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Invasion success of *Parthenium hysterophorus* L. may get restricted by resident arthropods in India

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Abstract
Invasive weeds establish in communities because they are better competitors than natives in absence of their natural herbivores. However, native arthropods may also evolve to adapt and harbor the invader affecting its dominance. Hence native arthropod fauna associated with *Parthenium hysterophorus* L. was studied and their role for weed suppression was assessed. A random survey undertaken in Jammu and Kashmir, India showed the presence of twenty one resident arthropods species harbouring this weed. Among these, three were of exotic origin already introduced in India while the remaining were native species. Therefore, we preferred the term resident arthropods. The most devastating polyphagous pests like *Spilosoma obliqua, Phenacoccus solenopsis, Pseudococcus comstocki and Tetranychus uriticae* completed their life cycle on the weed host without any significant reduction in their fitness attribute such as body weight and fecundity. The relationship between population of weed and resident insect was density dependent. Therefore, it is assumed that increasing abundance of resident insect will restrict and reduce the weed population in coming years. Potential effect of these arthropods additionally uncovered that many of them could stifle this weed in term of reduction of the floral capacity and seed bank The yield infestation relationship was best explained by log linear equation with highly significant relationship and coefficient of determination exceeding 90.0 per cent in case of all the four major insects. With every unit increase in population of *S. obliqia, P. solenopsis, P. comstocki* and *T. uriticae,* flowers reduction of this weed decreased to the extent of 1.76, 1.33, 0.77 and 0.77 per cent, respectively. Further, in a field trial conducted over the five successive years, we found that herbivory by native insects became significant only in the third years onwards with reduced weed biomass (57.54%) and soil seed bank (36.95%) at the end of 5^{th} year when compared to insecticide treated plots (without herbivory). Our findings suggest that although these herbivores cannot be advocated for applied biological control, yet their ability to evolve and to restrict the invasive weed in nature cannot be ruled out.

Keywords: *Parthenium hysterophorus*, arthropods, herbivory, resident insect

1. Introduction

The introduction and establishment of invasive plants into new habitats in which they have not coevolved with the native biota are identified as a major threat to biodiversity and ecosystem structure and function. For instance, congress grass or carrot grass, *Parthenium hysterophorus* L. (Asteraceae) which got originally introduced to India from the USA through the imported grains [1]. Since 1955 [2] is widely flourishing in pastures, wastelands and land under cultivation in India. This weed aggressively displaces native plants and forms monospecific stands threatening biodiversity and altering fundamental ecosystem properties. Escape from native insect herbivores is believed to be one of the primary causes contributing to the successful invasion of many introduced plants. Therefore, efforts on biological control of *Parthenium* were initiated in India in 1983 with the introduction of Mexican beetle, *Zygogramma bicolorata* from the native home. The beetle showed considerable potential in suppressing the weed in subsequent years [3-5]. Although classical control still remains immediate option to suppress these aggressive invaders and there is no denying the fact that the introduction of an exotic beetle have profound effects on weed suppression. Like other species, this plant has become unusually susceptible to native herbivores to the extent that so far it has been described as their alternate host only [6]. Unfortunately, effects of these herbivores on weed dynamics and ecosystem function has not been explored yet, in India. Evolution of invasiveness predicts that invasive plants begin to support diverse insect communities similar to those on native plants within few years after introduction and local herbivores in the introduced range may more likely begin to recognize and utilize the exotic species as a viable food alternative.

A shift in feeding preferences of native and accidentally introduced insect herbivores to this weed would likely have equally dramatic consequences on its population in future. Therefore, long term management strategy must encourage local herbivore recognition [7]. This is because the initial status of an introduced species may be a poor indicator of its future ecological success, so biological control of this weed must also be focused on re-establishment of feeding relationships with native herbivores. Native species may also evolve to become significant competitors with invasive species, and thus affect the fitness of invaders [8]. Hence native insect fauna associated with *Parthenium* in Jammu region was studied and their role for weed suppression was assessed. The study address the basic issues like (i) what kind of resident herbivores feed upon this weed, (ii) whether they cause substantial damage and (iii) can they restrict this weed in near future in terms of potential decrease in biomass and seed bank as well.

2. Materials and Methods

2.1 Sampling and Experimental sites

About 23 sites were sampled in outer plains and mid hills of Jammu region monthly with different collection methods with more or less regular periodicity from 2006 till 2016. All experimental trials were however conducted at Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu (32°39'13"N Lat., 74°48'16"E Long., 300 m asl) which is about 6 km from city of Jammu. The area surveyed experiences extreme summer and moderate winter with temperature occasionally falling below freezing. In winter dense smog causes much inconvenience and temperature even drops to 2 °C (36 °F) while in summer, particularly in May and June, extremely intense sunlight or hot winds can raise the mercury to 46 °C (115 °F). Average yearly precipitation is about 42 inches (1100 mm) with the bulk of the rainfall in the months from June to September, although the winters can also be rather wet. The vegetation is of subtropical type with dominant thorny bushes, evergreen shrubs, climbers and tall grasses. Most of the plants are broad leaved deciduous type. Owing to great diversity of trees along with thick undergrowth of bushes and scrubs open grazing in pasturelands and wasteland commonly known as *Kalahis* and *Shamlat*, respectively is very common wherein this weed has assumed serious proportions.

2.2 Sampling technique

The insects along with their immature stages were collected from the fields by various methods such as hand picking, stem beating and also with the help of entomological nets. Specimens i.e., eggs, larvae, pupae and adults were preserved by entomological methods and were later on identified with the help of available literature and identification services rendered by, IARI New Delhi and Zoological Survey of India, Entomology.

2.3 Insect infesting *Parthenium* and their feeding status

As mere presence of herbivore does not indicate phytophagy, only those insects were recorded that actually fed or reproduced on *Parthenium*. The nature of damage was confirmed and their ability to complete their lifecycle on this host was investigated.

2.4 Pest abundance and potential impact

The occurrence of these insects was expressed in term of their periodic activity over the year and relative frequency expressed in term of presence of insect recorded per hundred observations. Potential insects that completed their lifecycle on *Parthenium* were subjected to yield infestation relationship and fitness studies.

2.5 Yield infestation relationship

To establish the yield infestation relationship of major insect's variable number of insect was initially released on healthy plants grown under field cages (7 x 7 x 4 m) maintained separately for each insect species in last week of April for three consecutive years 2014, 2015 and 2016. After 45 days of release, the infested plants were randomly selected and tagged individually. Each plant was sampled for number of insects at fifteen days interval. At maturity, the plants were uprooted and number of flowers were counted and correlated with mean population of each insect accordingly (Figure 1).

2.6 Potential impact on plant attributes

Besides, potential impact of major insect communities on *Parthenium* was also worked out for each year as described above. For this, three week old healthy plants that were grown in earthen pots were inoculated with fixed number of insects (one day old) and then covered with screen mesh cages individually under growth room conditions. Each plant represent independent replicate and at least twenty replications were maintained for each insect. For each species, infestation levels consist of 50 neonate for hairy caterpillars, 5 crawlers for mealy bugs, 5 nymphs for aphids, 10 adult female for spider mites, 5 adults for defoliating beetles and 10 number of termite worker of unknown age but uniform size were released in root zone for termites. Simultaneously, a control group, free of insect infestation for each species was also maintained.

2.7 Host Suitability

In polyphagous insects, the suitability of a host species for larval development and survival differs between host plant species. In order to explore host suitability of native species, we examined whether they used it for extreme survival only or they were able to complete their development on it. Further, we also ascertained that whether feeding on this weed results in their fitness reduction in comparison to the most preferred host. All experiments were conducted in a growth room on a 16 L : 8 D cycle at 25ºC constant temperature and 50% relative humidity. Prior experimenting, it was established that the insect populations could be successfully switched among the main host and *Parthenium*. These populations were switched among these hosts at equal interval to eliminate the possibility of increased preference towards the food plant to which they were already exposed. However, each insect species was reared simultaneously in laboratory for at least 3 to 5 generations on their main host and *Parthenium* weed as well to acclimatize them for further investigations.

2.8 Field trials on resident insect herbivory

Since, native insect herbivores feed extensively on this weed mainly from April to August. We selected a site free currently invaded by this weed. An area of 100 m^2 was selected and temporarily fenced-off to avoid cattle damage. The selected area was allocated according to the paired-plot technique, comprising eight plots of 2.25 m^2 (1.5 m × 1.5 m) for each treatment. Prior assigning this area to treatments (paired plot technique) we removed all other vegetation from the experimental area and took soil samples for estimation of soil seed bank to ensure that the soil seed bank did not vary among plots. Upon germination of soil seed bank, in each experimental plot we removed all the germinating flushes except F_3 i.e., cohort of plants that germinated during ending March to first week of April. All plants of other flushes germinating before or after this period were removed. A uniform population of 200 plants was maintained in each plot. The protected plots were maintained free of native insects by using insecticides bifenthrin 0.06% at fortnightly interval to avoid herbivory by the native insects while, the unprotected plots of similar size were left exposed to native insects. To control for any effects of added water; moisture we sprayed protected plots with water-only on the similar dates. At harvest, the absolute number of flowers was counted from at least 20 plants from each plot in the laboratory. However, the seed count was calculated by multiplying the number of flowers by the mean number of seeds per capitulum (flower). The above-ground biomass of all the harvested plants was also recorded for each treatment. The sample plants were oven-dried for 48 h at 70ºC and the dry weights were determined as per standard procedures. For estimating the soil seed bank, the soil samples (16 cm^2 area, 2 cm depth) were collected at random from the three sites in each plot. The soil samples were uniformly spread on the top of plastic trays (18 cm × 12 cm × 5 cm) that were filled with steam-sterilized soil. The data on the number of germinating plants of *P. hysterophorus* were recorded for four consecutive weeks. The biological and reproductive attributes in term of developmental period, survival, body weight and fecundity were recorded on different hosts for major pests such as hairy caterpillar, *Spilosoma obliqua* Walker, mealy bugs, *Phenacoccus comstocki*, *Phenacoccus solenopsis* and spider mite, *Tetranychus uritacae*. Caterpillars were collected while in the early instars from each host and reared individually in closed plastic containers at ambient temperature in a laboratory. Thus, temperature conditions were similar for all growth measurements. We fed them leaves of the same species and age as those on which they were initially found. Leaves were replaced with fresh ones at least every other day. A moistened paper towel in each cup helped keep leaves fresh. For mealy bugs host plants viz., tomato, egg plant and congress grass were grown in pots. 30 days old plants were covered in muslin cages (Size : 20 × 40 × 85 cm) and 20 freshly emerged crawlers (< 24 h old) from the laboratory culture on each of the plant species were released on the top leaves of the respective caged plants. After 20 days of release, observations were recorded on body weight (mg) and development time (days). One plant was considered as one replicate and there were six replicates for each host plant. Similarly, survival of the adult females mites and their fecundity (number of eggs laid) over 5d was assayed. Freshly inseminated adult females were placed individually on 1.5 cm-diameter leaf disks of brinjal or *Parthenium* placed upon acrylamide gel in glass petriplate so as to keep the leaves fresh and to restrict them to move away from it. Each container/petriplate or potted plant was considered as one replicate and there were twenty five replicates for each host plant. Data were subjected to analysis of variance and were further subjected to appropriate test.

3. Results

3.1 Insect infesting *Parthenium* and their feeding status

The survey conducted in 23 locations for the period revealed that the weed harbored several native and exotic insect pests with their relative frequency varying over the years in (Table 1). Apart from insect pests, predators, parasitoids, naturals and detrivores were also found surviving on this host which was reported elsewhere. Among these pests, three were of exotic origin already introduced in India while the remaining were native species. The two major groups of defoliators that caused damage to plants were the caterpillars and beetles. Nevertheless, other chewing insects were found occasionally damaging the plants include grasshoppers, katydids and their relatives.

Table 1: Arthropod communities feeding on *Parthenium hysterophorus* in Jammu and Kashmir, India

Sl no.	Name of insect	Common name	Systematic position	Native/ Exotic	Feeding specificity	Relative frequency (%)
Defoliating insects						
1	*Spilosoma obliqua* Walker	Bihar Hairy caterpillar	Arctiidae: Lepidoptera	Native	Polyphagous	2.3
2	*Amasacta albistriga* Walker	Red hairy caterpillar	Arctiidae: Lepidoptera	Native	Polyphagous	3.7
3	*Myllocerus dentifer* (Fabricius)	Ash weevil	Curculionidae: Coleoptera	Native	Polyphagous	1.7
4	*Bruchidius* sp.		Chrysomelidae: Coleoptera	Native	Oligophagous	2.3
5	*Colasposoma semicostatum* Jacoby	Leaf eating beetle	Chrysomelidae: Coleoptera	Native	Polyphagous	2.7
6	*Altica* Spp	Blue Metallic Flea Beetle	Chrysomelidae: Coleoptera		Polyphagous	2.3
7	*Monolepta signata* Olivier	White spotted leaf beetle	Chrysomelidae: Coleoptera	Native	Polyphagous	2.3
8	*Epiblema lasiovalva* Razowski	White foot bell	Tortricidae: Lepidoptera	Native	Oligophagous	2.7
9	*Neorthacris acuticeps nilgriensis* Uvarov	Wingless Grasshopper	Acrididae: Orthoptera	Native	Oligophagous	2.7
Sucking Pests						
10	*Otinotus oneratus* Walker	Cow bugs	Membracidae: Hemiptea	Native	Polyphagous	1.0
11	*Empoasca flavescens* Fabricius	Jassid	Cicadellidae: Homoptera	Native	Polyphagous	0.3
12	*Nezara viridula* Linnaeus	Stink bug	Pentatomidae: Hemiptera	Native	Polyphagous	3.3
13	*Oxyrachis tarandus* Fabricius	Tree hopper/ cow bug	Membracidae: Hemiptera	Native	Polyphagous	2.7
14	*Pseudococcus comstocki* (Kuwana)	Comstock Mealy bug	Pseudococcidae: Hemiptera	Exotic	Polyphagous	2.3

15	*Phenacoccus solenopsis* Tinsley	Cotton mealy bug	Pseudococcidae: Hemiptera	Exotic	Polyphagous	1.7
16	*Aphis* sp.	Aphid	Aphididae: Hemiptera	Native	Polyphagous	1.3
17	*Rhophalosiphum maidus*	Corn leaf aphid	Aphididae: Hemiptera	Native	Polyphagous	1.7
18	*Aphis gossypii* Glover	Cotton aphid	Aphididae: Hemiptera	Native	Oligophagous	1.3
19	*Scirtothrips dorsalis* Hood	Chilli thrips	Thripidae: Thysanoptera	Native	Polyphagous	1.3
20	*Tetranychus urticae* Koch	Spider mite	Tetanychidae: Trombidiformes	Exotic	Polyphagous	1.7
Root feeders						
21	*Odontotermes obesus* (Rambur)	Termite	Termitidae	Native	Polyphagous	0.7

3.2 Defoliators
3.2.1 Caterpillars
Bihar Hairy caterpillar, *Spilosoma obliqua* Walker and Red hairy caterpillar, *Amasacta albistriga* Walker were found to occur frequently from August to February. Initially, gregarious young caterpillars fed upon the chlorophyll layer of leaf exposing the veins while late instar caterpillars were voracious. Affected leaves look dead, dried and easily fall off. In later stages, the entire plant was eaten (Plate 1 b-c) and looks like as if grazed by cattle. The percent infestation ranged from 6 to 13.5%. It was interesting to note that plants that harbored gregarious larvae dried without flowering.

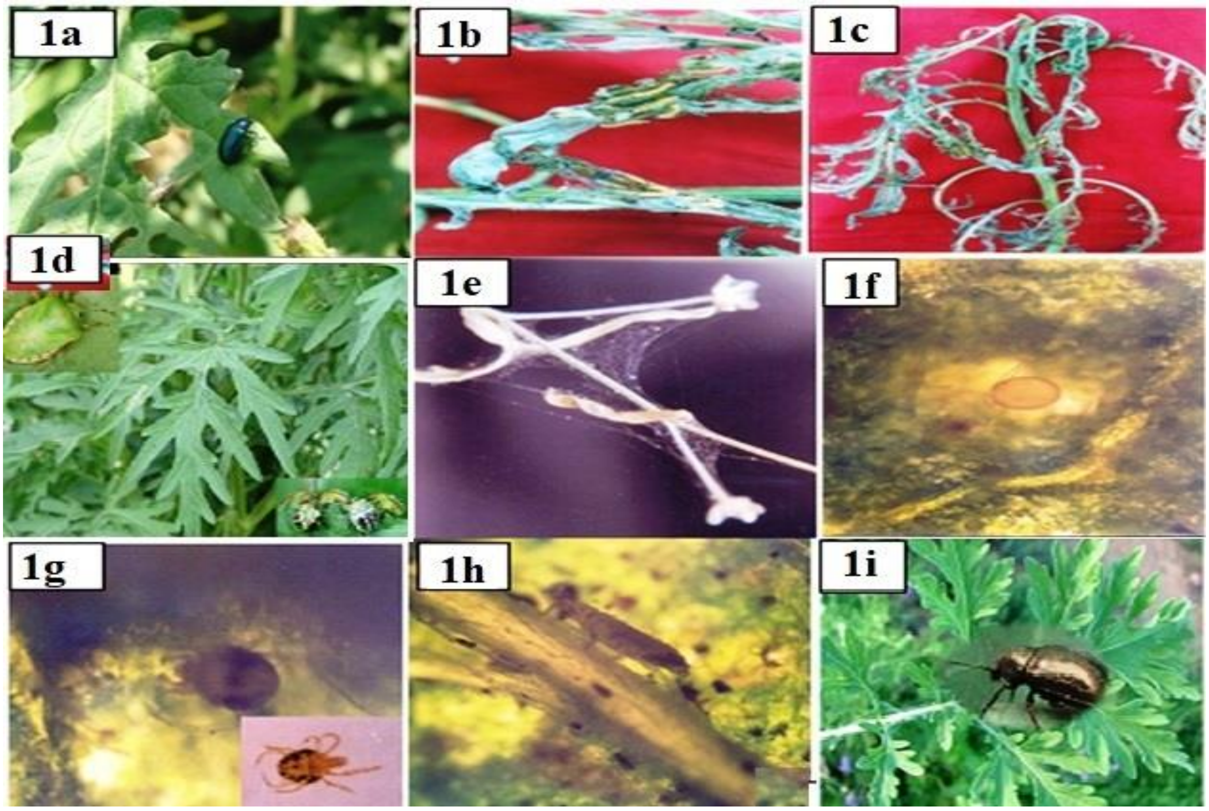


Plate 1: Arthropods infesting leaves of *P. hysterophorus* in India Flea beetle (*Altica spp.* **(a)** Hairy caterpillars (**b-c)** Stink bug (**d)** Spider mite webbing, eggs and adults (**e-g)** Thrips (**h)** **(i)** Flea beetle, *C. semicostatum*

3.2.2 Beetles and weevils
Among beetles and weevils, adult population of *Myllocerus dentifer* (Fabricius) was observed from the 1st week of July to the last week of August and reached peak numbers (2.4 weevils / plant) in the 3rd week of July. The percent plant infestation level was too low 3.5 to 11.9%. The exclusive biology of this pest on *Parthenium* could not be established and the impact of defoliation on flower production was not significant. However, in damaged plants symptom of some bacterial infection were noticed. Adults of *Bruchidius* spp. were first seen in the early spring when they probably emerged from overwintering. They fed on pollen and remain active throughout the blooming period from May through June up to September but did not result in much impact on flowers. In order to confirm their feeding on pollen, few beetles were dissected for presence of pollen in the gut. Female's eggs were also found glued onto small developing seed. The infestation was more in sunny, open sites in lower hills with seed destruction ranging between 2.8 to 18.3%. A Leaf eating beetle *Colasposoma semicostatum* Jacoby (Chrysomelidae: Coleopteran) (plate 1i) was found feeding on leaves of plant at Manthal, Udhampur during September – November. Some newly formed leaves of plant were found drooping and drying from plants. When critical observation were made in laboratory where beetle was released on healthy plant, it was found that, the beetle were seen making small holes on the leaf besides, feeding on the buds, stem and sometimes the surface of young flowers. Mostly it fed on the leaves near the base of petiole and also on cortex of petiole leading to eventual drooping of leaves and drying later on. Under field conditions, maximum damage was noticed during the monsoon season when adult were recorded feeding voraciously on the leaves. The damaged buds fail to flower. In severe infestation damage resulted in necrosis, reduced

growth and defoliation of the host plants. Another foliage feeders *Monolepta signata* was observed feeding on the parenchyma of the upper as well as lower leaf surface producing a lace like effect by riddling the leaves with numerous irregular holes but leaving the main veins intact. Lepidopteron adults of tortricid moth, *Epiblema* were also noticed on plants but their damage to plant could not be established. Nymphs and adults of orthopteran *Neorthacris acuticeps nilgriensis* occasionally fed on the leaves.

3.3. Sap sucking pests

Apart from these defoliators, many sucking pests were encountered and their damage was confirmed scientifically. Occurrence of Jassid, *Empoasca flavescens* Fabricius was noticed from July to October wherein both nymphs and adults were observed sucking the cells sap from leaves that became curly with burned edges showing “hopper burn” because of injecting toxins in the plant. They also suck the cell sap from tender’s stems of twigs. During the similar period, nymphs and adults of *Nezara viridula* (plate 1d) Linnaeus were also found devitalizing the host plants by sucking the cell sap from tender leaves and stems. Foliar distortion was also noticed during this period because of continuous sucking of cell sap by cow bugs *Oxyrachis tarandus* (Fabricius) and *Otinotus oneratus* (Walker). Considerable damage by mealy bug *Pseudococcus comstocki* and *Phenacoccus solenopsis* (plate 2c-e) was also observed. Although, this pest is polyphagous and remained present throughout the year on one or the other hosts plants, yet serious infestation was noticed on this plant during April onwards as temperature warms up when it started breeding on fresh flush of congress grass till September. The plant infestation by mealy bugs ranged between 6.3 to 21.8 and 3.2 to 12.3% with a mean population of 5.3 to 15.2 and 0.54 to 3.4 crawlers/plant for *P. solenopsis* and *P. comstocki*, respectively. Nymphs and adults of three different species of aphids (plate 2a-b), *Aphis* spp. *Aphis gossypii* Glover and *Rhopalosiphum maidis* caused damage by sucking the cell sap from twigs coupled with development of sooty mould on affected plants. While the former two species remained active on crop from ending February to second fortnight of May the incidence of the later species with severe infestation occurred during October to January at three isolated locations, wherein the organic matter in the soil was high coupled with high soil moisture.

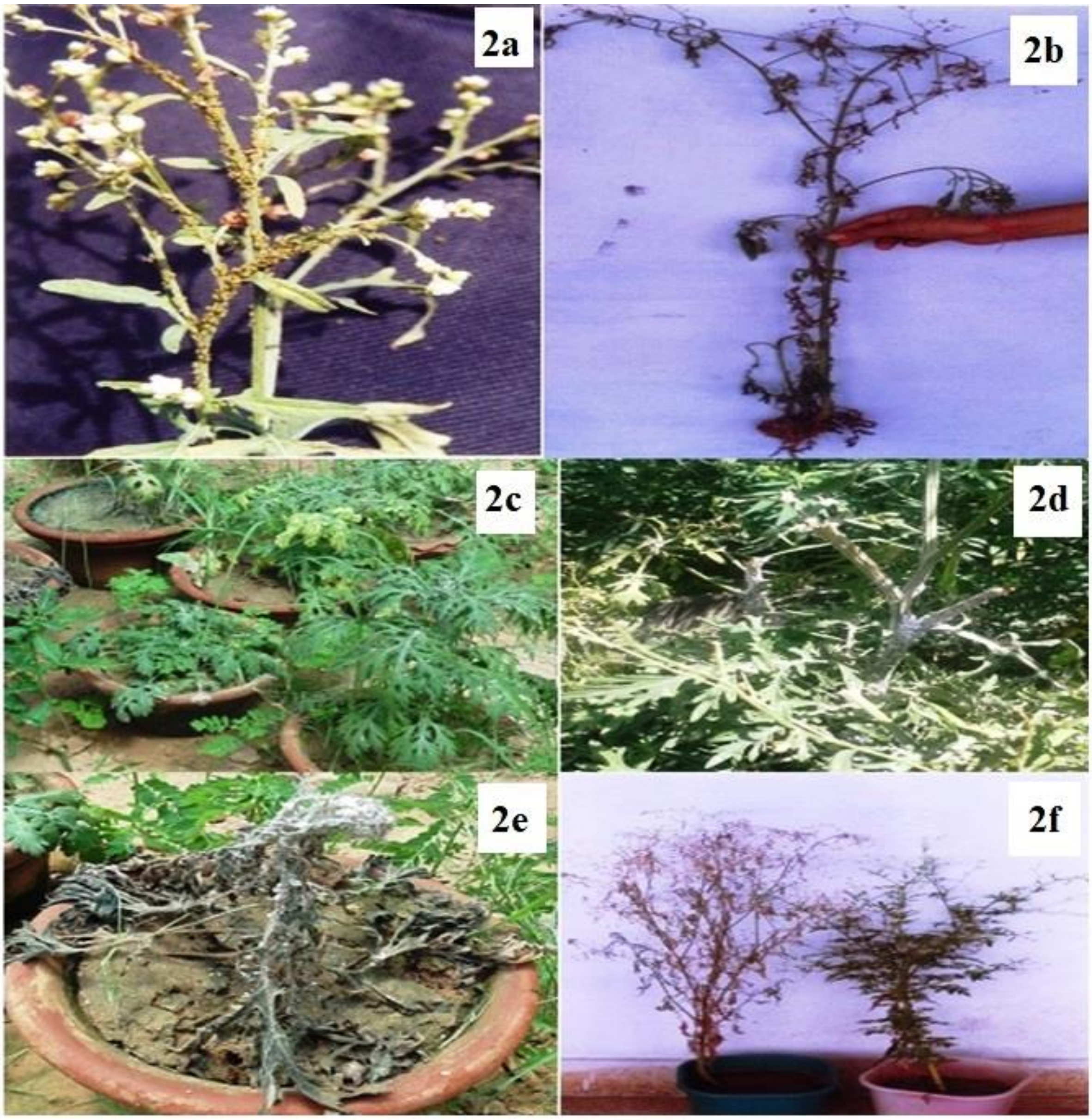


Plate 2: Arthropods Infesting stems and flowers with complete plant drying by aphid **(a-b)**, mealy bug (**c-e)** and spider mite (**f**)

In few cases the infestation was so high that about one third of the plants were found drying. When the potted plants (30 days old) were subjected to aphid infestation @ 5 alate/plant, the pest occupied all the plants within 20 days and resulted in about 40% reduction in flowering/plant. An unidentified Coccid spp. was also seen. Two spotted spider mite (plate 1e-g), *Tetranychus urticae* Koch remained associated with this plant almost throughout the year. The first appearance was noticed in February, when first germinating flush of the plant was noticed in field. Leaves got pale yellow to bronze stippled areas at any time from early spring and subsequent feeding caused small chlorotic spots which eventually coalesce followed by stippling and yellowing of entire leaf. The infestation remained during March to second fortnight of May and started declining thereafter up to ending December. When released @ 10 adult females/plant, it caused complete drying of plant within 42 days and about 48 adult, 81 nymph and over 134 eggs were observed on single leaves of the plant and resulted in about 73% reduction in flowering. Stippled or bleached upper foliage or flowers in spring was confirmed by the attack of thrips (plate 1f), *Scirtothrips dorsalis*, often with black frass on injured areas in field which was later confirmed in laboratory through artificial inoculation and subsequent examination of stippled areas with a 10x hand lens which showed that leaf tissue has been scraped away by this pest.

3.4 Root feeders
At some places root feeding termite *Odontotermes obesus* (Rambur) were found active, the first sign of attack being wilting/drying in the young plants followed by the death of the plant. All the termite-damaged plants could be easily pulled out and 98 per cent of them usually contain termites on them. In general the infestation remained very low 1.3 to 4.8 per cent but the maximum damage (8.7%) was seen done during pre-monsoon (May-June) period and minimum (0.4%) during September-October.

3.5 Pest abundance and potential impact
Over the period of study, the resident insect population of *S. obliqia*, *P. solenopsis*, *P. comstocki* and *T. uriticae* exhibited a significant relationship (P<0.05) with plant density with a coefficient of determination, R^2-value, of 76.85, 77.37, 68.83 and 84.78%, respectively Figure 1).

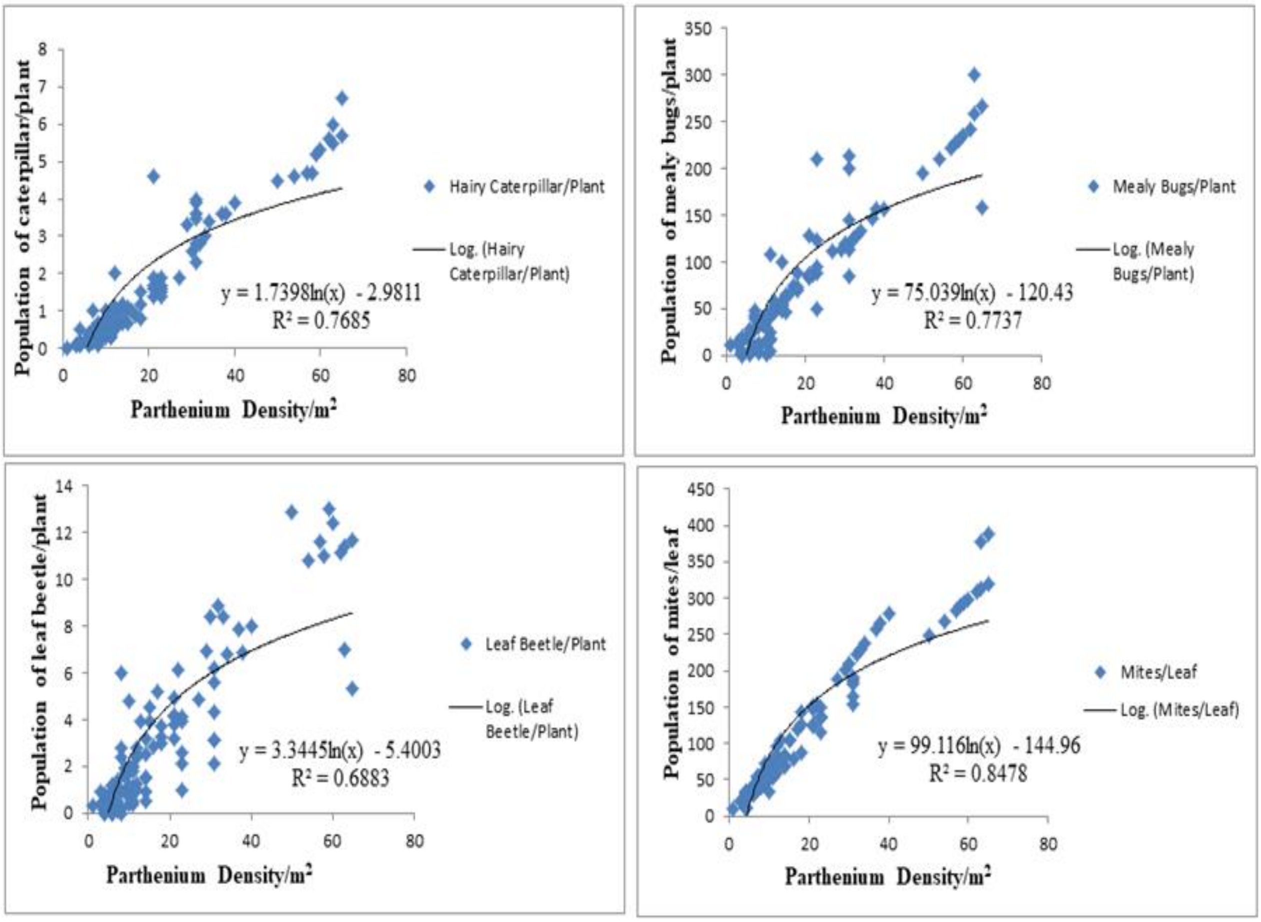


Fig 1: Relationship between the *Parthenium* density with resident population of *S. obliqia*, *P. solenopsis*, *P. comstocki* and *T. uriticae*.

3.6 Yield infestation relationship
Potential impact of major arthropods on this weed revealed that many resident insects can suppress this weed completely. For instance, yield infestation relationship was best explained by log linear equation with highly significant relationship and coefficient of determination exceeding 90.0 per cent in case of all the four major insects (Figure 2).

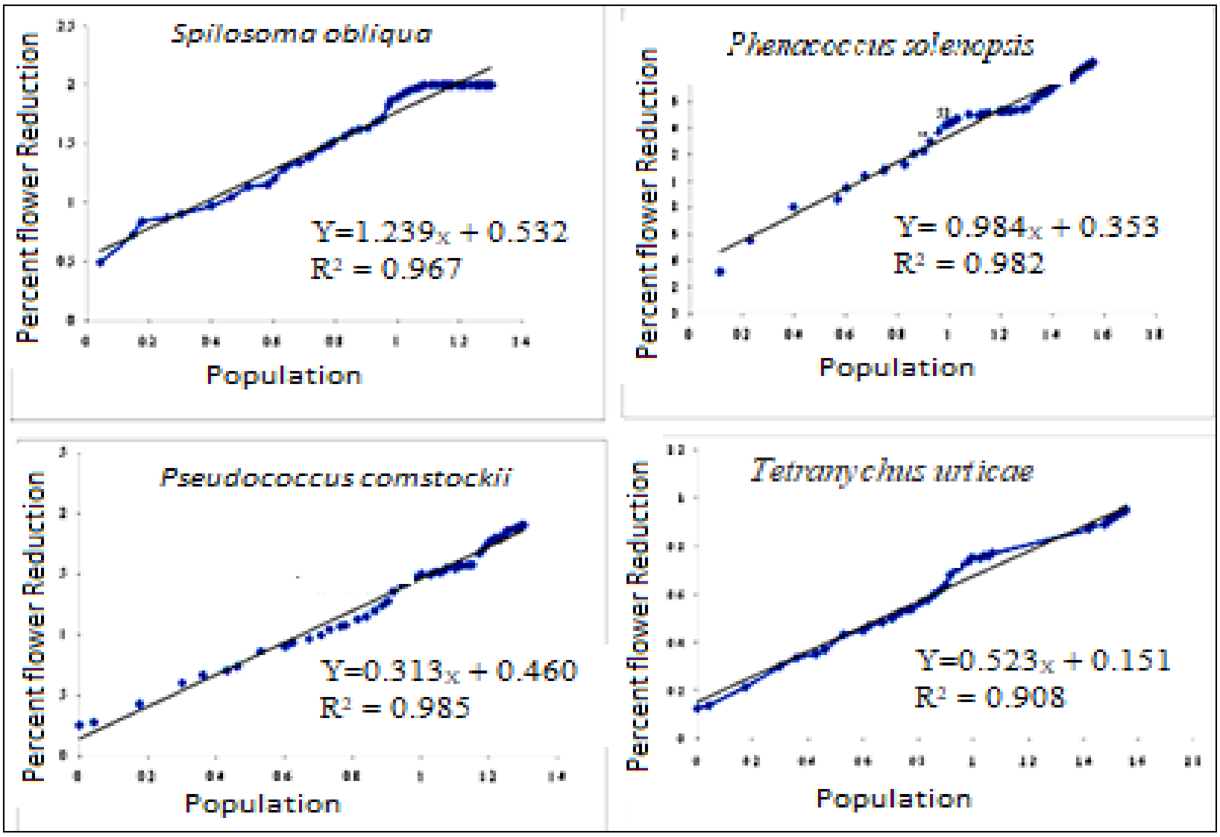


Fig 2: Yield infestation relationship (Log N) of major resident insect on *P. hysterophorus* under cage experimentation. Variable number of insects were released into the cages at peak incidence of each year i.e., (2013-15) and allowed to infest and breed until 90 percent flowering of plant. The Log linear relationship between percent flower reduction over control (with no insect) was plotted against the insect population

With every unit increase in population of *S. obliqia*, *P. solenopsis*, *P comstocki* and *T. uriticae* percent flowers reduction of *Parthenium* decreased to the extent of 1.76, 1.33, 0.77 and 0.77 per cent, respectively.

3.7 Potential impact on plant attributes

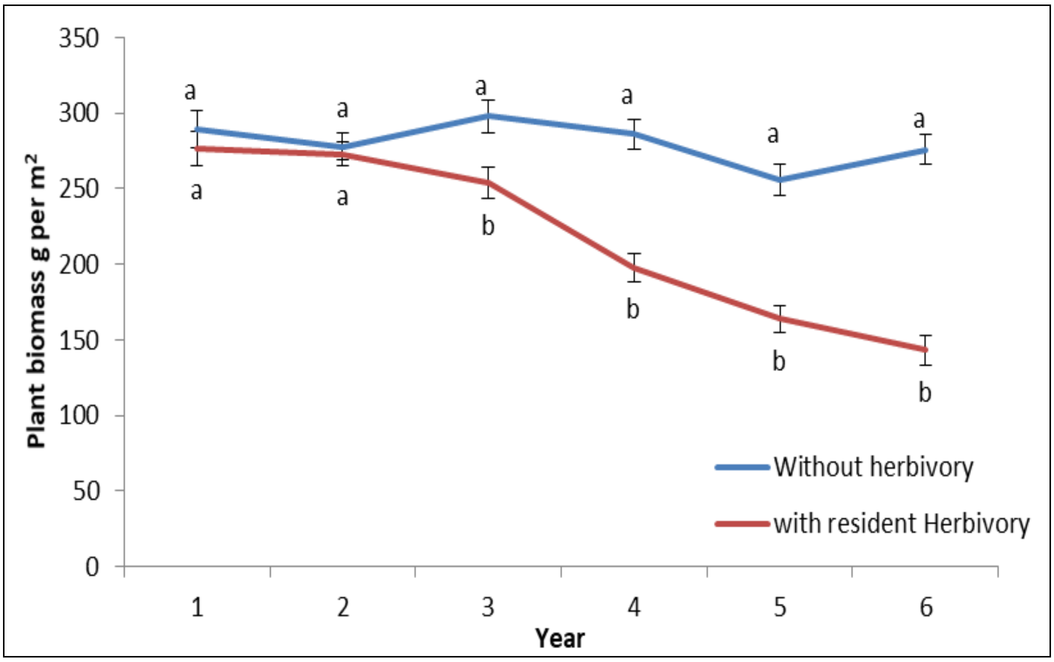
Further under cage experiments (Table 2), it was found that hairy caterpillar have potential to suppress this weed completely when released and maintained at uniform infestation level @ 50 neonates/plant in early stage. Native beetles also showed considerable reduction of *Parthenium* seed bank upto 60% when released @ 5 beetles/plant. In case of sucking pests, an infestation level of 5 aphids/twig could result in > 40% reduction in biomass and reduced seed bank by nearly 78%. More or less similar reduction levels were recorded in case of spider mite released @ 10/plant. However, mealy bugs @ 5 crawlers/plant exhibited complete reduction of the floral and seed bank capacity of *Parthenium* as the plant completely dried before flowering. Termites could only be established on the plants grown in pots supplemented with cellulose materials like cardboard or plant remains. The pest did not survive in plants gown on soil only. In termite infested pots all the plant died before 50% flowering but plant infestation was nearly 60%. Therefore, it was worked out on the basis of field observations which reflected that at an average infestation of about 3 grubs/plant. The potential of biomass reduction could be as high as 40.0% but in infested plants the seed bank reduction could be above 50% (Table 2).

Table 2: Potential impact on plant attributes (mean ± SE) at maturity when uniform population of major insect communities was released and maintained on *P. hysterophorus* in caged plants

Insect	Infestation level	% weight reduction biomass	Flower reduction (%)	Seed bank reduction (%)
Defoliators				
Caterpillar				
Hairy caterpillar, *Spilosoma obliqua* Walker	50 neonates/ plant	78.2 ± 8.6	100 ± 0.0	100 ± 0.0
Beetles				
Leaf eating beetle, *Colasposoma semicostatum*	5 beetle /plant	38.6 ± 5.3	51.3 ± 7.6	60.3 ± 10.2
White spotted leaf beetle, *Monolepta signata*	5 beetle /plant	22.2 ± 4.7	38.3± 7.7	41.2 ± 11.2
Sucking pests				
Aphid, *Rhophalosiphum maidus*	5/ nymphs (5 day old)/ twig	43.5 ± 11.6	73.2± 9.6	78.2 ± 6.7
Mealy bug, *Phenacoccus solenopsis*	5 crawlers/plant	74.3 ± 6.6	100 ± 10.1	100 ± 0.0
Spider mite, *Tetranychus urticae*	10 adult females/ plant	42.2 ± 7.2	43.4± 7.5	70.4 ± 13.5
Root feeder				
Termite, *Odontotermes obesus*	10/ plant	80.6 ± 6.8	100 ± 0.0	100 0.0

3.8 Field trials on resident insect herbivory

The field trial that was conducted under the same conditions over the 5 years (Figure 3) of the study showed that the magnitude of herbivory varied widely among successive years but herbivory by resident insects became significant only in the third years onwards with reduced weed biomass (t = 2.11) and soil seed bank (t = 3.45) when compared to insecticide treated plots (without herbivory). At the end of 5th year, the above-ground biomass of *P. hysterophorus* and soil seed bank through resident insect herbivore was reduced over no herbivore to the magnitude of 57.54 and 36.94 per cent.



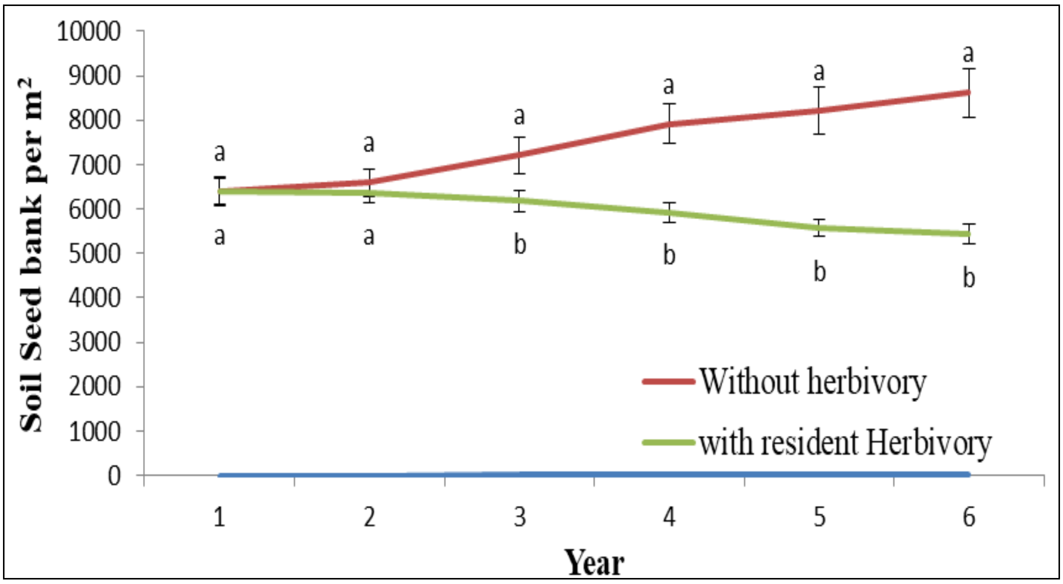


Fig 3: Impact of resident herbivory on the (a) biomass and (b) seed bank (%) of *Parthenium* when exposed to resident insects at for five successive years (2014-18). The bars indicate the standard error of the mean. Paired t test: for each parameter: Within series the means with the same l letter are not significantly different ($P < 0.05$).

All the three major insect's viz., hairy caterpillars, two species of mealybugs and two spotted spider mite complete their life cycle on this weed. Therefore, their developmental and reproductive attributes was compared on different host plants. It was found that hairy caterpillar, *S. oblique* could survive on this weed without any significant reduction in developmental period, pupal weight and fecundity when compared to its crop hosts like castor and mungbean. Similarly, in both the species of mealybugs, the developmental period from immature crawler to adult stage and body weight of females did not vary significantly on either of the three host viz., tomato, brinjal and *Parthenium* (Figure 4). The fitness attributes in term of body weight and fecundity were comparable to these crop hosts. We did not compare the developmental period of spider mites but it was ascertained that its fecundity for 5 days did not show significant variations when they were maintained experimentally on leaves of *Parthenium* and brinjal (Figure 5 and 6). These effects were consistent across the three time periods in which the mites were assayed.

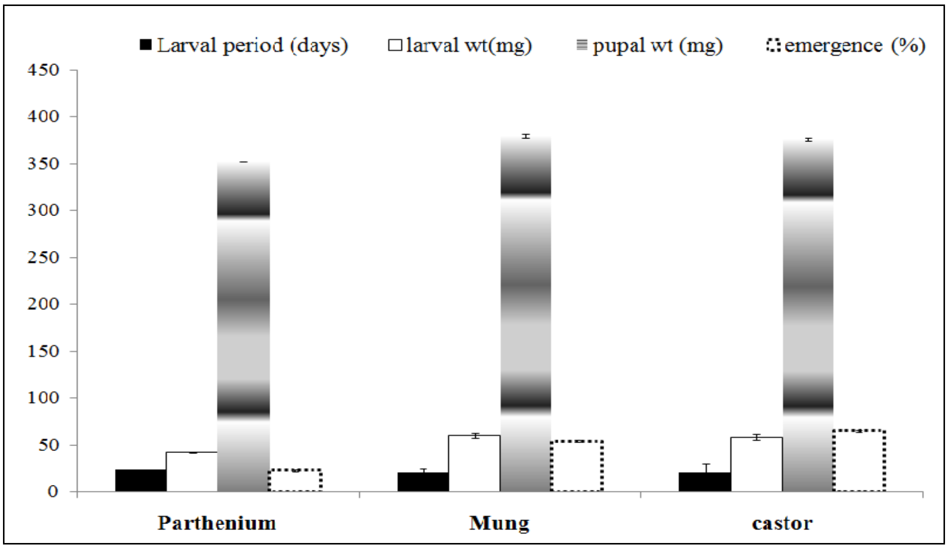


Fig 4: Comparative development of *Spilosoma oblique* on *P. hysterophorus* and other preferred hosts. Mean within a bars are not significantly different (*P*<0.05, Tukey HSDa).

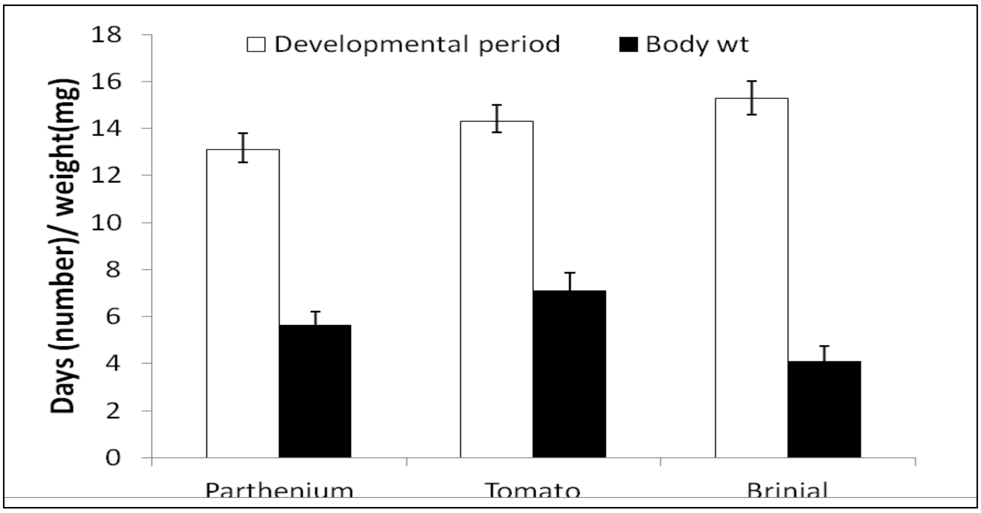


Fig 5: Comparative development period and body weight of female *P. solenopsis* on different host plants. Mean within a bars are not significantly different (*P*<0.05, Tukey HSDa).

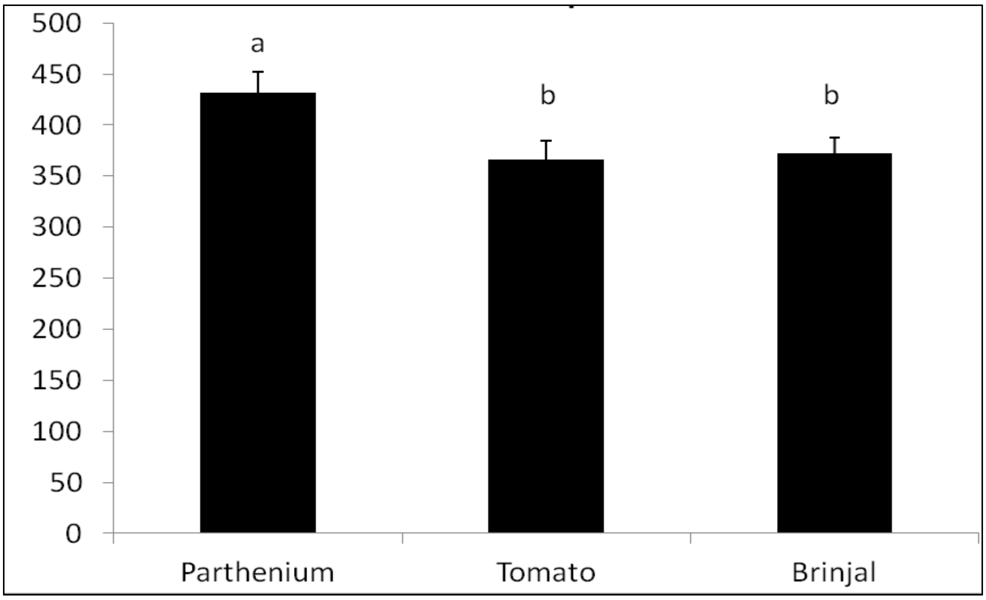


Fig 6: Comparative fecundity of female *P. solenopsis* on different host plants. Mean within a column superscripted by different letters are significantly different (*P*<0.05, Tukey HSDa).

4. Discussions

A large number of herbivores from the pool of resident species, both native and accidentally introduced were found associated with *Parthenium* in India. Initially pre-adaptation might have enabled this weed to find resources, escape from enemies or avoid abiotic perils but with the passage of time (over sixty years), both native herbivores (most impact was by generalists) started recognizing and selectively fed upon this weed that have not been selected to deter these herbivores. However, we are just beginning to appreciate their possible impact but we expect that over the time more herbivore species will get adapted to this weed. These findings suggest that plant invasion can also shift insect interaction and exotic plants can affect herbivores abundance [9]. Mitchell *et al*. (2006) [10] reported that initially the invader plants pass through chance and mortality filters during transport and establishment and may prosper due to ‘‘escape from enemies’’ (e.g.). Consequently, its colonizing a habitat may represent an instantaneous ‘‘niche-creation’’ process wherein invaders plant may have competitive advantages over ecologically similar natives e.g., enemy-free space (biotic communities) and thus become deleteriously invasive. In general, evolution of invasiveness predicts that invasive plants begin to support diverse insect communities similar to those on native plants within 300 years after introduction [11-12]. Even though resident herbivores may initially feed less on introduced host because of the lack of co-evolved relationship [13], but the colonists degree of pre-adaptation may strongly influence how quickly their population grows and the form and strength of their interactions with natives as reported in many invasive weeds like *Opuntia cactus* in Australia, invasive European Silene in North America and soapberry in Australia. The introduction of *Parthenium* weed in India dated back to 1956, such pre adaptions are evident within sixty years of invasiveness. This means that that the evolutionary adaptation and shifting of herbivores, on *Parthenium* is happening faster for some resident insects in India in contrast to that reported elsewhere. We used the term resident as many insect that harbored this plant had already been introduced in India long back. Nonetheless, it was surprising to observe that even though many of these exotic herbivores have recently been introduced in India yet their assemblages on this weed was most noteworthy. We also found a higher proportion of polyphagous arthropods attacking this weed while most of specialized monophagous and oligophagous insect avoided these plants. A high number of sap-sucking species hemipterans were overrepresented compared to other orders. Hemipterans are known to contain more generalist feeders, which could be responsible for the observed differences. Another explanation could be about certain plant defense systems (e.g. bitter glycoside parthenin).

Among the resident herbivores, *S. obliqia, P. solenopsis* and *T. uriticae* were the most frequent to utilize and exploit this weed. Many studies have shown that generalist exotic herbivores are more willing to feed on exotic plants species than are specialists [14-15]. Many of these exotic generalist herbivores have been accidently introduced in our country. For example, *P. solenopsis* has been described originally by Tinsley (1898) [16] in New Mexico, US which later spread Afrotropical, Australasian, Nearctic, Neotropical, and Oriental regions. It is speculated that the pest entered in India in late seventies through import of buying infested cotton from the USA [17]. Its ability to survive and breed on this weed and other multiple host plants remains a future area of concern for crop production, but native range of both herbivore and plant suggest that both the species has coevolved. However, whether this invasiveness could be termed as fortuitous bio-suppression is still debatable. Similarly, plant feeding two-spotted spider mite, *T. uriticae* was originally native only to Eurasia but now has acquired a cosmopolitan distribution. Outbreak of this mite was reported way back in 2000 on brinjal. We assume that spider mites that had adapted to a poor-quality host to escape heavy application of acaricides on main host crop. Such trade-offs in fitness on alternative hosts among herbivorous spider mites is well documented. Potential impact of major arthropods on this weed revealed that many resident insects have potential to suppress this weed completely. For instance, many a times *S. obliqia, P. solenopsis and T. uriticae* exhibited complete reduction of the floral and seed bank capacity of *Parthenium* as the plant completely dried before flowering. Moreover, all the three species completed their life cycle on this weed without any significant reduction in their fitness attribute such as body weight and fecundity.

Although, mean frequency of occurrence of these insects was lower but a stronger relationship between the abundance of four resident herbivores and weed density was established under natural condition. This indicates that as the invasiveness of weed increases there is every likelihood that the population of resident herbivore wills also increases. There is no denying the fact that the impact on of herbivory was not significant in the initial years in the field trial conducted but a significant incremental suppression after 2nd year in above ground biomass and soil seed bank was noticed in each successive year. Therefore, we except that in the coming years the resident herbivores will certainly restrict the invasiveness of this weed. For instance, we quantified the impact of varied population level on flower reduction of this weed and estimated that with every unit increase in population of *S. obliqia, P. solenopsis, P. comstocki* and *T. uriticae* percent flowers reduction of *Parthenium* decreased to the extent of 1.76, 1.33, 0.77 and 0.77 per cent, respectively. This demonstrated effect of herbivory on weed biomass and soil seed bank is crucial to the initial invasion and establishment of this weed.

It is well established that even though native plants are a preferred food for native insects, invasive weeds can benefit them by having an un-limiting foods source. Therefore, increasing species abundance and richness of herbivores that feed on invasive plants may increase with in invaded areas [18]. This increase can be caused by the dwindling native food sources and the abundance of the introduced food source and tendency of some herbivores to feed on the most encountered food source. The increasing number of generalists invading the area therefore had a suppressing effect on *Parthenium*, increasing their healthy growth and affecting their fecundity [19], For example, Lau (2012) [20] showed that as the invasive plant *Medicago* increased, the number of herbivores in the genus *Hypera* and predatory spiders also increased. But it was also found that there was no significant difference in densities of spiders in invaded versus un-invaded areas, suggesting that spiders are feeding on the food source that is nearest and available to them. We assume that declining population of native plants led to shifting behavior of *Colasposoma semicostatum* on this weed from its original host plants mainly *Pinus roxburghii, Vitex negundo* and *Cassia fistula* [21]. Similar behavior was anticipated for *Monolepta signata* Olivier which survive on many host plants growing in vicinity

[22].

Overall, our findings suggested that native and resident insects are now being able to recognize this weed as suitable host and can become important in limiting the *Parthenium* invasion. Resident herbivory also constrained this weed in term of biomass and soil seed bank. The results are of both basic and applied interest and add to our current understanding into the complexity and dynamics of invasion by this weed in India. Although these herbivores cannot be advocated for applied biological control, yet they have potential to regulate this weed in nature in coming years.

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