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Parthenium hysterophorus L. (Asteraceae), of Neotropical origin, is a serious weed of pastures, waste lands and agricultural fields in most parts of India. The allelochemicals produced by the plant prevent germination of local vegetation, due to which the weed grows in pure stands, threatening natural diversity. It also poses serious threat to human health, agriculture and livestock production. Although manual, chemical and competitive displacement methods have been advocated for the control of this weed these have not exerted any influence on the field population of the weed.

Biological control trials were initiated in India with the importation of the host-specific insect Zygorhyncha bicolorata Pallister (Coleoptera : Chrysomelidae) in 1983. Field releases were initiated in 1984, but a clear impact on the weed was apparent only in 1988. The present studies were initiated after population build up of the insect was noticed for the first time in July 1988.

Techniques were first standardized for mass rearing of the insect in the laboratory to meet the requirement of insects needed for experimentation.

Studies on the biology of Z. bicolorata during its normal breeding period in the rainy season showed that the insect completed its development in 27-29 days with the mean
egg, larval and pupal periods lasting for 5, 11.88 and 10.77 days respectively. When the insect was multiplied in the laboratory during winter the developmental period was prolonged to 33-37 days with the mean egg, larval and pupal periods being completed in 6.76, 14.30 and 13.81 days respectively. On the other hand the total duration of development was completed in 20-23 days during the summer months, with mean egg, larval and pupal periods of 4, 9.52 and 8.63 days respectively.

Adults oviposit generally on the ventral leaf surface. The larvae moulted thrice. The first two larval instars feed on terminal and axillary buds. The two later stage larvae, which can be distinguished by their darker spiracles, feed on the peripheral leaves. The full grown larvae burrow into the soil for pupation in small chambers 1-3 cm from the surface.

Both burrowing of mature larvae and emergence of adults from pupal chambers require moist soil. In the absence of moisture freshly formed adults can survive in the hard soil up to 12 days.

Sex ratio (1:0.43) is in favour of females. But males survive longer (122-271 days) compared to females (109-198 days) which, combined with their capacity to mate throughout their lives, ensured successful fertilization of females in the population.
The females laid 1695-3368 (mean 2820.9) eggs over a period of 29 weeks. This is nearly thrice they are reported to lay (836.1) in Mexico. Egg laying attains its peak during the 9th week after emergence.

Mortality was very high in the egg stage and a mean of 54% of the eggs laid by single mated females hatched. Hatchability of eggs was further reduced by multiple mating of the females to a mean of 42%. Single mated adults stopped egg laying after 7 weeks, while repeated mated females continued egg laying throughout their lives.

Even though diapause is obligatory in Z. bicolorata, not more than 72% of the adults collected from the field during November underwent diapause. The non-diapausing adults were unable to breed under field conditions, but could be made to breed in the laboratory. It was therefore possible to establish a continuous laboratory culture. However, continuous laboratory multiplication affected the sex ratio during the cold season. The sex ratio was found to reduce from 38% in June to about 13% during December in laboratory reared insects and to about 1% during the same period after 4 years of continuous laboratory multiplication.

The insects were able to complete their development at temperatures between 15-35 °C. Within this range the rate of development increased with increase in temperature at all
life stages. The rate of acceleration was high up to 25 °C and it decreased above 25 °C.

Of the various life stages adults had the widest range of tolerance for survival (5-40 °C), followed by larvae, pupae, and eggs. They could reproduce effectively between 20-30 °C only. Negligible numbers of eggs were laid at 15 and 40 °C. Egg laying capacity was reduced at 20 °C and continuous exposure to 35 °C terminated oviposition. Eggs laid at 40 °C did not hatch.

Continuous exposure of males to 40 °C for 5 days was found to cause complete sperm inactivation. But the effect was reversible.

High temperature affected survival of diapausing adults within the soil. They could tolerate continuous exposure to 40 °C for up to 10 days. Exposure to 45 °C caused complete mortality within a day.

The insect was found to require 407 day degrees for completion of its development. Based on this it is estimated that 5-6 generations are possible per year depending on time of emergence from diapause, which in turn depends on commencement of rains.

Adults of Z. bicolorata can enter diapause any time between July and December, with the percentage of diapause increasing every generation. They diapause even when
conditions are favourable and food is available. But diapause was possible only once in the life time of the insect. The number undergoing diapause was maximum (72%) in November under field conditions. The percentage of diapause among laboratory reared individuals was lower, i.e., 40%.

The insects defoliate parthenium plants in a given area before they migrate. In every area they leave behind some adults which undergo diapause and emerge during the following year after commencement of rains. This is very significant as the emerged adults can tackle the recurrent growth of the weed.

Freshly emerged adults are incapable of entering diapause without feeding. They diapaused between 30 and 75 days after emergence. Mating is not a prerequisite for diapause. Adults oviposited before, after or both before and after diapause. The life span of diapausing adults was prolonged by as much as 3 times over non-diapausing ones.

Soil moisture was not observed to play a direct role in diapause induction or emergence but was essential for burrowing. Temperature was not observed to play an important role in diapause induction. Diapause emergence took place only after exposure to higher temperatures that prevailed during summer.

Continuous exposure to 30, 35 and 40 °C for 22 days, 9 days and 10 hours respectively from February could induce
emergence within a week. This finding opens up the possibility of multiplication of the beetle during the off season for carrying out releases to tackle the weed growing around irrigated fields, etc.

Glass house studies indicated that 0.2 adult per plant was sufficient to defoliate seedling stage plants in 3 weeks while in the rosette stage 1 adult was required per plant. In the case of flower initiation and flowering stages release of 4 adults are needed for obtaining similar results. Defoliation by the beetle suppressed plant growth and flower production.

When more numbers of adults were released on the seedling stage plants defoliation was caused by the released adults themselves and egg laying was not observed. Reduction in egg numbers was noticed in all growth stages of the weed with increase in leaf damage. Similarly, egg laying was found to reduce with an increase in the number of adults per plant, indicating that oviposition is regulated by the leaf surface area available.

Life table studies showed that infertility of eggs (46-71.10%) was the key mortality factor followed by death during the pupal stage (15.76-21.38%). *Metarhizium anisopliae* infected 0.30-3.56% of the insects during the pupal stage in different generations. More mortality occurred during early larval stage (6.94-13.24%) as compared to later
stages (3.23-6.79%). No parasitoids or predators were recorded on the insect.

Key mortality factor analysis demonstrated that killing power was highest in the egg stage. Construction of survivorship curves showed that mortality acted heavily on the younger stages.

The generation trend index was high (181.51-511.76). Age specific fecundity life table studies showed that the insect has a high biotic potential. A single female can add 688.29 females to the population every generation lasting 79.42 days.

Z. bicolorata caused complete defoliation of P. hysterophorum under field conditions in Bangalore. The time of appearance of the insect, the number of adults per plant and the growth attained by the plant before the insects made their appearance were critical in determining the degree of weed damage. A population of 1 adult per plant was sufficient to bring about complete defoliation of the weed within 6 weeks in the seedling and rosette stage plants and about 8 weeks in the later stage plants. A lower initial population prolonged the time for defoliation while faster defoliation was obtained when more adults were present.

The early stage larvae fed on the terminal and axillary buds affecting plant growth and flower production. Older stage larvae and adults fed on the peripheral leaves
causing defoliation. The insects caused 50-98% reduction in flower production.

The defoliated plants supported a small population of adults, which fed on the emerging buds. The residual adult population prevented regrowth of affected plants, besides suppressing winter generation plants. This resulted in a reduction in weed density during the following year. Reduction in weed density was also aided by an increase in the population of grasses and other local vegetation, which competed with parthenium.

The insects suppressed parthenium even during 1990, when scanty rainfall was received. However, rainfall distribution was important for continued effectiveness of the beetle.

The adults are capable of migrating long distances with the help of prevailing winds. They migrated more in the easterly direction due to the westerly winds during the south west monsoon season. In three years the beetles spread over 10,000 sq km area from an initial area of about 10 ha. Z. bicolorata appears to be an effective biocontrol agent of P. hysterophorus, capable of bringing about permanent reduction in weed density. However, fluctuations are likely to continue for some more years due to the large reservoir of seeds present in soils infested by the weed.
In areas where the insects are only partially effective or have not reached their full potential, selective weedicide applications may be a useful means of bringing down weed densities, so that the insects can act on the low population of weeds present.

Studies with 16 weedicides showed that the different chemicals varied in their toxicity to the insect depending on its life stage. No single chemical was safe to all life stages. All tested chemicals caused mortality to adults emerging from pupae in addition to direct pupal mortality.

Since adults are least affected by the chemicals, application of weedicides to kill overwintering plants between December and May is recommended. Butachlor, alachlor and fluchloridone were the safest among the pre-emergent chemicals tested. Similarly sodium salt of 2,4-D, glyphosate and killer-700 could be recommended for killing the emerged plants, without much adverse effect on the larvae and adults.