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The authors' details and affiliations are provided below, following the reference section

Phenology and reproductive behaviour of endangered medicinal plant: *Valeriana jatamansi* Jones ex Roxb.

Urwah, Ashfaq Ahmad Mir, PA Khan, Amerjeet Singh, Mubariz Mehak, Anam Gowher Sofi, Aamir Majeed Baba, Mubashir Ahmad Mir, Sayed Adeel Mazahar and Irtizah Mushtaq

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Abstract
Understanding a species' phenology and reproductive biology is necessary for the restoration of endangered plant species. *Valeriana jatamansi* is an endangered plant in IUCN Red Data Book due to excessive deforestation and over exploitation. The study delves into the phenological patterns and reproductive strategies of this medicinally significant species across six distinct sources: JK1, JK2, JK3 (from Jammu and Kashmir), and HP1, HP2, HP3 (from Himachal Pradesh). *Valeriana jatamansi* Jones is a perennial herb that ranges in height from 14 to 45 cm belonging to the family Valerianaceae and order Dipsacales. *Valeriana jatamansi* exhibits remontant flowering behavior, re-blooming in spring and autumn. Spring phenophases showed better synchronization and longer duration compared to autumn. Spring flowering initiation occurred between 22 February to 25 with a duration of 53-55 days, while autumn flowering showed greater variation (November 4-8) lasting 42-46 days. The species exhibits a gynomonoecious reproductive system with hermaphrodite flowers. Pollination peaks occurred morning and evening, with *Apis mellifera* and *Musca domestica* as primary pollinators. The data produced by the current study may prove helpful and effective in various breeding methods and the preservation of this medicinal plant species.

Keywords: *Valeriana jatamansi*, phenology, reproductive biology, endangered medicinal plants

Introduction
Valeriana jatamansi Jones is also known as Indian valerian in English, Mushkbala or Sugandhbala in Hindi and Tagar in Sanskrit (Thakur *et al*., 2018) [21]. The term "Valerian" was originally used in the ninth century by an Indian physician, and it was taken from the word "Velo," which means "powerful drug" (Bhatt *et al*., 2012) [3]. *Valeriana jatamansi* Jones is a perennial herb that ranges in height from 14 to 45 cm. Belonging to the family Valerianaceae and order Dipsacales. The species is mostly found in the Himalayan regions of Afghanistan, Bhutan, Burma, India, Nepal, and Pakistan including cold and temperate regions at elevations of 1500–3000m *(*Ekhteraei *et al.,* 2010) [5]. *V. jatamansi* is known for the sedative and tranquilizing effects that are attributed to the presence of the bioactive chemical 'valepotriates' in the roots and rhizome [Wagner *et al*., 1980; Grusla *et al*., 1986; Houghton, 1999; Mishra, 2004] [24, 11, 12, 15]. *V. jatamansi* has antidepressant, anticonvulsive, antispasmodic, antitumor, cytotoxic, analgesic, laxative, carminative, anti-dyspeptic, antimicrobial, and a number of other pharmacological qualities (Dhiman *et al*., 2020) [4]. While having such valuable medicinal properties and being an endangered species, it is essential to conserve this medicinal herb and for that studying phenology and reproductive behaviour of *Valeriana jatamansi* Jones is necessary.

Phenology is the investigation of the planning of repeating organic occasions, the causes of their timing concerning biotic and abiotic powers, and the interrelation between periods of the same or different species (Leith, 1974) [13]. The information on timing of phenological occasions and their changeability can assist with getting more steady harvest yields and quality through improved and feasible harvest the board giving dates to ideal water system, fertilizing, and crop security (Ruml and Vulić, 2005) [18].

Study of reproductive biology is a crucial component of plant ecology that plays an important role in the conservation and management of a plant species by scientific way. It is

Corresponding Author:
Urwah
Division of Forest Biology and Tree Improvement, Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Benhama, Campus, Ganderbal, Jammu and Kashmir, India

the pollination that makes the first male and female interactions in plants which is also accompanied by natural biotic and abiotic factors. The successful pollination is represented by the pollinator's potential, daily opening and number of flowers. Therefore, the study of reproductive biology of flowering plants is essential to understand the breeding systems and pollination that helps in regulating the genetic structure of plant populations and determine the barriers of seed and fruit set for the purpose of conservation (Tandon *et al*., 2003) [22]. Although large efforts have been invested in research, documentation and analysis, of *Valeriana jatamansi* Jones (Syn. *V. wallichii* DC.) regarding its pharmacological makeup, chemical composition, and therapeutic applications, there remains a significant gap in understanding the species' phenology and reproductive biology that are key ecological aspects for its sustainable management, conservation and cultivation strategies.

Materials and Methods

The study was conducted at Faculty of Forestry SKUAST-Kashmir, Benhama Ganderbal during the years 2023 – 2024. The study of phenology and reproductive biology was conducted by sourcing rhizomes of *Valeriana jatamansi* of uniform size and weight. These rhizomes were collected from six locations across two regions: Jammu & Kashmir (JK1, JK2, JK3) and Himachal Pradesh (HP1, HP2, HP3). Three sources were selected from each region. The collected rhizomes were then planted in a randomized block design at the onset of spring-2023, and observations were systematically recorded throughout the growing season to capture the plant's growth, reproductive stages, and phenological events.

Phenology

Throughout the growing season, which included both the spring and autumn flowering phases, various observations were made on the phenology and reproductive biology of *Valeriana jatamansi*. The following parameters were recorded: initiation of vegetative bud burst, initiation of flower bud, commencement of flowering, peak period of flowering, duration of peak period of flowering, termination of flowering and duration of flowering. The observations were taken on alternate days.

Morphological observations

Average number of floral spikes per inflorescence, average number of floral clusters per spike and average number of flowers per cluster were recorded by randomly selecting four plants per replication and then evaluated for the same during the peak flowering period.

Reproductive study

The reproductive study of *Valeriana jatamansi* was carried out for sex determination in which flowers from ten randomly selected spikes per source were examined using a magnifying glass to determine whether they were staminate, pistillate, or hermaphrodite. Anthesis was recorded during the peak flowering hours between 6 a.m.–11 a.m. and 4 p.m.–7 p.m. Pollination was observed within the peak hours of anthesis. Pollinating agents, both biotic (such as insects, birds) and abiotic (such as wind), were observed for their role in transferring pollen. Pollinators were identified through direct observation during the peak flowering and anthesis periods.

Results and Discussion

Seasonal Phenology of *Valeriana jatamansi* Jones ex Roxb across different sources.

The seasonal phenology of *Valeriana jatamansi* Jones ex Roxb. revealed distinct variations between autumn 2023 and spring 2024 across sources JK1–JK3 and HP1–HP3 as mentioned in Table 1. In spring, the initiation of vegetative bud burst occurred earlier (7–15 February) compared to autumn (20–27 October), an effect of favourable temperatures and longer photoperiods promoting early growth. Flower bud initiation followed shortly after vegetative bud burst, occurring between 13–21 February in spring and 26 October–5 November in autumn, with the JK sources consistently showing earlier initiation, reflecting genotypic adaptation to local environments. Flowering commenced earlier and more synchronously in spring (22–29 February) than in autumn (4–12 November), indicating stable climatic conditions during the spring season. Peak flowering was observed between 10–27 March in spring and 10–29 November in autumn, with JK1 peaking earliest and HP2 latest in both seasons, demonstrating a slightly staggered but overlapping pattern. The duration of the peak flowering period was consistent across both seasons (14–16 days), reflecting robust physiological control. Termination of flowering occurred between 11–18 April in spring and 13–19 December in autumn, showing moderate overlap among sources. Overall flowering duration was longer in spring (53–55 days) than in autumn (42–46 days), with JK1 exhibiting the longest duration in both seasons, suggesting superior reproductive potential and adaptability. These patterns underscore how temperature, photoperiod, and genotypic differences govern phenological development, with spring conditions facilitating earlier and longer reproductive phases. The observations align with previous findings by Fenner 1998 [7], Ghelardini *et al*., 2006 [10], Liang and Schwartz 2014 [14], Reader 1982 [19], Elzinga *et al*., 2007 [6], Forrest and Miller-Rushing 2010 [8], and Fox *et al*., 1997 [9], which collectively highlight the interactive influence of environmental cues and genetic factors on phenological synchronization and duration in temperate species. Figure (1-4).

a. Spring b. Autumn

Fig 1: Initiation of vegetative bud burst

Table 1: Seasonal phenology of *Valeriana jatamansi* Jones ex Roxb. in Autumn 2023 and Spring 2024

Season	Sources	Initiation of vegetative bud burst	Initiation of flower bud	Commencement of flowering	Peak period of flowering	Duration of peak period of flowering	Termination of flowering	Duration of flowering
Autumn	JK1	20th Oct to 23rd Oct	26th Oct to 30th Oct	4th Nov to 6th Nov	10th to 24th Nov	15 Days	13th to 19th Dec	46 days
Autumn	JK2	21st Oct to 25th Oct	28th Oct to 2nd Nov	6th Nov to 9th Nov	13th to 27th Nov	15 Days	13th to 18th Dec	43 days
Autumn	JK3	20th Oct to 23rd Oct	25th Oct to 30th Oct	5th Nov to 9th Nov	11th to 25th Nov	15 Days	14th to 19th Dec	45 days
Autumn	HP1	22nd Oct to 27th Oct	29th Oct to 4th Nov	7th Nov to 11th Nov	14th to 28th Nov	15 Days	14th to 18th Dec	42 days
Autumn	HP2	23rd Oct to 28th Oct	31st Oct to 5th Nov	8th Nov to 12th Nov	15th to 29th Nov	15 Days	15th to 19th Dec	42 days
Autumn	HP3	22nd Oct to 27th Oct	30th Oct to 5th Nov	7th Nov 11th Nov	13th to 28th Nov	16 Days	14th to 19th Dec	43 days
Autumn	Overall range	20th to 28th Oct	26th Oct to 5th Nov	4th to 12th Nov	10th to 29th Nov	15 – 16 days	13th to 19th Dec	42 to 46 days
Spring	JK1	7th Feb to 10th Feb	13th Feb to 17th Feb	22nd Feb to 26th Feb	10thto 25thMar	16 days	12th to 17th April	55 days
Spring	JK2	9th Feb to 12th Feb	15th Feb to 18th Feb	22nd Feb to 26th Feb	11th to 26th Mar	16 days	11th to 16th April	54 days
Spring	JK3	8th Feb to 12th Feb	15th Feb to 19th Feb	25th Feb to 29th Feb	13th to 27th Mar	15 days	13th to 18th April	53 days
Spring	HP1	11th Feb to 15th Feb	16th Feb to 20th Feb	23rd Feb to 27th Feb	13th to 27th Mar	15 days	12th to 16th April	53 days
Spring	HP2	12th Feb to 15th Feb	17th Feb to 21st Feb	24th Feb to 29th Feb	14th to 27th Mar	14 days	13th to 18th April	54 days
Spring	HP3	10th Feb to 12th Feb	14th Feb to 19th Feb	23rd Feb to 28th Feb	12th to 27th Mar	16 days	12th to 16th April	53 days
Spring	Overall range	7th to 15th Feb	13th to 21st Feb	22nd to 29th Feb	10th to 27th Mar	14 to 16 days	11th to 18th April	53 to 55 days

Fig 2: Initiation of flower bud burst

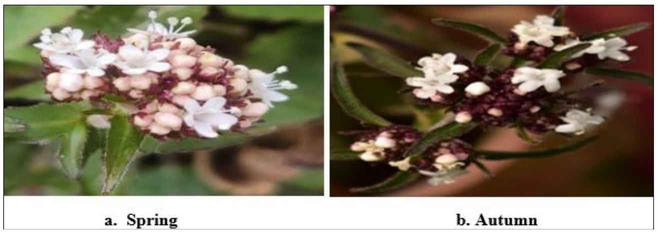


Fig 3: Commencement of flowering

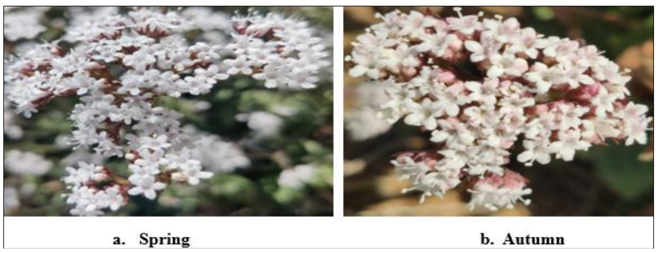


Fig 4: Peak period of flowering

Morphological observations

Morphological observations for *Valeriana jatamansi* across spring 2024 and autumn 2023 revealed clear seasonal and genotypic influences on floral traits. The average number of floral spikes per inflorescence was higher in spring (9.46–15.55) compared to autumn (7.65–8.82), indicating that favourable spring conditions promote spike development. Similarly, the average number of floral clusters per spike showed a marked seasonal decline, with JK1 achieving the highest values in both seasons (41.00 in spring, 25.45 in autumn) and HP2 and HP3 recording the lowest in autumn (13.76 and 13.73, respectively), reflecting reduced floral productivity under cooler autumn conditions. In terms of flowers per cluster, HP1 (73.52), HP2 (70.10), and JK3 (69.99) led in spring, while autumn values for all sources dropped, with HP3 showing the lowest (46.70), underscoring environmental sensitivity in flower production. JK sources generally performed better in spike and cluster production, while HP sources excelled in flowers per cluster, highlighting distinct genetic strengths. Across all traits, the seasonal reduction in autumn supports the conclusion that lower temperatures, shorter day lengths, and limited light availability constrain reproductive development, while spring conditions enhance it. These findings corroborate earlier reports by Singh and Gaurav 2010 [20] and Akter *et al.*, 2017 [1], which emphasize the combined influence of genotype and environmental factors on floral trait variability and productivity in medicinal plants.

Table 2: Morphological variation in *Valeriana jatamansi* across different sources during Autumn-2023 and Spring-2024.

Source	Avg. number of floral spikes per inflorescence	Avg. number of floral clusters per spike	Avg. number of flowers per cluster
JK1	8.65^{ab}	25.45^{a}	65.58^{a}
JK2	8.82^{a}	24.57^{a}	64.19^{a}
JK3	8.27^{ab}	23.75^{ab}	55.72^{ab}
HP1	8.10^{ab}	19.44^{b}	62.30^{a}
HP2	7.65^{b}	13.76^{c}	53.77^{ab}
HP3	7.69^{b}	13.73^{c}	46.70^{b}
JK1	10.10^{b}	41.00^{a}	61.28^{ab}
JK2	10.58^{b}	35.62^{a}	55.32^{b}
JK3	15.55^{a}	37.01^{a}	69.99^{ab}
HP1	9.81^{b}	24.06^{b}	73.52^{a}
HP2	9.46^{b}	15.75^{b}	70.10^{ab}
HP3	10.19^{b}	23.36^{b}	60.18^{ab}

*Values followed by the same superscript are not significantly different.

Reproductive Biology

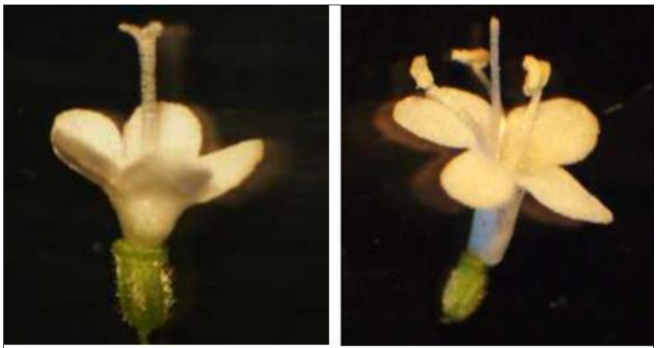
The observations and data collection related to reproductive biology were conducted solely during the spring flowering season. This approach was chosen to ensure consistency and focus on the primary flowering phase when environmental conditions and phenological events are most prominent.

Sex determination

The reproductive biology study of *Valeriana jatamansi* across six sources (JK1–JK3, HP1–HP3) confirmed a gynomonoecious system, with both pistillate and hermaphrodite flowers (Figure-5-a, b) present but hermaphrodites consistently dominant (ratios 66:34 to 70:30). Hermaphrodite numbers were highest in HP1 (69.82%) and JK1 (69.15%), lowest in HP3 (67.42%), yet maintained across regions, suggesting genetic stability and a mixed mating strategy that supports cross-pollination and reproductive assurance. These stable floral ratios align closely with Mukherjee & Chakraborty 2014 [16] and Thakur *et al*., 2018 [21], who documented similar patterns in temperate Himalayan populations, highlighting the ecological advantage of this trait in variable environments.

Table 3: Floral morphs in *Valeriana jatamansi* across six sources in spring 2024.

Source	Floral Morphs Observed		Ratio of H:P
	Avg. number of Hermaphrodites	Avg. number of Pistillates	
JK1	45.35	20.23	69.15: 30.85
JK2	42.59	21.60	66.35: 33.65
JK3	38.32	17.40	68.77: 31.23
HP1	43.50	18.81	69.82: 30.18
HP2	36.34	17.43	67.58: 32.42
HP3	31.49	1 5.21	67.42: 35.58



a. Pistillate Flower b. Hermaphrodite Flower

Fig 5: Sex Determination of *Valeriana jatamansi*

Anthesis and Pollination:

The anthesis period of *Valeriana jatamansi* was observed to occur consistently across six sources during two distinct temporal windows: morning (7:00–12:00 AM) and evening (5:30–6:30 PM). This bimodal anthesis pattern was closely associated with pollinator activity, with bees and flies serving as primary diurnal pollinators in the morning and crepuscular pollinators contributing to evening pollination. Similar observations were reported by Nautiyal *et al.*, (2009) [17] in *Aconitum heterophyllum*, a critically endangered medicinal plant of the Himalayas. This timing likely enhances the plant's chances of successful pollination by aligning flower availability with the activity periods of different pollinator groups.

Pollinating agent

Observations across all six sources identified two primary pollinators: bees **(***Apis mellifera***)** (Figure-6-a) and flies **(***Musca domestica***)** (Figure-6-b), with *Apis mellifera* being the dominant pollinator. The findings align with Verma *et al.*, (2019) [23], who documented similar pollinator diversity in *Valeriana wallichii*. However, the limited diversity of pollinators in *Valeriana jatamansi* suggests a more specialized relationship. This specialization may enhance pollination efficiency but also poses risks under environmental changes affecting pollinator populations, as noted by Bhatnagar and Kumari (2024) [2]. The consistency of pollinator types across all sources, suggests that *Valeriana jatamansi* has evolved specific floral traits that effectively attract these particular pollinators, possibly through visual or olfactory cues, as similarly noted by Verma *et al*., (2019) [23] in their study of *Valeriana wallichii.*

Fig 6: Pollinating Agents of *Valeriana jatamansi* Jones

Conclusion

In conclusion, *Valeriana jatamansi* has provided a comprehensive understanding of the specie's phenology and reproductive biology. Phenological stages such as vegetative bud burst, flower bud initiation, and peak flowering periods, revealed that genetic and environmental factors significantly influence these traits, with JK sources exhibiting earlier and more consistent flowering patterns. Additionally, the reproductive biology of *Valeriana jatamansi* was characterized by its gynomonoecious nature and cross-pollination mechanisms, contributing to genetic stability across varied environmental conditions.

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Author's details

Urwah

Division of Forest Biology and Tree Improvement, Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Benhama, Campus, Ganderbal, Jammu and Kashmir, India

Ashfaq Ahmad Mir

Division of Forest Biology and Tree Improvement, Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Benhama, Campus, Ganderbal, Jammu and Kashmir, India

PA Khan
Division of Forest Biology and Tree Improvement, Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Benhama, Campus, Ganderbal, Jammu and Kashmir, India

Amerjeet Singh
Division of Forest Products and Utilization, Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Benhama, Campus, Ganderbal, Jammu and Kashmir, India

Mubariz Mehak
Division of Forest Biology and Tree Improvement, Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Benhama, Campus, Ganderbal, Jammu and Kashmir, India

Anam Gowher Sofi
Division of Natural Resource Management, Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Benhama, Campus, Ganderbal, Jammu and Kashmir, India

Aamir Majeed Baba
Division of Wildlife Sciences, Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Benhama, Campus, Ganderbal, Jammu and Kashmir, India

Mubashir Ahmad Mir
Division of Silviculture and Agroforestry, Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Benhama, Campus, Ganderbal, Jammu and Kashmir, India

Sayed Adeel Mazahar
Division of Natural Resource Management, Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Benhama, Campus, Ganderbal, Jammu and Kashmir, India

Irtizah Mushtaq
Division of Forest Products and Utilization, Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Benhama, Campus, Ganderbal, Jammu and Kashmir, India