
REVIEW ARTICLE

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

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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 unreplicated 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 (Homoptera: 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 leafhopper by many authors in the past, the current acceptable usage restricts 'leafhoppers' 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,

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'the sugarcane lophopid planthopper' will be used to describe *P. perpusilla* in this review.

Pyrilla perpusilla sucks phloem sap from leaves and excretes honeydew onto foliage, leading to fungal diseases. 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), Meenoplidae (1), Derbidae (45), Dictyopharidae (9), Achilidae (1), Tropicuchidae (3), Issidae (2), Nogodinidae (4), Flatidae (4), Ricaniidae (4) and Lophopidae (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 Lophopidae. However, *Numicia viridis* Muir in the family Tropicuchidae has been recorded as an important pest of 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. pusana* (Distant), *P. p. coimbatorensis* Fennah, *P. p. chikka-ballapurana* Fennah, *P. p. thekkadiana* Fennah, *P. p. naraikkaduana* Fennah, *P. p. dhimbami* Fennah, *P. p. pirmedana* Fennah, *P. p. singhalensis* Fennah, *P. p. lycoides* (Walker) and five geographical sub-species of *P. aberrans*: *P. a. aberrans* Kirby, *P. a. palghati* Fennah, *P. a. consors* Fennah, *P. a. comes* Fennah, *P. a. achates* 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; Rajput *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 symbiotic 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; Dhaliwal & 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*, *Panicum maximum*, *Pennisetum typhoideum*, *Saccharum spontaneum*, *Sorghum bicolor*, *Sorghum halepense*, *Triticum sativum*, *Zea mays*, Leguminosae; *Cicer arietinum*, *Melilotus alba*, *Melilotus parviflora*, *Pisum sativum*, Moraceae; *Ficus infectoria*, *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; Pophaly & 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. Kumarasinghe, unpublished). Eggs of *P. perpusilla* have been found in cracks under the bark of *Melia indica* (neem), *Mangifera indica* (mango), *Sisso* sp. and *Acacia 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 37–880. 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) (Kumarasinghe & 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 (Kumarasinghe & 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' *Epiricania melanoleuca* (Fletcher) (Lepidoptera: Epipyropidae) 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 *Parachrysocharis javensis* 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 & Brar (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, *Cheiloneurus pyrillae* Mani, was first reported by Mani (1939) from Delhi. It was present in the Punjab in 1980–1981 (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, 1988; 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 papilionis* Ashmead. This parasitoid has been recorded throughout India. It showed maximum activity from September to

Table 1. Parasitoids, predators and pathogens of *Pyrilla perpusilla*.

Parasitoids	
Egg parasitoids	
Hymenoptera: Encyrtidae	<i>Cheiloneurus pyrillae</i> Mani
	<i>Ooencyrtus pyrillae</i> (Mani)
	<i>Proleuroceroides pyrillae</i> Shafee, Alam & Agarwal
Hymenoptera: Eulophidae	<i>Parachrysocharis javensis</i> Girault
	<i>Tetrastichus gala</i> Gholap & Chandale
Hymenoptera: Platygasteridae	<i>Platygaster</i> sp.
Nymphal parasitoids	
Hymenoptera: Dryinidae	<i>Agonatopoides pyrillae</i> (Mani)
	<i>Richardsidryinus pyrillae</i> (Kieffer)
Nymphal and adult parasitoids	
Lepidoptera: Epipyropidae	<i>Epiricania melanoleuca</i> (Fletcher)
Coleoptera: Stylophidae	<i>Pyrilloxenos compactus</i> Pierce
Predators	
Coleoptera: Coccinellidae	<i>Anegleis cardoni</i> (Weise)
	<i>Brumoides suturalis</i> (Fabricius)
	<i>Cheilomenes sexmaculata</i> (Fabricius)
	<i>Coccinella septempunctata</i> Linnaeus
	<i>Coccinella undecimpunctata</i> Linnaeus
	<i>Micraspis allardi</i> (Mulsant)
	<i>Propylea dissecta</i> (Mulsant)
Coleoptera: Staphylinidae	<i>Paederus fuscipes</i> Curtis
Hymenoptera: Formicidae	<i>Crematogaster walshi</i> Forel
Neuroptera: Chrysopidae	<i>Brinckochrysa scelestes</i> (Banks)
Neuroptera: Coniopterygidae	<i>Coniopteryx pusana</i> Withycombe
	<i>Nimboa basipunctata</i> Withycombe
Odonata: Gomphidae	<i>Platygomphus dolobratus</i> Selys
Araneida: Araneidae	<i>Cryptophora</i> sp.
Araneida: Clubionidae	<i>Clubiona drassodes</i> Cambridge
Araneida: Salticidae	<i>Menemerus</i> sp.
	<i>Plexippus</i> sp.
Araneida: Tetragnathidae	<i>Leucauge</i> sp.
	<i>Tetragnatha</i> sp.
Pathogens	
	<i>Aspergillus flavus</i> Link
	<i>Fusarium</i> sp.
	<i>Hirsutella</i> sp.
	<i>Isaria</i> sp.
	<i>Metarhizium anisopliae</i> Metschnikoff (Sorokin)
	<i>Mucor hiemalis</i> Wehmer

December in the Punjab, where 30–40% parasitism of *P. perpusilla* eggs by this species was recorded by Rahman, (1941). *Ooencyrtus pyrillae* has also been recorded from Pakistan, specifically the Punjab and North Western Frontier Province (Mohyuddin *et al.*, 1982) and from Sind (Rahim & Hashmi, 1984). However, as for *C. pyrillae*, above, most data are simply records, life-cycle information or comprise only percentage parasitism (e.g. Yadav, 1983; Yadav & Chaudhary, 1984; Bindra & Brar, 1978).

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 & Chandale, 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 *Syntomosphyrum udaipurensis* 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 4–28 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 hymenopterous sex ratios are common and have been reviewed by Waage (1982).

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

Another parasitoid of *P. perpusilla*, the stylophid *Haliotophagus* (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* has also 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 mis-identified records of *Anagyrus* sp. (Mohyuddin *et al.*, 1982) and *Rhopus fullawayi* (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 *P. javensis* 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 *Pseudogonatopus 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 pyrillae* (Kieffer) (known as *Chlorodryinus pallidus* Perkins, *Dryinus pyrillae* Kieffer and *Lestrodryinus 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). Its impact on *P. perpusilla* populations was not considered to be very great, particularly at high levels of host populations and it probably augments the effect of other parasitoids when host populations are low (Dhaliwal & Bains, 1983b).

Epiricania melanoleuca (Fletcher) (Lepidoptera: Epipyropidae) appears to be the most successful parasitoid¹ used during the past two decades against *P. perpusilla*. A large area of new research on this lepidopteran parasitoid was developed as researchers began to discover its usefulness in reducing pest populations by as much as 90–100%. *E. melanoleuca* belongs to the family Epipyropidae which has a distribution in tropical and warm temperate areas, mainly in Australia and in the Indian subcontinent. All the known members of the 32 species of the minute moths of this family are largely parasitic on Auchenorrhyncha but have also been recorded as parasitoids of lepidopterous larvae (Clausen, 1940; Holloway, 1986; Common, 1990). The female moths of *E. melanoleuca* lay 400–800 eggs. The larvae have been observed in an erect position, clinging to the margins of leaves by the pro-legs and waving the thorax back and forth ready to grasp a host when it passes. After catching a host the larva attaches itself by hooked claws with its head directed posteriorly. It is believed that the larva feeds through the host cuticle by penetrating it with sharp mandibles, allowing it to suck the host's body fluids. The larva passes through four or five instars on the body of the host and during this period it secretes a large amount

of wax over its body, making it conspicuous. The host dies after the parasitoid reaches the pre-pupal stage or soon after it has been released by the parasitoid. The larva pupates in a cocoon near the ground or on a leaf or a grass stem. The adult males which emerge are rapid fliers (Common, 1990).

Fletcher (1939) was the first to record this parasitoid, on *P. perpusilla* from India; he classified it as *Epipyrops melanoleuca* Fletcher. In 1983, the genus *Epipyrops* was transferred to *Epiricania* and the insect was renamed as *Epiricania melanoleuca* (Fletcher) (Krampl & Dlabola, 1983). The parasitoid is probably restricted to the drier belts of the sugarcane-growing tracts (Garg & Sethi, 1982). It has been recorded from other countries in Southern Asia such as Bangladesh (Miah *et al.*, 1986) and Pakistan (Mohyuddin *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 5 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,

¹Treated here as an externally-feeding parasitoid but would be classified as a predator which consumes one prey item only.

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, 1988). 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. Overwintering 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, *Ooencyrtus* 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 depended 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 Wratten & 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 *Anegleis cardoni* (Weise) (previously recorded as *Micraspis 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, *Brumoides suturalis* (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 *Pyriloxenos* above, little else is known. The coccinellid *Cheilomenes 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 Palearctic coccinellids, *Coccinella septempunctata* Linnaeus, and *C. undecimpunctata* 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 *Verania allardi* (Mulsant), is a predator of *P. perpusilla* eggs in India, Pakistan and Sri Lanka (Rajendra, 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 scelestes* (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 coniopterygid *Coniopteryx pusana* 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; Naraynan, 1948). Another coniopterygid predator of eggs and nymphs of *P. perpusilla*, *Nimboa basipunctata* Withycombe was first described by Withycombe (1925) and later redescribed by Mani (1939). It occurs all over India (Narayanan, 1953; Rajak *et al.*, 1987; Chaudhary & Sharma, 1988) but the only information on its phenology is that of Khan & Murthy (1956) who recorded it as active in September.

Apart from the above predators, the following organisms have all been recorded as predators of *P. perpusilla*: the ant *Crematogaster walshi* Forel., the staphylinid *Paederus fuscipes* Curtis, the dragonfly *Platygomphus dolobratus* Selys, the coccinellid *Propylea dissecta* (Mulsant), and the spiders *Clubiona drassodes* Cambridge, *Leucauge* spp., *Menemeris* spp. *Plexippus* spp. and *Tetragnatha* spp. (Misra, 1917; Brar, 1981; Dhaliwal & Bains, 1983b; Miah *et al.*, 1986; Mohyuddin & Hamid, 1987; Rajak *et al.*, 1987; Prasad *et al.*, 1988). There is, however, little quantitative information on the dynamics of their interaction with the pest.

Although it is apparent that populations of *P. pyrillae* were reduced by many of the parasitoids and predators occurring in the field (Dhaliwal & Bains, 1983b) with a major role for *E. melanoleuca*, *O. pyrillae* and *P. javensis* (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. (Zygomycetes) (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 (Zygomycetes) 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, malathion, 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], metepa [tris(2-methyl-1-aziridinyl phosphine oxide)] and HMAc [1,6-hexamethylenebis(1-aziridine carboxamide)] showed that tepa and metepa 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, fenthion, 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 bio-control activity has not recently been well quantified or ranked, are *Parachrysocharis*, *Ooencyrtus* and *Richardsidryinus*.

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 Diptrex-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 carbofuran, dimethoate or disulfoton while Rajput *et al.* (1985) and Marwat & 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 ratoons 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 & Wratten (1993) studied antibiosis 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 8606 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 Narayanan (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 pest under control in Pakistan by releasing *E. melanoleuca*, combined with sprays of malathion, dimethoate and chlorpyrifos. This combination of three extremely broad-spectrum insecticides with a parasitoid is surprising. It is not logical in terms of IPM strategy and it is unlikely that the parasitoid contributed much to control under these circumstances. Earlier work claiming to show the 'resistance' of *E. melanoleuca* 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. melanoleuca*, 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 & Wratten, 1979); wheat pests generally in the USA, Europe and Australasia (Wratten *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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References

- Abbas, H.M. & Khan, M.S. (1955) Insecticidal trials against *Pyrilla* (*Pyrilla perpusilla* Walk.) in N.W.F.P. *Proceedings of the 7th Pakistan Science Conference* 36–38.
- Agarwal, R.A. (1959) Insect resistance in Coimbatore canes – a review. *Indian Sugar* 8, 785–794.
- Agarwal, R.A. (1969a) Morphological characteristics of sugarcane and insect resistance. *Entomologia Experimentalis et Applicata* 12, 767–776.
- Agarwal, R.A. (1969b) *Pyrilla* infestation in Western Uttar Pradesh. *Indian Sugar* 19, 337–339.
- Ahmad, F., Tariq, Z.K. & Haque, H. (1970) Control of sugarcane *Pyrilla* and white fly by aerial application of emulsifiable concentrations at ultra-low-volume. *PANS* 16, 165–171.
- Appanna, M., Usman, S. & Sastry, K.S.S. (1954) A note on the change in the status of the sugarcane leaf hopper, *Dictyophora pallida* (Don.) (*Pyrilla perpusilla* Walker) in Mysore. *Mysore Agricultural Journal* 30, 19–26.
- Asre, R., Gupta, P.K. & Pawar, A.D. (1983) Control of sugarcane *Pyrilla* by its natural enemies. *Indian Farming* 33, 37–38.
- Avasthy, P.N. (1973) Leaf hopper (*Pyrilla perpusilla* Walker) of sugarcane. *Indian Sugar* 23, 11–14.
- Ayyar, T.V.R. (1984) *Handbook of economic entomology for South India*. 228 pp. India, International Books and Periodicals Supply Services.
- Bagal, S.R. & Patel, G.A. (1956) The sugarcane leaf hopper or *Pyrilla*. pp. 69–71 in *Crop pests and how to fight them*. Bombay, India, Maharashtra Publishing.
- Bains, V.K., Dilawari, V.K., Brar, R.S. & Dhaliwal, Z.S. (1982) A model for prediction of sugarcane *Pyrilla* outbreak in relation to high temperature during pre monsoon period in the Punjab. *Indian Journal of Ecology* 9, 298–302.
- Bal, R.S., Dhaliwal, Z.S. & Bains, S.S. (1989) A note on the overwintering of *Epiricania* (*Epipyrops*) *melanoleuca* Fletcher (*Epipyropidae*: *Lepidoptera*). *Journal of Insect Science* 2, 155–157.
- Bhatia, G.N. (1972) Massive aerial attack on sugarcane leaf hopper (*Pyrilla* spp.) by ULV application of malathion. *Pesticides* 6, 11–12.
- Bindra, O.S. & Brar, R.S. (1978) Studies on the natural enemies of *Pyrilla perpusilla* Walker in the Punjab. *Indian Sugar* 28, 247–252.
- Bindra, O.S., Singh, H. & Chaudhary, J.P. (1970) Ground application of ultra low volume sprays for the integrated control of sugarcane leaf hopper, *Pyrilla perpusilla* Walker. *Indian Journal of Entomology* 32, 4–6.
- Box, H.E. (1953) *List of sugarcane insects*. 101 pp. London, Commonwealth Institute of Entomology.
- Brar, R.S. (1981) The natural enemy complex of *Pyrilla perpusilla* Walker at Dhurai, Punjab. *Indian Journal of Entomology* 43, 441–443.
- Brar, R.S. & Bains, S.S. (1979) Population dynamics of *Pyrilla perpusilla* Walker – Mortality factors. *Indian Journal of Ecology* 6, 110–121.
- Brar, R.S. & Bains, S.S. (1980) Dispersion of eggs of *Pyrilla perpusilla* Walker during different seasons. *Indian Journal of Ecology* 7, 161–163.
- Brar, R.S. & Bains, S.S. (1981) The response of *Tetrastichus pyrillae* Crawford in oviposition on different egg stages of *Pyrilla perpusilla* Walker. *Indian Journal of Entomology* 43, 447–448.
- Brar, R.S., Avasthy, P.N. & Kishan Singh (1983) Sugarcane trash in relation to multiplication of *Pyrilla* and its parasitoid, *Epipyrops melanoleuca* Fletcher. *Maharashtra Sugar* 8, 35–37.
- Butani, D.K. (1964) Sugarcane leaf hopper *Pyrilla perpusilla* Walker – A review. *Indian Sugarcane Journal* 9, 60–75.
- Butani, D.K. (1972) Sugarcane and its problems – Parasites and predators recorded on insect pests of sugarcane in India. *Indian Sugar* 22, 17–31.

- Chaudhary, J.P., Kaushik, S.K., Singh, R. & Mrig, K.K.** (1987) Role of natural enemies in the suppression of sugarcane leaf hopper *Pyrilla perpusilla* Walker. *FAO Plant Protection Bulletin* **35**, 15–19.
- Chaudhary, J.P. & Sharma, S.K.** (1988) Biological control of *Pyrilla* using parasites and predators. pp. 186–206. in David, H. & Easwaramoorthy, S. (Eds) *Biological technology for sugarcane pest management*. India, Sugarcane Breeding Institute, Coimbatore.
- Chaudhary, J.P., Yadav, S.R. & Madan, Y.P.** (1984) Effect of strip spraying of malathion on the population of *Pyrilla perpusilla* Walker. and its parasitoid *Epipyrops melanoleuca* Fletcher. *Agricultural Science Digest* **4**, 123–125.
- Chaudhary, N.A. & Ansari, M.A.** (1988) Insect pests of sugarcane in Pakistan. *Progressive Farming* **8**, 10–18.
- Chaudhary, R.N. & Sharma, V.K.** (1990) A note on *Pyrilla perpusilla* Walker on maize. *Indian Journal of Plant Protection* **18**, 113–114.
- Cheema, P.S.** (1942) Effect of food on the longevity of *Tetrastichus pyrillae* Craw. *Indian Journal of Entomology* **4**, 94–95.
- Clausen, C.P.** (1940) *Entomophagous insects*. 688 pp. London. McGraw-Hill Book Company.
- Common, I.F.B.** (1990) *Moths of Australia*. 535 pp. Australia. Melbourne University Press.
- Cotterell, G.S.** (1954) Notes on insects injurious to crops in Afganistan. *FAO Plant Protection Bulletin* **2**, 53–55.
- Dean, G.J.** (1979) The major insect pests of rice, sugarcane and jute in Bangladesh. *PANS* **25**, 378–385.
- Dent, D.** (1993) *Insect pest management*. 604 pp. Wallingford, UK, CAB International.
- Desphande, V.G.** (1937) Important insect pests of sugarcane in Bombay Presidency. *Current Science* **6**, 33–35.
- Dhaliwal, Z.S. & Bains, S.S.** (1983a) A laboratory technique for rearing sugarcane leaf hopper *Pyrilla perpusilla* (Walker). *Uttar Pradesh Journal of Zoology* **3**, 164–165.
- Dhaliwal, Z.S. & Bains, S.S.** (1983b) Relative role of various parasitoids in limiting the population of sugarcane *Pyrilla* in the monsoon and post-monsoon seasons in the Punjab. *Indian Journal of Ecology* **2**, 294–302.
- Dhaliwal, Z.S. & Bains, S.S.** (1985) Numerical response of some important parasitoids of *Pyrilla perpusilla* (Walker) to the variable host population. *Indian Journal of Ecology* **12**, 126–132.
- Dhaliwal, Z.S., Bal, R.S. & Bains, S.S.** (1987) Lethal effect of high temperature on various life stages of *Pyrilla perpusilla* (Walker) and its important parasitoids. *Indian Journal of Ecology* **14**, 266–272.
- Fennah, R.G.** (1963) The species of *Pyrilla* (Fulgoroidea : Lophopidae) in Ceylon and India. *Bulletin of Entomological Research* **53**, 715–735.
- Fletcher, T.B.** (1914) Report of the imperial entomologist. *Report of the Agricultural Research Institute & College, Pusa*, 1913–14, 62–75.
- Fletcher, T.B.** (1939) A new *Epipyrops* from India (Lepidoptera: Epipyropidae). *Bulletin of Entomological Research* **30**, 293–294.
- Fletcher, T.B. & Ghosh, C.C.** (1919) *Report of the third Entomological meeting, Pusa*. **1**, 362–367.
- Francis, C.B.** (1933) A note on the sugarcane leaf hopper (*Pyrilla*) in South Arcot district. *Madras Agricultural Journal* **21**, 510–524.
- Garg, A.K. & Sethi, G.R.** (1982) Parasitization of *Pyrilla perpusilla* Walker by *Epipyrops melanoleuca* Fletcher. *Indian Journal of Entomology* **44**, 92–97.
- Gholap, M.S. and Chandale, A.G.** (1985) Incidence of sugarcane leaf hopper and parasitisation by its natural enemies in Western Maharashtra. *Journal of Maharashtra Agricultural Universities* **10**, 235–236.
- Gupta, B.D.** (1940) On *Epipyrops* (sp.n.) – a parasite on the nymphs and adults of sugarcane leaf hopper (*Pyrilla* spp.). *Current Science* **9**, 132–133.
- Gupta, B.D.** (1948) Control of sugarcane leaf hopper (*Pyrilla* spp.) in the U.P. *Indian Farming* **9**, 401–406.
- Gupta, B.D.** (1952) A resume of trials with DDT, BHC and some other insecticides against the sugarcane leaf-hopper (*Pyrilla perpusilla* Wlk.) in Uttar Pradesh. *Proceedings of the 21st Annual Convention of Sugar Technologists Association, India* **2**, 144–147.
- Gupta, B.D. & Avasthy, P.N.** (1954a) The alternate host plants and their role in the propagation of sugarcane pests. *Proceedings of the Sugar Technologists Association* **23**, 147–152.
- Gupta, B.D. & Avasthy, P.N.** (1954b) Some recommendations for the control of sugarcane pests in India. *Indian Sugar* **4**, 387–405.
- Gupta, B.D. & Avasthy, P.N.** (1956) Recent advances in sugarcane entomology in India. *Indian Sugar* **5**, 541–548.
- Gupta, B.D. & Avasthy, P.N.** (1959) Some recommendations for the control of sugarcane pests in India – Part I: Sugarcane leaf hopper *Pyrilla perpusilla* Wlk. *Indian Journal of Sugarcane Research and Development* **3**, 78–83.
- Gupta, K.M., Singh, N.L., Dayal, R. & Singh, I.** (1971) Observations on survival and dispersal of *Pyrilla* in relation to foliar density of sugarcane during hot weather. *4th Joint Convention of Sugar Technologists Association, Deccan Sugar Technologists Association, South Indian Sugar Technologists Association*. 1971, 9–11.
- Gupta, M. & Ahmad, I.** (1979) Effect of sub optimal temperatures on the hatching and incubation period of eggs of *Pyrilla perpusilla* Walker. *Current Science* **48**, 958–959.
- Gupta, M. & Ahmad, I.** (1982) Chemosterilization of *Pyrilla perpusilla* (Homoptera: Lophopidae) by some Aziridin compounds. *Colemania* **1**, 149–153.
- Gupta, M. & Ahmad, I.** (1983) Morphology of the Indian sugarcane leaf hopper, *Pyrilla perpusilla* Walker. *Folia Morphologica* **31**, 325–330.
- Holland, J.M., Cilgi, T., Frampton, G.K. and Wratten, S.D.** (1994) Arable acronyms analysed – a review of integrated farming systems research in Europe. *Annals of Applied Biology* **125**, 399–438.
- Holloway, J.D.** (1986) The moths of Borneo: key to families; Cossidae, Metarbelidae, Ratardidae, Dudgeoneidae, Epipyropidae and Limacodidae. *Malayan Nature Journal* **40**, 1–166.
- Hussain, M.A.** (1925) Report of the imperial entomologist. *Scientific Report of Agricultural Research Institute, Pusa*, 41 pp.
- Inayatullah, C. & Rahim, A.** (1991) Management of sugarcane *Pyrilla* (*Pyrilla perpusilla*) Walk. from Sind. *Indian Sugar* **40**, 739–742.
- Isaac, P.V.** (1946) Report of the imperial entomologist. *Scientific Report of the Agricultural Research Institute, New Delhi*. 1944–45. 73–79.
- Jadhav, R.B. & Varma, A.** (1988) Record of a hyperparasitoid and two predators on *Epiricania melanoleuca* in Maharashtra. *Journal of Biological Control* **2**, 133–134.
- Jagtap, A.P.** (1958) Studies in the entomogenous fungus *Metarhizium anisopliae* (Metsch) Sorok. *Current Science* **27**, 99–100.
- Jagtap, A.B., Avate, B.G. & Naik, L.M.** (1976) Comparative study against sugarcane leaf hopper *Pyrilla perpusilla* Walker (Lophopidae: Homoptera). *Pesticides* **10**, 46–47.

- Joshi, R.K. & Sharma, S.K. (1989) Augmentation and conservation of *Epiricania melanoleuca* Fletcher, for the population management of sugarcane leaf hopper, *Pyrilla perpusilla* Walker, under arid conditions of Rajasthan. *Indian Sugar* **39**, 625–628.
- Joshi, R.K. & Sharma, S.K. (1992) Seasonal parasitization and carryover of *Epiricania melanoleuca* Fletcher, an ectoparasite of *Pyrilla perpusilla* Walker under arid conditions. *Annals of Arid Zone* **31**, 33–35.
- Kalra, A.N. (1973) *Pyrilla*, a menace to sugarcane and sugar industry. *Indian Sugar* **23**, 737–739.
- Kay, D., Wratten, S.D. & Stokes, S. (1981) Effects of vernalisation and aphid culture history on the relative susceptibilities of wheat cultivars to aphids. *Annals of Applied Biology* **99**, 71–75.
- Kalra, A.N. & Srivastava, R.C. (1969) Relative toxicity of some insecticides to the sugarcane leaf hopper *Pyrilla perpusilla* Wlk. *Indian Journal of Entomology* **31**, 72–73.
- Khalsa, M.S. & Kapoor, G.P. (1960) Large scale trials for *Pyrilla* control through thermal aerosol in U.P. *Proceedings of the 4th all India Conference of Sugarcane Research and Development Workers, Waltair*. Pt. I, 35–36.
- Khan, A.M. (1977) Mycetomal bacteria of *Pyrilla perpusilla* Walker and effect of some drugs. *Indian Journal of Entomology* **39**, 8–11.
- Khan, M.Q. & Murthy, D.V. (1956) Insecticidal trials against *Pyrilla*. *Annual Report of Sugarcane Pest Scheme, Rudrur*, 1955–56, 9.
- Khan, M.R. & Khan, S. (1966) Bionomics and control of *Pyrilla pusana* Distant in Peshawar region. *Agriculture Pakistan* **17**, 385–414.
- Khan, M.V. & Shafee, S.A. (1979) Taxonomic studies on some Indian eulophid parasites (Hymenoptera: Eulophidae). *Journal of the Bombay Natural History Society* **76**, 324–334.
- Khanna, K.L. (1948a) *Annual Report of the Central Sugarcane Research Station, Pusa, Bihar, 1944–45*, 35–47.
- Khanna, K.L. (1948b) *Annual report of the central sugarcane research station, Bihar. ending 31.05.1947*, 91–106.
- Khanna, K.L., Sharma, S.L. & Hussain, M.Z. (1950) On *Pyrilla* infestation and varietal resistance in sugarcane. *Current Science* **19**, 251–253.
- Krampl, F. & Dlabola, J. (1983) A new genus and species of epipyropid moth from Iran ectoparasitic on a new *Mesophantia* species, with a revision of the host genus (Lepidoptera, Epipyropidae; Homoptera, Flatidae). *Acta Entomologica Bohemoslov* **80**, 451–472.
- Krishnanandam, Y. & Ramamurty, P.S. (1971) A correlative study of the neuroendocrine organs and oocytes maturation in *Pyrilla perpusilla* Walker. (Fulgoroidea: Homoptera). *Zeitschrift für mikroskopisch – anatomische Forschung. Leipzig* **84**, 257–285.
- Kulashreshtha, R.C. & Gursahani, K.A. (1961) An observation on an entomogenous fungus, *Metarahizium anisopliae* (Metsch.) Sor. *Indian Journal of Sugarcane Research and Development Workers* **5**, 163–164.
- Kumarasinghe, N.C. & Ranasinghe, M.A.S.K. (1985) Life history and monthly incidence of sugarcane leaf hopper *Pyrilla perpusilla singhalensis* (Homoptera: Lophopidae) in Kantale. *Proceedings of the 41st Annual Session of the Sri Lanka Association of Advancement of Science*, 1985, 38.
- Kumarasinghe, N.C. & Ranasinghe, M.A.S.K. (1988) Effect of environmental factors on populations of the sugarcane leaf hopper *Pyrilla perpusilla singhalensis*. *Proceedings of the 44th Annual Sessions of the Sri Lanka Association of Advancement of Science*, 1988, 70.
- Kumarasinghe, N.C. & Wratten, S.D. (1993) Host plant resistance in sugarcane (*Saccharum officinarum* L.) to the lophopid plant hopper *Pyrilla perpusilla* Walker. (Hom.; Lophopidae). *International Organisation for Biological and Integrated Control of Noxious Animals and plants/West Palaearctic Regional Section Bulletin* **16**(5), 144–154.
- Madan, Y.P. (1985) *Bionomics, effectiveness and mass multiplication of Epipyrops melanoleuca Fletcher, an ectoparasitoid on Pyrilla perpusilla Walker*. 138 pp. PhD thesis, Haryana Agricultural University, Hissar, India.
- Madan, Y.P., Chaudhary, J.P., Yadav, S.R. & Sharma, S.K. (1988) Biology of *Chrysopa (Anisochrysa)* sp. a predator of *Pyrilla perpusilla* Walker eggs, under laboratory conditions. *Agriculture Science Digest* **8**, 170–172.
- Madan, Y.P., Mrig, K.K. & Chaudhary, J.P. (1987) Effect of some semi-artificial diets on the fecundity and longevity of *Pyrilla perpusilla* Walker adults. *Indian Journal of Entomology* **49**, 496–501.
- Madan, Y.P. & Singh, R.A. (1979) Natural control of sugarcane leaf hopper, *Pyrilla perpusilla* Wlk. *Haryana Agricultural University Journal of Research* **9**, 337–339.
- Madan, Y.P. & Yadav, S.R. (1989) Facultative diapause in *Epiricania (Epipyrops) melanoleuca* (Fletcher), a nymphal and adult parasitoid of *Pyrilla perpusilla* Walker. *Agriculture Science Digest* **9**, 41–44.
- Mani, M.S. (1939) Description of new and record of some known chalcidoid and other hymenopterous parasites from India. *Indian Journal of Entomology* **1**, 69–99.
- Mani, M.S. (1942) Studies on Indian parasitic Hymenoptera II. *Indian Journal of Entomology* **4**, 153–162.
- Marwat, G.N.K. & Khan, A.A. (1987) Using granules against sucking insect pests of sugarcane. *Pakistan Journal of Agricultural Research* **8**, 57–60.
- Mathur, R.N. (1941) Certain physiological considerations in the damage caused to sugarcane by *Pyrilla*. *Proceedings of the 10th Annual Convention of Sugar Technologists, India*, 134–139.
- Mathur, R.N. & Gupta, B.D. (1940) An analysis of factors underlying the deterioration of sugarcane crop in the District of Meerut and Muzaffarnagar during the season 1937–38. *Proceedings of the 9th Annual Convention of Sugar Technologists Association, India*, 10 pp.
- Mehta, P.R. & Verma, B.K. (1976) *Plant protection*. 658 pp. Nasik, Farm information unit, Government of India Press.
- Miah, M.A.H., Khuda, A.K.M.Q. & Shahjahan, M. (1986) The problems of *Pyrilla perpusilla* and the impact of its natural enemies. *Bangladesh Journal of Zoology* **14**, 9–13.
- Misra, C.S. (1917) The Indian sugarcane leaf hopper, *Pyrilla aberrans* Kirby. *Memoirs of Department of Agriculture India (Entomology series)* **5**, 73–133.
- Misra, M.P. & Krishna, S.S. (1986) Variation in the reproductive performance of *Epiricania melanoleuca* (Fletcher) (Lep., Epipyropidae) in relation to stage and sex of the host *Pyrilla perpusilla* (Walker) (Hom., Lophopidae) during rearing. *Anzeiger für Schädlingskunde, Pflanzenschutz Umweltschutz* **59**, 20–21.
- Misra, M.P. & Krishna, S.S. (1987) Variation in sex ratio or age of sexes in mating pairs of *Epiricania melanoleuca* (Fletcher) (Lep., Epipyropidae) affecting reproductive potential of the parasite. *Journal of Applied Entomology* **104**, 208–210.
- Mogal, B.H., Rajput, S.G. & Mali, A.R. (1983) Effect of relative humidity on hatching of sugarcane *Pyrilla* (*Pyrilla perpusilla perpusilla* Walker) eggs. *Indian Sugar* **32**, 773–774.

- Mohyuddin, I. & Hamid, A.** (1987) Effect of post harvest burning of sugarcane trash on the incidence of *Tetrastichus pyrillae* (Crawford.) an egg parasitoid of *Pyrilla perpusilla* (Walk.) in Sind. *Proceedings of the 23rd Annual Convention of Pakistan Society of Sugar Technologists, Rawalpindi*. July 25–27, 1987, 292–306.
- Mohyuddin, A.I., Rahim, A. & Irshad, M.** (1982) Studies on population dynamics of *Pyrilla perpusilla* (Walk.), its natural enemies in Pakistan and possibilities of its control. *Proceedings of the 18th Annual Convention of Pakistan Society of Sugar Technologists, Rawalpindi*. 4–5 September 1982, 157–171.
- Mukerji, S. & Venkataraman, T.V.** (1948) Study on *Epipyrops melanoleuca* Fletcher (Lepidoptera: Epipyropidae), an ectoparasite of the sugarcane leaf hopper, *Pyrilla* spp. (Homoptera: Fulgoridae). *Proceedings of the Zoological Society, Bengal* **1**, 91–102.
- Muliyal, J.A. & Lakshmanan, K.** (1942) The effect of conserving healthy and parasitized eggs of *Pyrilla* spp. in wire gauze cages, on the population of the pest and the parasites. *Indian Journal of Entomology* **4**, 221–223.
- Narayanan, E.S.** (1948) On the bionomics and life history of *Coniopteryx pusana* Witherby, a predator on the eggs of *Pyrilla* species. *Indian Journal of Entomology* **4**, 15.
- Narayanan, E.S.** (1953) Seasonal pests of crops. The mustard sawfly *Athalia proxima* Klug. a pest in the nurseries of the cabbage family. *Indian Farming* **3**, 8–9, 30–31.
- Narayanan, E.S. & Kundanlal** (1953) Studies on chalcid egg parasites of *Pyrilla* spp. occurring in Delhi. Part I Bionomics of *Tetrastichus pyrillae* Craw., *Agentaspis pyrillae* Mani and *Cheiloneurus pyrillae* Mani. *Indian Journal of Entomology* **15**, 173–179.
- Nasir, M.M.** (1947) Biology of *Chrysopa scelestis* Banks. *Indian Journal of Entomology* **9**, 177.
- Neupane, F.P.** (1976) Studies on the effectiveness of different insecticides against the nymphs of sugarcane leaf hopper *Pyrilla perpusilla* (Walk.). *Nepalese Journal of Agriculture* **6–11**, 131–137.
- Niceville, L. de** (1903) Notes on insect pests from Entomological Indian Museum. *Indian Museum Notes* **5**, 43.
- Nicol, D., Copaja, S.V., Wratten, S.D. and Niemeyer, H.M.** (1992) A screen of worldwide wheat cultivars for hydroxamic acid levels and aphid antixenosis. *Annals of Applied Biology* **121**, 11–18.
- Nigam, H.** (1983) *Rhopus fullawayi* Timberlake (Hymenoptera: Encyrtidae) – record of egg parasitoid of *Pyrilla perpusilla* Walker. *Indian Journal of Entomology* **45**, 32.
- Noyes, J. & Hyat, M.** (1994) *Oriental mealybug parasitoids of the Anagrini* 560 pp. Wallingford, UK, CAB International.
- Padmanabhan, S.Y.** (1947) *Fusarium* sp. parasitic on *Epipyrops*, a lepidopteraous parasite of the sugarcane *Pyrilla*. *Proceedings of the Indian Academy of Science* **26**, 77–92.
- Patel, R.M.** (1955) Protecting sugarcane from pests and diseases. *Farmer* **6**, 27–29.
- Patil, A.S. & Hapase, D.G.** (1992) Sugarcane pest management under drought conditions in Maharashtra. *Cooperative Sugar* **23**, 531–533.
- Pawar, A.D.** (1981) Sugarcane *Pyrilla* attacking rice, and its biological control in India. *International Rice Research News Letter* **6**, 17.
- Pawar, A.D.** (1987) Biological control of sugarcane pests in India. *Plant Protection Bulletin* **39**, 1–6.
- Pierce, W.D.** (1914) Description of two new species of *Strepsiptera* parasitic on sugarcane insects. *Proceedings of the Entomological Society of Washington* **16**, 126–129.
- Pophaly, D.J. & Marwaha, K.K.** (1988) Relative residual toxicity of some insecticides against *Pyrilla perpusilla* Walker infesting maize. *Journal of Entomological Research* **12**, 12–15.
- Pradhan, S. & Satpathy, J.M.** (1953) Comparative toxicity of different modern insecticides against some Indian crop pests. *Proceedings of the 40th Indian Science Congress, Lucknow. Part III, Section 10*, 151–152.
- Prasad, J., Singh, R. & Pawar, A.D.** (1988) Augmentation of *Epiricania melanoleuca* for the control of *Pyrilla perpusilla* in Western Uttar Pradesh. *Plant Protection Bulletin* **40**, 29–31.
- Prasad, S.N. & Butani, D.K.** (1957) Laboratory trials on the chemical control of sugarcane leaf hopper (*Pyrilla perpusilla* Walker) *Indian Journal of Sugarcane Research and Development* **5**, 167–169.
- Pruthi, H.S.** (1937) Report of the imperial entomologist. *Scientific Report of Agriculture Research Institute, New Delhi*. 1936–37, 159–174.
- Putman, R.J. and Wratten, S.D.** (1984) *Principles of ecology*. 388 pp. London, Chapman and Hall.
- Radha, K., Nirula, K.K. & Menon, K.V.P.** (1956) The green muscardine disease of *Oryctes rhinoceros* L. II – The causal organisms. *Indian Coconut Journal* **9**, 83–89.
- Rahim, A.** (1989a) Abiotic factors influencing development and longevity of *Tetrastichus pyrillae* Craw. (Hymenoptera: Eulophidae), an egg parasite of *Pyrilla perpusilla* Walk. *Pakistan Journal of Science and Industrial Research* **32**, 820–822.
- Rahim, A.** (1989b) Efficacy of different organophosphorous insecticides against sugarcane leafhopper, *Pyrilla perpusilla* Walk. (Fulgoridae: Hemiptera) outbreak in Sind, Pakistan. *Proceedings of the Pakistan Congress of Zoology* (1989) **9**, 15–18.
- Rahim, A. & Hashmi, A.A.** (1984) Biological control of *Pyrilla perpusilla* Walker in Sind, Pakistan. *International Pest Control* Sept–Oct. 1984, 124–126.
- Rahman, K.A.** (1940) Important insect predators of India. *Proceedings of the Indian Academy of Sciences, B*. **12**, 47–74.
- Rahman, K.A.** (1941) Parasites of the insect pests of sugarcane in the Punjab. *Indian Journal of Agricultural Science* **11**, 119–128.
- Rahman, K.A.** (1942) Sugarcane *Pyrilla*. *Indian Farming* **3**, 378–380.
- Rahman, K.A. & Nath, R.** (1940) Bionomics and the control of the Indian sugarcane leaf hopper *Pyrilla perpusilla* Wlk. (Rhynchota, Fulg) in the Punjab. *Bulletin of Entomological Research* **31**, 179–190.
- Raja Rao, S.A.** (1954) Control of *Pyrilla* on sugarcane in Bombay-Deccan. *Proceedings of the 2nd Biennial Conference of Sugarcane Research and Development. Workers. Part I*, 56.
- Rajak, R.L., Pawar, A.D., Misra, M.P., Prasad, J., Varma, A. & Singh, G.P.** (1987) Sugarcane *Pyrilla* epidemics 1985 – A case study. *Plant Protection Bulletin* **39**, 1–9.
- Rajani, V.G.** (1960) Some modern insecticides and their efficacy against insect pests of sugarcane in Uttar Pradesh. *Proceedings of the 4th all-India Conference of Sugarcane Research and Development Workers, Waltair* **1**, 41–42.
- Rajendra, A.** (1979) Insect pests attacking sugarcane in Sri Lanka and the parasites and predators recorded on them. *Ceylon Journal of Science (Biological Sciences)* **13**, 29–35.
- Rajput, S.G., Mali, A.R. & Mogal, B.H.** (1985) Efficacy of granular systemic insecticides against sugarcane *Pyrilla* (*Pyrilla perpusilla perpusilla* Walker). *Pesticides* **19**, 44–45.
- Richards, P.B.** (1938) Effect of stripping of dry leaves for prevention of damage by *Pyrilla* attack (U.P. 1935–38). *Agriculture and Livestock in India* **8**, 259–261.
- Sarup, P., Singh, D.S., Amarpuri, S. & Lal, R.** (1970) Persistent and relative residual toxicity of some important pesticides to

- the adults of sugarcane leaf hopper *Pyrilla perpusilla* Walker (Lophopidae: Homoptera). *Indian Journal of Entomology* **32**, 256–257.
- Scopes, N.E.A., Randall, R.E. & Biggerstaff, S.M.** (1975) Constant temperature ventilated perspex cage for rearing phytophagous insects. *Laboratory Practice*, January 1975 33–34.
- Sen, A.C.** (1948) The *Pyrilla* pest of cane in Bihar and its control by utilization of its natural parasites. *Indian Journal of Entomology* **10**, 45–50.
- Sharma, S.K.** (1977) Need to undertake aerial spraying to control *Pyrilla* on sugarcane. *Sugar News* **9**, 9–15.
- Sheikh, F.R.** (1968) Control of sugarcane pests by air in Mardan district during Kharif – 1964. *Agriculture Pakistan* **19**, 673–684.
- Singh, H. & Kalra, A.N.** (1951) Sugarcane *Pyrilla* (*Pyrilla perpusilla* Wlk.) a serious pest of sugarcane. *Proceedings of the 1st Biennial Conference of Sugarcane Research & Development Workers, Coimbatore, Pt. II*: 100–107.
- Singh, O.P. & Dayal, R.** (1975) Some observations on *Epiropyg melanoleuca* Fletcher, an ectoparasite of *Pyrilla*. *Cane Growers Bulletin* **2**, 13–14.
- Sinha, M.M., Shreevstava, Y.P. & Prasada, G.** (1974) *Pyrilla* epidemic in North Bihar during 1973. *Indian Sugar* **24**, 251–254.
- Srinath, D. & Patel, H.K.** (1968) The effect of temperature and relative humidity on the incubation period of eggs of *Pyrilla perpusilla* Walker. *coimbatorensis* Fennah. *Andhra Agricultural Journal* **15**, 174–175.
- Srivastava, A.S.** (1954) Important pests and diseases of sugarcane in Uttar Pradesh and their control during 1954. *Proceedings of the 23rd Annual Convention of the Sugar Technologists Association, India* **2**, 158–165.
- Stebbing, E.P.** (1903) Insect pests of sugarcane in India. *Indian Museum Notes* **5**, 86–87.
- Subba Rao, B.R.** (1957) The biology and bionomics of *Lestodryinus pyrillae* Kieff. (Dryinidae: Hymenoptera) a nymphal parasite of *Pyrilla perpusilla* Walk., and a note on its role in the control of *Pyrilla*. *Journal of the Bombay Natural History Society* **54**, 741–749.
- Subba Rao, B.R.** (1979) Taxonomic studies on some encyrtid genera (Hymenoptera: Chalcidoidea: Encyrtidae). *Oriental Insects* **13**, 139–148.
- Teotia, T.P.S. & Rajani, V.G.** (1964) Effective control of the sugarcane leaf hopper, *Pyrilla perpusilla* Wlk by fogging gamma BHC in Uttar Pradesh. *Indian Sugarcane Journal* **9**, 19–22.
- Tewari, R.K., Srivastava, S., Mathur, Y.K. & Upadhyaya, K.D.** (1990) Bioassay of different insecticides and pyrethroids against the adults of sugarcane leaf hopper *Pyrilla perpusilla* Walker. *Indian Journal of Entomology* **52**, 358–363.
- Trehan, K.N.** (1957) Brief notes on crop pests and their control in the Punjab (India). *Journal of the Bombay Natural History Society* **54**, 581–626.
- Varley, G.C. and Gradwell, G.R.** (1970) Recent advances in insect population dynamics. *Annual Review of Entomology* **15**, 1–24.
- Varma, A.** (1986) The *Pyrilla*, *Pyrilla perpusilla* Walker. pp. 277–295 in David, H., Easwaramoorthy, S. & Jayanthi, R. (Eds) *Sugarcane entomology in India*, India, Sugarcane Breeding Institute, Coimbatore.
- Varma, A., Avasthy, P.N. & Agnihotri, V.P.** (1977) Record of three entomogenous fungi on sugarcane leaf hopper *Pyrilla perpusilla* Wlk. *Science and Culture* **43**, 282–283.
- Varma, A., Tandan, B.K. & Singh, K.** (1990) A new record of *Entomophthora* sp. (Zygomycotina: Entomophthorales) on sugarcane leaf hopper *Pyrilla perpusilla* (Homoptera: Lophopidae) from Uttar Pradesh. *Journal of Biological Control* **4**, 125–126.
- Venkatraman, T.S.** (1929) *Report of Government Sugar Exports, Coimbatore, 1928–1929*, 145.
- Vevai, E.J.** (1942) *Pyrilla* control by conservation of egg parasites. *Indian Journal of Entomology* **4**, 235–236.
- Vickerman, G.P. and Wratten, S.D.** (1979) The biology and pest status of cereal aphids (Hemiptera: Aphididae) in Europe: a review. *Bulletin of Entomological Research* **69**, 1–32.
- Waage, J.K.** (1982) Sex ratio and population dynamics of natural enemies – some possible interactions *Annals of Applied Biology* **101**, 159–164.
- Wajih, I. & Hamid, S.** (1983) Control of sugarcane *Pyrilla* in Sind. *Pakistan Journal of Agricultural Research* **4**, 255–259.
- Williams, J.R., Metcalfe, J.R., Mungomery, R.W. & Mathes, R.** (1969) *Pests of sugarcane*. 568 pp. London, Elsevier Publishing Company.
- Withycombe, C.L.** (1925) *Memoirs of Department of Agriculture, India. (Entomology Series)* **9**, 1–20.
- Wratten, S.D. & van Emden, H.F.** (1995) Habitat management for enhanced activity of natural enemies of insect pests. pp. 117–146 in Glen, D.M., Greaves, M.P. & Anderson, H. (Eds) *Ecology and integrated farming systems*. London, Wiley.
- Wratten, S.D., Elliott, N.C. & Farrell, J.A.** (in press) Wheat. in Dent, D. (Ed.) *Integrated pest management*. London, Chapman and Hall.
- Yadav, H.N. & Sharma, S.P.** (1977) A new record of *Ooencyrtus* spp. (Encyrtidae) as a parasite of *Epiricania melanoleuca* Fletcher. *Indian Sugar Crops Journal* **4**, 98.
- Yadav, R.P.** (1983) *Bionomics, effectiveness and basic requirements for mass multiplication of common egg parasitoids of *Pyrilla perpusilla* Walker*. PhD thesis, Haryana Agricultural University, Haryana, India, pp. 198.
- Yadav, R.P. & Chaudhary, J.P.** (1984) Laboratory studies on biology of *Ooencyrtus papilionis* Ashmead (Hymenoptera: Encyrtidae), an egg parasitoid of the sugarcane leaf hopper (*Pyrilla perpusilla* Walker). *Journal of Entomological Research* **8**, 162–166.
- Yadav, R.P. & Chaudhary, J.P.** (1986) Longevity and development of the egg-parasitoid, *Cheiloneurus pyrillae* (Hymenoptera: Encyrtidae) at different combinations of temperature and relative humidity. *Entomophaga* **31**, 107–111.
- Yadav, R.P. & Chaudhary, J.P.** (1988) Studies on the combined effects of constant temperature and relative humidity on progeny production and sex ratio of *Cheiloneurus pyrillae* Mani, an egg parasitoid of *Pyrilla perpusilla* Walker. *Beitrag zur Entomologie* **38**, 233–238.

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