Host Suitability Studies of the Moth, *Pyrausta perelegans* Hampson (Lepidoptera: Pyralidae), as a Control Agent of the Forest Weed Banana Poka, *Passiflora mollissima* (HBK) Bailey, in Hawaii

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Abstract. *Passiflora mollissima*, locally known as banana poka, is a cultivated vine native to the higher Andes Mountains of northern South America. Introduced to Hawaii as an ornamental or for its fruit, the plant has escaped cultivation and become the most serious weed in our mountain rain forests. The South American pyralid moth, *Pyrausta perelegans*, was selected as a promising candidate for release in Hawaii as a biological control agent. A detailed study was conducted on its biology and feeding behavior under quarantine conditions in Hawaii. These tests indicate that this insect has closely co-evolved with banana poka and cannot survive and reproduce on any agricultural or native Hawaiian plants or any of the other species of *Passiflora* presently found in Hawaii, including the commercially grown passion flower (*Passiflora edulis*). The results of these tests were submitted to Hawaii Department of Agriculture Plant Quarantine Branch with a request that this insect be approved for release as a biological control agent for *Passiflora mollissima*. Approval was granted by the Board of Agriculture on July 19, 1990 (Permit 11-91-H-4728). Subsequently, colonies of the insect were released on Hawaii in the Olaa Forest near Volcano Village and Laupahoehoe Forest Reserve, at Kula on Maui, and Kokee State Park on Kauai. It is presently confirmed to be established on the islands of Hawaii and Maui.

Keywords: *Passiflora mollissima*, *Pyrausta perelegans*, biological control of weeds, Hawaiian rain forest

The continual existence of the unique native forests of Hawaii is threatened from many different sources, with the invasion by introduced plants being one of the most severe (Gardner and Davis 1982). Of the many species of weeds established in our forests, one of the most damaging and widespread is *Passiflora mollissima* (HBK) Bailey (Warshauer et al., 1983, LaRosa 1984, 1987), commonly called banana poka or banana passion flower. A tendril-bearing, woody, liana (vine), banana poka was native to the rain forests of the higher Andes Mountains of South America and is now extensively cultivated for its large, yellow, edible fruit (Vanderplank 1991).

Introduced as an ornamental, or for its fruit, to the island of Kauai sometime before 1910, banana poka reached the island of Hawaii before 1921 and the island of Maui around 1971 (LaRosa 1984). Once established as an ornamental, it escaped from cultivation and became established in higher elevation, mountain rain forests. Birds and pigs readily feed on its fruit and spread the seeds in their droppings. The juvenile vines rapidly climb native trees to reach the forest canopy, then spread out into the crowns. Impact is wide ranging and pronounced: branches and limbs of mature trees are often broken by the increased weight of the mass of the vines, wind throw during storms is increased due to their larger surface area, and growth is reduced due to shading. The most severe impact, however, is on shrubs and young native trees. In open areas, the rapidly growing vines quickly form thick mats that cover any elevated object and smother or crush small trees and shrubs.

A survey by Warshauer et al. (1983) indicates that the vine is now found on over 20,000 hectares of our forests, of which 5,000 hectares contain plant densities high enough to adversely affect the native forests. No accurate surveys have been made on the rate of banana poka spread in our forests, but under ideal conditions it is estimated at between ¼ and ½ kilometer a year (Personal observation, Kula, Maui).

Conventional control methods, including mechanical weeding, use of herbicides, and even grazing by cattle, can readily control banana poka in limited areas. However, these methods of control are of little use in our native forests due to the size of the areas infested and the impact such control methods have on the native ecosystems we are trying to protect. It is generally agreed that the only feasible method of controlling this weed is through the use of classical biological control (hereinafter “biocontrol”): the locating, testing, introducing, and establishing of its natural enemies (Waage et al., 1981, Gardner and Davis 1982).

Initial efforts at identifying the natural enemies of banana poka began in 1982, when the State of Hawaii Department of Land and Natural Resources sponsored an exploratory trip by USDA Entomologist Robert Pemberton to survey the insects associated with this plant in its native range in South America. After extensively searching in Colombia, Ecuador, and Peru, Pemberton identified over 100 insects that attack either banana poka or closely related species of *Passiflora* (Pemberton 1989). Subsequently, several of the most promising insects were collected and shipped to an insect quarantine facility at Hawaii Volcanoes National Park (hereinafter “HVNP”) for detailed studies.

The first insect to be studied was a medium-sized, metallic blue moth, *Cyanotricha necyria* (Felder and Rogenhofer), the larva of which consume the older leaves of banana poka (Markin and Nagata 1989, Markin et al., 1989). A permit for its release was granted by the State of Hawaii in October 1987, and the insect was released at several locations on the islands of Kauai, Maui, and Hawaii but does not appear to have become established (Campbell et al., 1995).

This report presents the results of a 4-year study on the biology and feeding behavior of a second biocontrol agent, the pyralid moth, *Pyrausta perelegans* Hampson.

Biology

In South America, where banana poka is grown in small plantings around homes and as a commercial crop for local markets (Castanaeda 1956, Martin and Nakasone 1970), the moth *P. perelegans* is an important pest attacking this plant (Chacon and Rojas 1984, Posada et al., 1976). The insect was therefore relatively well known at the beginning of this study, with some information available on its biology (Rojas and Chacon 1982). This information, along with additional observations made during the collection of this insect in South America and rearing colonies of it in quarantine in Hawaii, have given us a fairly complete understanding of the life history of this moth.

The insect is found in the Andes Mountains of Venezuela, Colombia, and Ecuador in the Alto Plano, a vegetation zone between 2,500 and 3,000 m elevation. The area has a cool, moderate climate (10–25^{o}C), with clear, warm mornings and foggy, cool afternoons. The temperature and rainfall are similar to the higher elevations of Hawaii where banana poka is found. The Alto Plano is ideally suited for agriculture and very heavily settled and cultivated. Today the native forest of the area has been eliminated, and no naturally growing wild banana poka plants have been found. *Pyrausta perelegans* used in this study, therefore, were observed or collected on feral and domestic plants.

Eggs are circular in shape but with irregular outlines laid singly on the underside of the banana poka leaves. They are flattened, about 0.5 mm across, and glue tightly to the developing leaf, usually near the growing tip of the shoot. When newly laid, they are whitish, but fertile eggs soon become transparent and almost invisible on the leaf. At ambient outside temperatures in the quarantine facility at HVNP, eggs require 11 days to hatch in summer and 14 days in winter.

Upon hatching, larvae are 1.5 mm in length. Before beginning to feed, most migrate to the tips of the developing shoots on which the eggs were laid. Here in groups of 3 to 5, they begin to mine the growing shoot, eventually killing 2 to 5 cm of the tip. Single larvae may also seek shelter between two touching leaves and begin feeding. The larvae remain in their mines or shelters for approximately two weeks and pass through several molts. When approximately 6 mm long, larvae migrate back along the stem, locating and attacking a developing flower bud. A solitary larva enters the open bracts at the base of the calyx tube and chews a 2 mm opening to gain entrance into the developing flower. After sealing the opening with a layer of silk, the larva completes development inside the flower bud (Fig. 1), consuming the developing stamens and pistils.

During development, larva pass through 5 instars requiring 41 days in summer and 68 days in winter. The first 4 instars are light green, with a slightly brown head capsule and very distinct rows of black pinaculae. The final instar is even lighter green and lacks the black pinaculae. In the HVNP quarantine, feeding on flower buds in a petri dish, larva require 3 to 4 buds to complete development. Several buds are required since they begin to deteriorate before larval feeding is completed. We suspect that on growing plants in the field, the bud remains suitable long enough that a larva might complete its development in a single bud. Feeding destroys the bud and causes it to abort, but not before the mature larvae (length approximately 2 cm) has emerged. If no buds are available, or if all are attacked by other larvae, a larva can also complete development feeding on foliage. The larva usually locates two leaves in contact and uses silk to seal them together and form a feeding chamber.

Pupation occurs in a protected area between adjacent leaves or within a folded leaf where the larva spins an open, net-like cocoon in which it spends 3 to 5 days as a prepupa. Pupa are light brown in color and approximately 1 cm long. Pupation lasts 21 days in summer and 31 days in winter. Total development from egg to adult at ambient summer temperatures at HVNP (elevation 1,100 m) requires 73 days in summer and 113 days in winter. Rojas and Chacon (1982) report that in the field in Colombia, development of the larval and pupal stages requires 116 days at 8.7°C and 75 days at 13.7°C.

The female moth is approximately 12 mm long with a wingspan of 4 cm (Fig. 2). The body is light brown in color and the forewings white with brown margins on the leading edge and a distinct reddish band along the trailing edge. Males are slightly smaller, with a wingspan of 3 cm. Coloration is similar but without the red band on the trailing edge. Mating takes place within one day of emergence, and oviposition begins within 24 hours. A female is capable of laying 150 to 250 eggs within a period of a week or less.

Mining by early instar larvae always kills the vine tip but has little effect on the plant since lateral buds behind the mined area soon develop into new leaders to replace the damaged tip. The main impact of feeding is destruction of the flower buds, which drastically reduces fruit yield in South America. If high population levels develop in Hawaii, the expected impact would not be an immediate decrease in existing stands of banana poka, but a decrease in replacement of plants in infested areas and a slowing of the expansion into new areas.

Figure 1. Fourth instar larva (length 8 mm) of *Pyrausta perelegans* inside calyx tube of a developing bud of its host, *Passiflora mollissima*.

Figure 2. Female of the moth *Pyrausta perelegans* (wingspan approximately 4 cm). Wings are white with brown parallel margins on the leading edge and a narrow red band on the trailing edge.

Materials and Methods

Host Specificity Tests

Pyrausta perelegans pupa collected in the State of Narino in southwestern Colombia near the towns of Pasto and Ipialis were shipped to an approved insect quarantine facility located at 1,200 m at HVNP, island of Hawaii. The facility's internal temperature was maintained within 3^{o}C of ambient outside temperature by constant circulation of filtered outside air. The insects were therefore raised and studied under similar temperature and humidity conditions to which they would be exposed when released in the field. Testing and studies were limited to insects from the first or second laboratory generations.

Pupae were removed from their cocoons and placed in groups of about 20 in open petri dishes in a 50 x 50 x 40 cm glass-topped sleeve cage in which the adults emerged. Adults were fed honey streaked on the glass top of the cage and provided wet dental wicks for moisture. Mating readily took place in the cage, and females laid eggs on bouquets of banana poka foliage. The bouquets were changed every other day. By placing the base of the exposed bouquets in water and covering the rest with a perforated plastic sack, the foliage would remain fresh long enough for the eggs to hatch. To obtain first instar larvae for use in host testing, the eggs were allowed to hatch and the larvae were collected with a camel hair brush as they migrated to the shoot tip.

Preliminary Screening

Initial host testing utilized 5 first instar larvae collected before they had begun feeding. Larvae were placed in 1.5 x 10 cm plastic petri dishes, the bottoms of which were lined with damp tissue paper. Shoot tips or developing leaves of the plant to be tested were then added. At 2- to 3-day intervals, the dishes were examined to determine the number of living larvae and signs of feeding (holes in the plant tissue or frass). Leaves were replaced when they showed signs of wilting. Each test of a different species of plant was replicated 3 times using a total of 15 larvae and parts of 3 different plants. If high mortality occurred from handling during the transfer of the larvae, *i.e.*, if more than 5 of the 15 larvae died within 24 hours, the test was repeated. Each time a series of test plants was set up, an identical check using the same number of larvae in 3 petri dishes but with banana poka shoot tips and foliage was included. The average was one check for every 3 to 7 species of plants tested.

Plants to be tested were selected by several criteria. The first group of plants were 11 of the 20 species of *Passiflora* found in Hawaii (Neal 1965); the next 10 species represented families of plants believed to be phylogenetically related to *Passiflora* (Takhajan 1980); the third group of 22 species included representative of native forest trees and shrubs found growing in areas where banana poka is established; and the fourth group of 40 species included representatives of the major agricultural crops and ornamentals found in Hawaii.

Testing of Passion Flower

In host testing of biocontrol agents, closely related species of plants in the same genera as the target weed are generally found to be most at risk from attack. For banana poka, this group includes the 20 other species of *Passiflora* that are established in Hawaii (Neal 1965). Some feeding on most of these species of *Passiflora* would probably be acceptable since none are native, most being either minor ornamentals or weeds (Haselwood et al., 1983). The exception is the passion flower (*P. edulis* Sims), which is commercially grown on a small scale (approximately 100 acres in 1984 [Anonymous 1985]). As an agricultural plant, it represents the most sensitive plant at risk from the agent we wished to introduce. In the preliminary screening test, feeding was observed on passion flower. The question therefore was: Under natural conditions, if *P. perelegans* selected passion flower for oviposition, would any larvae be able to complete their development and produce adults, thereby completing their life cycle utilizing this potential host?

In an effort to observe feeding behavior and possible development under a situation as close as possible to field conditions, tests were conducted using potted and fully mature passion flower plants containing growing shoot tips, all sizes of leaves, flower buds, and green fruit. The plants were held in a 40 x 50 x 100 cm tall glass and screen cage in the quarantine. Fifty early instar larvae, or 100 eggs ready to hatch, were added and the feeding behavior and development of the larvae observed. This test was replicated 6 times using passion flower plants from different commercial plantings around the islands. Four similar-sized mature banana poka plants in similar cages were set up as a check.

Results

Seventy-two species of plants (other than *Passiflora*) representing 45 families were tested, and the results were all negative. As might be expected of any starving animal, the larvae tasted some of the plants, probably in an effort to identify those that might be edible. No evidence, however, was found of consistent feeding, as would be indicated by the presence of frass. Also, larva showed no growth, and all starved to death in 9 days or less, indicating that these plants were unsuitable hosts. Detailed results of these tests are on file with the Hawaii Department of Agriculture Plant Quarantine Branch in Honolulu (Markin and Nagata 1990).

A different situation occurred when 11 species of *Passiflora* were tested (Table 1). On these species, most larvae quickly starved to death, but a few identified the plant as a possible host and began to feed. Many larvae showed definite growth, but most stopped feeding within 7 to 14 days, although some lived for as long as 8 weeks.

The ability of larvae of *P. perelegans* to feed and develop on passion flower (*P. edulis*) in the preliminary series of tests emphasized the need for a definitive test using larger passion flower plants more typical of those that the insects would encounter in the field. In this test, mature potted passion flower plants containing all stages of leaf development, growing tips, flower buds, and developing fruit were used with approximately 50 early instar larvae added to each plant. Table 2 shows the results of this test. On mature passion flower plants, the behavior of larva was similar to that observed on banana poka. The larvae migrated to the ends of the shoots of the passion flowers and attempted to feed gregariously in the developing tips or constructed shelters between leaves and began to feed. For the first 2 weeks, feeding and growth was comparable to that on banana poka plants. However, by the time the larvae had reached 3 mm in length, feeding and growth definitely began to slow and by the third week, usually stopped. Larvae could be found for 2 additional weeks, indicating they were able to obtain enough moisture and substance from passion flower to stay alive. Of the approximately 400 larvae placed on the mature passion flower plants, most died before reaching 5 mm. Two lived for more than 60 days and reached 12 mm before dying. The plants showed no effect from the feeding, although a few tips were killed and some buds may have been aborted.

By contrast, larvae on the banana poka plants in adjacent cages developed normally and emerged as adults after 57 days. However, low pupation was observed, probably due to the poor quality of the food available. Fifty larvae per cage quickly consumed all new tips, flower buds, and new leaves, so their final development had to be completed on the oldest leaves of the plant, which may have been unsuitable.

Discussion

Banana poka proved to be the natural and primary host of *P. perelegans*. Other than the family Passifloraceae, all plants tested were found to be totally unsuitable as potential hosts

Table 1. Screening tests of *Pyrausta perelegans* on representative species of Hawaiian *Passiflora*.

Plant family and scientific name	Results and observations
Passifloraceae	
Passiflora alata, Dry land	Tasting. No growth. All dead in 9 d.
Passiflora edulis Sims	Light feeding. Growth to 5 mm. All dead in 32 d.
Passiflora foetida L.	Good feeding. Growth to 12 mm. All dead in 41 d.
Passiflora grandilla	Light feeding. Growth to 3.0 mm. All dead in 17 d.
Passiflora liguliaris Juss.	Light feeding. Growth to 3.5 mm. All dead in 11 d.
Passiflora mollissima	Good feeding. 8 pupae in 51 d.
(HBK) Bailey	Good feeding. 9 pupae in 45 d.
	Good feeding. 3 pupae in 42 d.
	Good feeding. 10 pupae in 45 d.
	Good feeding. 12 pupae in 42 d.
	Good feeding. 5 pupae in 51 d.
	Good feeding. 10 pupae in 43 d.
	Good feeding. 10 pupae in 37 d.
	Good feeding. 7 pupae in 37 d.
	Good feeding. 7 pupae in 38 d.
	Good feeding. 5 pupae in 48 d.
	Good feeding. 7 pupae in 44 d.
	Good feeding. 16 pupae in 43 d.
Passiflora pulchella (HBK)	Good feeding but no growth. All dead in 10 d.
Passiflora quadrangularis L.	Tasting. No growth. All dead in 6 d.
Passiflora suberosa L.	Good feeding. Growth to 22 mm. All dead in 56 d.
Passiflora vitifolia (HBK)	Good feeding. Growth to 22 mm. All dead in 56 d.
Passiflora incarnata L.	Good feeding. Growth to 13 mm. All dead in 24 d.
Passiflora subpeltata Ortega	Light feeding. Growth to 2.0 mm. All dead in 12 d.

for this moth. This included the families Caricaceae (papayas) and Violaceae (violets and pansies), believed by taxonomists to be distantly related to the Passifloraceae and the Cucurbitaceae, the family believed to be most closely related to Passifloraceae (Takhajan 1980).

Based on the negative response of *P. perelegans* to the selection of non- *Passiflora* species offered, which included agricultural and ornamental plants as well as native forest species, it was concluded that the release and establishment of *P. perelegans* in Hawaii posed no threat to any of the non-*Passiflora* plants in Hawaii.

The release of *P. perelegans* might pose a very small threat to 20 species of *Passiflora* in Hawaii (Neal 1965). All these species have been introduced, either for ornamentals (the plants bear showy flowers) or for their fruit. Several species, including *Passiflora foetida* L., *P. putchella* HBK, *P. suberosa* L., *P. laurifolia* L., and *P. subpeltata* Ortega, have escaped from cultivation and are now considered weeds (Haselwood *et al.*, 1983). Ten of the most common species of *Passiflora* in Hawaii were included in this host test (Table 1). As expected, being closely related to banana poka, *P. perelegans* responded more positively to them than other species of plants.

Table 2. Feeding test of *Pyrausta perelegans* on passion flower. Plants used were mature and contained growing tips, all sizes of leaves as well as flower buds and developing fruit. Plants were in 11-liter plastic pots and held in 40 x 50 x 100 cm cages.

Plant family, scientific name	Common name	Test no.	Larvae no./size	Results and comments
Passifloraceae				
Passiflora mollissima (HBK) Bailey	Banana poka	1	50/1st instars	16 pupae @ 32 d
		2	50/1st instars	29 pupae @ 32 d
		3	100 eggs, >50% hatch	8 pupae @ 38 d
		4	100 eggs, >50% hatch	5 pupae @ 38 d
Passiflora edulis Sims	Commercial passion flower	1	42/1st instars	Some tip feeding. Maximum size 3 mm. No sign of larvae after d 18.
		2	50/1st and 2nd	Light feeding on leaves. 2 larvae grew to 12 mm by d 60. Dead by d 65.
		3	100 eggs, >50% hatch	No feeding. No larvae seen after d 7.
		4	100 eggs, >50% hatch	No feeding. No larvae seen after d 7.
		5	53/1.5–3 mm	2 tips mining. Maximum size 4 mm. No larvae seen after d 21.
		6	50/1.5–3 mm	1 tip mining. Maximum size 4 mm. No larvae seen after d 21.

Larvae forced to feed on these species showed growth, indicating that the larvae could utilize them as a food source, but larval development took considerably longer than on banana poka and none developed into pupae. Feeding and development on these species of *Passiflora* occurred when the larvae were offered only small portions of the plant in a petri dish, a totally unnatural feeding situation, and it is unlikely that similar attacks on these *Passiflora* in the field would occur.

The response of *P. perelegans* to the agriculturally important passion flower, *P. edulis*, was the same as its response to the other species of *Passiflora*. Larvae attempted to feed but showed little growth or development.

The chance that *P. perelegans* encountering passion flowers and attempting to use them as a potential host is reduced by the geographic isolation between banana poka from most other *Passiflora* species in Hawaii. Banana poka is found at an elevation of 900 to 2,100 m, while passion flower and most other ornamental species are located in a zone ranging from sea level to 300 m. It is therefore unlikely that these other species will normally be exposed to *P. perelegans*.

Still, a scenario could occur in which *P. perelegans* females could be blown downslope from banana poke areas to the coastal zone where passion flower is grown. A female *P. perelegans*, finding no banana poka, could lay eggs on passion flower, and resulting larvae would attempt to feed. However, the evidence obtained from this study indicates that the larvae would not be able to complete their development and that it would be impossible for passion flower to support a permanent population.

Based on the results of these studies, a request for permission to import and release *P. perelegans* in Hawaii was submitted to the Plant Quarantine Branch of the Hawaii Department of Agriculture (hereinafter HDOA). The permit was approved and issued on November 20, 1990 (Permit 11-91-H-4728). Colonies of this insect were removed from quarantine and released in the Olaa Forest near Volcano Village and the Laupahoehoe Forest on the island of Hawaii in early 1991. Additional colonies were released in the summer of 1991 at Kokee State on the island of Kauai and the Kula area of Maui. Monitoring of the release sites and the surrounding area through June 1994 failed to detect establishment at Kokee. Populations at Olaa, Kula, and Laupahoehoe have been found but at low levels: usually less than one *P. mollissima* bud in every 100 is attacked. *Pyrausta perelegans* has therefore been declared established in Hawaii (Campbell et al., 1995), although its population is too low to have any effect on banana poka at this time.

Taxonomic Identification

The identification of *P. perelegans* used in these tests and released in Hawaii was based on specimens collected near Pasto and Ipialis in Colombia, and Merida in Venezuela, South America, and submitted to the Biosystematics and Beneficial Insects Institute of Beltsville, Maryland, USDA Agricultural Research Service. Actual identification was done by the cooperating entomologist, A. Solis, of the University of Maryland. Specimens were retained by the USDA Insect Identification Branch. Once approval for release was received, additional specimens were deposited in the collections of the HDOA, Hilo Office; the HDOA main office in Honolulu; the University of Hawaii's Department of Entomology, Manoa; and the Bishop Museum. There is occasionally some confusion over the identification of the Hawaiian form of banana poka. We have followed the two most recent published taxonomic reviews of the subject (LaRosa 1987, Vanderplank 1991) and retained the name *P. mollissima*.

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