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LIFE CYCLE DYNAMICS AND INVASIVE RISK OF *Parthenium hysterophorus* L. IN RICE ECOSYSTEM OF TEMPERATE KASHMIR

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ABSTRACT

***Parthenium hysterophorous*, globally recognised as one of the most problematic invasive weed species, demonstrates remarkable adaptability across tropical, subtropical, and warm temperate environments. This study, the first of its kind from Kashmir valley, investigated the life cycle dynamics of *P. hysterophorus* within rice agroecosystem under temperate conditions. The population was characterized in relation to geographic distribution, prevailing weather conditions, soil properties, taxonomic features, and biometric parameters. *Parthenium* plants were observed at varied phenological stages, including seedling/rosette, branching and flowering phases. Morphological measurements revealed considerable variation in plant height (7 to 76 cm), leaf count (3 to 26 plant^{-1}), flower and bud production (0-230 plant^{-1}), and shoot fresh weight (6-58 g plant^{-1}). Several plants cut 15-45 cm aboveground regenerated successfully through lateral shoots and new leaves. The high variability in plant height, branching, flower production, and biomass was presumably due to the differences in phenological stages. The field observations indicated that seeds over-wintered under sub-zero temperatures and high soil moisture, germinated during late spring, and reached reproductive maturity by the end of October. Mature seeds exhibited 65% germination under laboratory conditions, confirming the successful completion of life cycle under temperate Kashmir conditions. The study highlights the invasive potential of parthenium to establish and proliferate within rice ecosystems of Kashmir, posing a serious threat to local cropping systems under changing climatic scenarios. Comprehensive surveillance, early detection, targeted eradication, and long-term monitoring are, therefore, essential to mitigate its spread in Kashmir.**

Keywords: Biodiversity, Kashmir, invasion, *Parthenium hysterophorus,* phenology, weed

INTRODUCTION

Parthenium hysterophorus L. (Asteraceae) is one of the world's most destructive invasive weed species owing to its broad ecological adaptability, rapid spread, and detrimental effects on biodiversity, agricultural productivity, human and animal health, and ecosystem functioning (Navie *et al.,*1996). *P. hysterophorus,* a native to tropical America, has successfully invaded tropical, subtropical, and warm temperate regions across Asia, Africa, Australia, and the Pacific (Adkins *et al.,* 2019). Its global distribution has expanded from 10 countries in 1970 to 46 countries in 2020, establishing it as one of the world's most problematic invasive weeds (Mao *et al.,* 2021). The species disrupts ecosystem processes, reduces agricultural productivity, and poses a significant threat to food security (Khan *et al.,* 2013; Paini *et al.,* 2016). Although initially confined to rangelands and wastelands, *P. hysterophorus* has progressively invaded cultivated lands, where it aggressively competes with crops like sorghum, rice, wheat, maize, and tomato, causing substantial yield losses (Shabbir *et al.,* 2024). Its exceptional invasiveness is attributed to prolific seed production, rapid early growth, extensive branching, a well-developed root system, and strong allelopathic potential, enabling it to outcompete crop plants for light, water, nutrients, and space (Zimdahl, 2004; Shi and Adkins, 2018).

The successful establishment of *P. hysterophorus* across diverse climatic and physiographic regions reflects its remarkable ecological plasticity and wide environmental tolerance. Although the species originated in the tropics, where warm temperatures and adequate moisture favour rapid growth and reproduction, it has increasingly colonized cooler and high-altitude environments. Within Indian subcontinent, the weed is well established in India, Nepal, Bhutan, and Pakistan (Shrestha *et al.*, 2019). In Bhutan, the plant has been reported up to 2,600 m amsl elevations (Tshering and Adkins, 2012), and predictive models suggest that its potential distribution could increase by approximately 400% under projected global warming scenarios of 1.4-1.8°C (Dorji *et al.*, 2022). Similarly, climate suitability modelling (CLIMEX) predicts a northward expansion of the species in Pakistan under future warming scenarios, with Pakistan-occupied Kashmir and Khyber Pakhtunkhwa becoming increasingly susceptible to its invasion (Shabbir *et al.*, 2023). Although *P. hysterophorus* has occasionally been reported from countries such as Poland, Belgium, Sweden, and the Netherlands, it has failed to establish persistent populations because of unfavourable cold climatic conditions (Shabbir *et al.,* 2024). In Indian Himalayan region, the weed has expanded from subtropical areas into temperate zones, occurring up to 2,200 m amsl in Tehri Garhwal, Uttarakhand (Kumar *et al.*, 2022). In Himachal Pradesh, it has spread aggressively up to 2,000 m amsl and has sporadically been observed in central Himalayan valleys at elevations approaching 2,400 m (Dogra *et al.*, 2011). In Poonch (J&K) the species has been reported with a maximum frequency of 96% and density of 28.8% (Manzoor, 2019).

In Kashmir valley, the first occurrence of *P. hysterophorus* was reported from Residency Road near Jhelum Bund, Srinagar (Yaqoob *et al.*, 1988). Later, Muzafar *et al.* (2015) reported small, localized weed colonies from Lasjan By-pass, Bemina (Srinagar), and a graveyard in Sopore. However, no study demonstrated the successful life cycle completion or establishment of self-sustaining populations under temperate conditions of Kashmir valley. During a routine survey of weeds associated with rice agroecosystems, a satellite population of 28 plants of *P. hysterophorus* was spotted on a pathway in rice fields at Padgampora in Pulwama district of Kashmir on 23 September 2025. The site was studied for its geographical characteristics, soil properties, weather conditions (Nov. 2024-Oct. 2025), plant morphology and biometric characteristics. The present study was aimed to assess the life cycle completion and biometric characteristics of parthenium in relation to the prevailing weather conditions in Kashmir. The findings provide the first comprehensive assessment of the species' phenology and invasive risk within rice agroecosystems of temperate Kashmir.

MATERIALS AND METHODS

A weed survey was conducted in rice fields on 20 ha area in Seed Multiplication Farm, Padgampora district Pulwama (J&K) and a population of 28 plants of parthenium was noticed on 23 September 2025. The morphological and morphometric characters were matched with the standard key (Naidu *et al*., 2012) and online sources (*https://gobotany.nativeplanttrust.org/species/parthenium/hysterophorus/*). The plant identity was confirmed by the Centre for Biodiversity & Taxonomy, University of Kashmir, Srinagar (J&K). The data was recorded with respect to the site coordinates, geotagged information, morphological features of plant, and ecological association with other weeds. The area received a clean-up using a brush cutter on 22 August 2025. The weather data of Automatic Weather Station, KVK (SKUAST-Kashmir), Malangpora, just 1.5 km away from the site was used to study weather conditions that prevailed during the study period. The data related to plant biometric parameters and weather were collected and analysed using Analysis ToolPak in Microsoft Excel.

Site characteristics and soil properties

The site (33°53'54.04"N, 74°59'37.10"E) lies at an altitude of 1582 m amsl, 4.5 km away from the west of National Highway 44, 1.22 km north of Awantipora, Pulwama road, and 1.5 km away west of Padgampora village (Fig. 1). The parthenium population was spotted on a pathway between large rice seed multiplication fields. The patch was 4 m wide and 14 m long with 1.2 m deep irrigation/drainage channels on both sides. Soil was silty clay loam, with pH 7.13, EC 1.38 ds cm^{-1}, organic carbon 1.3%, N 372 kg ha^{-1}, P_2O_5 36 kg ha^{-1}, K_2O 248 kg ha^{-1} and S 16.5 kg ha^{-1}. The spot had sufficient soil moisture (20% w/w) and abundant daily sunshine. The other weed species were also identified and recorded.

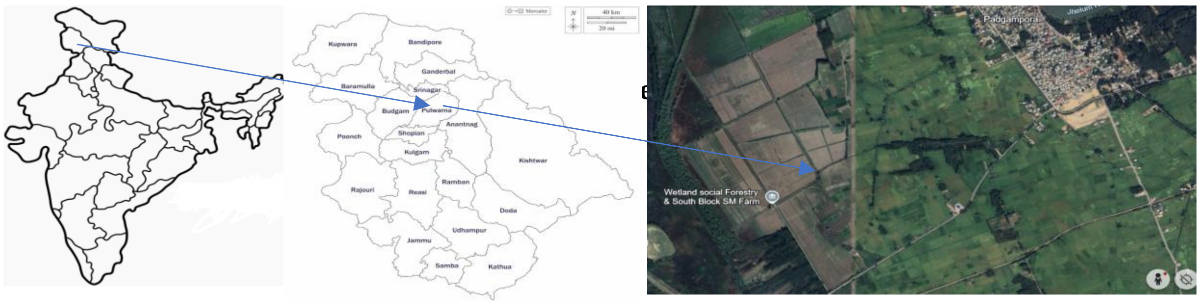

Fig. 1: Location map of the site where parthenium population was recorded

Weather conditions during the study period

The weather conditions were analysed for temperature (maximum minimum and mean), relative humidity, and precipitation from 1st November 2024 to 6th October 2025. The cumulative growing degree days (GDD) was calculated from 12th to 40th meteorological week using the following formula:

$$GDD = \frac{(T\,max + Tmin)}{2} - TBase \text{ (T Base =10°C)}$$

Biometric observations

The seedling, vegetative rosette, flowering, and maturity stages were closely monitored and studied. Data was recorded for plant height, number of leaves $plant^{-1}$, number of flowers, shoot dry weight, shoot moisture, root length, and root fresh weight. The plants were kept under observation to record the other phenological stages. At flowering stage, the number of flowers $plant^{-1}$ were counted from a sample of five plants. The root and shoot of five adult plants were dried in an oven at 65°C till constant weight. The seed size was measured using Cilika TF100 (10X) binocular microscope. The seeds were counted manually and weight measured on electronic balance (0.001 g). The seeds collected were subjected to germination test in a seed germinator at 25^0C.

RESULTS AND DISCUSSION

Weekly weather data, including maximum, minimum, and mean air temperature, relative humidity, and precipitation, were recorded from 1st November 2024 to 6th October 2025. During winter period (44th to 9th Standard Meteorological Week [SMW] i.e. 29th October 2024 to 4th March 2025, the maximum temperature (T_{max}) ranged from 2.93 to 23.29°C, while minimum temperature (T_{min}) varied from -7.09 to 1.99°C (Fig. 2). The corresponding mean temperature (T_{min}) ranged from -0.24 to 12.31°C. Total precipitation received during study period was 137 mm, nearly 65% below the long-term normal, resulting in drought-like conditions across the Kashmir valley throughout winter and early spring seasons. The mean relative humidity (RH) during this period ranged from 64.9 to 92.4%. During the subsequent growing season (10th to 40th SMW i.e. 5th March to 6th October 2025), $T_{max,}$ T_{min}, $T_{mean,}$ and RH was 14.5-35.2°C, 0.78-20.37°C, 7.5-27.8°C, and 51-84%, respectively. Cumulative precipitation received from 1st January and 6th October 2025 was 443 mm. Based on a base temperature used for the study, the cumulative growing degree days (GDD) from 12th to 40th SMW was 1,888 degree-days, providing favourable thermal conditions for the growth and development of *P. hysteronphorus*.

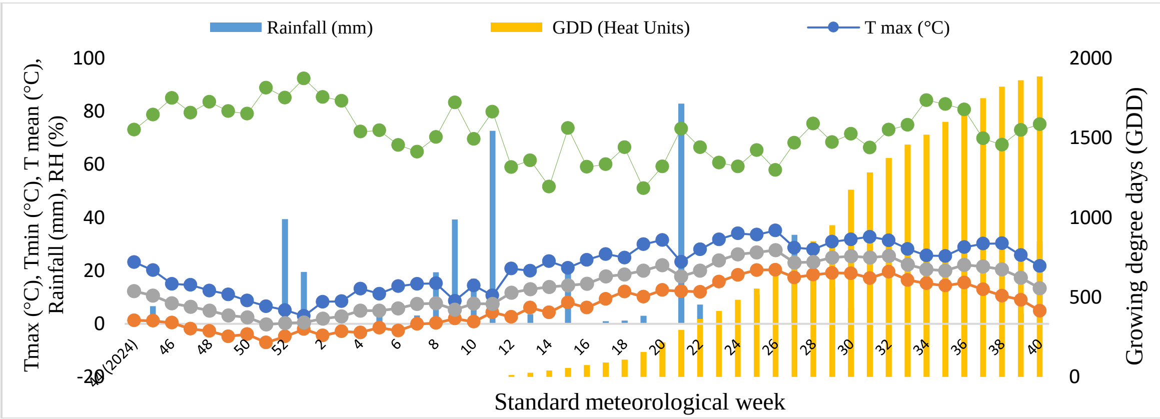

Fig. 2: Weather data during from November 2024 to 13th October 2025

Taxonomic description and identification

Parthenium hysterophorus is an erect, annual herb with profuse branching and a characteristic annual growth habit (Fig. 3). During initial stages of development, plants formed a compact basal rosette of leaves before producing an erect, branched stem. The population comprised individuals at different phenological stages, including seedling/rosette, vegetative branching, flowering, seed maturation, and senescence, indicating staggered germination. Mature plants attained heights ranging from 20 to 75 cm. The lower leaves were large, deeply bi-pinnatifid to bi-pinnatisect, resembling carrot leaves, and measured 10-15 cm in length with 9-13 lobes. In contrast, the upper leaves were smaller (4-8 cm long), less dissected, and possessed 6-8 lobes without further subdivision. Leaves were arranged alternately, forming a basal rosette during juvenile stage, with petioles up to 2 cm long. Both leaf surfaces, particularly the abaxial surface, were covered with short, appressed pubescence. Mature plants produced 2-8 primary branches. The stems were green with prominent dark-green longitudinal grooves and were densely covered with stiff, hirsute hairs.

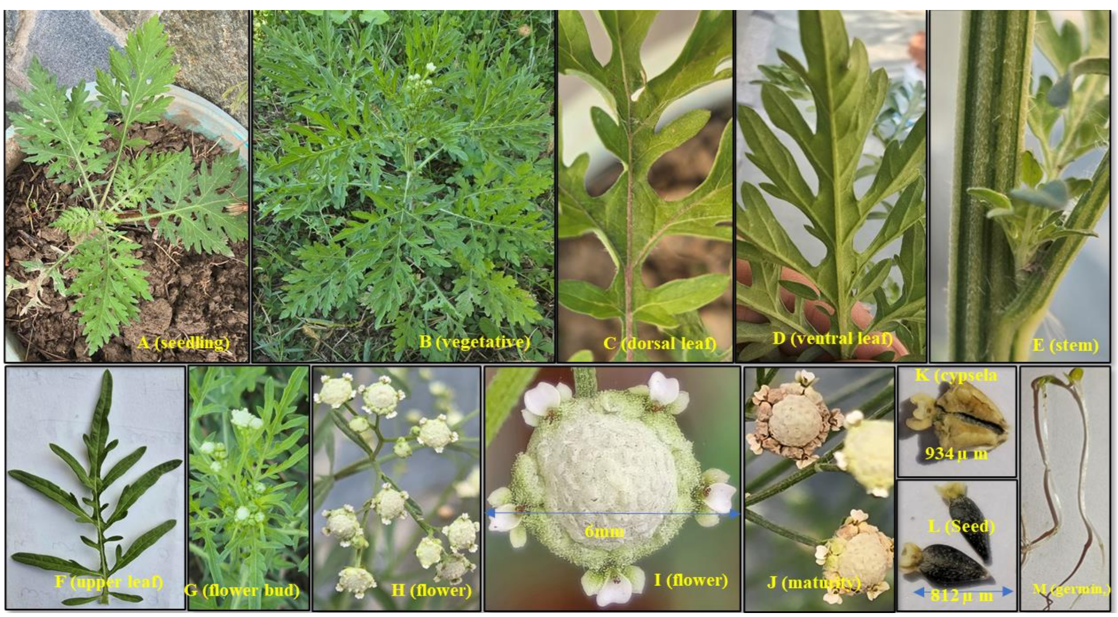

Fig. 3: Phenological stages of *Parthenium hysterophorous:* A: Seedling/ Rosette stage; B-F: Vegetative stage; G-I: Flowering stage; J-L: Maturity/ Senescence stage; M: Germination stage

The inflorescence consisted of numerous terminal capitula borne on pedicels measuring 1-6 mm in length. The flower heads were creamy white, 4-6 mm in dia., and comprised five minute ray florets

(0.3-0.8 mm long) surrounding centrally located tubular disc florets. Each capitulum was enclosed by two rows of green involucral bracts. Flowering commenced during late September and continued through October. As the capitula matured, they gradually turned light brown in the 1st week of October. Each mature capitulum produced 4-6 cypselae. The obovoid cypselae measured 920-934 µm in length and were readily dispersed by wind or mechanical disturbance. The seeds measured 780-812 µm in length, were wedge-shaped, black, and possessed 2-3 small pappus scales that facilitated dispersal.

Following seed maturation, the plants entered senescence phase. With the onset of severe autumn frosts (< -2°C) during November, the aerial portions of all plants completely dried and died, confirming the annual life cycle of *P. hysterophorus* under temperate Kashmir conditions. The mature seeds survived the winter under sub-zero temperatures and moist soil conditions. Seedling emergence was observed during late March to early May of the following growing season when mean daily temperatures increased to 10-20°C. Laboratory germination tests showed 65% germination of mature seeds, confirming their viability. These observations demonstrated that *P. hysterophorus* successfully completed its life cycle under temperate conditions of Kashmir valley through sequential stages of seed germination, vegetative growth, flowering, seed production, senescence, overwintering of seeds, and the establishment of a new generation.

Biometric parameters and phenology

All 28 plants were evaluated for biometric parameters (Table 1). Of these, 10 plants were at the seedling/rosette stage, seven had been mechanically cut by a brush cutter at heights of 10–45 cm above ground level and subsequently regenerated, three reached the branching stage without flowering, and five attained the flowering stage. Plant height ranged from 7 to 76 cm, while the number of leaves and flowers plus flower buds varied from 3-26 and 0-230 plant^{-1}, respectively. Fresh shoot weight ranged from 6 to 58 g plant^{-1}, with corresponding dry shoot weights of 1.19-11.90 g plant^{-1}. Shoot moisture content varied between 78.6 and 87.3%. Root length ranged from 4.2 to 6.9 cm, with fresh and dry root weights of 0.45-0.92 g and 0.15-0.30 g plant^{-1}, respectively. As expected, seedlings accumulated considerably less root biomass than mature plants. The founder population at the site most likely originated from seeds dispersed by wind from nearby roadsides or introduced through contaminated farm machinery or crop seed.

Table 1: Descriptive statistics of the biometric parameters studied for the parthenium population

Descriptive statistical parameters	Plant height (cm)	No. of leaves plant^{-1}	New leaf sprouts plant^{-1}	No. of branches plant^{-1}	No. of Flowers + flower buds Plant^{-1}	Shoot Fresh wt. plant^{-1} (g)	Shoot Dry wt. plant^{-1} (g)	Shoot Moisture (%)	Root Length (cm)	Root Fresh weight (g)	Root Dry weight (g)
Minimum	7.0	3.00	2.00	0.0	0.00	6.10	1.19	78.60	4.20	0.45	0.15
Maximum	76.0	26.00	5.00	8.0	230	58.10	11.90	87.30	6.90	0.92	0.30
Mean	28.1	9.50	3.57	1.62	26.15	18.57	3.60	80.30	5.75	0.71	0.23
Standard error	4.1	1.19	0.37	0.53	12.15	2.94	0.57	0.31	0.17	0.03	0.01
Standard deviation	21.1	6.05	0.98	2.68	61.90	14.98	2.90	1.59	0.89	0.14	0.04
$CD_{0.05}$	8.53	2.45	0.90	1.08	25.02	6.05	1.17	0.64	0.36	0.06	0.02

P. hysterophorus is dispersed through wind, water, animals and anthropogenic activities (Ruping *et al.*, 2021), enabling it to colonize diverse habitats, including agricultural ecosystem (Navie *et al.*, 1996). The occurrence of plants at different phenological stages—seedling, resetting, branching, flowering, senescence & seed germination—indicated asynchronous or staggered germination within the population. Approximately 38% plants were at the seedling stage, suggesting delayed germination, which may be attributed to the persistent soil seed bank and prolonged seed viability, with an estimated seed-bank half-life of approximately six years (Navie *et al.*, 1998). Seed dormancy in *P. hysterophorus* is influenced by temperature and solar radiation during seed development (Javaid *et al.*, 2010), while the prolonged drought experienced in Kashmir valley between March and May 2025 may also have contributed to staggered seedling emergence.

Plants that were mechanically cut at heights of 18-45 cm above ground level regenerated vigorously through the production of lateral shoots following the loss of apical dominance. One regenerated plant successfully flowered and produced seeds, demonstrating the species' remarkable regenerative capacity. Similar post-cut regeneration, flowering, and seed production have previously been reported by Dhawan and Dhawan (1996). The substantial variation observed in plant height, branching, reproductive structures, and shoot biomass primarily reflected differences in phenological stage, as confirmed by relatively high values of standard error, standard deviation, and variance for these traits. The well-developed root system (4.2-6.9 cm) and considerable root biomass indicated efficient below-ground resource acquisition, which enhanced plant survival and competitive ability under field conditions (Hamblin *et al.*, 1990).

The 1,000-seed weight of mature seeds collected during the second week of October was 458 mg, which agrees closely with the range of 360-460 mg reported by Dolai *et al.* (2013). Flowering continued throughout October, and mature seeds were produced before the onset of winter. However, severe frosts (< - 2°C) during November resulted in complete senescence and death of the aerial plant parts, confirming the annual growth habit of the species under temperate Kashmir conditions.

Based on field observations, *P. hysterophorus* required approximately 180 days from germination to flowering and 190-200 days to initiate seed set under Kashmir conditions. Nearly 20% population reached the flowering stage, with mature seeds developing approximately 20 days later, by the 2nd week of October. Laboratory evaluation demonstrated 65% germination of mature seeds, confirming seed viability and the successful completion of life cycle under temperate conditions. Field observations further suggested that seeds overwintered under sub-zero temperatures and germinated during late March to early May, when mean daily temperatures was between 10 and 20°C. Although the base temperature for germination reportedly is 7.2°C, the optimum germination occurs at near 20°C (Afzal *et al.*, 2022).

The prevailing environmental conditions, *viz*., favourable temperatures, adequate sunshine, fertile silty clay loam soil, conducive soil moisture, and near-neutral soil pH, supported vigorous vegetative growth and reproductive development. Based on accumulated thermal units, the species required 1700-1750 GDD to reach flowering and 1890-1920 GDD to initiate seed set. Lalla (2012) reported that *P. hysterophorus* requires > 220 days to complete its life cycle under cooler environments (25/18°C day/night temperatures). The completion of life cycle under temperate Kashmir conditions revealed phenotypic plasticity and adaptive capacity of weed. Combined with projected regional warming, this study indicated the potential of *P. hysterophorus* to establish self-sustaining population and progressively invade temperate agro-ecosystems of Kashmir valley. Similar upward expansion of the species has already been documented in the Himalayan region of Bhutan (Dorji *et al.*, 2022), Nepal (Shrestha *et al.*, 2019), Himachal Pradesh (Dogra *et al.*, 2011), Uttarakhand (Kumar *et al.*, 2022), and Pakistan (Shabbir *et al.*, 2023). Rising temperatures are widely recognized as one of the principal drivers aiding the invasiveness of alien plant species into higher latitudes and elevations (Ziska and McConnell, 2016).

Ecological note

The parthenium population was found associated with typical temperate weed community occurring on the ridges, bunds, and pathways adjoining rice fields in Kashmir. The associated weed flora comprised of *Trifolium repens*, *Cynodon dactylon*, *Setaria* spp., *Symphyotrichum subulatum*, *Ranunculus acris*, *Plantago major*, *Equisetum* spp., *Potentilla reptans*, *Daucus carota*, *Rumex* spp., *Geranium nepalense*, *Xanthium strumarium*, *Clinopodium umbrosum*, and *Oenothera rosea*. These species are distinctive components of temperate agro-ecosystems of Kashmir and commonly occur along field margins, bunds, and pathways surrounding rice fields. The associated vegetation produced substantial biomass under adequate sunshine and sufficient soil moisture. Adult *P. hysterophorus* plants were noticeably taller than the surrounding vegetation, indicating their competitive growth potential. The well-drained yet moist habitat, coupled with abundant solar radiation, provided favourable conditions for the growth and development of *P. hysterophorus*. Nevertheless, the weed had not yet formed dense mono-specific stands or displaced the native weed flora, suggesting that the population was in the early stages of establishment. The presence of plants at different phenological stages and the successful production of viable seeds indicated that *P. hysterophorus* has established a self-sustaining population at the study site. However, the onset of severe autumn frosts limits plant survival and reproductive success, so restricts seed production and subsequent population expansion. Parthenium plants in vegetative or flowering stage reportedly can survive mild frost (approx. -2°C), after which further growth and seed production are severely restricted (Williams and Groves, 1980). These climatic constraints may limit the plant invasiveness in Kashmir, although continued warming under changing climate could enhance its establishment, spread, and competitive ability in temperate agro-ecosystems.

Conclusion: The present study provides the first evidence of the occurrence and successful life cycle completion of *Parthenium hysterophorus* under rice agro-ecosystem of temperate Kashmir. The presence of plants at different phenological stages indicated staggered germination and demonstrated its ability to establish under the prevailing climatic conditions. The production of viable, mature seeds before the onset of winter frost confirmed that *P. hysterophorus* can successfully complete its annual life cycle in temperate Kashmir, highlighting its ability to establish self-sustaining populations. Irrigated rice fields and wetlands are generally unsuitable for the establishment and spread of *P. hysterophorus* because of prolonged soil saturation, adjacent well-drained habitats like field bunds, pathways; and foothill ecosystems provide favourable niches for its establishment and proliferation. Rising temperatures and changing climatic conditions may further enhance the suitability of these habitats, thereby increase the risk of invasion of *P. hysterophorus* into agricultural landscapes. Immediate surveillance, systematic mapping, early detection, eradication of nascent populations, and strict quarantine measures are, therefore, essential to prevent its establishment and spread before it becomes a major invasive weed of both crop and non-crop ecosystems.

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