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Phenological attributes of *Ajuga bracteosa*: an unusual case from Kashmir Himalaya

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Abstract: There is a general belief among the ecologists that the high altitude flowering plants attain their blooming peak during short growing season and exhibit synchronous flowering. We made observations on the phenology of a common roadside herb *Ajuga bracteosa* in Kashmir Himalaya during April to December 2012. Unlike most of the angiosperms in Kashmir, this species had bimodal amplitude and relatively low flowering synchrony. The total flowering duration was divisible into three phases i.e., first peak, lull, and second peak. The species exhibited a prolonged flowering episode which lasted for about 23 - 26 weeks. The mean flower longevity was 5.8 days. In addition to longer flowering durations, individual plants also had more evenly distributed amplitude. Fruit set ranged from 85 % to 92 %. These traits make *A. bracteosa* much more adaptive and allows it to grow in a wide range of habitats.

Key words: *Ajuga bracteosa*, bimodal flowering, phenology, reproductive success, synchrony, verticillaster.

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Plant species thriving at stressful and highly seasonal environments exhibit conspicuous morphological and phenological syndromes that demonstrate the adaptive strategies. Comparisons of phenophases of plant species growing at high altitudes can illustrate such strategies. High altitude genotypes might be adapted to local and more extreme environmental conditions as demonstrated in their seminal studies by Clausen *et al.* (1940, 1941, 1948) on several North American plants including *Achillea millefolium* L. and *Potentilla glandulosa* Lindl. Low winter temperatures and snow accumulation restrict vegetative activity to the spring and summer months where flowering must be completed sufficiently early to permit fruit maturation and seed dispersal. The sequential events of life cycle have thus important consequences on plant fitness. A detailed study of these factors is essential to a fuller understanding of the modes of adaptation of plants to different environmental conditions. Comparisons of phenological behaviour and reproductive capacities between populations in various habitats allow some assessment of fitness of plants i.e., their ability to acclimatize in different environmental conditions as well as the integrated efficacy of individual processes involved in growth and reproduction. Variation in reproductive phenology accounts for differences in pollination success between population and species (Gross & Werner 1983; Waser 1978), influences gene flow between and within populations (Fripp *et al.* 1986), affects seed size (Jerling 1988) and timing of seed dispersal (Lacey & Pace 1983). For instance, synchronized flowering can maximize outcrossing and maintaining health of populations (Augspurger

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Table 1. Summary of phenology of *Ajuga bracteosa*.

Phenophase	Population	Earliest	Latest	Range (Days)
	Dachigam	2 April	27 May	54
Sprouting	Drang	8 April	28 May	49
	Betab Valley	8 April	24 May	45
	KUBG	30 March	28 May	58
	Dachigam	20 April	29 October	191
Bud burst	Drang	23 April	25 October	184
	Betab Valley	26 April	19 October	175
	KUBG	23 April	7 November	196
	Dachigam	12 May	8 November	178
	Drang	15 May	1 November	168
Anthesis	Betab Valley	19 May	22 October	155
	KUBG	14 May	14 November	182
	Dachigam	22 May	18 November	178
	Drang	27 May	10 November	165
Seed set	Betab Valley	29 May	6 November	159
	KUBG	24 May	22 November	180
	Dachigam	02 November	11 December	40
	Drang	24 October	28 November	36
Senescence	Betab Valley	21 October	22 November	33
	KUBG	08 November	21 December	44

1981; Primack 1985). In contrast, asynchronous flowering can impede gene flow (Cruzan *et al.* 1994; Primack 1985;) and reduce reproductive success (Fox 1990; Rathcke & Lacey 1985). Each of these traits can vary among plants and, if this variation is genetically determined (e.g. Ashman & Majetic 2006; Baker *et al.* 2005; Conner 2006), can be subject to selection.

We conducted a study on the phenology and reproductive performance (in terms of seed production) of a perennial herb, *Ajuga bracteosa* Wall. ex Benth. (Lamiaceae) in Kashmir Himalaya. Major objectives of the study were to: (i) document the phenological response during growing season and ascertain the temporal variation in flowering, and (ii) determine the phenological attributes and flowering synchrony in the species. All observations in the field were made during April to December 2012 at three sites i.e., Betab valley (34° 2' N, 75° 20' E, 2405 m a.s.l.), Drang (34° 2' N, 74° 25' E, 2235 m a.s.l.) and Dachigam (34° 04' N, 75° 59' E, 1900 m a.s.l.). In addition to these, one transplanted population was established and monitored at Kashmir University Botanical Garden (KUBG- 34°5'N, 74°48'E, 1595 m a.s.l.).

For documenting the phenology of the species 45 randomly selected healthy individuals were tagged in all the three natural populations as well as in a transplanted population at KUBG. These individuals were then monitored throughout the growing season to record the onset and duration of various phenological events from sprouting to senescence on a fortnightly basis. The phenophases recorded were: active vegetative growth, presence of flower buds, flowering, seed set, and die-back of aboveground parts. Plants were considered vegetatively active at the first signs of vegetative bud break, in flowering as the first flowers opened, and in fruit as the first seeds appeared. The lengths of the active vegetative growth (prefloration), and the flowering and fruiting (postfloration) periods were estimated from the first and last dates on which the respective phenophases were observed. To understand the flowering phenology, following parameters were recorded for each tagged plant: onset (date first flower opened), end date (date last flower opened), duration, intensity, synchrony and mean flowering amplitude (number of flowers produced per unit time) following Dafni (1992) and Newstrom *et al.* (1994). Intensity was estimated as the maximum number of flowers on a census day (Herrera 1986). Flowering synchrony was quantified at both the individual and the population levels. Individual flowering synchrony (Xi) is the

Table 2. Phenological variables of *Ajuga bracteosa* in four populations.

VariableS	Mean population values	Populations				Comparison of means
		Betab Valley	Drang	Dachigam	KUBG	
Duration	170.9 ± 6.99	163.4 ± 6.58	168.6 ± 6.31	171.4 ± 6.80	180.2 ± 8.29	*
Intensity	45.75 ± 9.05	25.4 ± 6.77	41.2 ± 8.32	64.5 ± 12.43	51.9 ± 8.67	NS
Synchrony	0.55 ± 0.15	0.64 ± 0.21	0.55 ± 0.14	0.53 ± 0.15	0.50 ± 0.17	NS
Amplitude	0.48 ± 0.26	0.30 ± 0.22	0.37 ± 0.21	0.69 ± 0.32	0.54 ± 0.29	*

* $P < 0.05$; NS = not significant.

relative overlap between the blooming period of a given individual and all other plants in the population. It was calculated according to Augspurger's method (1983), modified from Primack (1980) as follows:

$$X_i = \left(\frac{1}{n-1}\right)\left(\frac{1}{f_i}\right)\sum_{j=1}^{n} e_{j\neq i}$$

where, e_j is the number of weeks individual i and j overlapped in their flowering; fi is the total number of week's individual i was in flower, and n is the number of individuals in the sample. X varies from 1 (plant flowering overlaps with that of all other individuals) to 0 (no overlap with any other individuals).The overall synchrony of the population (Z) is the average synchrony of individual plants.

Individuals of the species over-winter in the form of underground rhizomes. The leaves first emerge in the early April (Table 1), and senesce at the end of each growing season by early December. Flowering in *A. bracteosa* had bimodal amplitude and the total flowering duration was divisible into three phases i.e., first peak, lull, and second peak. The rate of flower production was highest during first peak (late June) followed by second peak (mid August to early October) and late flowering in November. Flowering in most of the individuals (ca. 63 %) was interrupted by a brief period of lull (up to 15 days) when no flowers were produced. The period of lull was observed during late July to early August. The total flowering duration of the population was 24 weeks. In addition to longer flowering durations, 78 % of individual plants also had more evenly distributed amplitude. Mean duration of flowering (first bloom to last flower) was 102 days, but the number of days of actual flowering was only 74. Because of these gaps in blooming, mean synchrony of plants was much lower (0.55). The maturation of fruits starts in late May to early June and is completed by early to ending November. The duration of seed maturation ranges from 159 - 180 days.

The timing of inflorescence expansion and floral maturation varied among individuals. The total duration of flowering was 155 - 182 days but there were marked differences among selected plants in the timing and the extent of the different reproductive phases, ranging from a few days (flower anthesis- 5 - 7 days) to more than 2 weeks (seed maturation- 14 - 18 days). The mean number of open flowers per plant ranged from 47 (Betab Valley) to 122.60 flowers (Dachigam). The mean flower longevity was 5.8 days (range 5 - 7 days). Early and late flowering plants show a much lower flowering intensity. The overall flowering synchrony (Z) increased from 0.50 - 0.64 along an altitudinal gradient. It was observed that more than 70 % of marked plants had a flowering synchrony value of less than 0.75, although values ranged from 0.30 to 1, with an overall mean synchrony of 0.55 (Table 2). Fruit set ranged from 85 % to 92 %, but these differences were not statistically significant. Seed number per plant peaked at early July and mid-October and these dates correspond closely to the peak flowering dates.

Most striking feature in the phenology of *A. bracteosa* was the long flowering period and bimodal pattern. Plants in seasonal environment are known to maximise flowering during spring due to optimum temperature, and high insect activity (Baker *et al.* 1982; Kummerov 1983). In the study area, temperature increased steadily from early April to July and decreases after August. Bimodal phenological patterns have been reported in several species (Castillo Landero 2003; Ruiz *et al.* 2000). According to Bawa (1983), such extended blooming has several advantages such as (a) a reduced risk of reproductive failure; (b) an increased chance of mating with more individuals; and (c) a better control of the relative investment in flowers and fruits.

Two flowering peaks occurring in different times of the year may be related to different environmental stimuli (Engel & Martins 2005). Climatic factors such as high soil moisture and relative humidity due to heavy rainfall, low air and soil temperatures, low wind velocity and low solar radiation levels provide optimal external environmental conditions for flowering (Gunarathne & Perera 2014). Flowering phenology is a temperature-dependent phenomenon in many cases (Gunarathne & Perera 2014; Rathcke & Lacey 1985) and the cumulative effects of temperature and soil moisture can influence the bud initiation and intensity of flowering (Diekman 1996; Molau *et al.* 2005; Rathcke & Lacey 1985). Flowering time and duration can be limited by weather conditions such as drought, hail storm, etc. In the present study peak flowering was observed in June. As the season progresses, air temperature and precipitation increases rapidly till late August. While the role of temperature on the flowering has been well established (Tookel *et al.* 2005; Valverde *et al.* 2004), very few studies have studied relationships between precipitation and flowering.

Like several Chamaephytes (e.g., many members of Plumbaginaceae, Acanthaceae, and Lamiaceae), *A. bracteosa* exhibits staggered flowering and seed setting. Though, synchrony of flowering facilitates interchange of genes (Augspurger 1981), asynchrony has other advantages in terms of maximizing visits by larger number of pollination vectors and adaptability to unpredictable environments. It is argued that peculiar phenological traits of *A. bracteosa* makes it much more stress tolerant and adaptive to diverse habitats. Further long term observations on these populations based on more quantitative approaches (e.g., Silva *et al.* 2014) as well as experimental studies under varying moisture and temperature conditions will be needed to ascertain the reasons for the observed trends in this species.

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