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DETERMINATION OF SEED GERMINATION OF MEDICINAL FENUGREEK (TRIGONELLA FOENUM-GRAECUM L.) UNDER THE CLIMATIC CONDITIONS OF SURKHANDARYA REGION

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Abstract

This study determined the optimal parameters required for the germination of medicinal fenugreek (Trigonella foenum-graecum L.) seeds under laboratory and open-field conditions as the initial and most critical stage of the introduction process. Laboratory experiments were conducted in thermostats under five constant temperature regimes: 10°C, 15°C, 20°C, 25°C, and 30°C. According to the results, the highest germination rates were recorded at 20°C (95%) and 25°C (96%). Field trials were carried out in 2023–2025 in two districts of Surkhandarya Region: Termez, characterized by sandy desert soils, and Uzun, characterized by light sierozem soils. The experiments were conducted during late autumn and early spring sowing periods. The highest field germination was observed in the early spring sowing variants, planted in late February, where the germination rate reached 93.5–94.0%. The obtained results provide a scientific basis for the cultivation of this species under different agroecological conditions of the region and for the production of high-quality raw material for the pharmaceutical industry.

Keywords: fenugreek, Trigonella foenum-graecum, introduction, laboratory germination, field germination, temperature regime, Termez, Uzun, sowing date.

Introduction

At present, the domestication of non-traditional vegetable and medicinal plants, the wider use of their therapeutic properties, and the supply of the pharmaceutical industry with high-quality natural raw material are among the most urgent scientific and practical tasks worldwide. In the Republic of Uzbekistan, a number of important governmental decisions, including Presidential Resolutions No. PP-4670, PP-4901, and PP-251, have been adopted to protect wild medicinal plants, cultivate them under controlled conditions, and establish their seed production systems. These documents define the expansion of scientific research in this field as a priority direction [1].

The demand for natural medicinal raw material is steadily increasing in the modern pharmaceutical industry. Medicinal fenugreek (Trigonella foenum-graecum L.) is of significant

scientific and practical importance as a source of biologically active compounds, particularly the alkaloid trigonelline and the steroidal saponin diosgenin, both of which are widely used in medicine [4]. Obtaining these valuable secondary metabolites at a high level requires the production of biologically pure seed material with high germination capacity and strong seed vigor.

The soil and climatic conditions of Surkhandarya Region differ from those of many other regions due to their sharply continental character, high heat resources, and spring temperature fluctuations. Under such extreme conditions, the success of plant introduction largely depends on the correct assessment of the biological potential of seeds at the initial stage. Although laboratory germination indicators reflect the genetic capacity of the seed, fluctuations in temperature and moisture under field conditions can substantially modify these values. Therefore, predicting field germination on the basis of laboratory seed vigor and developing optimal sowing periods for open-field cultivation constitute a relevant scientific problem.

The aim of the study was to determine the effects of different temperature regimes and sowing periods under laboratory and field conditions on the germination indices and seedling emergence dynamics of fenugreek seeds, and to scientifically substantiate the most suitable parameters for cultivation.

Materials and Methods

The object of the study was fenugreek (Trigonella foenum-graecum L.), an annual medicinal herbaceous plant belonging to the Fabaceae family. The plant forms sickle-shaped curved pods, each containing an average of 10–20 seeds. Depending on agroecological conditions, one model plant may produce approximately 800 to 1,500 seeds. The seed is covered with a hard coat, and the average weight of 1,000 seeds is 15–20 g.

Laboratory experiments were carried out according to the methodologies of I.V. Belolipov and Yu.M. Murdakhayev [1] in digital laboratory thermostats under five constant temperature regimes: 10°C, 15°C, 20°C, 25°C, and 30°C. In each treatment, 100 seeds were placed on moistened filter paper in Petri dishes in four replications. Germination energy and total germination were determined by counting germinated seeds on predetermined observation dates.

Field experiments were conducted during 2023–2025 in two agroecologically different districts of Surkhandarya Region: Termez District, representing sandy desert soils, and Uzun District, representing light sierozem soils. Sowing was performed in two periods: late autumn, at the end of November, and early spring, at the end of February. The experiment was arranged in four replications using a control spacing scheme of 70 × 10 cm. The sown seeds were covered with a 2–3 cm soil layer, and systematic phenological observations were conducted until complete seedling emergence. Only organic agricultural practices were applied during the experiment; mineral fertilizers were not used.

General Characteristics of Fenugreek (Trigonella foenum-graecum L.)

Taxonomy

Fenugreek belongs to the order Fabales, the family Fabaceae, and the genus Trigonella. Under the conditions of Uzbekistan, the species Trigonella foenum-graecum L. is cultivated. Fenugreek, also known as shambhala, belongs to the genus Trigonella L. within the tribe Trifolieae and includes approximately 70 species. The ancient Greeks referred to some Trigonella species as “Bukeras” or “Aigokeras,” meaning cow horn or carob, because of the characteristic shape of their

pods. Linnaeus derived the generic name from the Latin word "trigonum," referring to the triangular form of the plant's three-leaflet apex, Trigonella foenum-graecum [5]. In addition, two species of the genus Trigonella L. are cultivated: Trigonella foenum-graecum L. (fenugreek) and Trigonella caerulea L. (blue fenugreek).

Botanical characteristics

Under the conditions of Uzbekistan, fenugreek is an annual herbaceous plant that reaches 50–80 cm in height. The stem is almost cylindrical and hollow. During the early developmental stage, it is pubescent; later, it becomes glabrous and dark green. Lateral branches develop from the leaf axils. The leaves are trifoliate, resembling clover leaves. The leaflets are approximately 5.3 mm long, while the upper leaves are slightly thicker and pubescent. The leaflets are nearly uniform in size, 10–40 mm long and 8–15 mm wide, and have an obovate form. At the lower part, they consistently become triangular. The middle leaflet has a long petiole, whereas the lateral leaflets are attached by short petiolules. The bases of all three leaflets have entire margins, while the upper parts are dentate. However, unlike clover, the extension of the veins is not clearly expressed. The stipules are relatively large and vary in shape from triangular and lanceolate to ovate.

The flowers are 10–18 mm long, appear singly or in pairs in the leaf axils, and are sessile. The petals are yellowish white and sometimes slightly pinkish. The corolla is twice as long as the calyx and consists of an outer standard, two inner wings, and a keel. The wing petals are half as long as the standard. The keel is blunt or rounded, but as long as the calyx. The calyx tube is leathery, and the petals are surrounded at the base by six-part sepals. The surface of the calyx is distinctly pubescent. Fruit development begins within 10 days after flowering [5, 12]. The pods are 5–11 cm long, curved, and pointed at the tip, containing on average 10–20 seeds. The seeds are 3–5 mm long, hard, angular, slightly rough, and their color ranges from light yellow to dark brown. The characteristic odor of fenugreek becomes noticeable when the seeds are rubbed between the fingers [12, 13].

Figure 1. General appearance and seed morphology of fenugreek (Trigonella foenum-graecum L.).

The seeds, which have a very strong odor, contain 6.5% fixed oil and a 32.3% mixture of mucilaginous polysaccharides [14]. They are also rich in protein (25%) and contain several chemical compounds, including trigonelline, an alkaloid without marked physiological effect; choline; saponins; cholesterol; lecithin oils; essential oils; bitter substances; tannins; and coloring substances. The seeds have a strong coumarin-like aroma [5]. The detection of a saponin called diosgenin in the seed embryo contributed to the spread of fenugreek cultivation in Europe, America, and East Africa. Diosgenin is a valuable compound used in the synthesis of corticosteroids [15]. According to the cited study, the chemical and mineral composition of fenugreek seeds is presented in Table 1. The seeds were found to be rich in essential amino acids such as valine, phenylalanine, lysine, glycine, aspartic acid, glutamic acid, serine, and leucine [16].

Table 1. Chemical and mineral composition of fenugreek seeds

No.	Chemical composition	%	Mineral element	mg/100 g
1	Moisture	4.3	Na	49.0
2	Crude protein	27.3	K	1306.0
3	Crude fat	6.7	Fe	22.5

4	Crude fiber	6.7	Ca	158.0
5	Nitrogen-free extract / nitrogenous compounds	51.2	P	415.0
6	Ash	3.8	Mn	1550.0
7			Zn	9.9
8			Cu	331.0

An analysis of the chemical and mineral composition of fenugreek seeds shows that they contain high levels of protein (27.3%) and nitrogenous compounds (51.2%), which are essential both for the human organism and for the early seedling stage. These indicators represent the main reserve sources that support rapid development of the seed embryo.

Studies Conducted on Fenugreek

Studying the laboratory germination biology of seeds has fundamental importance in the introduction of medicinal plants into new climatic conditions and in the establishment of cultivated plantations. Seed germination is a complex physiological and biochemical process, the intensity of which is directly related to environmental factors, particularly temperature regimes.

In Uzbekistan, a broad methodological foundation for introducing medicinal and non-traditional plants, germinating their seed material under laboratory conditions, and evaluating ecological parameters of seedling emergence was developed by I.V. Belolipov and Yu.M. Murdakhayev [1]. According to these researchers, determining the temperature limits of seedling emergence for each introduced plant species makes it possible to forecast its subsequent ontogenetic development. B.Yo. Tokhtayev and Kh.Q. Qarshiboyev conducted systematic studies on seed science of medicinal plants and the assessment of their physiological responses to various abiotic stress factors, including temperature fluctuation and drought, under laboratory models [2].

Their findings indicate that an optimal temperature environment maximizes the viability and vigor of seedlings. O.K. Khojimatov also substantiated the need to control seed-quality indicators in the laboratory according to GOST standards when forming the raw-material base of medicinal plants belonging to the flora of the republic [3].

A specific feature of fenugreek is that its seed seedlings serve as an active center for the synthesis of valuable secondary metabolites from the earliest developmental stages, especially the alkaloid trigonelline and the steroidal saponin diosgenin. The formation of these substances in the germinating embryo under laboratory conditions and their chemical analysis have been studied in depth by scientists of the Institute of the Chemistry of Plant Substances of the Academy of Sciences of the Republic of Uzbekistan [4].

At the international level, one of the most authoritative researchers of the germination physiology of Trigonella foenum-graecum L. is G.A. Petropoulos [5]. In his fundamental monograph, he demonstrated that fenugreek seeds have a hard seed coat, that the optimal temperature range for their germination in laboratory thermostats is 20–25°C, and that germination energy reaches its highest level within this range. Canadian researcher S.N. Acharya and co-authors developed a breeding approach for selecting cold-tolerant lines by evaluating genetic capacity and seedling vigor of fenugreek seeds under laboratory conditions [6].




Figure 1

Iranian researchers A. Mehrafarin and H. Rezazadeh studied the germination kinetics of fenugreek seeds under different digitally controlled temperature environments and the effect of temperature on trigonelline content in seedlings [7]. They found that temperatures either above or below the optimal level of 20–25°C inhibit enzymatic processes. Pakistani researcher M.S.A. Ahmad conducted a detailed analysis of the correlation between temperature and the activity of hydrolytic enzymes in fenugreek seeds, especially alpha-amylase and protease, which break down reserve carbohydrates, by inducing thermal stress under laboratory conditions [8].

Determination of Seed Germination in Fenugreek (Trigonella foenum-graecum L.)

Fenugreek (Trigonella foenum-graecum L.) is an annual medicinal herbaceous plant of the Fabaceae family. Members of this family are widely distributed across different regions of the world and are of major importance in food production, medicine, and agriculture.

The plant selected as the scientific object forms sickle-shaped curved pods; each pod contains an average of 10–20 seeds, and one model plant can produce 800–1,500 seeds depending on agrotechnical conditions. The seed is covered with a hard coat, and the average weight of 1,000 seeds is 15–20 g.

A laboratory experiment was conducted to determine the quality indicators and germination capacity of fenugreek seeds, as well as the effect of temperature on seed germination. As a result, the optimal temperature for seed germination was identified.

Figure 2. Germination of seeds under laboratory conditions, % (2023–2025).

To determine the optimal temperature, 100 seeds were placed in each of four Petri dishes and incubated in thermostats at 10°C, 15°C, 20°C, 25°C, and 30°C. Seed germination ability and total germination were determined by counting germinated seeds on specific observation dates.

The experiments showed that the optimal temperature for germination of Trigonella foenum-graecum L. seeds under laboratory conditions was 20–25°C. Within 3–5 days, germination reached 95–96% under these temperature regimes. It should be noted that temperatures of 10–15°C prolonged the duration of germination to 12–14 days. Conversely, temperatures above 30°C accelerated initial germination, but due to rapid moisture evaporation and hardening of the seed coat, the final germination rate decreased slightly to 90%.

Overall, the experimental results demonstrated that the optimal temperature for germination of Trigonella foenum-graecum L. seeds is 20–25°C, at which the germination rate reached its

maximum value of 95–96% within the first 3–5 days. A decrease in temperature to 10–15°C significantly extended the germination period to 12–14 days and reduced germination to 80%. An increase in temperature to 30°C enhanced early seedling emergence, but rapid moisture loss and hardening of the seed coat resulted in a slight decrease in final germination to 90%.

Table 2. Laboratory germination of fenugreek (Trigonella foenum-graecum L.) seeds, % (2023–2025)

Seeds, pcs.	Temp., °C	15.02	20.02	25.02	30.02	05.03	10.03	15.03	Total, pcs.	Germ., %
100	10	-	-	15	25	20	15	5	80	80
100	15	-	10	30	25	15	5	-	85	85
100	20	45	35	15	-	-	-	-	95	95
100	25	55	30	11	-	-	-	-	96	96
100	30	60	20	10	-	6	-	-	90	90

Note: the date “30.02” is retained as it appears in the source table and should be clarified before journal submission.

Field Germination of Seeds

Because fenugreek has a biological characteristic of relative cold tolerance, seeds sown in open-field conditions were found to germinate actively when soil temperature reached 10–12°C.

To determine the field germination of fenugreek seeds, experiments were conducted in 2023–2025 in two districts of Surkhandarya Region: Termez, representing sandy desert soils, and Uzun, representing light sierozem soils. Seeds were sown in two periods: late autumn, at the end of November, and early spring, at the end of February. The seeds were sown separately in pre-prepared 70 cm rows in four replications using the control scheme of 70 × 10 cm. After sowing, the seeds were lightly covered with a 2–3 cm layer of soil, and phenological observations were carried out until full seedling emergence. The seeds sown in early spring were maintained according to the moisture level of the surface soil layer.

The experimental data showed that seed germination in the early spring sowing variants, planted on 22–25 February, was closely associated with soil-climatic conditions and moisture balance, reaching the most favorable values of 93.5–94.0%. Under the sandy soil conditions of Termez, due to the rapid rise of spring temperature, seeds fully emerged within a short period of 10 days. In the relatively heavier light sierozem soils of Uzun District, complete emergence required 12 days.

Seeds sown in late autumn, on 25–28 November, germinated in a short period due to autumn soil moisture and favorable temperature, entering the seedling phase in the first half of December. Owing to the high cold tolerance of fenugreek, winter cold did not damage the young seedlings. The seedlings overwintered as green plants, and their growth and development processes only slowed during this period. With the rise of air temperature in early spring, their active growth resumed.

The lower germination rate observed in the late autumn sowing period, 84.0–88.5% in the generalized data and 88.5–89.5% in the field tables, compared with the early spring period, was mainly due to soil temperatures at the end of November being slightly below the optimal range. Thus, seed germination in fenugreek is directly associated with air and soil temperatures. A prolonged temperature range of 10–15°C extends the duration of germination, whereas temperatures above 20°C accelerate the overcoming of seed-coat hardness and increase germination intensity. Under laboratory conditions, the optimal temperature for fenugreek seed

germination is 20–25°C. Under field conditions, early spring sowing resulted in a germination rate of approximately 93.5–94.0%, primarily determined by soil moisture and spring soil temperatures above 10–12°C.

The correct selection of temperature parameters during the germination period establishes a physiological basis for the stable activation of valuable secondary metabolite synthesis in young seedlings from the earliest developmental stages, particularly the alkaloid trigonelline and the steroidal saponin diosgenin [7].

Table 3a. Field germination of fenugreek (Trigonella foenum-graecum L.) seeds under Termez District conditions, % (2023–2025), control scheme 70 × 10 cm

Row	Seeds	25.11 start	25.11 end	25.11 %	22.02 start	22.02 end	22.02 %	28.11 start	28.11 end	28.11 %	25.02 start	25.02 end	25.02 %
1	100	05/XII	08/XII	90.0	01/III	03/III	93.0	09/XII	12/XII	89.0	06/III	08/III	94.0
2	100	06/XII	09/XII	91.0	02/III	04/III	94.0	10/XII	13/XII	88.0	07/III	09/III	95.0
3	100	05/XII	08/XII	88.0	01/III	03/III	92.0	08/XII	11/XII	89.0	06/III	08/III	93.0
4	100	06/XII	09/XII	89.0	02/III	04/III	95.0	09/XII	12/XII	88.0	07/III	09/III	94.0
Average				89.5			93.5			88.5			94.0

Table 3b. Field germination of fenugreek (Trigonella foenum-graecum L.) seeds under Uzun District conditions, % (2023–2025), control scheme 70 × 10 cm

Row	Seeds	25.11 start	25.11 end	25.11 %	22.02 start	22.02 end	22.02 %	28.11 start	28.11 end	28.11 %	25.02 start	25.02 end	25.02 %
1	100	05/XII	08/XII	90.0	01/III	03/III	93.0	09/XII	12/XII	89.0	06/III	08/III	94.0
2	100	06/XII	09/XII	91.0	02/III	04/III	94.0	10/XII	13/XII	88.0	07/III	09/III	95.0
3	100	05/XII	08/XII	88.0	01/III	03/III	92.0	08/XII	11/XII	89.0	06/III	08/III	93.0
4	100	06/XII	09/XII	89.0	02/III	04/III	95.0	09/XII	12/XII	88.0	07/III	09/III	94.0
Average				89.5			93.5			88.5			94.0

Results and Conclusions

The laboratory results indicate that fenugreek seeds are highly sensitive to changes in temperature. Based on the general conclusions of I.V. Belolipov, Yu.M. Murdakhayev, and local researchers Kh.Q. Qarshiboyev and B.Yo. Tokhtayev regarding the introduction of medicinal plants, the determination of temperature limits for seed germination under new climatic conditions plays a decisive role in the subsequent ontogenetic development of seedlings.

The study proved that the optimal temperature range for fenugreek seeds is 20–25°C, because the maximum germination potential was realized within a short period at this temperature level. At lower temperatures, 10–15°C, the extension of embryonic development up to almost one month is explained by the hardness of the seed coat and the slow rate of enzymatic processes. However, the fact that the plant can still produce up to 80% germination at low temperatures indicates a certain biological level of cold tolerance. This laboratory model can serve as a reliable criterion for scheduling open-field sowing in Surkhandarya conditions when soil temperature reaches the required threshold.

Laboratory experiments showed that the most favorable temperature environment for seedling emergence of introduced fenugreek seeds was 20°C and 25°C. Under these regimes, the highest germination rates were achieved, 95.0% and 96.0%, respectively.

The minimum temperature threshold, or biological zero, for fenugreek seed germination is approximately 10°C. At this temperature, germination dynamics are prolonged and final germination decreases to 80.0%. Although 30°C accelerates seedling emergence, it reduces the final germination rate by 6.0% compared with the 25°C treatment.

Under field conditions, the most suitable sowing period for fenugreek cultivation in the sandy desert soils of Termez and the light sierozem soils of Uzun in Surkhandarya Region is early spring, at the end of February. During this period, field germination reaches 93.5–94.0%, and seeds fully emerge within 10–12 days.

The high cold tolerance of the plant also allows late autumn sowing at the end of November, when field germination reaches 88.5–89.5%. These indicators confirm the possibility of creating a stable and environmentally clean organic raw-material base for this plant in the region.

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