International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2025; 9(3): 01-06
www.biochemjournal.com
Received: 01-12-2024
Accepted: 06-01-2025

Farkhanda Altaf
Division of Forest Products and Utilization, SKUAST-K, Jammu & Kashmir, India

Dr. Amerjeet Singh
Division of Forest Products and Utilization, SKUAST-K, Jammu & Kashmir, India

Corresponding Author:
Farkhanda Altaf
Division of Forest Products and Utilization, SKUAST-K, Jammu & Kashmir, India

Phenological strategies of *Atropa acuminata* Royle ex Lindley in response to habitat heterogeneity and altitudinal variability

Farkhanda Altaf and Amerjeet Singh

DOI: https://www.doi.org/10.33545/26174693.2025.v9.i3a.3876

Abstract
For *Atropa acuminata*, a phenological exploration was performed in which several aspects, including documentation and analysis of life cycle events were examined in order to gain key benefits associated with plant-environment relations. In the context of ongoing global environmental shifts, changes in the timing of plant life cycle events are increasingly recognized as sensitive indicators of ecological transformations. Given the previously undocumented phenological patterns of *Atropa acuminata*, this study is the first systematic examination of its phenological dynamics from a conservation standpoint. The study, undertaken at five distinct elevations ranging from FOF Benhama (1783 m) to Bandipora (3000 m), investigates the effect of altitudinal gradients on plant phenology. The results indicate a clear temporal shift in phenological phases thereby reflecting the adaptive phenotypic plasticity of the species in response to varying altitudinal climates. The findings indicate a clear temporal shift in phenological phases starting with sprouting which commenced in early March at lower altitudes (FOF: 1783 m) and extending into April at higher elevations, Flowering timing was also found to be altitudinally dependent, with bud sprouting occurring on April 15 at FOF, May 15 at Tangmarg, and May 28 at Bandipora. Leaf fall beginning earliest at Benhama on October 8 and lasting 47 days whereas leaf fall began latest at Bandipora (November 15) and lasted for 25 days. The peak of anthesis occurred between 8-9 AM and 9-10 AM, suggesting specific temporal windows for pollination events.

Keywords: *Atropa acuminata* Royle ex Lindley, anthesis, phenology, phenotypic plasticity, temporal shifts

Introduction
Phenology, derived from the Greek words phaino (to appear) and logos (discourse or study) (Ness *et al*., 2012) [8], describes the temporal evolution of biological events as influenced by cyclical environmental factors. Phenology, which was first explicitly described by Charles Morren in 1849, studies the periodicity of life-history events in organisms, notably plants, where phenophases such as budburst, anthesis, fruit maturation, and senescence—serve as key indicators of ecological synchrony. As phenology has been found to be key to understanding plant responses to environmental stimuli, it has the potential to form the basis of conservation frameworks for endemic, endangered, and commercially relevant taxa. But, despite an increasing global interest in reproductive processes of rare and vulnerable medicinal plants, and of those with restricted distribution especially, detailed phenological records are still scarce.

It is essential to properly record flowering phenology to quantify reproductive success over different environmental gradients (Trunschke & Stocklin, 2017) [10]. Flowering a crucial predictor of reproductive success in angiosperms, acts as an essential controlling factor of not just the efficiency of pollination but also the setting of seeds, their dispersal, and even determines the chances of survival of populations and the continuity of genes (Körner, 2003) [5]. Climate change is exacerbating the effects on synchronization of phenological events, with variations in the timing of crucial life-history events disturbing ecological relationships at all trophic levels (Habibullah *et al*., 2022; Ju *et al*., 2022) [3, 4]. Major shifts in temperature regimes, new patterns of precipitation, and snowmelt shifts are some of the identified causes of these phenological shifts especially in high elevation areas which are already highly susceptible to microclimatic changes (Winkler *et al*., 2018) [11].

Understanding these phenological responses is therefore essential for predicting ecosystem stability, assessing species adaptability, and guiding conservation efforts in the face of rapid environmental change.

Materials and Methods

Species sampled

Atropa acuminata, commonly known as the Indian belladonna, was selected as the focal species for investigation of the present study due to its ecological significance and pharmaceutical potential. *Atropa acuminata*, a perennial herb from the Solanaceae family, is widely distributed throughout the Himalayas. The genus Atropa, which includes four species (*Atropa acuminata* Royle ex Lindley, *Atropa belladonna* L, *Atropa baetica* Wilk., and *Atropa pallidiflora* Schonb. Tem), is found throughout the Mediterranean region, South Europe, and Asia (Anonymous, 1948) [1]. It is the sole member of the Atropa genus that grows natively in the wild in India. It has a close botanical affinity with *Atropa belladonna*, often known as Deadly Nightshade, which is native to Europe and North Africa (Thakur and Pandit 2023) [9] and therefore the name Indian Belladona.

Study area

The current study was conducted in Kashmir Himalayas at five distinct locations to examine the altitudinal variation in the phenology of *Atropa acuminata* Royle ex Lindley. The vegetation of the area is temperate and subalpine type harbouring enormous floristic diversity. These sites exhibits significant elevational and climatic variations making them ideal for current studying.

Survey and sampling

The growth phases of *Atropa acuminata* Royle ex Lindley were analyzed at different times of the year at five selected sites viz; Bandipora, Sonamarg, Tangmarg, Nagdandi and Experimental field of FPU. These sites were selected to encompass a range of altitudinal gradients and habitat characteristics, with precise geospatial coordinates and elevation data presented in Table 1. A total of 50 robust and representative individuals, ten from each site, were tagged for longitudinal phenological monitoring over two consecutive growing seasons. Four branches on each plant, oriented in the East, West, North, and South directions, were marked with metal tags to track growth phases. Observations were made weekly, while daily monitoring was conducted during peak flowering and fruiting periods. Detailed temporal data on the Initiation, completion, and duration of each phenophase were recorded to construct a comprehensive phenological framework.

Table 1: Description of the study sites.

Study Site	District	Altitude (m asl)	Latitude and Longitude
Experimental field of FPU Division	Ganderbal	1,783	34°16′44″N 74°46′31″E
Nagdandi	Anantnag	1,936	33°73′11″N 75°14′87″E
Tangmarg	Baramulla	2309	34°06′09″N 74°24′13″E
Sonmarg	Ganderbal	2800	34°18′00″N 75°18′00″E
Bandipora	Bandipora	3000	34° 64′94″N 74°73′66″E

Results and Discussion

The present study revealed that the timing (initiation and completion) and duration of all the phenophases varied significantly across the selected sites (Table 2). Plant populations at low elevations exhibit a clear precedence of the vegetative and reproductive phases in their life cycle compared to those growing at higher elevations. The timing of sprouting of *Atropa acuminata* showed a clear altitudinal gradient, whereby establishment occurred progressively later with increasing altitude. At the lowest altitude site, Benhama (1783 m), sprouting started earliest (5 March) and lasted overall for 36 days. Where as at the highest altitude (Bandipora (3000 m)) sprouting was significantly delayed (April 18), and the recent sprouting duration of 22 days was substantially longer than at lower altitudes. Leaf initiation followed a similar pattern, with Benhama recording the earliest onset on March 25, extending over 52 days. In contrast, Nagdandi and Tangmarg exhibited initiation dates of April 10 and April 20, respectively, while Bandipora experienced the latest onset on May 8, with a reduced duration of 33 days.

Flower bud initiation was observed as early as the 15 of April at lower elevations, persisting until the first 6 of September, with a total duration of up to 141 days. Conversely, at higher altitudes (Bandipora, 3000 m), initiation was significantly delayed to late spring (May 28) and concluded by 8 October, spanning approximately 112 days.

The timing of flowering onset also exhibited a pronounced altitudinal effect, with Benhama (1783 m) recording the earliest flowering initiation on May 10, extending over 133 days. In contrast, Bandipora (3000 m) displayed a delayed onset on June 14, with a comparatively shorter duration of 114 days. Anthesis duration varied significantly across altitudes, ranging from a condensed 20 day period at Bandipora to an extended 58 day period at Benhama (Table 2). Petal detachment also exhibited altitudinal variation, with Bandipora recording the shortest detachment duration of 97 days, whereas Benhama exhibited the longest at 118 days.

Fruit formation commenced earliest at Benhama on June 10, extending over 112 days while as at the highest altitude, Bandipora recorded the latest fruit formation onset on July 25, with a total duration of 85 days. The extended duration at Benhama suggests more favorable conditions for fruit development at lower altitudes. Similarly, fruit maturation was recorded earliest at Benhama, beginning on June 25 and extending over 117 days. In contrast, maturation at Bandipora commenced on August 6 and lasted 89 days.

Leaf fall also followed an altitudinal sequence, beginning earliest at Benhama on October 8 and lasting 47 days. At Bandipora, leaf fall started latest on November 15, with a shorter duration of 25 days. All the phenophases except senescence showed an overlap with the preceding phase (Table 2). Our study delineated a pronounced temporal disparity across all phenophases, commencing with the sprouting of *Atropa acuminata* Royle ex Lindley along altitudinal gradient. Parallel findings were reported by Magray *et al*. (2024) [7] in their study on *Phytolacca acinosa* across temperate to subalpine ecotones of the Kashmir Himalaya, wherein dormant perennating buds transitioned into juvenile shoots in response to site-specific environmental cues. Their observations further underscored considerable variation in sprouting phenology, initiating between early April and mid-May at lower elevations (Drung), while at higher elevations (Doodhpathri), bud break was substantially delayed, occurring from mid-May to mid-June. A comparable altitudinal trend was evident in senescence, with earlier onset at lower elevations and a progressive delay at higher altitudes. The timing of phenophases was predominantly regulated by snowmelt dynamics, Winkler *et al*. (2018) [11], who posited that snowmelt timing critically influences community composition, phenology, and physiological performance of alpine plants, thereby modulating the growing season and reproductive success. A nuanced understanding of phenological patterns, particularly flowering dynamics, is imperative for formulating robust conservation strategies and advancing the large-scale cultivation of alpine taxa vulnerable to climatic fluctuations (Bernardello *et al*., 2001) [2].

Table 2: Reproductive biology of *Atropa acuminata* Royle ex lindley

Reproductive biology		Bandipora (Altitude = 3000)	Sonmarg (Altitude = 2800)	Tangmarg (Altitude = 2309)	Nagdandi (Altitude = 1936)	FOF (Altitude = 1783)
Budburst	I	18(4)	12(4)	1(4)	18(3)	5(3)
	C	10(5)	5(5)	28(4)	20(4)	10(4)
	D	22 days	23 days	28 days	33 days	36 days
Leaf initiation	I	8(5)	30(4)	20(4)	10(4)	25(3)
	C	10(6)	5(6)	30(5)	22 (5)	16(5)
	D	33 days	37 days	40 days	42 days	52 days
Floral budburst	I	28 (5)	22 (5)	15(5)	25(4)	15(4)
	C	20 (9)	18(9)	15(9)	10(9)	6(9)
	D	112 days	116 days	120 days	132 days	141 days
Commencement of flowering	I	14(6)	10(6)	30(5)	14(5)	10(5)
	C	8(10)	5(10)	28(9)	25(9)	22(9)
	D	114 days	115 days	123 days	131 days	133 days
Anthesis	I	15(7)	8(7)	22(6)	10(6)	2(6)
	C	5(8)	30(7)	15(7)	25(7)	30(7)
	D	20days	22days	23days	45 days	58 days
Petal detachment	I	10(7)	1(7)	25(6)	18(6)	2(6)
	C	15(10)	8(10)	6(10)	2(10)	28(9)
	D	97 days	99 days	113 days	107 days	118days
Fruit formation	I	25(7)	18(7)	5(7)	24(6)	10(6)
	C	18(10)	15(10)	10(10)	5(10)	30(9)
	D	85 days	89 days	97 days	103 days	112 days
Fruit maturation	I	6(8)	26 (7)	20(7)	10(7)	25(6)
	C	5(11)	30(10)	28(10)	25(10)	20(10)
	D	89 days	96days	100 days	107 days	117 days
Colour change in leaves	I	30 (9)	26 (9)	20 (9)	10(9)	5(9)
	C	15(11)	12(11)	10(11)	6(11)	4(11)
	D	47 days	46 days	51 days	57 days	60 days
Leaf fall	I	15(11)	5(11)	24(10)	15(10)	8(10)
	C	10(12)	6(12)	1(12)	30(11)	24(11)
	D	25 days	31 days	38 days	46 days	47 days

The number outside the parenthesis depicts the date and inside depicts the month
I = initiation, C=Completion, D=Duration

a b

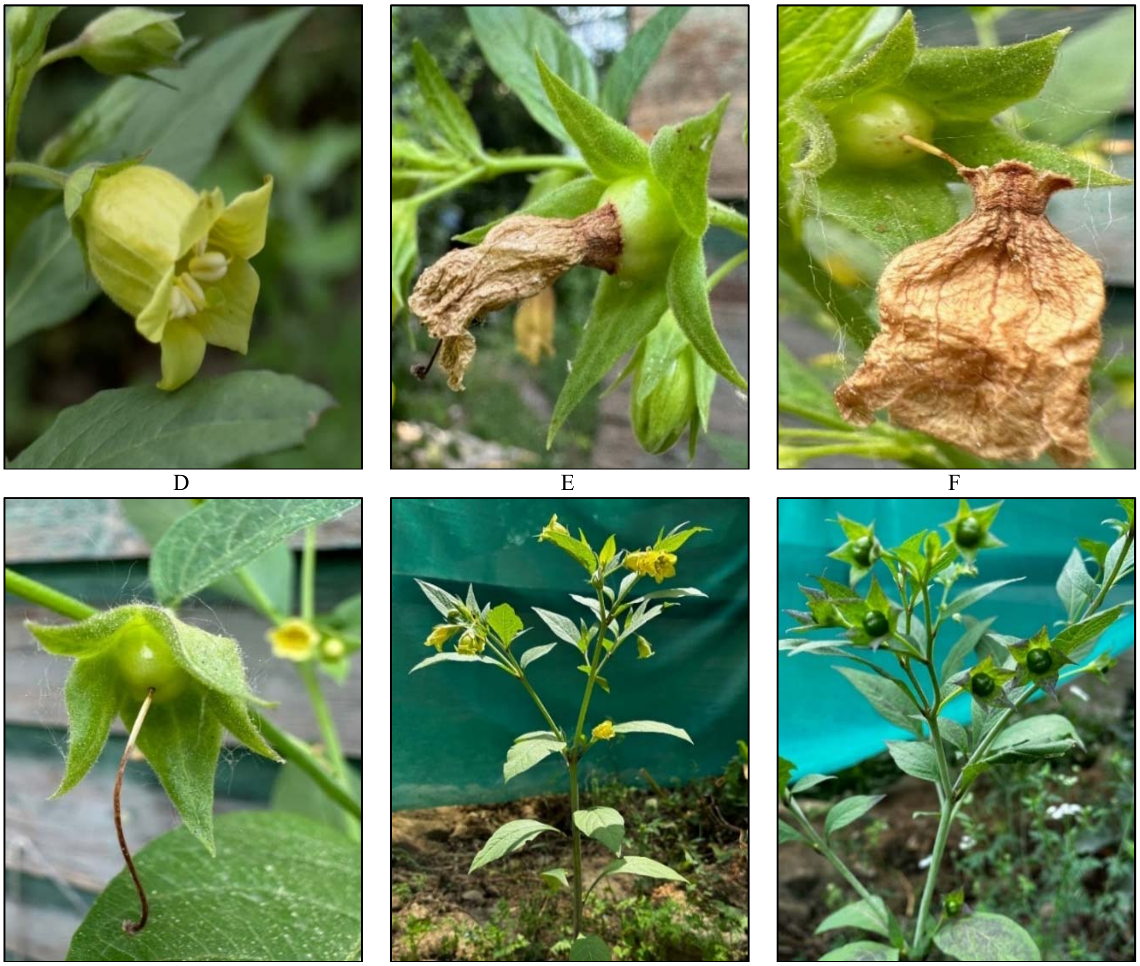
Fig 1 (a-b): Bud burst and leafing in Atropa *acuminata*

Fig 2(c-f): Overview of changes in Leaf color and fall

g H

Fig 3(g-h): Overview of fruit and seed maturation

A B C



D E F

G H I

Fig 4: A, B, C and D illustrate the stages of floral bud development. E, F and G depict the stages of petal detachment . Figure H shows the peak flowering period, and Figure I indicates the cessation of flowering

Timing of flower opening in *Atropa acuminata*

The temporal dynamics of flower opening in *Atropa acuminata* were studied at one-hour intervals throughout a five-day period (June 3-7). Table 3 revealed a temperature-mediated trend, with peak flower opening occurring between 8:00 and 9:00 AM (57.27%±2.90), followed by a gradual decrease. By 11:00 a.m., no more blooms had opened. This temporal tendency corresponds exactly to the incremental rise in ambient temperature, emphasizing its critical significance as a regulating component in floral anthesis. The diurnal blooming observed is a clever phenological adaptation to high-altitude temperate environments, with peak anthesis coincident with optimal climatic conditions and pollinator activity. Early early flower opening reduces the hazards associated with high noon temperatures and low humidity, conserving floral integrity and increasing reproductive fitness. Similar trends in alpine and temperate plants highlight the ecological significance of timing anthesis with pollinator availability throughout moderate heat regimes (Kudo & Hirao, 2006) [6].

Table 3: Timing of flower opening in *Atropa acuminata* Royle ex Lindley

Date of Observation	No. of Buds observed	Percent flowers opened between					Temperature	
		6-7 AM	7-8 AM	8-9 AM	9-10 AM	10-11AM	Maximum	Minimum
3-June	30	-	13.33	60	20	6.67	22.3	9.8
4-June	30	3.33	10	56.67	30	3.33	24.0	10.4
5-June	30	6.66	10	53.33	30	-	26.0	11.3
6-June	30	3.33	10	56.67	30	3.33	24.6	11.2
7-June	30	6.66	10	60	23.33	-	25.8	12.4
Mean±S.D	30	4.66±1.92	17.33±1.49	57.27±2.90	18.00±4.71	2.66±1.78		

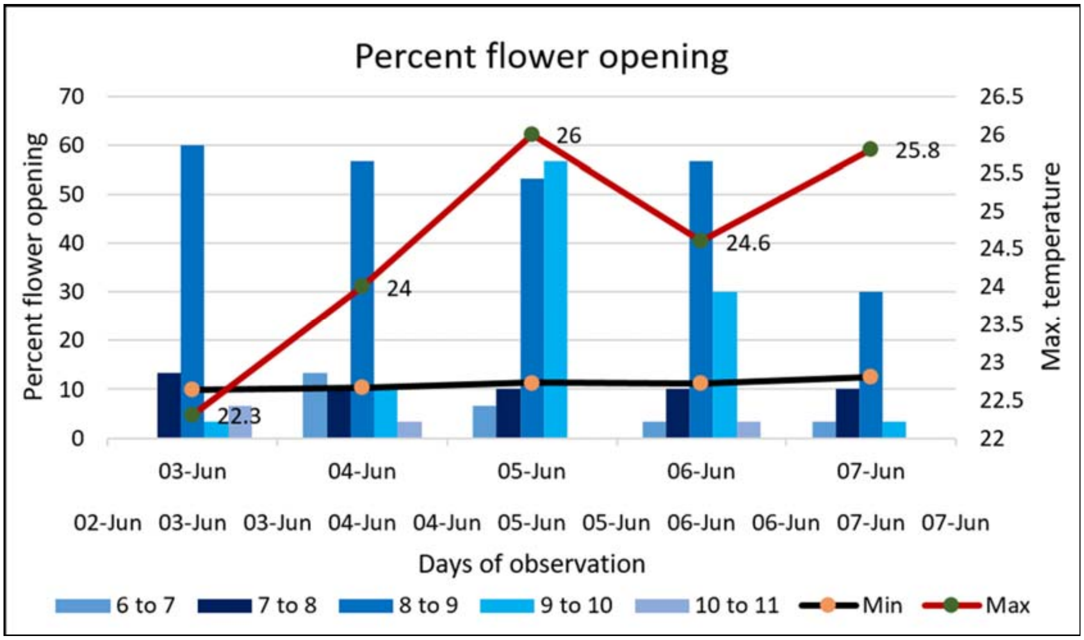


Fig 5: Impact of max. and min. temperature on flower opening timing in *Atropa acuminata.*

Conclusion

This study provides clear evidence that lowland plants start both the vegetative and flowering stages at a much earlier time than highland plants. The significant variation in phenophases across the five study sites revealed the phenomenal phenotypic plasticity of the species, and their adaptive resilience to different environments. A distict altitudinal trend was found for flowering duration, extending to 141 days at 1783 m and reducing to 112 days at 3000 m, thus suggesting that the cooler temperatures promote delayed reproductive processes. Along an elevational gradient, temperature again proves to be the foremost environmental driver in both the timing of and duration of phenological events.

References

1. Anonymous. Wealth of India: A Dictionary of Indian Raw Materials and Industrial Products. New Delhi: CSIR; 1948. p. 135-137.
2. Bernardello G, Anderson GJ, Stuessy TF, Crawford DJ. A survey of floral traits, breeding systems, floral visitors, and pollination systems of the angiosperms of the Juan Fernández Islands (Chile). Bot Rev. 2001;67(3):255-308.
3. Habibullah MS, Din BH, Tan SH, Zahid H. Impact of climate change on biodiversity loss: Global evidence. Environ Sci Pollut Res. 2022;29(1):1073-1086.
4. Ju P, Yan W, Liu J, Liu X, Liu L, He Y, *et al*. Plant phenology and its anthropogenic and natural influencing factors in densely populated areas during the economic transition period of China. Front Environ Sci. 2022;9:622.
5. Körner C. Alpine plant life: Functional plant ecology of high mountain ecosystems. Mt Res Dev. 2003;41(4).
6. Kudo G, Hirao AS. Habitat-specific responses in the flowering phenology and seed set of alpine plants to climate variation. Popul Ecol. 2006;38(1).
7. Magray JA, Wani BA, Islam T, Nawachoo IA. From sprouting to senescence: Phenological chronicles of *Phytolacca acinosa* Roxb. in the Himalayan Highlands. Reprod Biol. 2024.
8. Ness S, Reimer P, Love J, Schloss WA, Tzanetakis G. Sonophenology: A multimodal tangible interface for the sonification of phenological data at multiple timescales. J Multimodal User Interfaces. 2012;5:123-129.
9. Thakur P, Pandit V. Green synthesis of silver *Atropa acuminata* nanoparticles: Characterization and anti-diabetic potential. J Adv Zool. 2023;44(5):1101-1115.
10. Trunschke J, Stöcklin J. Plasticity of flower longevity in alpine plants is increased in populations from high elevation compared to low elevation populations. Alpine Bot. 2016;127:41-51.
11. Winkler DE, Butz RJ, Germino MJ, Reinhardt K, Kueppers LM. Snowmelt timing regulates community composition, phenology, and physiological performance of alpine plants. Front Plant Sci. 2018;9:1140.