REVIEW ARTICLE

The sugarcane lophopid planthopper *Pyrilla perpusilla* (Homoptera: Lophopidae): a review of its biology, pest status and control

N.C. Kumarasinghe
Division of Pest Management, Sugarcane Research Institute, Uda Walawe, Sri Lanka

S.D. Wratten
Department of Entomology and Animal Ecology, Lincoln University, Canterbury, New Zealand

Abstract

The biology, damage and control of the sugarcane pest *Pyrilla perpusilla* Walker are reviewed. The present systematic position, distribution and the range of alternative host plants are surveyed and the life cycle and the extent of damage caused by the pest are considered in detail. The factors influencing the abundance of the insect are discussed, with emphasis on their use in reducing the population of the pest. Much of the published data in this area is based on un replicated observations. However, potential biological control agents for the insect are evaluated with special reference to the most effective nymphal and adult ‘parasitoid’, the moth *Epiricania melanoleuca* (Fletcher). Many other potential biological control agents have received some study, but in most cases, little more than basic biological information on phenology and life cycle has been published. As considerable changes in chemical control practices over the past fifty years have occurred, these, together with other control methods such as agronomic, mechanical, cultural and host plant resistance approaches are discussed along with prospects for the future, sustainable control of the pest. Research areas which are in need of more work are identified; these are biological control and cultural practices. It is suggested that an integrated approach to future research should be made, incorporating at least host-plant resistance and predation.

Introduction

The sugarcane lophopid planthopper *Pyrilla perpusilla* Walker (Hemiptera: Auchenorrhyncha: Lophopidae) is a serious pest of sugarcane in the Oriental region but it has also been recorded as a pest of other crops such as wheat, maize and millet. Although this species has been described as a leaffopper by many authors in the past, the current acceptable usage restricts 'leaffoppers' to Cicadellidae and 'planthoppers' to Fulgoridae. As the term 'planthopper' has commonly been used in the past for another sugarcane pest, the delphacid *Perkinsiella saccharicida* Kirkaldy,
In this review, *Pyrilla perpusilla* will be used to describe *P. perpusilla*. This direct and indirect damage affects sugar yield and quality (Butani, 1964; Bindra & Brar, 1978; Asre et al., 1983). Losses ranging from 2–34% in sucrose content of the cane and from 3–26% in the purity of the sugar have been recorded in a large number of papers since 1940, most of which have occurred in regional journals of the Indian sub-continent, which are rarely available internationally. Many of the papers have been un-refereed 'short notes', therefore the publications referred to in this review are mainly the larger, more substantial contributions to the subject.

Up to 28% of potential yield has been lost due to this pest and poor growth of seed sets and difficulties in milling cane from affected plants have also been recorded. However, despite the high economic importance of *P. perpusilla*, no review has been published apart from that of Butani (1964) which appeared in an Indian journal which is not widely available. This paper concentrates on work done over the last fifty years on the biology and pest status of this pest.

**Morphology and systematic position**

Box (1953) listed over 300 Auchenorrhyncha species associated with sugarcane. Half of these are in the 12 families of the Fulgoroidea: Cixiidae (14), Delphacidae (53), Meenopidae (1), Derbidae (45), Dictyopharidae (9), Achilidae (1), Tropiduchidae (3), Issidae (2), Nogodinidae (4), Flatidae (4), Ricanidae (4) and Lophidodeae (12). These Fulgoroidea species include the well-known delphacid sugarcane pest *Perkinsiella saccharicida* Kirkaldy in the Oriental and Pacific regions. *Pyrilla perpusilla* is the only pest species of any importance in the Lophidodeae. However, *Numicia viridis* Muir in the family Tropiduchidae has been recorded from sugarcane in South Africa.

Fennah (1963) reviewed all the species of the genus *Pyrilla* occurring in India and Sri Lanka and described the distinguishing characters of the various sub-species. He suggested that there were two polytypical species present, namely *P. perpusilla* (Walker), widespread in India, Sri Lanka and Thailand and *P. aberrans* (Kirby) occurring in Sri Lanka and South India. He described ten geographical sub-species of *P. perpusilla*. These are: *P. p. perpusilla* (Walker), *P. p. psarana* (Distant), *P. p. coimbatorensis* Fennah, *P. p. chaika-bailupurana* Fennah, *P. p. tekkaduana* Fennah, *P. p. naraikaduana* Fennah, *P. p. dhimbami Fennah*, *P. p. pirmadana* Fennah, *P. p. singhalensis* Fennah, *P. p. lycoides* (Walker) and five geographical sub-species of *P. p. aberrans*; *P. a. aberrans* Kirby, *P. a. palghati* Fennah, *P. a. consors* Fennah, *P. a. comes* Fennah, *P. a. achatensis* Fennah. There was no indication of any difference in pest status in different areas attributable to the different sub-species, but there were records of a few sub-species of *P. perpusilla* which were restricted to some areas of the region. Examples are: *P. p. coimbatorensis* in Andhra Pradesh (Srinath & Patel, 1968). *P. p. perpusilla* in Maharashtra (Mogal et al., 1983; Raiput et al., 1985) and *P. p. singhalensis* in Sri Lanka (Kumarasinghe & Ranasinghe, 1985, 1988). However, although Fennah (1963) reported the presence of *P. aberrans* in South India and Sri Lanka, there were no further reports of its occurrence in Sri Lanka except that by Rajendra (1979). As it has not subsequently been found in Sri Lanka (N.C. Kumarasinghe, unpublished) there are doubts about the validity of the Fennah and Rajendra records.

Adult *P. perpusilla* is a pale tawny-yellow soft-bodied insect with the head prominently drawn forward. Wingspan varies from 16–18 mm and 19–21 mm for males and females, respectively. Females lay white to greenish yellow eggs which are 0.9–1.0 mm long and 0.45–0.64 mm wide. Newly emerged nymphs are 0.8–1.0 mm long and milky white in colour and pass through five instars to reach maturity. Each nymphal instar bears characteristic anal filaments which are slightly longer than the body. Recent morphological and physiological studies on *P. perpusilla* included oocyte maturation (Krishnanandam & Ramamurthy, 1971), work on the symbiont bacterium *Klebsiella* spp. in the mycetomes (Khan, 1977) and a detailed morphological description of the different stages (Gupta & Ahmad, 1983).

**Distribution**

*Pyrilla perpusilla* has been recorded from many parts of Asia since 1903. Cotterell (1954) reported localized severe outbreaks of the pest in the eastern province of Afghanistan and it has also occurred in Bangladesh (Fennah, 1963; Miah et al., 1986; Dean, 1979). The species has occurred throughout India, sometimes at epidemic levels (e.g. Stebbing, 1903; Rahman & Nath, 1940; Dhalwai & Bains, 1985). In Nepal, Neupane (1976) reported the pest from six districts, while in Pakistan, it has been recorded from most of the country (e.g. Sheikh 1968; Rahim, 1989a, b). In Sri Lanka, the species has been recorded from the Eastern and South Central provinces (Kumarasinghe & Ranasinghe, 1985, 1988, respectively).

*Pyrilla perpusilla* also occurs elsewhere in Asia such as Burma, Indo-China, Thailand (Fennah, 1963) and in Cambodia, Indonesia, Laos and Vietnam (Varma, 1986).

**Alternative hosts**

The original host of *P. perpusilla* is unknown and it has been recorded feeding and/or reproducing on a wide range of plants other than sugarcane. In India, Nepal and Pakistan *P. perpusilla* has been recorded as feeding on the following plants. Gramineae: *Andropogon sorghum*, *Avena sativa*, *Bambusa arundinacea*, *Hordeum vulgare*, *Oryza sativa*, *Panicum colonum*, *Pennisetum typhoideum*, *Saccharum spontaneum*, *Sorghum bicolor*, *Sorghum halepense*, *Triticum sativum*, *Zea mays*, *Leguminosae*: *Cicer arietinum*, *Mucuna alba*, *Melilotus parviflora*, *Psoralea sativa*, *Moraceae*: *Ficus religiosa*. Key references, from a large number which give incidental information on host plants, are Butani, 1964; Khan & Khan, 1966; Williams et al., 1969; Chaudhary et al., 1987; Chaudhary & Ansari, 1988; Popahly & Marwaha, 1988; Chaudhary & Sharma, 1990.

Egg masses of *P. perpusilla* have been collected on peas (*Pisum sativum*) and bamboo (*Bambusa arundinacea*) (Fletcher & Ghosh, 1919) and Gupta & Avasthy (1954a) reported maize (*Zea mays*), sorghum (*Sorghum spp.*), and pearl millet (*Pennisetum americanum*) as breeding places for *P. perpusilla* during the pre-monsoon period in the Punjab. Sinha et al. (1974) found the insect and its egg masses on oats (*Avena*...
fatua), barley (Hordeum vulgare), and maize, while P. perpusilla has also been observed breeding on rice (Oryza sativa) in Haryana, India (Pawar, 1981). Although a wide host range makes control more difficult, some workers have used maize and wheat to culture the insect in laboratories for experimental purposes (N.C. Kumarsinghe, unpublished). Eggs of P. perpusilla have been found in cracks under the bark of Melia indica (neem), Mangifera indica (mango), Sissu sp. and Acaia indica where these trees adjoined heavily infested fields (Wajih & Hamid, 1983). However, during heavy outbreaks, egg masses are laid indiscriminately on whichever plants are available near the sugarcane fields (Gupta & Avasthy, 1954a).

Biology and behaviour

The biology and the behaviour of P. perpusilla were first described by Fletcher (1914) in Bihar, India. A large number of workers have recorded basic biological data on P. perpusilla, but many studies are incomplete and of little general applicability. For instance, studies of the insect's development rate have been made under semi-controlled temperature conditions and humidities (sometimes without the temperature/humidity range being given) and the sugarcane cultivar used is often not stated (e.g. Gupta & Ahmad, 1983; Dhaliwal et al. 1987). The most useful original references covering biology are: Rahman 1940; Khan, & Khan 1966 and Madan, 1985; while Gupta & Ahmad (1983) and Dhaliwal et al. (1987) should also be consulted, but the above caveats should be borne in mind. From these and other minor references, the insect's bionomics can be summarized. The adult life span varies from 14–200 days and females live for a slightly longer period than males. The female has a pre-copulation period of about 11 days, copulation takes place during the day and is complete within two hours. Generally the female takes 45–60 minutes for a single oviposition after a pre-oviposition period of 3–47 days, depending on the season and climatic conditions. Between two and 25 days can occur between successive ovipositions. Eggs are laid during the day, on the abaxial surface of the leaves along the midrib. They are deposited in four to five rows and are covered with a waxy thread-like material secreted by the female. During the winter, eggs are laid on the inside of the base of the leaf sheath, giving some protection from adverse climatic conditions. The female usually uses a lower, shady, concealed site for oviposition. In winter, females lay eggs between the stalks and the dried leaf sheaths. Twenty to fifty eggs are laid at a time, with a life-time fecundity of 37–680. The incubation period varies with season and ranges from 6–30 days. Pyrilla perpusilla has five nymphal instars, each occupying 7–41 days with a maximum total nymphal period of 134 days, although Rajak et al. (1987) recorded six nymphal instars in north India. The ideal temperature for nymphal development seems to be c. 30°C, with a RH of c. 80% (Gupta & Ahmad, 1983). There are three to four generations of the insect in India and Pakistan.

Laboratory rearing

Gupta & Ahmad (1979) studied the effect of refrigeration on the eggs of P. perpusilla and found that those at an advanced stage (72–120 h) can be stored at 6–8°C, but 24–48-hour-old eggs cannot be refrigerated. A temperature range of 15–17.5°C was the optimum for the storage of P. perpusilla eggs for a maximum period of 15 days (Yadav, 1983). Eggs within 10 days of storage gave the highest hatching rate.

Dhaliwal & Bains (1983a) developed a technique to culture P. perpusilla on cut sugarcane leaves. They used a plastic tube containing cut sugarcane pieces on which the insects fed. The tube was sealed with cotton wool and sunk into wet sand. Chaudhary & Sharma (1988) developed a technique using glass jars. This was a simple design and involved the use of an additional artificial diet as well as sugarcane leaves. The bottom of the jar contained moist sand into which cut cane leaves were inserted. An additional diet of a 5% solution of sugar and 'protinules' (a source of food with protein) was placed on a sponge in a Petri dish in the jar. The leaves were changed at 5–7-day intervals and the diet was changed every second or third day. No information was given as to the relative use made by the insects of the plant and the diet mixture; in a paper a year earlier which used a range of diets, the fecundity of P. perpusilla was highest on a diet containing 2.5% sugar and 2.5% 'protinules' but the insects did not survive on the diet without cane leaves (Madan et al., 1987).

In culture in the UK, sugarcane plants grown from sets were planted in John Innes No. 2 compost and the insect was maintained satisfactorily at 26–28°C in ventilated Perspex boxes in a culture room based on the design of Scopes et al. (1975) (Kumarsinghe & Wratten, 1993).

Effect of the abiotic environment

Although climatic conditions are likely to play an important role in the population dynamics of the pest, much of the literature is anecdotal rather than experimental. For instance, Rahman & Nath (1940), Narayanan (1953), Gupta (1948), Gupta & Avasthy (1954b, 1959), Avasthy (1973) and Varma (1986) recorded seasonal population changes of the pest in north India, where it had to overcome unfavourable conditions twice a year, but the causes of population change are rarely analysed. The overwintered nymphs became adults by the middle of March and oviposition began in April. The pest reproduced rapidly during the month of April and in the first two weeks of May. The migration of nymphs and adults to the newly planted crop occurred in June. However, a large number of nymphs and adults left the crop during this month when the temperature was above 41°C. The few insects remaining deposited eggs in July and the migration of P. perpusilla to newly-planted crops also took place at this time. The intensity of attack was generally heavy in September and October. In November and December adults died due to low temperatures (below 9.4°C) (Williams et al., 1969). The cycle was continued by the overwintering nymphs which developed into adults during the month of March. Khan & Khan (1966), Wajih & Hamid (1983) and Mohyuddin & Hamid (1987) reported a similar pattern of seasonal changes of populations in Pakistan. The nymphs migrated to wheat (Triticum aestivum), barley, oats and clover (Trifolium repens) from December onwards where they moulted to the adult stage in April. There were two peaks of populations, in May and November, respectively. In Sri Lanka, where there are only minor seasonal changes in temperature, two population peaks were observed, just before the two monsoon rainy seasons (Kumarsinghe & Ranasinghe, 1988).
There are conflicting opinions in the literature on the effect of dry periods or high humidity on the pest; views are often given on the role of these factors based on field observations, with no experimental control of variables. For instance, workers from Mathur (1941) to Patil & Hapase (1992) considered low humidities to lead to high pest populations, while a range of papers covering a similar period (Gupta, 1948 to Rajak et al., 1987) came to the opposite conclusion.

Similar conflicting anecdotal information concerns the effect of rain, with work from the 1950s (Singh & Kalra, 1951) to the 1980s (Kumarasinghe & Ranasinghe, 1988) considering heavy rain to reduce populations while Khan & Khan (1966) thought the opposite. Hot, dry winds during summer have reduced numbers of *P. perpusilla* in India (Rajak et al., 1987) and in Pakistan (Khan & Khan, 1966), and high winds in Sri Lanka have led to widespread dispersal of the insect (Kumarasinghe & Ranasinghe, 1988).

In terms of ranking biotic and non-biotic factors, Brar & Bains (1979) and Bains et al. (1982) suggested that temperatures above 43°C acted as an important mortality factor in the first generation but that adult migration and natural enemies were the main mortalities in the second and third generations. In the fourth, the most important mortality factors were considered to be reduced fecundity due to the parasitoid *Epiricenia melanoleuca* (Fletcher) (Lepidoptera: Epiprypidae) and the effect of low temperature (see under Biological control). The analyses of Brar & Bains (1979) which led to some of these conclusions were based on the calculation of 'k'-values (Varley & Gradwell, 1970), which are proportional mortality rates calculated by subtracting the logarithm of the numbers of an organism after a mortality has acted from the logarithm of the numbers before its action. They can be used to detect density dependence, potential population regulation and the causes of population fluctuations. However, this k-factor analysis requires certain rigorous biological and statistical criteria to be met (Putman & Wratten, 1984). It was not clear, for instance from the Brar & Bains work whether these criteria were in fact satisfied. Also, although k-values were calculated, they were not used to detect density dependence or fluctuation causes, but were merely ranked. It was suggested that the highest was the 'key factor' causing population change, but this was not justified. The paper is useful in that it is one of the few on *P. perpusilla* which attempts to quantify population changes, but it does not fully pursue this and its conclusions are not justified, for the reasons given above. The work of Bains et al. (1982) comprised fitting a polynomial regression of the insect's population size against temperatures in the range 34–44°C. The paper suggested that this curvilinear relationship could be used in pest forecasting. However, the regression model was based on only eight points, the graphical representation appeared to have been extrapolated beyond the data range, and no suggestions were given as to how the information could in fact be used for pest forecasting.

The role of non-climatic conditions such as fertilizer, irrigation, lodging and growth form of the crop have been implicated in the population development of the pest, but these have generally been derived from field observations without controls (e.g. Mathur, 1941; Gupta, 1948; Gupta et al., 1971; Avasthy, 1973).

**Approaches to control**

**Agronomic control**

Khan & Khan (1966) and Mohyuddin & Hamid (1987) described the use of agronomic methods to control the pest in Pakistan. Changing sowing and harvesting dates could reduce the effects of the pest by exploiting its phenology, and the burning of trash also had a beneficial effect on pest control. However, Mohyuddin & Hamid (1987) considered that, in the absence of burning, populations of the parasitoid *Panachroctosarhis jovines* Girault (Hymenoptera: Eulophidae) developed earlier and stopped the pest's population growth before it caused yield losses. There is an obvious, though not quantified, trade-off between these two effects of burning. Joshi & Sharma (1989) controlled the pest successfully by distributing sugarcane trash with cocoons of *E. melanoleuca* in the harvested fields. This 'seeded' the field with the natural enemy for the next season's crop. However, Khan & Khan (1966) showed that the practice of ratooning (continuing with three or four generations of the crop) greatly increased the pest populations, as the crop became a more or less continuous host for the pest. In contrast, however, crop rotation had no observed effect on pest control.

**Biological control — parasitoids**

Initial attempts from the 1920s to the 1940s to identify the parasitoids of *P. perpusilla* have been exploited more recently for use in attempts at integrated pest management programmes.

*Pyrilla perpusilla* is attacked by sixteen species of natural enemy in India (Butani, 1972). Chaudhary & Sharma (1988) demonstrated that no insecticidal control was carried out in the ten-year period before 1988 in Haryana, India, as about 80% of the *P. perpusilla* population was killed by egg parasitoids and the remaining 20% by a complex of nymphal adult parasitoids and predators. Their conclusion, that natural enemies can be important for this pest, was supported by Bindra & Bar (1978), who described the inter-relationship of five species of parasitoids and seven species of predators in controlling *P. perpusilla* in Punjab, India. Table 1 summarizes the parasitoids, predators and pathogens which have been recorded attacking *P. perpusilla*.

Of the egg parasitoids (table 1), the encyrtid hymenopteran, *Chelomorpus pyrillae* Mani, was first reported by Mani (1939) from Delhi. It was present in the Punjab in 1960–1981 (Dhaliwal & Bains, 1983b) and was recorded from Delhi, Haryana, Punjab and Uttar Pradesh by Rajak et al. (1987). In India, the parasitoid is active from December to January (Narayanan & Kundanlal, 1953) and from August to December (Asre et al., 1983). Although several publications refer to this parasitoid's basic biology, longevity, fecundity, etc. (Chaudhary & Sharma, 1986; Yadav & Chaudhary, 1986, 1988), there appears to have been little quantification of the parasitoid's effects on the host's population.

Another encyrtid, *Ooencyrtus pyrillae* (Mani), was also first reported by Mani (1939) from India. Some authors refer to this species as *Ageniaspis pyrillae* Mani while Subba Rao (1979) incorrectly synonymized it with *Ooencyrtus papillonis* Ashmead. This parasitoid has been recorded throughout India. It showed maximum activity from September to...
Table 1. Parasitoids, predators and pathogens of Pyrilla perpusilla.

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<th>Parasitoids</th>
<th>Predators</th>
<th>Pathogens</th>
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<td><strong>Egg parasitoids</strong></td>
<td><strong>Coleoptera</strong></td>
<td><strong>Asparagus flavus</strong> Link</td>
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<td>Hymenoptera: Encyrtidae</td>
<td>Coccinellidae</td>
<td>Fusarium sp.</td>
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<td>Cleptommus pyrillae Mani</td>
<td>Coccinellidae</td>
<td>Heterodera sp.</td>
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<tr>
<td>Ooencyrtus pyrillae (Mani)</td>
<td>Coccinellidae</td>
<td>Heterodera sp.</td>
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<td>Proleuroceroides pyrillae Shafee, Alam &amp; Agarwal</td>
<td>Coccinellidae</td>
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<td>Parachrysocharis javensis Girault</td>
<td>Coccinellidae</td>
<td>Heterodera sp.</td>
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<tr>
<td>Tetrastichus gali Gholap &amp; Chandle</td>
<td>Coccinellidae</td>
<td>Heterodera sp.</td>
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<td>Hymenoptera: Eulophidae</td>
<td>Coccinellidae</td>
<td>Heterodera sp.</td>
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<td><strong>Nymphal parasitoids</strong></td>
<td><strong>Coleoptera</strong></td>
<td><strong>Mesorhizobium anisopliae</strong> Metschnikoff (Sorokin)</td>
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<td>Neuroptera: Coniopterygidae</td>
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<td><strong>Predators</strong></td>
<td><strong>Neuroptera</strong></td>
<td><strong>Macrophomina phaseolina</strong> (Dixon)</td>
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<td>Coleoptera: Coccinellidae</td>
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The third encyrtid parasitoid in table 1, Proleuroceroides pyrillae Shafee, Alam & Agarwal was first recorded from India and Pakistan in the 1980s (Mohyuddin et al., 1982; Gholap & Chandle, 1985) but no substantive biological data are available.

Parachrysocharis javensis Girault is a eulophid parasitoid previously known as Tetrastichus pyrillae Crawford until recently by most authors, while Khan & Shafee (1979) identified it as Synonymorphus sulaposensis Khan & Shafee. The earliest record was from India (Mani, 1939). Workers in Pakistan (Mohyuddin et al., 1982; Sri Lanka (Rajendra, 1979) and Bangladesh (Miah et al., 1986) considered it to be an important biocontrol agent, but few experimental data exist. Kalra (1973) recorded a high level of parasitism when P. perpusilla populations were high. In this study, percentage parasitism was very low during September–October as the eggs of P. perpusilla are mostly laid in the leaf sheath of the plant at that time, where they are thought to be partly protected. In the laboratory, Brar & Bains (1981) showed that P. javensis ‘preferred’ freshly laid to three-day-old eggs for oviposition; seven-day-old eggs and those near hatching were totally rejected. The longevity of P. javensis was greatest when it fed on P. perpusilla honeydew (Cheema, 1942). Yadav (1983) showed that females laid 4–26 eggs and egg-to-adult success varied from 77 to 96%; the proportion of females to males in the population varied from 2 to 46 throughout the year. Such variations in hymenopteron sex ratios are common and have been reviewed by Waage (1982).

The eulophid Tetrastichus gali Gholap & Chandle is another parasitoid recorded from North India but very little is known about it apart from the report by Gholap & Chandle (1985) on its occurrence; it is likely that this parasitoid is in fact Apoecistocerus gali (Walker).

Another parasitoid of P. perpusilla, the stylopod Halotophagus (as Pyrilloxenos) compactus Pierce was first reported from Bihar, India by Pierce (1914) and Misra (1917) later described it in detail. The work of Rahman & Nath (1940) and Rahman (1941) showed that the parasitoid is active throughout the year, with a life span of 39–45 days and five generations per year in the Punjab. In Andhra Pradesh, India, however, the activity of the parasitoid is restricted to September/October (Khan & Murthy, 1956). According to Rajak et al. (1987) P. compactus also has been recorded from Haryana, India. No information exists, however, on its effectiveness as a parasitoid of P. perpusilla.

In addition to the above species there are some misidentified records of Anagrus sp. (Mohyuddin et al., 1982) and Rhozipa fullonuvi (Timberlake) (Hymenoptera: Encyrtidae) (Nigam, 1983; Chaudhary & Sharma, 1988) as parasitoids of P. perpusilla; however these species parasitize only mealybugs (Noyes & Hyat, 1994).

Encouraging parasitoids of P. perpusilla to build up their populations via the conservation of parasitized eggs has been studied since the 1940s by researchers in India. Muliyal & Lakshmanan (1942) used cages to confine the adult parasitoids and achieved an increase in parasitism of P. perpusilla eggs from 26% to 73%. Vevai (1942) conducted similar experiments with cages, but allowed the parasitoids, but not P. perpusilla, to escape through the cage mesh into the field. The cages were refilled once a month with new eggs and observations were recorded fortnightly. The fields eventually became free of the pest, but the experiment had
no control(s) so the conclusion that the parasitoids reduced pest numbers is not valid.

Isaac (1946) observed a 16% increase in parasitism of *P. perpusilla* eggs in Karnal (Punjab) after the addition of egg parasitoids to the field. This was later confirmed by Khanna (1948a,b). Sen (1948) found that there was a significant increase in the intensity of parasitism per egg mass in the treated plots (i.e. fields with added parasitoids). These treated plots also gave a higher yield than the control. Eggs parasitized by *J. jaegersis* can be stored for a maximum of 35 days, while those parasitized by *O. pyrillae* and *C. pyrillae* can be stored successfully for up to 40 days at 17.5°C (Chaudhary & Sharma, 1988).

Of the nymphal parasitoids, the dryinid Agonatopoides *pyrillae* (Mani) has been recorded as *Pseudokonatus pyrillae* Mani on nymphs of *P. perpusilla* in India (Mani, 1942; Rajak et al., 1987), but no population information is available. Females of another dryinid parasitoid, *Richardsidryinus pyrilae* (Kieffer) (known as *Chlorodryinus pallidus* Perkins, *Dryinus pyrillae* Kieffer and *Listrodryinus pyrillae* Kieffer by most of the previous workers) oviposit on the first or second abdominal segment of the host (Bindra & Brar, 1978). The larva sucks the haemolymph from the body and the host dies when the larva is in the penultimate instar. It parasitizes mostly the second, third and fourth instar nymphs (Rahman, 1941; Subba Rao, 1957). Fully grown larvae attached to the host body are covered with a cyst-like structure and the host dies soon after the larva emerges prior to pupation. It pupates on leaves or in the soil (Bindra & Brar, 1978; Asre et al., 1983). The parasitoid is widespread in all the sugarcane growing areas of India (Francis, 1933; Appanna et al., 1954; Rajak et al., 1987) and also occurs in Bangladesh (Miah et al., 1986) and Pakistan (Muhuyuddin et al., 1982), although in Sri Lanka it does not occur naturally.

The morphology and biology of the parasitoid have been described by a number of authors, beginning with Fletcher (1939). Most recent accounts are those by Madan (1985), Misra & Krishna (1986, 1987). The egg is oval and dark brown and less than 0.5 mm in length. The incubation period varies from 4 to 13 days. The newly hatched larva measures 0.5 mm in length and passes through four instars to reach a maximum body length of about 3 mm. When the newly-hatched larva detects a nymph or adult of *P. perpusilla*, it stands erect on the hind pro-legs, clings to the legs of the host and moves to the thoracic region. It fastens itself on to one side of the abdomen of the host and begins to feed. It develops a waxy covering over the body during the 5–7 days of host feeding. On some occasions, up to five larvae have been found on a single host. The fully-grown larva leaves the host, pupates on the surface of the leaf and spends 4–11 days in the pupal stage. Often the host dies after it has been released by the parasitoid. The pupa is cream coloured when fresh but gradually becomes brown. It is dorso-ventrally flattened with several rows of spines on the dorsal surface at the anterior boundary of 5–8th abdominal segments.

The adults are dark blue, with a wingspan from 8–10 mm, and live for 1–7 days in the field. The male is a rapid flier with a smaller body than that of the female, which is less active. The males fly to newly-emerging females and mate with them near the cocoon from which the females have emerged. Oviposition starts within 15 minutes of copulation and is completed within 1–4 hours. The female oviposits on the lower surface of leaf, producing irregular streaks of eggs. The moth’s fecundity is high, with more than 1000 eggs being laid. Maximum fecundity seems to be achieved at around 27°C (Misra & Krishna, 1987).

Gupta (1940) showed that females of *P. perpusilla* become incapable of oviposition after they have been parasitized by *E. melanoleuca* and the sex, age and the stage of the host do not influence host choice by the parasitoid (Mukerji & Venkataraman, 1948). The mature parasitoid larvae appeared to be unaffected by BHC or DDT (Singh & Kalra, 1951) or by low concentrations of malathion (Bindra et al., 1970; Chaudhary et al., 1984). Singh & Dayal (1975) also showed that 5–7-day-old larvae were not affected by insecticides due to their waxy covering. Garg & Sethi (1982) confirmed this although the larvae pupated prematurely after insecticide spraying. This robustness of the parasitoid, if highly developed as the literature suggests, makes it theoretically possible to release it or enhance its numbers along with some chemical control schedules.
especially as Madan & Singh (1979) suggested that the increase rate of the parasitoid population is much faster than that of the host. However, these ideas concerning the parasitoid’s ‘resistance’ to pesticides need to be confirmed with replicated, controlled experiments. One of the most important characters of the parasitoid is its ability to exploit all the biotypes of *P. perpusilla* in different climatic regions. Other attributes include a short life cycle and a high reproductive rate under a wide range of conditions (Chaudhary & Sharma, 1986). The larva is very active and has a well developed searching ability for its host.

Mass rearing of the parasitoid in the laboratory has often been achieved, and is helped by the insect’s short life cycle. Many eggs can be collected, as a single egg mass contains around 250. These may be kept alive for a long time under low temperatures and can easily be brought to conditions leading to hatching. Ovoviviparousness of the parasitoid occurs either as the pupa (Gupta, 1948; Joshi & Sharma, 1992) or as an egg (Bal et al., 1989; Madan & Yadav, 1989).

Fungal pathogens and insects attack the parasitoid. Also, *Oenopyrus* sp. (Hymenoptera: Encyrtidae) has been observed as a cocoon hyperparasite (Yadav & Sharma, 1977). Jadhav & Varma (1988) recorded *Chrysopa* sp. (Neuroptera: Chrysopidae) as a predator of the cocoons; however, whether these hyperparasitoids and predators significantly affect the moth’s population dynamics remains unknown.

**Field releases**

Successful control of the pest through field releases of parasitoid adults and augmentation of the numbers eggs and pupae of *E. melanoleuca* has been achieved by several workers in India and Pakistan during the past two decades. One augmentation method involves the collection of egg masses and pupae of *E. melanoleuca* from the plant with a piece of the leaf to which they were attached. Very large numbers of egg masses or cocoons have been released, including up to 0.5 million eggs/ha in Uttar Pradesh in 1976 (Asre et al., 1983; Prasad et al., 1988). Madan (1985) pointed out, logically, that the number of cocoons to be released per hectare for effective control of the pest depend upon the field density of the pest. It seems that the very large densities of from 2000 to 10,000 cocoons and from 80,000 to 100,000 eggs per hectare may be necessary when the pest numbers reach 1.25–7.5 individuals per leaf. Whether releases on this scale are economically justified needs to be evaluated; the requirements of the parasitoid when not dependent on the host seem to be unknown but a knowledge of them would have the potential to be exploited to enhance its numbers by ecological means – see Wreten & van Emden in press for a review of this approach to natural-enemy enhancement. In the case of the very large-scale releases of eggs and cocoons detailed above, it appears that very labour-intensive programmes are involved. Their value in relation to orthodox control measures needs to be evaluated.

**Biological control — predators**

The coccinellid *Anagis cardoni* (Weise) (previously recorded as *Microaspis cardoni* (Weise) by Mohyuddin et al. (1982) and Rahim & Hashmi (1984)) is a predator of *P. perpusilla* eggs and nymphs in Pakistan, with peak populations in July, August and October. No other published information is available. Another coccinellid, *Bromoides sutherlandi* (Fabricius) is reported to feed on the eggs and nymphs of *P. perpusilla* throughout India (Rajak et al., 1987; Prasad et al. 1988). It also occurs in Pakistan (Khan & Khan, 1966; Mohyuddin et al., 1982; Rahim & Hashmi, 1984), where it has a life cycle lasting 25–30 days with activity throughout the year but, as for *Pyrrlicanium* above, little else is known. The coccinellid **Chelomomes sexmaculata** (Fabricius) which has also been known by its synonym *Menochilus sexmaculatus* (F.) has been recorded from India and Pakistan as a predator of *P. perpusilla* eggs and nymphs (Mohyuddin et al., 1982; Dhaliwal & Bains, 1983b; Rahim & Hashmi, 1984; Rajak et al., 1987). The common Palaearctic coccinellids, *Coccinella septempunctata* Linnaeus, and *C. unicepunctata* Linnaeus feed on *P. perpusilla* eggs all over India and Pakistan (Rahman & Nath, 1940; Khan & Khan, 1966; Mohyuddin et al., 1982; Rajak et al., 1987; Dhaliwal & Bains, 1983b; Rahim & Hashmi, 1984; Chaudhary & Sharma, 1988). Their role as predators of *P. perpusilla* is not known, however. The coccinellid *Micraspis allardi* (Mulsant), recorded previously as *Vermia allardi* (Mulsant), is a predator of *P. perpusilla* eggs in India, Pakistan and Sri Lanka (Rajendr, 1979; Mohyuddin et al., 1982, Rajak et al., 1987). Rahim & Hashmi (1984) published phenological data but nothing else is known in relation to *P. perpusilla*.

The predatory chrysopid *Brinckochrysa sceletes* (Banks) seems to have potential as a predator of *P. perpusilla*, as it has been widely reported as preying upon all stages of the pest in India and Pakistan (Nasir, 1947; Dhaliwal & Bains, 1983b; Rahim & Hashmi, 1984; Chaudhary & Sharma, 1988).

The coniopterigyrid *Coniopteryx pyrana* Withycombe is also a predator with potential. It has been recorded from many parts of India since 1937 (Khan & Murthy 1956; Rajak et al. 1987; Chaudhary & Sharma, 1988). The adult lays eggs singly near the egg masses of *P. perpusilla* and the larva feeds on them. The adult feeds on *P. perpusilla* honeydew. The life-cycle takes 4–5 weeks in summer (Pruthi, 1937; Narayan, 1948). Another coniopterigyrid predator of eggs and nymphs of *P. perpusilla*, *Nimbou basipunctata* Withycombe was first described by Withycombe (1925) and later redescribed by Mani (1939). It occurs all over India (Narayan, 1953; Rajak et al., 1987; Chaudhary & Sharma, 1988) but the only information on its phylogeny is that of Khan & Murthy (1956) who recorded it as active in September.

Apart from the above predators, the following organisms in all have been recorded as predators of *P. perpusilla*: the ant *Crematogaster walshi* Forel, the staphylinid *Paederus fusicollis* Curtis, the dragonfly *Platygomphus dolabratus* Selys, the coccinellid *Propylea dissecta* (Mulsant), and the spiders *Clubiona drassoides* Cambridge, *Leucage* spp., *Menemera* spp., *Plexippus* spp. and *Tetragyna* spp. (Misra, 1917; Brar, 1981; Dhaliwal & Bains, 1983b; Miah et al., 1986; Mohyuddin & Hamid, 1987; Rajak et al., 1987; Prasad et al., 1986). There is, however, little quantitative information on the dynamics of their interaction with the pest.

Although it is apparent that populations of *P. pyrilla* were reduced by many of the parasitoids and predators occurring in the field (Dhaliwal & Bains, 1983b) with a major role for *E. melanoleuca, O. pyrilla* and *P. jacensis* (Madan et al., 1988), the real level of importance of these three, and
other species as control agents has not been assessed. Most published work is descriptive or concerns topics such as phenology, fecundity and relationships with temperature, etc.

Biological control – pathogens

Six species of pathogenic fungi have been recorded so far on P. perpusilla but Metarhizium anisopliae (Metschnikoff) Deuteromycetes Sorokin is the only pathogen which has been used for biological control purposes. This pathogen has been recorded as being important in the control of P. perpusilla in many parts of India (Avasthy, 1973; Kalra, 1973; Asre et al., 1983; Rajak et al., 1987, Pawar, 1987). The fungus is dark green in colour and the hyphae penetrate the insect through the cuticle. The dead bodies of the insects (nymphs as well as adults) remain stuck on the abaxial surface of sugarcane leaves. The fungus appears when rainfall and humidity are high. The isolation, culturing and use of Metarhizium in the control of P. perpusilla has been studied since the 1950s. Raja Rao (1954) showed that it can be cultured in an artificial medium and sprayed in an aqueous suspension onto hosts. Radha et al. (1956) also cultured it, having isolated the fungus from P. perpusilla. Jagtap (1958) achieved a 91–98% level of mortality of nymphs and 90–95% for adults after spraying with a highly concentrated suspension of the fungus, while Kulashreshtha & Gursahani (1961) recorded a 60–75% level of natural mortality of nymphs and adults in India in 1957, 1958 and 1959 when rainfall was high.

Other pathogenic fungi, Aspergillus flavus Link (Deuteromycetes) (Asre et al., 1983), Entomophthora spp. (Zygomyctes) (Varma et al., 1990), Fusarium spp. (Deuteromycetes) (Varma et al., 1977; Asre et al., 1983), Hirsutella sp. (Deuteromycetes) (Butani, 1964; Asre et al., 1983; Rajak et al., 1987), Mucor hiemalis Wehmer (Zygomyctes) and Isaria spp. (Deuteromycetes) (Varma et al., 1977) have all been recorded as pathogens of P. perpusilla in the field but, as with some of the predator records, data do not extend much beyond recording occurrence only.

Chemical control

A great deal of laboratory and field research on insecticidal control of P. perpusilla has been conducted over the past fifty years. Laboratory research carried out during 1953–1976 to find effective insecticides for P. perpusilla was mainly based on organochlorine and organophosphate insecticides. The recommendations included the use of a wide range of compounds, many of which were broad-spectrum: toxaphene, carbophenothion, endrin, dichlorvos, isobenzan, malation, methyl parathion, monocrotophos, parathion, phosphamidon and toxaphene (Prasad & Butani, 1957; Kalra & Srivastava, 1969; Sarup et al., 1970; Neupane, 1976). More recent studies by Gupta & Ahmad (1982) with chemosterilant aziridine compounds, namely tepa [tris(1-aziridinyl)phosphine oxide], metepe [tris(2-methyl-1-aziridinyl)phosphine oxide] and HMAC [1,6-hexamethylenebis (1-aziridine carboxamide)] showed that tepa and metepe produced permanent sterility, but only in females.

Ground spraying

The use of organochlorine insecticides such as BHC and DDT attracted the attention of many workers after 1949 (Srivastava, 1954; Patel, 1955; Bagal & Patel, 1956) but even by the early 1950s, those compounds were beginning to be replaced with new insecticides such as phosphamidon, diazinon, endrin, fenithion, parathion, malathion and toxaphene (e.g. Pradhan & Satpathy, 1953; Rajani, 1960; Khan & Khan, 1966; Bindra et al., 1970). After 1970, the most frequently used insecticides were organophosphorous compounds, with occasional use of carbamates, such as carbaryl, and pyrethroids such as permethrin (Sinha et al., 1974; Neupane, 1976; Jagtap et al., 1976; Tewari et al., 1990). There is little recent information on pesticide use against this pest. Information from the pesticide companies Bayer (India) Ltd and Chemical Industries (Colombo) Ltd (R.D. Kapoor and A. Jayawardena, respectively) indicates that the insect is currently normally controlled by parasites and is not usually considered an economic pest. The parasitoids mentioned in this context, although their biocontrol activity has not recently been well quantified or ranked, are Parachorroscharis, Ooencythus and Richardsidrymus.

Aerial spraying

Aerial spraying of insecticides for P. perpusilla control began in the early 1950s with endrin, BHC or malathion (Abbas & Khan, 1955; Agarwal, 1969b). Many of these persistent and broad spectrum compounds have subsequently been superseded, but malathion is still being widely used because of its cheapness (e.g. Ahmad et al., 1970; Bhatia, 1972; Mogal et al., 1983; Rahim, 1989b). The possible environmental consequences of widespread use of the broad-spectrum organophosphorus compound malathion for P. perpusilla control have not been investigated.

Dusting

The use of organochlorine insecticides such as BHC, DDT or toxaphene in dust form controlled the pest effectively from the late 1940s to the early 1970s (e.g. Gupta, 1952; Trehan, 1957). Avasthy (1973) recommended 5–10% BHC dusts for P. perpusilla control at maxima of 27 and 72 kg/ha at early and fully grown stages of the crop, respectively. However, the use of dusts declined subsequently, probably because of practical difficulties in the field.

Fogging

Suspensions of BHC, DDT, toxaphene, endrin and malathion as fogs have been attempted by researchers in India since the late 1950s. Some workers used thermal aerosol or oil carriers such as Dijetrex 3 or kerosene to apply the above insecticides as fogs in fields (Gupta & Avasthy, 1959; Khalsa & Kapoor, 1960; Teotia & Rajani, 1964).

Soil application

Sharma (1977) reported the successful control of the pest by the soil application of carbophuran, dimethoate or disulphonyl while Raiput et al. (1985) and Marwai & Khan
(1987) also used carbofuran and disulfoton as granules to achieve the same purpose. However, in large plantations this method may not be practical because of the high cost and the labour requirements.

Cultural practices

Removal of sprouts from the stubbles of the ratios was effective in decreasing pest populations as the eggs and the developing stages of the pest are removed by this process (Avasthy, 1973). However, the studies of Brar et al. (1983) showed that trash burning or mulching do not affect the pest's populations as the development from nymphs to adults takes place on the living plant.

Host plant resistance

The sugarcane variety Co 223, with soft and broad leaves was the first to be shown to be particularly susceptible to P. perpusilla; this was in the Punjab (Venkataraman, 1929). Similarly, P. perpusilla was first noticed in Sind, Pakistan when the broad-leaved variety Co 622 was introduced in the late 1950s (Wajih & Hamid, 1983). The susceptibility to P. perpusilla of varieties of sugarcane with soft, broad, succulent leaves has been reported by a number of researchers subsequently (e.g. Rahman & Nath, 1940; Agarwal, 1969a; Mehta & Verma, 1976; Rajak et al., 1987). Resistance in varieties with shorter, narrow, erect or semi-erect leaves and a tight and enveloping leaf sheath was detected during the same period (Gupta, 1948; Khanna et al., 1950; Gupta & Avasthy, 1954a; Agarwal, 1959; Avasthy, 1973; Wajih & Hamid, 1983). Many sugarcane varieties have been classified as 'susceptible' and variety names can be found in papers as early as Francis (1933), and more recently in Wajih & Hamid (1983). Many sugarcane varieties have been classified as resistant, ranging from the work of Rahman (1942) to that of Avasthy (1973). One variety, Co 313 was highly 'susceptible' in 1940 but the level of susceptibility decreased after an eight-year period (Gupta, 1948); it was finally recorded as resistant by 1959 (Agarwal, 1959). What these levels of 'resistance' mean in practice is difficult to deduce; methodology can markedly affect cultivar rankings in resistance bioassays (e.g. Kay et al., 1981).

In terms of mechanisms of resistance, Khanna et al. (1950) showed that the phloem bundles of the resistant sugarcane variety Bo3 were protected by a 'shield', formed by the fusion of the vascular sheaths and a sclerenchymatous rib below it. This structure made it difficult for the insect to penetrate the phloem. Kumarasinghe & Wraaten (1993) studied antibiotic and antixenosis for first and third instar nymphs of P. perpusilla on 23 sugarcane varieties of a wide genetic range. The varieties came from the Sugarcane Research Institute, Sri Lanka. A significant reduction of first instar nymphal growth rate occurred on the varieties M 550-60, SL 8600 and RAGNAR, although there was no significant effect on the third-instar nymphs. These preferred the varieties VATU over RAGNAR in antixenosis experiments, with no 'preference' observed for other varieties. Two hydroxamic acids, DIBOA and DIMBOA were detected in sugarcane. These compounds may contribute to resistance to the pest, as they do for aphids in cereals (e.g. Nicol et al., 1992).

Mechanical control

The use of mechanical methods to control P. perpusilla began early this century. Niceville (1903) first reported control of P. perpusilla in this way by collecting sugarcane leaves with egg masses and burning them. Hussain (1925) also recommended the collecting of egg masses (and adults in bags) for control. This was later confirmed by several other authors, e.g. Desphande (1937); Trehan (1957) and Avasthy (1973), although Khan & Khan (1966) pointed out the difficulty of the method at an advanced stage of the crop. Stripping of dry leaves bearing eggs of P. perpusilla has been practised by many researchers for a long time (Mathur & Gupta, 1940; Avasthy, 1973). Richards (1938) and Gupta (1948) suggested that stripping had other advantages, such as an increase in sugar content as well as the germination of seed sets as it provided more space for light and air to penetrate to the crop. Gupta (1948), however, showed that stripping also has disadvantages, such as high cost, mechanical damage to the eye buds by mammalian pests and field workers, together with a greater level of lodging of the crop.

Francis (1933) was able to catch an average of 2000 adults per night using light traps but considered this method to be impracticable because of the number of light traps required for large areas. However, despite this, Ayyar (1984) recommended light traps along with the other mechanical control methods. Overall, such mechanical methods, if they are to be of real value, need to be justified in terms of the population dynamics of the pest and the labour costs involved.

Past control strategies and future prospects

The early control tactics recommended by Narayananan (1953) and Gupta & Avasthy (1956) were based mainly on chemical control using organochlorine insecticides, together with the manual removal of stubbles. The destruction of egg masses, nymphs and adults via collection of plant parts, was also employed.

In 1973, Kalra recommended the burning of all trash after the harvest, the removal and destruction of egg clusters of P. perpusilla, spraying the crop with BHC, toxaphene or malathion and the ploughing of those fields not intended for ratooning, soon after harvest. These recommendations, however, were based on the use of what would now be regarded as unsuitable products; the suggestion of ploughing after harvest does not seem to be based on a logical knowledge of the pest's biology. It is highly mobile, so ploughing stubble is unlikely to contribute much to pest control.

Dhaliwal & Bains (1985) advocated biological methods, via the manual augmentation of the numbers of the egg parasitoid O. pyrillae in fields early in the monsoon season, and the similar augmentation of E. melanoleuca populations in fields with low levels of parasitism. In both cases, the proposed methods are labour-intensive and need to be justified economically.

The recommendations by Wajih & Hamid (1983) included proper sanitation of sugarcane before transport from one area to another, removal of other host plants in the vicinity, maintaining the natural habitats of natural enemies, releasing parasitized eggs of Perpusilla where the infestation is building up, developing a varietal complex of
narrow leaved commercial varieties, regular surveying of cane fields, regulating the use of nitrogen fertilizer and increasing potash application where populations of P. perpusilla are present. These proposals make sound sense in terms of integrated pest management (IPM), but the practice of IPM is much more complex than an iteration of its components (see Dent, 1993). Brar and Bains (1980) proposed the thorough removal of egg masses of the pest from plantations. Inayathullah & Rahim (1991) brought the proposed the thorough removal of egg masses of the pest its components (see Dent, 1993). Brar and Bains (1980) practice of IPM is much more complex than an iteration of parasitoid contributed much to control under these circum-
stances. Earlier work claiming to show the 'resistance' of E. melanololca to many insecticides needs to be confirmed. Control methods in the 1980s and 1990s are dominated biological methods, which include the release of the parasitoid E. melanololca, developing varieties resistant to the pest, cultural and mechanical methods such as removing stubbles and proper sanitary methods before transportation of planting materials.

There is ample scope for more, directed work on this important pest, especially in the areas of host-plant resistance, biocontrol and cultural control. Much of the early work has been piecemeal and integrated pest management (Dent, 1993) programmes for P. perpusilla are not yet in place. There is a danger that a method or a biocontrol agent will be taken up on the basis of limited quantitative evidence of its value, rather than a careful exploitation of important aspects of the pest's ecology. However, in Europe, the USA and elsewhere, many pests do not yet have a true IPM complex directed at their management, e.g. cereal aphids in Europe (Vickerman & Wratton, 1979); wheat pests generally in the USA, Europe and Australasia (Wratton et al., 1995). Considering the socio-economic impediments to sustained IPM research in the countries where P. perpusilla is most damaging, useful research progress has been made. What is needed now is a rigorous experimental evaluation of the potential of the components of IPM, as they concern P. perpusilla, and the integration of the best of these into one large scale experiment. Such approaches can be costly, and of necessity multi-season, as the European experience has shown (Holland et al., 1994), so funding at more than the regional level may be necessary to achieve the goal of a practically-useful understanding of the 'sustainable' control of P. perpusilla.

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