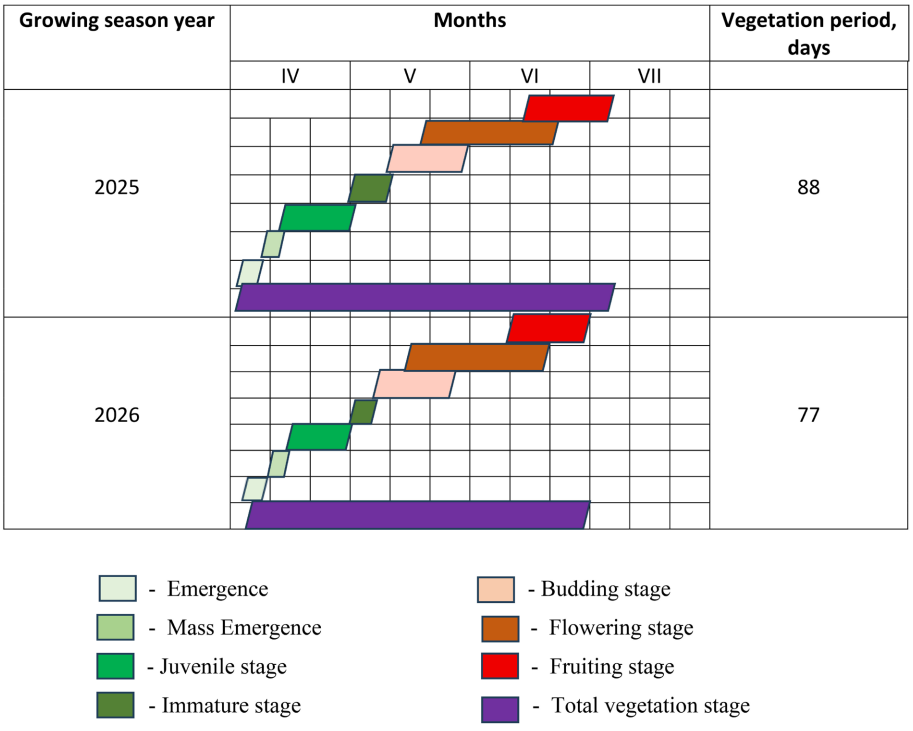


Figure 11. Phenospectrum of *Plantago ovata* Forssk.

Table 7. Morphometric and climatic indicators of the plant during the juvenile stage (2025-2026).

Indicators	2025	2026
Duration of first true leaf formation (days)	4 - 5	5 - 6
Duration of juvenile stage (days)	12 - 14	10 - 12

Continued

Plant height (cm)	3.0 - 4.5	6.0 - 8.0
Leaf length (cm)	3.0 - 4.0	6.0 - 7.5
Leaf width (cm)	0.4 - 0.5	0.5 - 0.6
Primary root length (cm)	2.0 - 2.5	3.0 - 4.5
Mean daytime temperature (˚C)	+24…−26	+24…−28
Relative air humidity (%)	29 - 36	36 - 46

The stages of generative development also differed depending on climatic conditions. In 2025, budding began during the second decade of May (29˚C, 26% humidity), whereas in 2026 this stage occurred during the first decade of May (30˚C, 23% humidity). In 2025, flowering took place at a temperature of +30˚C to 38˚C and relative humidity of 19% - 35%, with plant height reaching 16 - 18 cm. In 2026, however, flowering occurred at a temperature of +24˚C to 39˚C and relative humidity of 36% - 56%, with plant height reaching approximately 30 - 33 cm. This indicates that the soil moisture factor had a positive effect on vegetative biomass (Figure 12, Table 8).



Figure 12. Generative period of *Plantago ovata* Forssk., 2025-2026.

Table 8. Onset dates of the generative period stages of *Plantago ovata* (2025-2026).

Developmental stage	Year	Onset time	Temperature (˚C)	Relative humidity (%)
Budding	2025	May, 2nd decade	+31	26
	2026	May, 1st decade	+30	23
Flowering	2025	May, 3rd decade	+30	22
	2026	May, 2nd decade	+32	17
Seed formation	2025	Iyun 2nd decade	+34	19
	2026	Iyun 2nd decade	+33	24

The seed formation stage began during the second decade of June in both 2025 (+34˚C, 19% humidity) and 2026 (+33˚C, 24% humidity). In both years, this stage proceeded under conditions of high temperature and differing humidity, which influenced the final stages of plant vegetation.

Overall, across the developmental stages of *Plantago ovata*, the year-to-year variability of climatic conditions—particularly air temperature, relative humidity, and soil moisture—emerged as the principal ecological factor. The species vegetation period was found to encompass all developmental stages and to exhibit the capacity for successful development under the conditions of the Tashkent oasis. However, annual differences in climatic conditions had a considerable effect on the duration of vegetation and on morphometric indicators. This indicates the need to adapt cultivation technologies to local agroecological conditions in the regions where the species is being introduced (Table 9).

Table 9. Phenological stages of *Plantago ovata* during 2025-2026.

Year	Sowing	Emergence	Mass emergence	Budding	Flowering	Seed formation	End of vegetation
2025	04.04.	09.04.	14.04.	10.05.	19.05.	13.06.	06.07.
2026	07.04.	13.04.	18.04.	06.05.	15.05.	10.06.	30.06.

Phenological observations conducted on *Plantago ovata* during 2025-2026 indicate that the species completed the stages of ontogenesis fully and successfully during the introduction process under the conditions of the Tashkent oasis. The vegetation period of the plant was recorded as 88 days in 2025 and 77 days in 2026. All developmental stages of the plant (emergence, leaf formation, budding, flowering, fruiting, and seed formation) were fully expressed. This confirms the species' agroecological adaptability and its high capacity for growth and development in the region of introduction.

Ontogenetic processes are not determined solely by internal factors; their realization is also directly dependent on the abiotic factors of the external environment. In particular, factors such as light, temperature, and humidity exert a strong influence on the morphophysiological development of plants. It was established during the study that growth may, in some cases, proceed slowly, yet this does not preclude a subsequent acceleration of the developmental process. Conversely, rapid growth may in some instances be accompanied by a slowdown in the developmental process. Such discrepancies indicate a high degree of phenotypic plasticity in plants with respect to external factors. For medicinal plants such as Plantago ovata in particular, this phenomenon broadens the possibilities for adaptation to climate change.

Plantago ovata is an annual, self-pollinating plant, and seed formation depends mainly on the number of flowers, pollination efficiency, and climatic conditions. Seed yield is shaped by the interaction of biological (genetic), ecological, and agrotechnical factors. In particular, pollination rate, fruit set level, and the number of

inflorescences per plant are among the key indicators.

In cultivating *Plantago ovata* under the conditions of the Tashkent oasis, organic fertilizers—cattle manure, sheep manure, and chicken manure—were applied in three different variants, and their effect on seed yield was evaluated (Figure 13, Table 10).

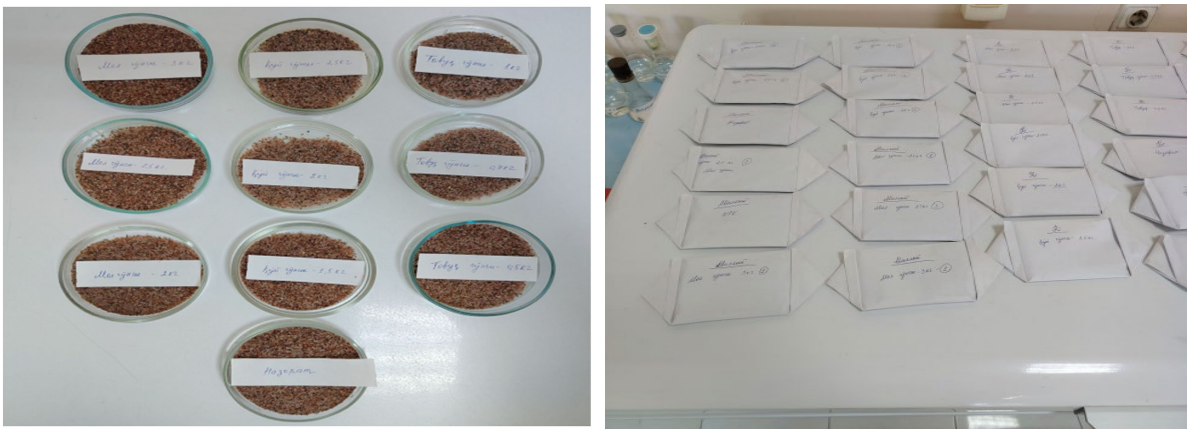


Figure 13. Seed yield of *Plantago ovata* Forssk.

Table 10. Actual seed raw material of *Plantago ovata*.

Organic fertilizers	Variants, 1 × 1 m²	Seed yield	Total seed yield
Cattle manure	3 kg	23.72 g	25.02 g
	2.5 kg	27.16 g	
	2 kg	24.19 g	
Sheep manure	2.5 kg	34.52 g	37.63 g
	2 kg	40.24 g	
	1.5 kg	38.13 g	
Poultry manure	1 kg	12.77 g	15.19 g
	0.7 kg	15.63 g	
	0.5 kg	17.18 g	
Control	-	27.49 g	27.49 g

The application of different types and rates of organic fertilizers had a significant effect on the seed yield of *Plantago ovata.* Among the tested treatments, sheep manure exhibited the highest effectiveness. The maximum seed yield (40.24 g·m^{-2}) was obtained with the application of sheep manure at a rate of 2.0 kg·m^{-2}, while the average seed yield of the sheep manure treatments reached 37.63 g·m^{-2}. Cattle manure also increased seed production, with the highest yield (27.16 g·m^{-2}) recorded at a rate of 2.5 kg·m^{-2} and an average yield of 25.02 g·m^{-2}. In contrast, poultry manure resulted in the lowest seed productivity among the fertilized treatments. The highest yield in this group (17.18 g·m^{-2}) was observed at a rate of 0.5 kg·m^{-2}, whereas the average yield was only 15.19 g·m^{-2}. In the control treatment,

seed yield reached 27.49 g·m^{-2}, exceeding all poultry manure treatments and remaining comparable to the cattle manure treatments. These findings suggest that excessive or unsuitable rates of poultry manure may negatively affect the growth and seed production of *P. ovata* under the experimental conditions. Overall, the results indicate that sheep manure, particularly at a rate of 2.0 kg·m^{-2}, is the most effective organic fertilizer for increasing the seed yield of *Plantago ovata* under the conditions of the Tashkent oasis.

4. Conclusion

The results of the present study demonstrated that *Plantago ovata* Forssk. successfully adapts to the soil and climatic conditions of the Tashkent oasis and completes its full ontogenetic development cycle. The highest seed germination rate was recorded at temperatures of 20˚C - 25˚C, while gibberellin treatment increased both germination energy and seed viability. Field experiments revealed that well-decomposed cattle manure ensured high germination rates and uniform seedling establishment. In addition, the use of seeds not older than one year contributed to better plantation formation. The vegetation period lasted 88 days in 2025 and 77 days in 2026, confirming the influence of annual climatic conditions on plant development. Distinct vegetative and generative developmental stages were clearly observed during the study. The vegetative stage was characterized by intensive plant growth and the formation of vegetative organs, whereas the generative stage was marked by seed production and the influence of climatic factors on seed yield. The experimental results indicated that sheep manure was one of the most effective organic fertilizers for increasing the seed productivity of *Plantago ovata* Forssk. Introduction studies conducted during 2025-2026 confirmed that *P. ovata* can be successfully cultivated under the conditions of the Tashkent oasis. The species exhibited stable growth, a high degree of adaptability to local agroclimatic factors, and considerable introduction potential. The obtained results provide a scientific basis for the cultivation, breeding, and sustainable production of medicinal raw materials derived from *Plantago ovata.* Future research should focus on a more comprehensive investigation of the species' agronomic performance, biochemical composition, pharmacological properties, and the development of environmentally friendly cultivation technologies.

Author Contributions

Conceptualization, N.A.Y. and T.X.M.; methodology, N.A.Y. and T.X.M.; validation, N.A.Y., T.X.M., and R.X.A.; formal analysis, N.A.Y. and T.X.M.; investigation, N.A.Y. and V.A.S.; data curation, N.A.Y. and V.A.S.; writing—original draft preparation, N.A.Y.; writing—review and editing, T.X.M. and R.X.A.; visualization, N.A.Y. and V.A.S.; supervision, T.X.M. and R.X.A.; project administration, N.A.Y. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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