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Climate assorted phenology of *Plagiochasma appendiculatum* Lehm. & Lindenb. and *Reboulia hemispherica* (L.) Raddi.

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ABSTRACT

Phenological studies have been conducted for *Plagiochasma appendiculatum* and *Reboulia hemispherica* growing in different habitats at Sunderbani area of Rajouri district in Jammu and Kashmir in foothills of the Himalaya. Fortnightly populations of both species have been observed for one year and noted that both the taxa prefer autumn as the favourable period for male receptacles and winters for female ones. In both cases, luxuriance of the species has been observed as negatively correlated with temperature and almost neutral with relative humidity.

Keywords: Phenology, *Plagiochasma appendiculatum*, *Reboulia hemispherica,* receptacles, luxuriance.

Phenology is the study of periodic life cycle events of plant and animals influenced by seasonal and inter-annual variations in climate as well as habitat factors. Literature is replete with the works on the phenology of angiosperms (Kumar *et al.* 2011, Koul and Sharma 2013), gymnosperms (Dickie *et al.* 2010) and pteridophytes (Lee *et al.* 2009). In bryophytes, studies like morphogenesis of gametangial initiation have revealed that the periodicity of vegetative growth (both sexual and asexual) is controlled by physical and chemical factors like light, temperature, humidity and hydration, carbohydrates, nitrogenous substances, growth regulators, chelating agents and pH (Ridgway 1967, Benson-Evans and Hughes 1955, Chopra and Rawat 1977,Vashistha 1985). In case of bryophytes, mosses are investigated for phenological details (Ayukawa *et al.* 2002, Stark 2002, Silva and Valio 2011. However, liverworts and hornworts are mostly ignored. Few reports which are available on phenology of liverworts e.g. Moya 1992, Lindberg *et al.* 2000, Laaka-Lindberg 2005 have motivated researchers to work on same aspect of liverwort phenology in NW Himalaya (Kumari 2009, Kapoor 2009, Sharma 2010, Madhu 2014).

Jammu province in NW Himalaya is an important niche for hepatic diversity. It inhabits more than 120 species including 30 chambered species (Gupta 2002,Tanwir 2005, Tanwir *et al.* 2008). Most of the liverworts have been investigated for a large number of aspects including intra- and interspecific diversity, morphogenetic range and a few aspects of reproduction.

The present communication deals with the phenology of two thalloid liverworts *viz a viz Plagiochasma appendiculatum* and *Reboulia hemispherica* growing in foothills of Shiwalik ranges (Sunderbani) in NW Himalaya.

MATERIAL AND METHODS

Study area–Populations of *Plagiochasma appendiculatum* (both on epilithic and non-epilithic substrate) and *Reboulia hemispherica* (non-epilithic substrate) have been geo-referenced and photographed *in situ* in the field between 549-610m and 549m, respectively (Table 1). The area represents a transition zone between subtropical and temperate Himalaya in the foothills of Shiwaliks in Sunderbani area of Rajouri district in Jammu and Kashmir (Fig.1 a,b). The vegetation usually comprises Chir-pine (*Pinus roxburghii* Sarg.), broad-leaved deciduous as well as evergreen and scrub forests, interspersed with frequent grassland patches and agricultural croplands.

Table 1— Investigated populations of Plagiochasma appendiculatum and Reboulia hemispherica

Taxa	Sites
Plagiochasma appendiculatum	Shiv Kashi (N33°03'24" E74°29'00"; 610masl) Bajabain (N33°03'00" E74°25'05"; 549masl) Thandapani (N33°03'33" E74°29'15"; 595masl) Seri (N33°04'15" E74°19'32";; 564masl)
Reboulia hemispherica	Bajabain (N33°03'00" E74°25'05"; 549masl)

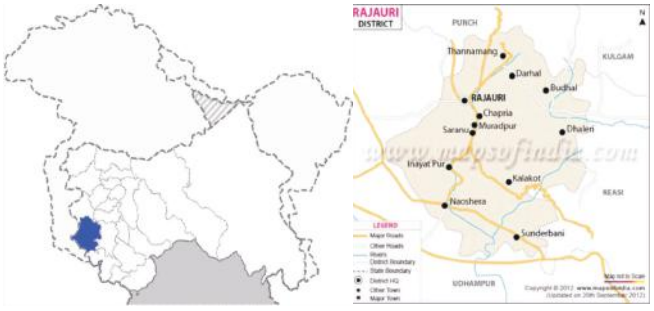

Fig.1a– Jammu and Kashmir; 1b : District Rajouri

Plagiochasma appendiculatum Lehm. & Lindenb-Thalli of *P. appendiculatum* are characterized by large, thick, dichotomously branched green patches with smooth dorsal surface and undulate margins. They have a distinct midrib and one row of appendiculate scales on each side of the midrib.

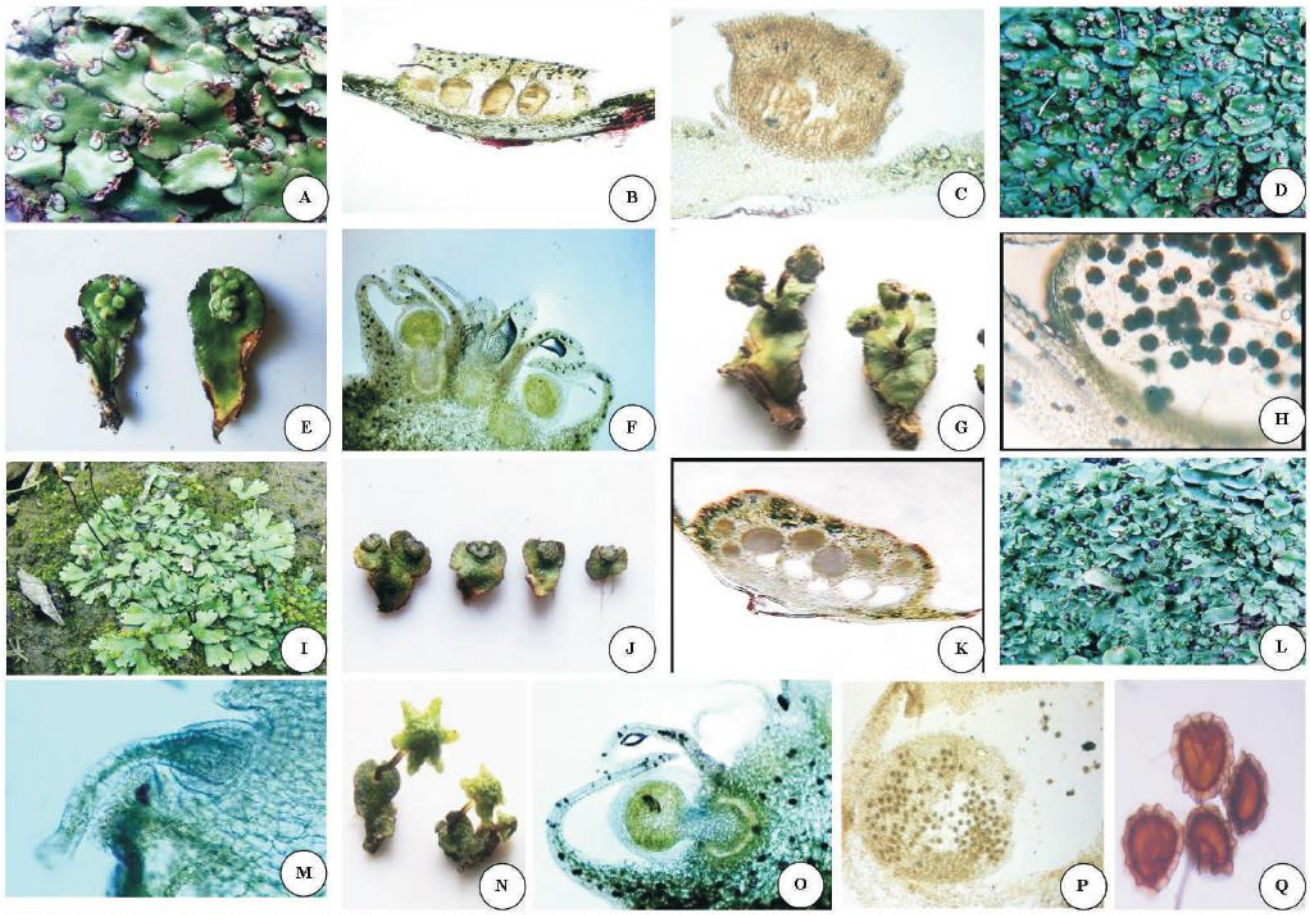

Fig. 2: *Plagiochasma appendiculatum* (A-H) and *Reboulia hemispherica* (I-Q) ; A patch of thalli with male receptacles (A); VS of developing male receptacles (B); VS of dehisced male receptacles ©; initiation of female receptacles (D); trilobed female receptacles (E); VS of mature female receptacles (F) Stalked female receptacles (G); Sporophyte with spores and elaters (H); A patch of *Reboulia hemispherica* (I); Few male thalli (J) VS passing through male receptacles showing antheridia (K); A patch with female receptacles (L); VS passing through young female receptacle (M); Few thalli with mature female receptacles (N); VS passing through mature female receptacle (O); Spore mother cells in a capsule (P); Magnified view of spores (Q).

Male receptacles are horse-shoe shaped and sessile (Fig.2A). Female receptacles are sessile or stalked, usually with 2-5 lobes, situated on the thallus in rows or scattered (Figs. 2D, E, G).

Reboulia hemispherica (L.) Raddi-The individuals of *R. hemispherica* are medium-sized, dichotomously branched, flat and leathery forming loose mats. Adaxial side of the thallus is pale or glaucous green with red or purplish margins. The surface is smooth, with a faint network of lines and inconspicuous air pores. The male receptacles are sessile often purplish cushions (Fig.2J) and female receptacles are borne on short, terminal stalks and are green and hemispherical with 4 to 7 spreading or deflexed lobes (Figs.2L, N).

Abiotic factors—Parameters like pH of substrate, air temperature and relative humidity have been recorded during the study period of one calendar year.

Soil pH—To determine the soil pH, a soil mixture was prepared by thoroughly dissolving10g of air-dried soil in 20 ml of distilled water (1:2). The prepared suspension was stirred regularly over a period of 1 hr prior to determination of pH value. The pH values displayed on pocket size pH meter (model: Hanna) were recorded by putting the electrode of the instrument in the soil : water (1:2) suspension of each site separately (Gliessman 2000).

Air temperature and relative humidity—Both the parameters have been recorded periodically using portable thermometer and hygrometer (MEXTECHM288CTH).

Phenological data—Different developmental stages divided into five categories (vegetative, asexual, sexual, spores/ elaters and senescence), of both the taxa have been recorded by visiting study area periodically for one complete year. Sexual stage (event) has been further divided into male and female sub-events, both of which were again trifurcated into three categories *viz. initiating receptacles* (I); young receptacles (Y) and mature receptacles (M) (Fig. 3).

Morpho-anatomical—Portion of plant patch has been removed from substratum and brought to the laboratory for the morpho-anatomical studies as per the suggestions of Kumari (2009).

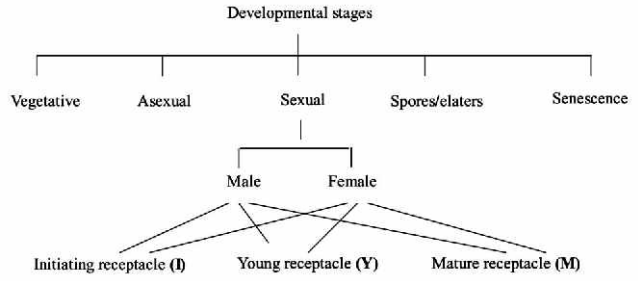

Fig. 3—Various phenology events

RESULTS

Plagiochasma appendiculatum-The taxon has been georeferenced on epilithic (rocks and stones) and non-epilithic (soil) habitats in the month of June with luxuriant growth in the form of vegetative patches till mid August. Initiation of male receptacles has been recorded during August (Table 2) and grows to maturity with fully developed antheridia in September (Figs.2A, 2B). The dehiscence starts in ending September/October (Fig.2C). Similarly, female receptacles also initiate during ending of October (Fig.2D) and appear as a differentiated structure called archegonia during November. A female receptacle matures in December (Fig.2E). The post-fertilization changes like degeneration of neck cells of archegonium and swelling of venter accommodating partly differentiated sporophytes can be observed during December (Fig.2F). For anatomical details, mature sporophytes collected during January (Figs. 2G, H) reveals that the spores of the species are brownish, rounded or triangular with longated elaters, each with bispiral thickenings as one of the important characteristic feature of the species. Sporophytes dehisce between mid of February to March whereas patches began to dry in the mid of April and remain in dry condition till June/July of next year. Regeneration starts again in June/July after the first shower of rains due to western disturbances (Fig.4A).

Reboulia hemispherica—Emergence of new thalli of *R. hemispherica* has been recorded in the month of July (Table 2 and Fig. 2I) and initiation of male receptacles in mid of August. Young receptacles observed in ending August or starting of September possess antheridia at different developmental stages (Figs. 2J, K). Matured receptacles have been observed in mid September which began to dehisce during the end of September. With the commencement of the female reproductive phase (Fig. 2L), young archegonia appear within a week (Fig. 2M) of initiation of female reproductive phase and mature during end of January (Figs. 2N, O). Sporophytes with spores and elaters develop during mid February (Figs. 2P, Q) and dehisce in mid of April. Anatomical details reveal that spores are globular, winged structures and elaters bispiral. Patches embark on to dry during mid May and remain as such till the beginning of July (Fig. 4C).

Data regarding effect of average temperature and average relative humidity on luxuriance of taxa reveals that both the taxa grow luxuriantly over a wide range of temperature and relative humidity. *P. appendiculatum* shows maximum abundance at 14-30°C, while *R. hemispherica* at 14-35°C and decreases with rise in temperature. Relative humidity, on the other hand, did not show any significant effect on luxuriance in both the taxa (Table 2 and Figs.4B, D).

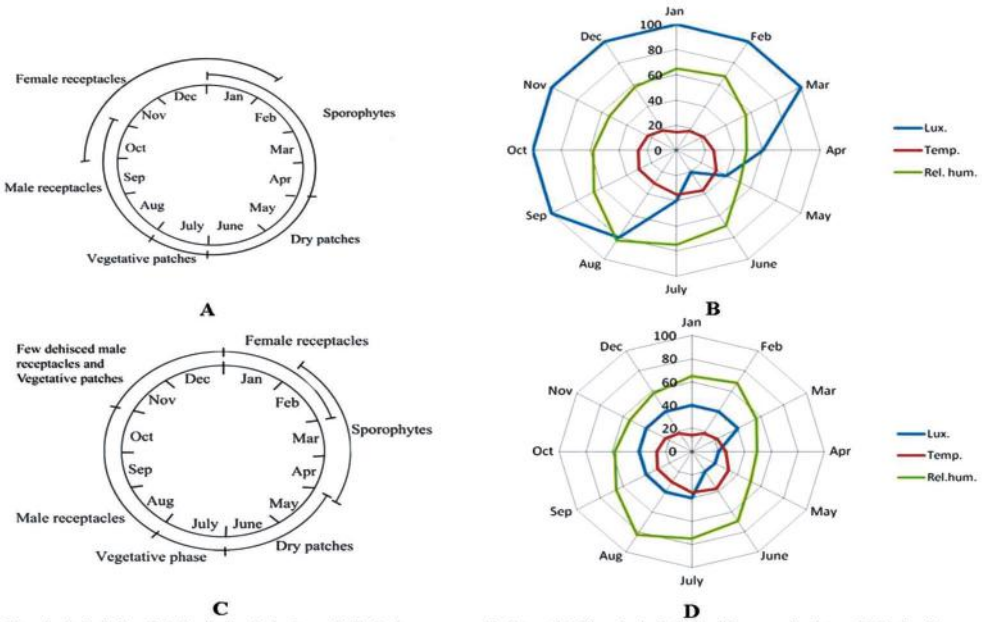

Fig. 4: Phenological clock of *Reboulia hemispherica* and *Plagiochasma appendiculatum* (A), Phenological clock of *P. appendiculatum* (B) Radar diagram showing the effect of temperature and relative humidity on luxuriance of *P. appendiculatum* (C), Phenological clock of *R. hemispherica* (D), Radar diagram showing the effect of temperature and relative humidity on luxuriance of *R. hemispherica* .

Table 2-Phenological table of

	Plagiochasma appendiculatum and								*Reboulia hemispherica*							
	VP	Asexual	Sexual			Spores/Elaters	Dry patches	VP	Sexual		Spores/Elaters	Dry patches	Average temperature (in °C)	Average Relative humidity	Luxuriance of *Plagiochasma appendiculatum*	Luxuriance of *Reboulia hemispherica*
	DD	Inn	Male	Female					Male	Female						
January	+	-	-	-	+(M)	+/+	-	+	-	+(I,Y,M)	-	-	14.2	65	+++++	++
February	+	-	-	-	-	+/+(D)	-	+	-	+(M)	+/+	-	17.9	68	+++++	++
March	+	-	-	-	-	D	-	+	-	-	+/+	-	21.8	56	+++++	++
April	+	-	-	-	-	D	+	+	-	-	+/+(D)	-	25.7	49	+++	+
May	-	-	-	-	-	-	+	-	-	-	-	+	32.1	51	++	+
June	+	-	-	-	-	-	+	-	-	-	-	+	36.9	69	+	+
July	+	-	-	-	-	-	-	+	-	-	-	-	35.4	75	++	++
August	+	-	-	+(I,Y)	-	-	-	+	+(I,Y)	-	-	-	30.1	83	++++	++
September	+	-	-	+ (Y,M,D)	-	-	-	+	+(Y,M,D)	-	-	-	29.9	66	+++++	++
October	+	+	+	+(M,D)	+(I)	-	-	+	+(D)	-	-	-	26.3	58	+++++	++
November	+	-	-	-	+(Y)	-	-	+	+(D)	-	-	-	22.9	54	+++++	++
December	+	-	-	-	+(Y,M)	-	-	+	+(D)	-	-	-	18.2	58	+++++	++

+ = present; - = absent; I= Initiating receptacles; Y= Young receptacles; M= Mature receptacles; D= Dehisced receptacles; DD= Death and decay of older parts of thalli; Inn= Innovations; VP= Vegetative patches.

Table 3-Comparison of reproductive phenology of *P. appendiculatum* and *R. hemispherica* in NW Himalaya

Studies	Male phase (months)	(Female phase (months)	Sporophytic phase (months)	Total duration of reproductive phase (months)
P. appendiculatum				
Sharma (2010)	Dec-Mar	Dec-Apr	Feb-Apr	4 (Dec-Apr)
Madhu (2014)	Aug-Dec	Sep-Dec	Jan-Mar	8 (Aug-Mar)
Current study	Aug-Oct	Oct-Jan	Jan-Apr	9 (Aug-Apr)
R. hemispherica				
Madhu (2014)	June-Nov	Sep-Feb	Mar-Apr	11 (June-Apr)
Current study	Aug-Dec	Jan-Feb	Feb-May	10 (Aug-May)

DISCUSSION

Plagiochasma appendiculatum is an abundant liverwort in Jammu province and has been reported from all the districts of the province over an altitudinal range of 300-3500masl (Gupta 2002, Tanwir 2005, Tanwir *et al.* 2008, Sharma 2010 and Riaz 2013). It exhibits tremendous variability in the morpho-anatomical features of gametophyte as well as sporophyte (Nath and Nivedan 2007, Awasthi *et al.* 2012, Bhagat and Langer 2013). Literature review reveals that although detailed studies on habitat, morphology, anatomy and spore: elater ratio has been conducted by various researchers but very few reports on phenological events of the species are available. Distribution pattern of the species in the Jammu province can be gauged between 305 - 2512masl e.g. Sharma 2010, Madhu, 2014. The species is known for its luxuriance during winter months (December to February) at an elevation of 350 masl in NW Himalaya e.g. Sharma 2010. However, with the increase in elevation between 549-610masl in the foot hills of Shivaliks of Himalaya, a gradual shift in growth period from winter to summer months is observed (Table 3). This shift of growing period means significant variation in the length of vegetative phase which results variation in the luxuriance of the vegetative and reproductive phases of the species. The main cause of the shift of luxuriance may be because of the environmental factors prevailing in the study area (Table 2).The duration of male reproductive phase is noted as 5 months in middle Himalaya region, however because of the monsoon rains (availability of water) up to September in the foothills of Himalaya the period has been reduced to 3 months only. Luxuriance of *P. appendiculatum* is negatively correlated with temperature and neutral with relative humidity (Table 2 and Fig.4B).

Reboulia hemispherica is a sub-cosmopolitan (except sub-antarctic and arctic regions) purple margined hepaticis reported from South India, Central India, Sikkim, Bengal, Western Himalaya and Punjab Plains (Bir and Chopra 1972, Pant 1983, Singh and Singh 2002) between elevation gradient between 340-3500masl. Because of many factors the species has been disappeared from various regions of the country including the Himalaya, South and Central India (Pant 1983). In Shiwalik foothills of NW Himalaya, the vegetative phase is observed between July-Aug (Table 2) because of the late delivery of the western disturbance. Reproductive phase of *R. hemispherica* has been recorded between June-April in temperate middle Himalaya; however, in Shiwalik foothills of the NW Himalaya, the same phase of the life cycle of species has been recorded in the months of Aug-May. The delay in this phase may be because of the rains of western disturbances. More precisely, male and female reproductive phases are noticed at early period in other parts, whereas, in foothills of NW Himalaya it is delayed (Table 3).

CONCLUSIONS

Beside morpho-anatomical variation in *P. appendiculatum,* the growing period also varies from one geographical location to another. In northern plains luxuriance in the vegetative growth of species has been observed in winter months (December-January), however, in foothills of Himalaya luxuriance in the same life event i.e., vegetative growth of the species is a normal event in summer month i.e., July. This shift in the luxuriance in the vegetative growth of the species from winter to summer months along the altitudinal gradient from northern plains to foothills of Himalaya may be because of temperature requirement and availability of water in both the regions. Accordingly shift in other life events are also observed like initiation of male and female receptacles, maturation of the reproductive organs, differentiation of female parts etc. More interesting life event like presence of dry patches in the month of May and June and further growth of the dry patches after June indicates the direct effects of rains shower occur in the foothills of NW Himalaya due to western disturbances. An after effect of monsoon and shift in post-fertilization changes and differentiation of sporophytes is also observed in winter months in December in foothills of the Himalaya. For more authentication and confirmation, anatomical details are also worked out. The observations also indicate that male receptacles need comparatively lower temperature for their emergence in foothills of NW Himalaya. Similar pattern was observed in case of female receptacles

also. Present observations on the contarary, clearly reveal that luxuriance showed negative correlation with temperature and none with relative humidity. However, *R. hemispherica* at study site and reference site does not show any significant difference in the time of life events. Therefore, the species is cosmopolitan in its occurrence in the Himalayan habitats.

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