Int.J.Curr.Microbiol.App.Sci (2026) *15*(7): 200-206

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 15 Number 7 (2026)**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2026.1507.18

Seasonal and Diurnal Flowering Phenology of Vigna Umbellata under Introduction Conditions in the Arid Continental Climate of Uzbekistan

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Keywords

Vigna umbellata, flowering phenology, seasonal flowering dynamics, diurnal flowering dynamics, bioecological adaptation, introduction, relative air humidity, air temperature.

Article Info

Received:
15 May 2026
Accepted:
28 June 2026
Available Online:
10 July 2026

A B S T R A C T

Vigna umbellata is a high-protein leguminous crop. However, its bioecological characteristics have not been sufficiently studied under the conditions of Uzbekistan. The research was carried out at an experimental field in Karmana district, Navoi region. The flowering dynamics of the plant were studied using the methods of A.N. Ponomaryov and Z.G. Bespalova. The results showed, for the first time under the climatic conditions of Karmana, that the diurnal and seasonal flowering dynamics of *V. umbellata* are scientifically related to abiotic factors. Based on the obtained results, this species can be recommended for cultivation as a promising leguminous crop in the arid regions of Uzbekistan.

Introduction

Background: To ensure global food security, it is necessary to identify and introduce leguminous crops with high nutritional value and adaptability to unfavorable environmental conditions. Under climate change, underutilized legumes are attracting increasing attention as resources for improving sustainable agriculture. *Vigna umbellata* (rice bean) is one of the promising protein-rich crops resistant to abiotic stresses. However, the successful introduction of a new crop into previously untested regions largely depends on its reproductive development, especially the flowering stage, which strongly affects ecological adaptation and seed formation. In plants, flowering is a key process that reflects the relationship among phenophases and the adaptation of a plant to new introduction conditions (1).

Flowering is a process that occurs at different levels in different plant species, and a comprehensive study of the flowering biology of a particular plant is an essential component of bioecological research (2).

Literature review: Previous studies have shown that sowing date and plant density significantly affect the vegetative growth and reproductive development of *Vigna umbellata* (3). However, these studies have mainly focused on agronomic traits rather than on flowering dynamics in arid continental environments. Studies conducted under Indian conditions described the morphobiological features of *V. umbellata* and recorded that, during flowering, each raceme usually forms 5–20 flowers and the peduncle may reach up to 20 cm in length. Although these data characterize the reproductive biology of the species, the diurnal and seasonal rhythm of flower opening and its relationship with ecological factors were not considered in detail (4).

Recent molecular-genetic studies have identified genetic mechanisms related to flowering time, maturity, and seed traits, and have mapped genes and markers controlling flowering. These works are important for explaining the genetic basis of flowering; nevertheless, how this genetic potential is expressed under different ecological conditions, especially in introduced areas, remains insufficiently clarified (5). In addition, tolerance to abiotic and biotic stresses has been widely studied in wild and cultivated species of the genus Vigna. Researchers emphasize that *V. umbellata* has a certain level of adaptation to drought, salinity, and high temperature and is a valuable genetic resource for breeding (6,7). However, most existing studies focus on stress tolerance, genetic diversity, and seed germination, while the flowering phenology of the plant and the relationship between its diurnal flowering rhythm and ecological factors have been scarcely investigated. Therefore, studying the flowering dynamics of *V. umbellata* under introduction conditions in an arid continental climate is important for assessing the ecological adaptation and reproductive biology of the species, as well as for scientifically substantiating its introduction as a promising leguminous crop in Uzbekistan.

Research gap: Despite extensive research on agronomic traits, molecular genetics, and stress tolerance, very limited information is available on the seasonal and diurnal flowering characteristics of *V. umbellata* under arid continental climate conditions. Moreover, such research has not previously been conducted in Uzbekistan. Studying the flowering phase of a plant under introduction conditions is an important indicator for determining its degree of adaptation to the climatic conditions of the growing environment. Observation of seasonal flowering dynamics in relation to ecological factors is of great importance for identifying such indicators as the onset of flowering, mass flowering, final flowering, and the possibility of achieving high seed productivity, all of which characterize the adaptive capacity of the plant.

The main aim of this study was to determine the diurnal and seasonal flowering dynamics of *V. umbellata* under the conditions of Karmana district, Navoi region.

Novelty: The scientific novelty of the study lies in the fact that the seasonal and diurnal flowering dynamics of *Vigna umbellata* were evaluated comprehensively for the first time under the arid continental climate conditions of Uzbekistan. Under introduction conditions, the relationship between the flowering rhythm and the main abiotic factors, including air temperature and relative air humidity, was determined. The results enrich scientific knowledge on the flowering biology of *V. umbellata*, provide new data for assessing its bioecological adaptation and reproductive success, and serve to substantiate its promising introduction and cultivation potential in the arid regions of Central Asia.

Materials and Methods

Study area

The study was carried out in an experimental field belonging to the Navoi Regional Agroservices Center of the Republican Agroservices Center under the Scientific Center for Knowledge and Innovations in Agriculture, located in Karmana district, Navoi region (40°05′47″ N, 65°23′15″ E). The region is characterized by hot summers, low annual precipitation, and a dry continental climate (8). Climatic data for the observation years were obtained from the Navoi Regional Department of Hydrometeorology (UzHydromet) (9).

Plant material

The experiment was conducted in 2024–2025. In the field, 40 plants were selected and marked separately in four replications, with 10 plants in each replication. The results were calculated on the basis of 10 plants.

Experimental design

Seeds were sown in the first and third ten-day periods of April using a 30 × 10 cm planting geometry. The

experiment was conducted under identical field conditions in both growing seasons. In order to assess the natural adaptability of the species to local environmental conditions, no mineral or organic fertilizers were applied during the experiment. Weeds were not removed during the vegetation period. Irrigation was carried out once a month by furrow irrigation, depending on the available water supply of the experimental field.

Flowering observations

Flowering dynamics were studied according to the methods of Ponomaryov (10) (1960) and Bespalova (11) (1965). During seasonal observations, the beginning, peak period, and end of flowering were recorded throughout the vegetation period. To determine the diurnal flowering rhythm, the number of newly opened flowers was counted every hour during the flowering period. To assess the relationship with flowering activity, data on air temperature and relative air humidity were obtained from the nearest meteorological station. Observations were carried out daily from 07:00 to 18:00, and only newly opened flowers were recorded at each observation time.

Climatic observations

Daily meteorological data, including mean, minimum, and maximum air temperature, relative air humidity, and precipitation, were obtained from UzHydromet. These data were used to analyze the effects of climatic factors on seasonal and diurnal flowering dynamics.

Statistical analysis

The obtained data were processed using Microsoft Excel 2021 (Microsoft Corp., USA). Descriptive statistical parameters, including arithmetic mean values, were calculated. Graphs were prepared using Microsoft Excel 2021.

Results and Discussion

Seasonal climatic conditions (2024–2025)

Certain differences in climatic conditions were observed between 2024 and 2025 (Figure 1). During the active vegetation period (May–September), the mean air temperature was 26.1 °C in 2024, whereas it reached 27.6 °C in 2025. Thus, the second observation year was 1.5 °C warmer during the vegetation period. The amount of precipitation also differed: in 2024, total precipitation from May to September was 12.0 mm, while in 2025 this value amounted to only 0.14 mm. This indicates that the vegetation period passed under arid conditions. Relative air humidity showed seasonal variability throughout the year. During the flowering period (June–July), relative humidity ranged from 20.4% to 21.3% in 2024 and from 28.8% to 23.2% in 2025. Thus, despite a sharp decrease in precipitation, relative humidity during flowering remained comparatively higher in 2025.

Seasonal flowering dynamics

Seasonal observations showed that *Vigna umbellata* successfully completed its reproductive development under the climatic conditions of Karmana district (Navoi region) in both years of the study. However, the timing and duration of flowering differed between 2024 and 2025, indicating that annual climatic variability influenced flowering phenology (Table 1).

As shown in Table 1, the first flower opened on 22 June in 2024, whereas in 2025 the flowering phase began 12 days earlier, on 10 June. Similarly, the peak flowering period shifted from 29 June–12 July in 2024 to 25 June–5 July in 2025. Despite these differences, the flowering duration remained relatively stable: 34 days in 2024 and 36 days in 2025.

In 2025, an acceleration of reproductive development was observed as a result of changes in climatic conditions.

The influence of environmental conditions on the flowering phenology of *V. umbellata* has been reported in various sowing environments (Shilpa *et al.,* 2025). The obtained results indicate that the flowering phenology of rice bean is highly sensitive to annual climatic variability.

Bioecological observations showed that flowering in both years coincided with increasing air temperature and a period of minimal precipitation (Figure 1). The highest flowering rate was observed when the mean monthly air temperature ranged from 29.0 to 31.9 °C and precipitation was minimal. The ability of *V. umbellata* to maintain active flowering under such conditions indicates that this species is well adapted to the arid continental climate of Navoi region.

Figure.1 Seasonal climatic conditions in the Navoi region during the study period: (a) 2024; (b) 2025. The green line indicates mean monthly air temperature (°C), blue bars represent relative humidity (%), and red bars show monthly precipitation (mm).

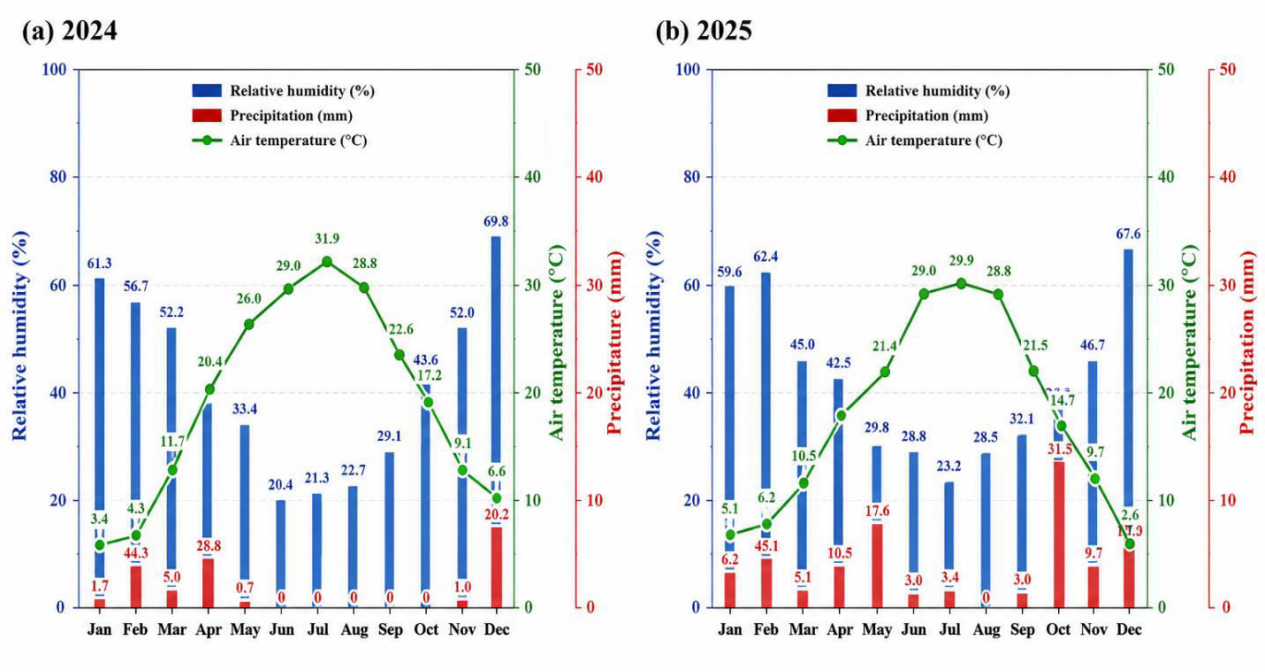

Figure.2 Seasonal dynamics of newly opened flowers in relation to daily air temperature and relative humidity in the Navoi region: (a, c) 2024; (b, d) 2025.

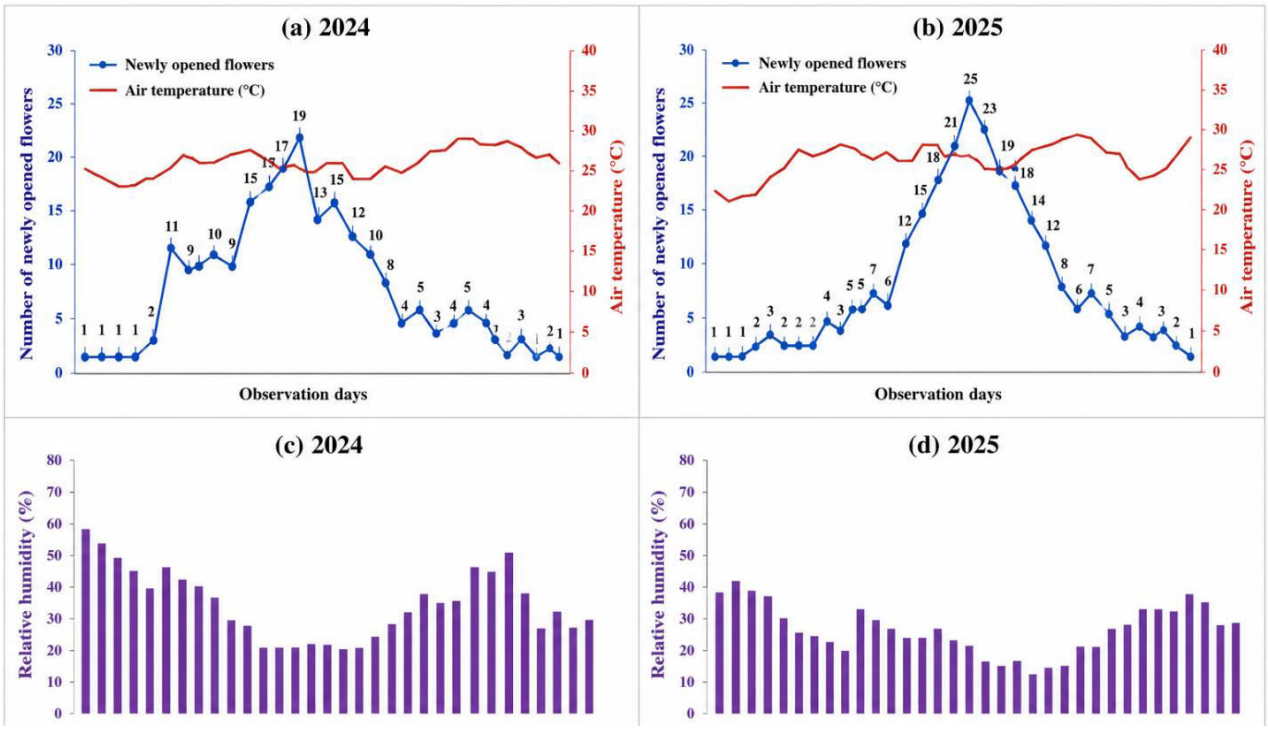

Table.1 Seasonal flowering of *V. umbellata* (2024–2025)

Observation years	Flowering process			Flowering duration (days)
Observation years	onset period	mass flowering	final period	Flowering duration (days)
Karmana district, Navoi region				
2024	22.06	29.06–12.07	25.07	34
2025	10.06	25.06–05.07	15.07	36

Table.2

Time	Flowers 2024	Temp 2024	RH 2024	Flowers 2025	Temp 2025	RH 2025
7:00	2	27.1	40	4	27.5	26
8:00	4	29.1	31	9	29.1	24
9:00	10	30.7	28	7	30.9	22
10:00	3	31.8	26	2	33.7	18
11:00	0	32.6	24	0	35.2	16
12:00	0	33.2	23	0	35.6	16
13:00	0	33.8	22	0	35.9	15
14:00	0	34.5	21	0	36.4	14
15:00	0	34.9	20	0	36.6	14
16:00	0	34.9	20	0	36.7	14
17:00	0	36.1	18	0	37.1	15
18:00	0	35.9	18	0	36.5	17

Note: Zero values indicate that no new flowers opened during the respective hours of the day.

Diurnal flowering rhythm

Observation of the diurnal flowering dynamics of *V. umbellata* showed that flower opening mainly begins in the morning. Flower opening started in the early morning and gradually increased until it reached a maximum in the morning; thereafter, flowering intensity gradually declined in the afternoon. This pattern confirms that *V. umbellata* is characterized by a daytime flowering type. In both observation years, the diurnal flowering dynamics were recorded on the sixteenth day of flowering (Table 2).

In 2024, the opening of new flowers began at 07:00. The main portion of flowers opened at 09:00, reaching 10 flowers. After 11:00, no new flowers opened; however, the flowers that had opened earlier remained open throughout the day. A total of 19 new flowers opened during the day. In 2025, flower opening also began in the morning, with maximum flowering observed at 09:00, when 9 flowers opened; at 10:00, another 7 flowers opened, and no new flowers opened later in the day. A total of 22 flowers opened during the day.

In both years, flower opening was observed between 07:00 and 10:00. This indicates that the species has a morning diurnal flowering rhythm. In 2025, flowering intensity was higher than in 2024, which suggests that *V. umbellata* is adapting to the climatic conditions of Navoi region.

The flowering period of the plants lasted approximately 35–40 days, and each flower remained open for only one day. This indicates that the flowering of *V. umbellata* is of the daytime type. Most representatives of the *Fabaceae* family usually demonstrate a similar flowering type.

In this pattern, flowers begin to open in the early morning, remain open for several hours, and complete their functional role on the same day. Such a flowering type shows that the duration of flowering results from

the continuous daily opening of new flowers and may enhance the reproductive adaptability of the plant under drought conditions.

According to the study results, *Vigna umbellata* successfully completed its generative phase under the arid climatic conditions of Navoi region. Meteorological differences between the study years had a noticeable effect on flowering phenology. In 2025, compared with 2024, flowering began earlier during the vegetation period, and seasonal flowering intensity increased. This indicates an increasing level of adaptation of the species under introduction conditions.

Diurnal observations showed that the main part of *V. umbellata* flowers opened between 07:00 and 08:00 in the morning. This diurnal rhythm may be regarded as one of the bioecological adaptation mechanisms of reproductive processes under arid climate conditions.

This study provides the first detailed characterization of the seasonal and diurnal flowering biology of *Vigna umbellata* under the desert-region conditions of Uzbekistan. The obtained results serve as a scientific basis for further research on the introduction of the species, improvement of its agrotechnology, and its wider implementation as a promising leguminous crop in arid regions.

Author Contributions

Makhfuza Nazaralieva: Investigation, formal analysis, writing—original draft.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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How to cite this article:

Makhfuza Nazaralieva. 2026. Seasonal and Diurnal Flowering Phenology of Vigna Umbellata under Introduction Conditions in the Arid Continental Climate of Uzbekistan. *Int.J.Curr.Microbiol.App.Sci.* 15(7): 200-206.
doi: https://doi.org/10.20546/ijcmas.2026.1507.018