REVIEW

SUGARCANE ROOT BORER *POLYOCHA DEPRESSELLA* SWINHOE: AN OVERVIEW

J. Srikanth*, R. Jayanthi and K.P. Salin

Abstract

Polyocha depressella Swinhoe (=*Emmalocera depressella* (Swinhoe)) (Lepidoptera: Pyralidae) is the only species of borer infesting the underground portion of sugarcane and, hence, referred to by its common name root borer or rootstock borer. Generally considered a minor pest of sugarcane in India, it occurs more predominantly in the subtropical north Indian sugarcane belt, Gujarat, Maharashtra, Karnataka and Andhra Pradesh. After its first report of occurrence in Tamil Nadu in 1990, it remained either dormant or unnoticed for a couple of decades and started re-emerging in the early part of 2015. Despite its more or less pan India distribution, much of the earlier work was restricted to the north Indian sugarcane belt due to its persistent occurrence and more serious damage. In this overview, the work carried out on root borer in subtropical India so far is reviewed and notes on its occurrence in the southern states are presented. Besides, the possible causes for its occurrence, research priorities needed and provisional control measures to be adopted in tropical India are outlined.

Key words: Sugarcane, root borer, *Polyocha* (=*Emmalocera*) *depressella*, tropical India, management, overview

Introduction

Root borer *Polyocha depressella* Swinhoe (=*Emmalocera depressella* (Swinhoe)) (Lepidoptera : Pyralidae) had been placed in the guild of minor moth borers of sugarcane in India, albeit with the tag 'relatively important' attached to it, by Avasthy and Tiwari (1986). Although these workers outlined the taxonomy of the species in detail and the borer was referred to as *E. depressella* as the valid name for long, recent literature (Beccaloni et al. 2003; CAB Thesaurus 2014; EPPO 2015) indicates *Polyocha depressella* Swinhoe as the preferred name. It is the only species of borer infesting the underground portion of canes and, hence, generally referred to as 'root borer' (Avasthy and Tiwari 1986). The term itself, however, is a misnomer since the larva in any stage does not or cannot bore into the root system.

Geographical distribution

With a predominant or restricted presence in Asia, the pest was described as the most destructive of the insects that attack the underground parts of sugarcane in India and Pakistan (Cheema 1953a). Besides, Gotterell (1954) reported it from Afghanistan and Avasthy and Tiwari (1986) included Malaysia and Bangladesh, besides Pakistan, in its geographical range.

In India, it occurs on sugarcane in the north Indian sugarcane belt, northern areas of Gujarat, Maharashtra, Karnataka and Andhra Pradesh states (Avasthy 1967); it was noted as a pest of rare occurrence in Assam (Anonymous 1936). Extensive surveys in subtropics indicated that Yamunanagar of Haryana and Muzaffarpur of Bihar were more prone to attack than Haryana (Anonymous 1993).

J. Srikanth*, R. Jayanthi and K.P. Salin
Section of Entomology, Sugarcane Breeding Institute, Coimbatore - 641 007, India
*email : srikanth_jsk@yahoo.co.in

The borer was recorded in West Nimar Valley of Madhya Pradesh (Das and Veda 2005). The reports of Jayanthi and David (1990), Alagesan et al. (1990) and Anonymous (1993) constitute the first records of occurrence and observations on the borer in Tamil Nadu state. Despite its more or less pan India distribution, much of the earlier work was restricted to the north Indian sugarcane belt due to its persistent occurrence and more serious damage. In this paper, the work carried out on root borer in subtropical sugarcane belt of the country is reviewed and notes on its occurrence in the southern states are presented. Besides, an overview of the causes for its occurrence, research priorities and provisional control measures for tropical India are outlined.

Damage and losses

Symptoms of attack

Very early observations on damage indicate that root borer attacks sugarcane in the early stages (Pruthi 1937) when the crop is 2-4 months old and causes damage throughout the year (Isaac 1939; Anonymous 1943). Deadhearts are produced in the young crop which, though resemble those produced by shoot borer, cannot be pulled out (Khan and Singh 1942). The deadheart does not emit any offensive smell and often one or two leaves adjacent to the central leaf whorl also dry up. There is only one entry hole near the base of the shoot (Rahman and Singh 1942; Cheema 1948). In early April, the newly hatched larvae crawl down and bore into the base of young plants about 2.5" below ground level resulting in drying of the central spindle in about 17 d and the entire plant in 37-43 d. After July, the larvae attack side tillers more frequently than the main or mature side shoots making one to seven holes in the internodes below ground level and sometimes disperse from one shoot to another (Cheema 1953a). Attack in the later stages of crop leads to yellowing of leaves in the post-monsoon period and this yellowing is due to the obstruction of free flow of nutrients from roots to leaves (Pannu et al. 1990).

Attack rates

Infestation rates by root borer ranged 3.2-11.55% in 1933-34 (Isaac 1936) but the economic loss due to the borer was very small in the crop season of 1934-35 at Pusa (Pruthi 1936). In Uttar Pradesh (U.P.), the incidence of the borer in millable sugarcane over a decade averaged 23.9% (Gupta et al. 1966). Variable infestation rates were recorded in Karnataka (3.16%), Tamil Nadu (1.0-11.6%) and Gujarat (12.3%) (Anonymous 1993).

Yield losses

Among the five generations examined in April, May, June, July and September, larvae of the first generation killed all shoots attacked but those of the last generation had no apparent effect on the weight of the cane. Attack in the second, third and fourth generations reduced cane length by 66.2, 14.3 and 5.2% and cane weight by 73.0, 17.0 and 6.5%, respectively (Cheema 1953a). In U.P., affected canes suffered an average loss of 4.6% in length, 1% in internode diameter and 2% in number of internodes. The average loss in weight of millable canes at the 100% level of incidence was estimated to be 2.5%, the maximum loss being 12% (Gupta et al. 1966). Although heavy infestations of the borer in eastern U.P. resulted in cane yield losses of up to 70% (Khanna and Sharma 1969), lower cane yield reduction of up to 10% was also observed (Anonymous 1993). In south Gujarat, root borer reduced cane length by 11.72-18.58, 4.76-21.19, 4.60-10.78, 8.20-15.43 and 7.87-11.63% and cane yield by 6.93-20.65, 2.50-25.47, 0.72-2.75, 3.16-34.20 and 4.62-4.83%, respectively in the varieties CoC 671, Co 8338, Co 6806, Co 6304 and Co 62175

(Pandya et al. 1996a). Studies during 1990-91 showed that reduction in weight of canes infested only with the borer averaged up to 4% whereas weight loss in canes infested with the borer and infected with root rot fungus *Fusarium* averaged 36.7-62.5% (Sardana 1993). Subsequent studies too indicated that there was no significant reduction in cane weight and juice quality in later stages of the crop growth due to root borer attack alone. However, wilt and root borer-wilt complex together affected cane yield and quality significantly (Sardana et al. 2000).

In two-year field experiments in Pakistan, the linear association between cane height and root borer population was not significant though the borer, together with two other borer species, contributed to 36% variation in cane height (Ansari and Arain 1997).

Quality losses

Canes attacked by the borer were heavier and contained more sucrose than uninfested ones in one year but the weight of infested canes was less than that of the uninfested ones and the sucrose content was greater only in some test varieties (Pruthi and Narayanan 1939). Infestation in the last four generations reduced sucrose, total solids and purity coefficient (Cheema 1953a). An average increase of 0.16 units in sugar recovery due to the attack, the cause of which was not known, was observed (Gupta et al. 1966). Reduction in sucrose percentage in the juice by about 0.3% was observed (Anonymous 1993). However, juice quality was affected more by combined borer infestation and wilt infection than by infestation alone (Sardana 1993).

In field tests on susceptibility of selected varieties in Pakistan, root borer infestation significantly reduced total soluble salt or solutes (9.98%), sucrose (10.32%), commercial cane sugar (10.29%) and glucose (30.00%) contents and increased fibre content (6.65%) in affected canes (Ansari et al. 1994).

Host plants

Besides cultivated varieties of sugarcane, root borer has been reported to survive on several alternative hosts (Table 1) in subtropical sugarcane growing states of the country whereas no such information is available with respect to the tropics. However, in large-scale monocultures of sugarcane, alternative hosts represent occasional deviations under the exceptional condition of scarcity of main host and play less than minimal role in the survival of the borer. Alternative hosts will be of even less significance in tropical sugarcane belt due to the greater spatial and temporal continuity of the crop.

Biology

Moths emerge during the early morning hours and mating occurs in the early hours of night. Eggs are laid singly on the upper and lower surfaces of the leaves (Fig. 1) along the midrib and rarely on the stem. The neonate larva crawls to the base of the stem and enters by making a single hole at or just below the ground level. The larva feeds in an irregular semi-circular pattern. Prior to pupation, the larva cuts an opening to the exterior and constructs a silken tube up to the surface of the soil in line with the tunnel to ensure easy emergence of the adult. Often pupation occurs in the silken tube outside the cane. Larvae hibernate during October-February (Cheema 1953b). Descriptions of various life-stages (Fig. 1) and life-history parameters of the borer studied by various workers were compiled and presented in considerable detail by Avasthy and Tiwari (1986). In later studies on biology carried out at Navsari in south Gujarat, fecundity of females

Table 1. Alternative host plants of sugarcane root borer *Polyocha depressella* in India

Host	Locality	Reference
Andropogon sorghum	Haryana	Sardana (1999a)
Erianthus munja Roxb.	Bihar, Punjab	Nair et al. (1971)
Erianthus sara Aitch.	Punjab	Nair et al. (1971)
Pennisetum purpureum Benth.	Punjab	Nair et al. (1971)
Saccharum ravennae L.	New Delhi	Isaac (1941)
Saccharum spontaneum L.	Bihar, Punjab	Nair et al. (1971)
Sclerostachya fusca (Roxb.) A. Camus	Bihar	Nair et al. (1971)
Sorghum halepense Pers.	Punjab	Nair et al. (1971)
Sorghum vulgare Pers.	Punjab	Nair et al. (1971)

ranged 200 - 325 eggs. Egg, larval, pre-pupal and pupal stages lasted 5-7, 57-96, 1-2 and 9-11 d, respectively. After nine larval instars, pupation took place in the damaged portion of the cane (Fig. 2). The longevity of male and female adults was 4-9 and 4-12 d, respectively with a ratio of 1:1.1. While

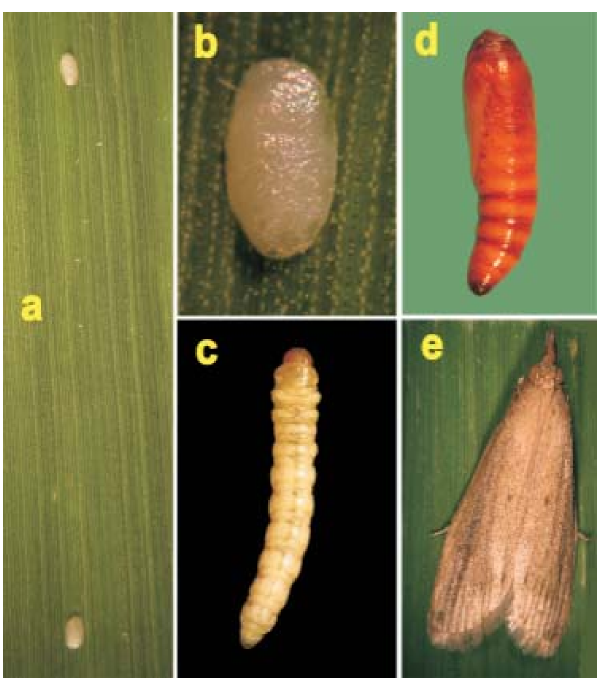

Fig. 1. Life stages of sugarcane root borer *Polyocha depressella*: (a) singly laid eggs on leaf lamina (b) single egg (c) grown-up larva (d) pupa (e) moth

the pre-oviposition, oviposition and post-oviposition periods ranged 1 - 3 d each, total life period from egg to adult ranged 76-120 d (Pandya et al. 1996b).

Root borer attacked the crop in the germination, tillering, growing and maturity stages and larvae pupated in March. Adults emerged by the end of March/beginning of April. Mating began in the early hours of night and continued until early morning. The durations of pre-mating, mating and post-mating periods ranged 17.12 - 19.00 h, 18.50 - 27.50 min and 7.25 - 8-75 d, respectively. The duration of the pre-oviposition, oviposition and post-oviposition periods ranged 3.46 - 4.00, 3.25 - 4.25 and 1.25 - 1.50 d, respectively. Maximum fecundity (270.5 eggs) was observed in the second generation. Incubation period was 4.26 - 7.86 d with an average of 65.49% hatchability. Larvae passed through five instars and the duration of the total larval period was 27.0 - 39.8 d. The duration of the pupal period was 7.41 - 10.74 d. Males were shorter lived than females. The duration of the life cycle was 56-73 d. Three generations per year in U.P. and five in the Indian Punjab were observed (Singh et al. 1996a).

The larvae entered into hibernation between 20th November and first week of December during 1993-

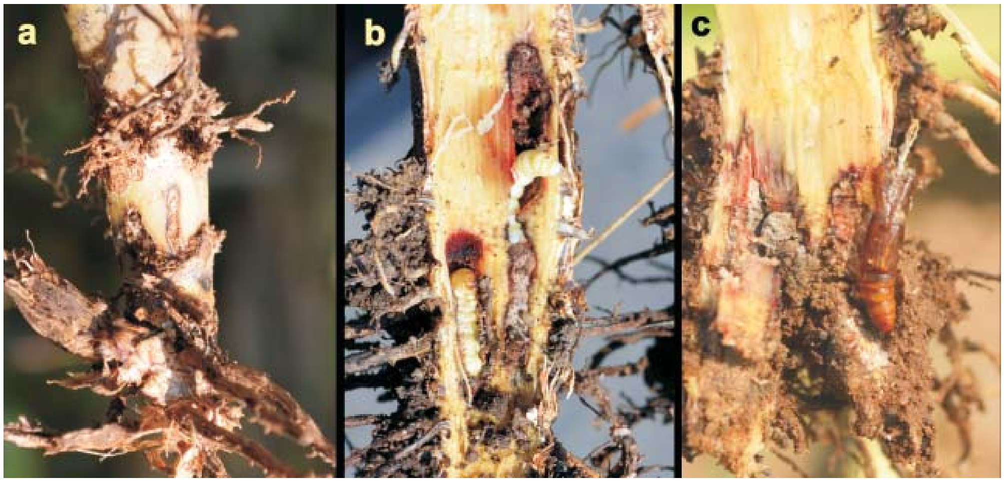

Fig. 2. Damage symptoms and stages of root borer *Polyocha depressella* in late stage sugarcane: (a) external bore holes on cane surface (b) internal tunnels with larvae (c) pupal case in damaged cane

94 in Karnal. About 80% of the larvae in tunnels were found with their heads upwards at an average depth of 3.4 cm. The average length of the tunnel was 5.8 cm with a maximum of 13.0 cm. Infection by pathogens, predation, irrigation and mechanical injury of stalks caused larval mortality (Sardana 1996a). After hibernation during December-March, root borer passes through four overlapping generations. Adults emerge in April and mate in the evening hours. Maximum number of eggs was laid at 27°C. While the incubation period ranged 7-12 d and 5-8 d, pupal period ranged 7-18 and 8-12 d at 27 and 33°C, respectively. At temperatures below 15°C, adults laid very few eggs which did not hatch and pupae did not develop (Sardana 1998a).

Ecology

Seasonal dynamics

At Pusa, root borer was very active from the beginning of May to mid-June, a period when other borers were rendered almost inactive by the hot weather (Fletcher 1932). The borer was reported to cause serious damage during April-September (Isaac and Misra 1933). Following first adult emergence in March and oviposition soon after, deadhearts first appeared in April and reached their peak in June or July. The activity decreased during the monsoon months but increased again soon after the rains. Deadhearts caused by root borer were comparatively few in winter (Pruthi and Narayanan 1938). At Kanpur, the borer was scarce during January-February (Anonymous 1942). In Haryana, the population remained low during May-June and peaked during July-October (Sardana 1995 and 1997a). Light trap studies (1998-2000) in Haryana revealed adult emergence and borer activity during April-November with four peaks of adult moth catches which indicated four broods of the borer in a year. Incidence in the field with light traps was lower than that in the field without light traps in both years and it peaked during October - November in both fields. The incidence varied from 1.0% (January - March) to 17.1% (November) during 1998-99 and from 0.7% (April) to 12.1% (November) during 1999-2000 (Sardana 2001a).

In a six year (1989-94) study on population dynamics of the borer using light traps at Navsari, Gujarat, adult activity was observed more or less throughout the year with the highest numbers of adults captured during the second half of September. The study indicated three peak periods of adult emergence, i.e. March, May-June and September-October in a year (Pandya et al. 1996c). The borer was observed throughout the year in extensive surveys carried out in Gujarat during 1992-1995 (Pandya et al. 1995 and 1996d). In population dynamics studies from January 1995 to December 1996 using light traps, adults were caught throughout the study period, except in the second fortnight of March 1995, and first and second fortnights of November and December 1996. In 1995, the pest was active from January to December with a population peak in the second fortnight of September. In 1996, pest activity was observed from January to October with a population peak occurring in the first fortnight of September (Pandya et al. 1998). In further studies in Gujarat, the borer was observed throughout the cropping season (Pandya and Patel 2007a).

In regular surveys (2001-2004) conducted in 16 sugar mills located in nine districts of Punjab, root borer, along with early shoot borer, white grub and whitefly, was considered a localized pest and September was the right time to conduct surveillance for the borer (Mann et al. 2006a). In light trap studies in Pakistan, root borer populations peaked during fourth week of August (Rana et al. 1992).

Light trap monitoring studies at Coimbatore showed low moth catches in two different years which indicated negligible pest occurrence in the area (Jayanthi et al. 1992; Jayanthi and Salin 1993).

Density independent factors

The borer was active at high temperatures and moderate humidity levels and tolerant to rain to an extent of 45 cm after which its population declined (Gupta, 1953). Maximum temperature showed a significant positive correlation with the relative proportion of the borer (Tanwar and Bajpai 1993). In Haryana, borer activity during 1992-93 showed significant negative correlation with maximum temperature and positive correlation with RH. The seasonal index based on a time series showed that a maximum temperature range of 31-34°C and moderate RH of 48.2-78.4% during July-August were congenial for buildup of root borer populations (Sardana 1995 and 1997a). The variation in the highest incidence (40.0 - 90.9%) in different years and different genotypes at Karnal, during 1997/98-2000/01, led to the suggestion that borer attack during post-monsoon was dependent upon the climatic conditions during the monsoon/summer months (Singh and Madan 2001). Light trap studies in Pakistan indicated that average maximum temperature of 34-37°C, minimum temperature of 20-27°C and RH of 52-70% were conducive to building up borer population levels (Rana et al. 1992).

Density dependent factors

The earliest report of *Trichogramma chilonis* Ishii (= *Trichogramma minutum* Riley) on root borer at Pusa (Table 2) documented egg parasitism rates of 3-4% until the end of May and 40% in June with usually three parasitoids per egg (Pruthi 1936).

Trichogramma intermedium Howard reported on eggs of root borer as a first record in India (Pruthi 1940) was considered a synonym of *T. minutum* (Begum and Anis 2014), all of which are regarded as *T. chilonis* (Nagarkatti and Nagaraja 1979). In the Punjab, two unidentified species of *Trichogramma* were bred from eggs of root borer and other borers (Rahman 1941). *Trichogrammatoidea bactrae* Nagaraja was recorded from root borer, besides other hosts (Nagarkatti and Nagaraja 1977), as the only species of the genus to have been reared in the laboratory from sugarcane borers but considered not very

Table 2. Hymenopteran parasitoids recorded on sugarcane root borer *Polyocha depressella* in India

Family	Parasitoid species	Reference
Trichogrammatidae	*Trichogramma chilonis* Ishii	Pruthi (1936); Pruthi (1940)
	Trichogrammatoidea bactrae Nagaraja	Nagarkatti and Nagaraja (1977); Nagarkatti (1980)
Aphelinidae	*Encarsia udaipuriensis* (Shafee)	Hayat (1989)
Bethylidae	*Goniozus indicus* Mues.	Pruthi (1941)
Braconidae	*Ascogaster* sp.	Rahman (1941)
	Chelonus sp.	Rahman (1941)
	Phanerotoma hendecasiella Cam.	Pruthi (1940)
	Rhaconotus scirpophagae Wlkn.	Rahman (1941)
	Stenobracon deesae Cam.	Pruthi (1936); Isaac (1937); Narayanan (1938); Rahman (1941)
Chalcididae	*Neohybothorax* sp.	Sardana (1994b)
Ichneumonidae	*Mesostenoideus emarginatus* Walker	cited in Avasthy and Tiwari (1986)

important as a control agent (Nagarkatti 1980). The aphelinid *Encarsia udaipuriensis* (Shafee) was described using specimens obtained from eggs of *P. depressella* (Hayat 1989).

Among the braconid larval parasitoids recorded by various workers (Table 2), and later compiled by Box (1953), *Stenobracon deesae* Cam. parasitized root borer larvae to a level of 3-4% up to the end of June at Pusa during 1934-35 (Pruthi 1936). During 1935-36, parasitism rates of *S. deesae* in sugarcane fields, where the adults were seen in small numbers from the last week of April to the beginning of July, varied from 3 to 5% (Narayanan 1938). In a much later study, 10 species of braconinae parasitoids had been reported attacking lepidopteran pests of rice including *E. depressella* (Haris and Ahmad 2002).

At Pusa, *S. deesae* parasitism was followed by an unidentified bethylid to the tune of 10% but only in winter when the cane was already damaged (Pruthi 1936). The bethylid *Goniozus indicus* Mues. was later reported from the borer at Delhi (Pruthi 1941). In Gujarat, *Goniozus* sp. showed maximum parasitism during 1993-94 (24.42%) and minimum during 1995-96 (10.71%); average natural parasitism during the years of study was 18.35% (Bhatt et al. 1996).

Among other natural enemies, the chalcidid *Neohybothorax* sp. was found parasitizing the borer in Karnal as a first record in India (Sardana 1994a). The entomopathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* were isolated from larvae of the borer (Sardana 1997b).

Dispersion and sampling plans

The borer followed a negative binomial distribution pattern in the field (Sardana 1994b). Eggs of four broods of the borer on four varieties, viz. Co 89003, CoJ 64, Co 1148 and Co 7717 followed a negative binomial series in most cases. Dispersion statistics also indicated clumped to random pattern and the contagious distribution of eggs was ascribed to environmental heterogeneity (Sardana 1996b). Amongst the different transformations used to stabilize variance for egg counts of the borer, x+1 and log[log(x/2)] showed non-significant correlation coefficients and rendered the variance independent of the mean (Sardana 1997c). A sample size of 40 shoots was sufficient for estimating damage by the borer on sugarcane in Punjab State (Singla and Duhra 1991).

Agronomic factors favoring buildup

The borer was especially injurious in ratoon crops at Pusa (Isaac and Misra 1933); crops planted in October and ratoon crops were more severely attacked by borers than those planted in February and were a source of infestation for the latter (Pruthi 1936). Generally, the ratoon was more infested than the plant crop and increase in its acreage led to the build-up of root borer population. Moreover, borer incidence and population were generally high in unirrigated fields and in sandy or sandy loam soils (Gupta and Avasthy 1952). In western U.P., Haryana and Bihar, varieties Co 89003 and CoJ 64 were comparatively more infested during the early stages of crop growth. There was an appreciable increase in the incidence of the third generation (Anonymous 1993). In Tamil Nadu, infestation occurred mainly in Co 8021 and Co 7704 but CoC 671 was somewhat less affected (Alagesan et al. 1990). Heavy soil retarded borer activity but water-logging and flood conditions had no effect on it (Anonymous 1943). Infestation was most pronounced in light soils in drought-prone areas and in plots planted and ratooned in March-May (Alagesan et al. 1990).

Organic matter, total nitrogen and available sulfur content showed significant negative influence on root borer infestation level whereas pH, available phosphorus and exchangeable potassium did not show any significant effects on this pest in studies in Bangladesh. Based on the results, addition of organic matter, lime and sulfur was suggested to reduce root borer infestation (Kundu et al. 1994).

Disease association

In a six year (1989-90 to 1994-95) study in southern Gujarat, a highly significant positive correlation between root borer and disease incidence was observed in wilt affected farmers' fields with Chi square values of 34.02 – 55.00 and coefficient of correlation of 0.50 - 0.60 in different years (Pandya et al. 1996e). Studies on root borer and wilt at Karnal indicated that association between the two biotic stresses existed in varieties which were prone to wilt and root borer attack (Sardana et al. 2000). Root borer, with other biotic stresses such as internode borer and red rot, was observed to act as a pre-disposing factor in aggravating the build-up of wilt disease (Viswanathan et al. 2006). Field survey and field and laboratory experimentation indicated that wilt and root borer incidence were positively correlated. While root borer infestation in wilted canes ranged 76.48-100.00% during different years, only 23.33-44.54% of root borer infested canes showed wilt symptoms. Root borer was able to carry the wilt pathogen and induce symptoms in next year's ratoon crop. Wilt did not affect the root borer larval development as the larvae reared on healthy canes and wilt infested canes weighed statistically similar (Mann et al. 2006b).

Control measures

Cultural and mechanical methods

Removal and destruction of deadhearts, avoidance of ratooning, collection and burning of stubble and trash after harvest, and trapping adults on dark nights by hurricane lanterns hung over pans of water covered with a film of kerosene are some cultural and mechanical control measures recommended (Isaac and Misra 1933). Similar cultural means of control were recommended in the compilation by Avasthy and Tiwari (1986). In Haryana, an irrigation interval of 10 d was most effective followed by intervals of 20 and 30 d in reducing the incidence of shoot borer and root borer in a ratoon crop. Higher numbers of millable canes and cane yield/ha were obtained with an irrigation interval of 10 d than with an interval of 30 d. There were no significant differences in sugar recovery values amongst the different irrigation intervals (Mrig et al. 1995). In two study years, i.e. 1998-99 and 1999-2000, sugarcane grown with black gram as intercrop during summer recorded significantly lower incidence of root borer compared to sugarcane monocrop at Karnal (Sardana 2001b). Coriander intercrop in autumn planting suppressed second brood population of root borer in field trials that involved two plant and one ratoon crops (Sardana and Misra 2003).

Varietal resistance

Five varieties commonly grown in north Bihar were ranked in the order of increasing susceptibility to root borer as Co 299, Co 313, Co 210, Co 213 and Co 331 at Pusa during the sugarcane season of 1935-36 (Pruthi and Narayanan 1938). The varieties Co 307, Co 312, Co 313, Co 320, Co 321, Co 346, Co 348, Co 354, Co 356, Co 419, Co 421, Co 453, Co 552, Co 557, Co 617, Co 638, Co 639, Co 643, Co 644, CoS 109, BO 3, BO 10, BO 34 and BO 54 were listed as harbouring low infestation of the borer (Avasthy and Tiwari 1986). Early and midlate varieties screened for reaction to the borer in southern Gujarat during 1989-91 revealed that Co 6808 was the least susceptible, Co 6304, Co 7527, CoA 7602, Co 7910, Co 8021, Co 8320, Co 8323, Co 85014, Co 85018 and Co 85246 were moderately susceptible, and CoC 671 and Co 8136 were susceptible (Patel et al. 1996a). At Kantali in southern Gujarat, Co 6806, Co 8105, Co 8338 and Co 8341 showed the lowest susceptibility (<6.79%) among the eight early varieties tested. Among the nine mid-late varieties tested, two were rated susceptible (>14.65%) and seven moderately susceptible (6.79 - 14.65%) (Patel et al. 1996b).

Of the 41 sugarcane genotypes screened for multiple resistance to major borer pests during 1993-94 and 1994-95, the three genotypes NG 77-159, IK 76-84 and IK 76-166 showed relative multiple resistance/ tolerance to major borer pests including early shoot borer, stalk borer, top borer and root borer (Sardana 1998b). In a study on the field reaction of 14 interspecific hybrid (ISH) clones of *Saccharum officinarum*, *S. barberi*, *S. robustum* and *S. spontaneum* to major borer pests during 1996-97 and 1997-98 at Karnal, some clones showed low incidence of individual borer pests; clone ISH 123 had low incidence of all the borer pests (Sardana 1999b).

Among the 26 genotypes tested in Haryana for two years, CoH 89, CoH 84, S 87/256 and CoH 56 that showed mean larval population of 10-20 thousand larvae/ha and root borer incidence of 20.0-27.8% were categorized as moderately resistant; Co 1148, Co 7717, S 86/46, S 85/94 and S 85/314 with 121.60-180.0 thousand larvae/ha and 62.45-67.40% incidence were categorized as highly susceptible (Singh et al. 2001). Of the 93 genotypes tested at Karnal, none was tolerant to root borer, 21 (22.6%) were moderately tolerant, 32 (34.4%) were susceptible and 40 (43.0%) were highly susceptible (Singh and Madan 2001). In field trials with promising clones/varieties against borer pests in three cropping seasons, root borer infestation was observed to be higher in UP 01105 (10.44%) followed by UP 01104 (9.22%) and CoP 02181 (9.21%) (Hari Chand et al. 2010).

Biological methods

In one of the earliest observations on biological control of the borer, mass liberations of *T. chilonis* made against another borer near Sugauli in north Bihar indicated reduced infestation by not only the target pest but also root borer (Isaac 1941). In field liberations of *T. chilonis* against moth borers in Bengal, there was no initial egg parasitism of root borer or stem borers. However, parasitism rates in root borer increased from 21.85% in August to 28.68% in October in release plots as compared with 5.5 and 0%, respectively in the controls; in stem borers, parasitism levels increased in both release and control plots. The average yield from the release plots was almost a third greater than that from the controls (Pruthi 1946). In Gujarat, release of *T. chilonis* at 60,000/ha starting from 45 DAP up to harvest at an interval of 10 days gave encouraging results in reducing the incidence of borers including root borer (Pandya 1997a). However, some earlier observations from UP and Bihar (Avasthy and Tiwari 1986) and later studies in Haryana (Sardana 2000a) indicated the ineffectiveness of *T. chilonis* releases against root borer. Large-scale inundative releases of *T. chilonis* under area-wide control programme kept three borers including root borer below economic threshold levels in Pakistan (Ashraf and Fatima 1996).

In biological studies on *S. deesae*, larval period in the host lasted 22-25 d and pupal period 10 d during monsoon months. Adult females lived for 36 h if unfed but lived for 7-10 d if fed on sugar solution; males died within 36 h even if fed (Narayanan 1938). *Trichogramma chilonis* and *S. deesae* were observed to provide a low degree of biological control (Khanna and Sharma 1969). *Campyloneurus mutator* (F.) (Hymenoptera: Braconidae), recorded on the larvae of stalk borer near Gauhati, Assam, failed to parasitize root borer when various borer species were tried as hosts (Saxena 1967).

In biological control attempts with exotic parasitoids, the Cuban fly *Lixophaga diatraeae* (Tns.) (Diptera: Tachinidae) did not parasitize root borer in the laboratory (Saxena and Dayal 1965). A strain of *L. diatraeae* that was obtained from Formosa in 1963-64 attacked a much smaller percentage of root borer larvae than some other sugarcane borer larvae when maggots dissected from gravid females were exposed to them (Jai Rao 1967).

A root borer isolate of the entomopathogenic fungus *B. bassiana* at 10^7 spores/ml caused 100% mortality of the borer with a shorter incubation period than shoot borer isolate in laboratory studies (Easwaramoorthy and Santhalakshmi 1993). In field studies, however, *B. bassiana* application did not reduce the incidence of root borer considerably (Sardana 2000a). Laboratory studies indicated the suitability of 3-6% molasses, rice, chopped carrots, pressmud and gingelly cake for mass production of root borer isolate of *B. bassiana* (Abraham et al. 2003).

Behavioural methods

In preliminary work on pheromone of root borer, attempts to extract sex pheromone from virgin females using the 'aerial method' suggested by the Regional Research Laboratory, Trivandrum (Jayanthi et al. 1992), or evaluation of rubber septa impregnated with crude pheromone extracts from abdominal tips of virgin females for moth catch efficiency (Jayanthi and Salin 1993) did not yield desired results.

Chemical methods

In very early attempts to control root borer and shoot borer at Sriganganagar, Rajasthan, soil treatments with aldrin or γ BHC (lindane) at sowing followed by post-germination sprays of DDT, BHC, isobenzan, phosphamidon, endrin and parathion in various combinations enhanced root borer numbers abnormally in treated plots, though shoot borer populations were slightly reduced (Khan and Joshi 1969). Application of γ BHC had a beneficial effect on germination in late-planted crop, apparently due to the protection afforded to setts against termites, root borer and top borer (Singh and Kumar 1979).

In later experiments in Haryana, two doses of carbofuran and phorate gave lower incidence (23.8 and 21.8%) of root borer than their recommended or higher doses at the end of June (33.4 and 32.3%) or July (26.5 and 25.6%, respectively) (Mrig and Chaudhary 1992). In further studies, γ-HCH [lindane] and heptachlor each at 1.25 kg a.i./ha, aldrin at 1.0 kg a.i./ha and endosulfan at 0.5% kg a.i./ha as emulsions, carbofuran at 1.0 kg a.i./ha and phorate at 2.0 kg a.i./ha as granules, and HCH at 5 kg a.i./ha as dust applied during April against shoot borer did not produce any beneficial effect in controlling root borer (Mrig and Chaudhary 1993).

In field efficacy studies at Karnal, heptachlor 20EC, chlordane 20EC and quinalphos 5G at 1.0 kg a. i. ha^{-1} were superior to other insecticides; cartap-hydrochloride 4G, ebuphos 10G and chlorpyrifos 20EC also reduced incidence. The incidence of the borer was significantly less when insecticides were applied twice, i.e. at planting (pre-monsoon) and the end of August (post-monsoon) than when applied at one of the two stages (Singh et al. 1996b). In contrast, field studies during 1990-95 with seven insecticides indicated their ineffectiveness at the concentrations tested; increased incidence of the pest was observed in some of the treatments (Sardana 1996c). In Gujarat, phorate 10 G at 1 kg a.i./ha applied three times recorded minimum incidence of root borer, and other borers and scale insect (Pandya 1997b).

At Karnal, fipronil (Regent) 0.3 G and 5 SC at 200 g a.i./ha reduced the incidence of the borer more significantly than the standard Sevidol 8G or Furadan 3G or chlorpyrifos 20 EC. Neither liquid nor granular formulations were observed to cause phytotoxic symptoms in sugarcane plant. Regent application did not affect cane thickness and juice quality significantly but led to higher cane yields when sprayed at 200 g a.i./ha (Sardana 2001c). In further studies, imidacloprid (0.05 kg/ha), carbofuran (1.5 kg/ha) and neem seed kernel extract (NSKE) (10%) significantly reduced root borer incidence. In one of the study years, only imidacloprid was effective in reducing the incidence (Sardana 2001d).

In a comparative field efficacy trial of insecticides, chloropyrifos 20 EC was superior with highest germination (36.33 - 38.00%), lowest cumulative incidence (8.94 - 7.11%) and highest yield (77.33 - 79.77 t/ha) followed by imidacloprid 17.8 SL, the corresponding figures being 35.33- 36.16%, 10.88- 9.78% and 76.00 - 77.66 t/ha, respectively (Kumar et al. 2011).

Five botanical products evaluated in the field in Bangladesh reduced white grub population and infestation caused by borers including rootstock borer. Tobacco plant powder at 100 kg/ha applied in March, April and August showed the highest efficacy of 40.49% in controlling the rootstock borer infestation (Abdullah et al. 2006).

Integrated management

Cultural, mechanical or chemical measures recommended against shoot borer were suggested to effectively control root borer (Khanna and Sharma 1969). A two-year study at Karnal indicated that root borer population could be managed only by adopting various techniques like flooding of fields, use of light traps, application of imidacloprid insecticide and release of the biological control agent *T. chilonis* together/or in a sequential manner (Sardana 2000b). In Navsari, Gujarat, a maximum protection treatment comprising sett treatment with 0.1% dimethoate; 1 kg carbofuran/ha at 30 d after planting (DAP) and 1 kg phorate/ha at 60 DAP; 0.075% endosulfan at 120 DAP; 1 kg carbofuran/ha at 150 DAP; release of *T. chilonis* seven times at 40,000 parasitoids per hectare at 15 d interval beginning 135 DAP; detrashing of lower leaves at 6, 7 and 8 months after planting recorded the lowest incidence of root borer along with other borers (Pandya and Patel 2007b).

Root borer in tropical sugarcane belt

Overview

In addition to the observations of its distribution in the northern areas of Gujarat, Maharashtra, Karnataka and Andhra Pradesh made by Avasthy (1967), its first occurrence in Tamil Nadu was reported by Jayanthi and David (1990) in the cane areas of M/s Vellore Cooperative Sugar Mills, north Arcot dt, during December 1989. In surveys, 24 out of the 68 plots (35.3%) in light soils and 26 out of 65 plots (40.0%) in heavy soils recorded the pest; 64% affected plots were contributed by ratoon crop. The borer was subsequently recorded from Chenglepet, Coimbatore and Madurai districts. The newly introduced variety Co 8021 was more susceptible in comparison with other varieties (Jayanthi and David 1990). Reporting the occurrence of the borer from the same sugar mill area at about the same time, Alagesan et al. (1990) observed that nearly 30% of clumps in a ratoon crop were infested as a result of which one or two of the 4-5 tillers/clump became millable but the rest dried up; also, infestation was more common in Co 8021 and Co 7704 than CoC 671 (Alagesan et al. 1990).

Summarizing the status of the borer in other parts of south India, Jayanthi and David (1990) observed that in Karnataka, the large-scale occurrence during 1989 in Bhadravati area of M/s Mysore Paper Mills was restricted to Co 8021 alone with attack in 15% area. Although soil moisture stress was a pre-disposing factor, Co 62175 and KHS 3296 did not show borer attack which indicated varietal preference. In Gujarat, its incidence ranged 5-60% during 1986-89. The predominance of the high sugared CoC 671 and the general behavior of adult to lay eggs singly were attributed to its widespread distribution. In a subsequent report (Anonymous 1993), variable infestation levels were recorded in the states of Karnataka, Tamil Nadu and Gujarat.

The surge in the root borer incidence, observed by the present authors in the sugarcane tracts of Tamil Nadu during 2014-15 (R. Jayanthi et al. unpubl. data), can possibly be explained in the backdrop of varietal and crop protection practices adopted subsequent to its first appearance in 1989 (Jayanthi and David 1990; Alagesan et al. 1990). The pest remained at low levels probably due to the discontinuance of the cultivation of Co 8021 which was found to harbor greater levels of infestation than a few other varieties (Jayanthi and David 1990; Alagesan et al. 1990). The subsequent spread of the popular Co 86032 in Tamil Nadu may have conferred incidental resistance against the pest for over two decades. Root borer populations sustained by other susceptible varieties grown as isolated sugarcane islands may have served as the inoculum for the spread and adaptability of the pest to the predominant Co 86032 over the last two decades.

Despite reports of ineffectiveness of *T. chilonis* releases against root borer (Avasthy and Tiwari 1986; Sardana 2000a), control of the borer obtained when releases were made against the native borer complex (Isaac 1941; Pruthi 1946; Ashraf and Fatima 1996) suggested indirect impact of the parasitoid. It is possible that the use of the parasitoid against internode borer in the state gave incidental control of root borer. Declining use of *T. chilonis* against internode borer could be one of the reasons, though difficult to establish conclusively, for the rising levels of root borer in the sugarcane under tropical Tamil Nadu conditions. The role of other parasitoids and pathogens, recorded as low-mortality agents in earlier studies, is unclear at this stage. Nevertheless, it would be interesting to observe if the present increase in root borer populations represents only a sporadic outbreak which will stabilize over time as it generally happens with pests in the tropical sugarcane crop system, considered a semi-perennial habitat more stable than its subtropical counterpart (Srikanth and Salin 2003).

Regardless of the reasons conjectured for its upsurge, the borer is more likely to follow the pattern of year-round occurrence observed in Gujarat (Pandya and Patel 2007a; Pandya et al. 1995 and 1996c) than the pattern of low activity during May-June and peak population during July-October with specific broods reported in Haryana (Sardana 1995 and 1997a; Sardana 2001a). The mild climate devoid of extremes, and spatial and temporal continuity of the crop under tropical conditions together with the ability of the borer to attack both early (Cheema 1948) and late (Pannu et al. 1990) stages of the crop might favour overlapping generations and round-the-year activity just as shoot borer (Srikanth et al. 2001, 2002 and 2009), internode borer or top borer exhibit.

Research priorities

The re-emergence of the borer after a gap about 25 years necessitates comprehensive studies on the pest since no information is available on the pest except for the observations of Jayanthi and David (1990), Alagesan et al. (1990) and Anonymous (1993) made during its brief incursion in the early 90s. One of the first priorities would be to assess its status not only in Tamil Nadu where it is being noticed currently but also in the neighboring sugarcane growing states of Karnataka and Andhra Pradesh, particularly wherever Co 86032 is under cultivation to ascertain its role in promoting the borer. Attack rates and yield losses, known to decrease across generations of the borer in subtropical conditions (Cheema 1953a), need to be assessed in the light of possible continuous generations in tropical conditions. The possibility of variety-dependent (Pandya et al. 1996a) and wilt-exacerbated (Sardana 1993) losses deserves attention.

Basic information on field biology and population dynamics is required to understand the number of generations and the consequent damage potential in different seasons. Natural enemy complex and dynamics need to be determined since tropical sugarcane belt is characterized by year-round activity of borer (Srikanth et al. 2001 and 2002) and sucking pests (Srikanth et al. 2012a), and/or their natural enemies (Easwaramoorthy et al. 1996; Srikanth et al. 1999, 2009), often with effective natural regulation (Srikanth et al. 2012b). This aspect gains credence from the recent detection at Coimbatore of the hispa *Asamangulia cuspidata* Maulik (Coleoptera: Chrysomelidae: Cassidinae: Hispini), originally from Pusa, Bihar, and its maintenance at virtually undetectable levels by natural enemies, some of which appear to be new associations (J. Srikanth et al. unpubl. data). Such knowledge enables planned introductions of natural enemies from subtropical belt, if they have not already accompanied the borer. The identification of potential candidate biological control agents including entomopathogemic fungi, besides the previously tested and used *T. chilonis*, could lead to their mass multiplication, field evaluation and large-scale colonization in the inoculative or inundative mode.

Varietal screening carried out from early '40s revealed differential susceptibility in Bihar, Karnal and Gujarat. Although identification of resistant sources from varieties under cultivation is unlikely to lead to complete replacement of the predominant variety, such sources, preferably combining good ratooning ability, can serve as alternatives in varietal management on a short-term basis. Other cultural and mechanical measures that produced encouraging results in subtropical India such as addition of organic matter, growing intercrops, frequent irrigation and use of light traps need to be examined. Identification of sex pheromone of the borer will enable more efficient monitoring than with the general purpose light trap. Several insecticides have been evaluated in the subtropics with promising results but since many are obsolete or restricted for use, newer ones need to be evaluated in the tropics too as a part of effective chemical control measures.

Interim control measures

In the absence of comprehensive information on the biology and behavior of the borer in tropical India, the knowledge generated in the subtropical sugarcane belt could serve as the basis for the formulation of provisional control measures as follows:

1. Short-term replacement of the current variety with a suitable alternative, preferably with good ratooning ability, even with unknown status of resistance
2. Avoidance of ratoons in farms with severe infestation
3. Deep ploughing and destruction of stubbles by burning or flooding
4. Deep harvesting of crop intended to be ratooned
5. Growing black gram and other pulses as intercrops
6. Use of light traps to collect moths at regular intervals beginning early in the season
7. Uprooting and destruction of infested plants in the early stages
8. Water management through frequent light to medium irrigations
9. Release of *T. chilonis* in a sequential manner from early stages of crop on an area-wide basis
10. Need based application of fipronil 5% SC or 0.3% GR at 75-100 g a.i./ha (as per Central Insecticides Board and Registration Committee website www.cibrc.nic.in, cited in Ramasubramanian and Srikanth (2015))

Acknowledgements

We thank Dr. Bakshi Ram, Director, SBI, CBE, for the academic encouragement and logistic support.

References

Abdullah M, Biswas MM, Rahman MA (2006) Evaluation of botanical products against some major insect pests of sugarcane. Planter 82(964):463-469.

Abraham T, Easwaramoorthy S, Santhalakshmi G (2003) Mass production of *Beauveria bassiana* isolated from sugarcane root borer, *Emmalocera depresella* Swinhoe. Sugar Tech 5(4):225-229.

Alagesan K, Mahendran VP, Pandian KRG (1990) A new pest of Tamil Nadu recorded in the Vellore Co-op. Sugar Mills area. SISSTA Sug J 16(2):13-15.

Anonymous (1936) Agriculture and Animal Husbandry in India 1933-34 & 1934-35 Pt. I. Crop Production. 390p.

Anonymous (1942) Short notes and exhibits. Indian J Ent 4(1):87-95.

Anonymous (1943) Resume of the Work done at the Sugarcane Research Station, Bihar, during 1939-40. Rep agric Dep Bihar 1939-40, pp.69-75.

Anonymous (1993) Root borer in sugarcane. Sugarcane Breed Inst Newsl 12(4):1-2.

Ansari AH, Arain AR (1997) Linear association of cane height and borer population in sugarcane. Pakistan Sug J 11(4):15-17.

Ansari AH, Mirza AA, Lodhi AH, Safdar O, Akbani AK (1994) Evaluation of varietal susceptibility against sugarcane *Saccharum officinarum* (Linn) root borer *Emmalocera depresella*. Sarhad J Agric 10(5):515-520.

Ashraf M, Fatima B (1996) Success of *Trichogramma chilonis* (Ishii) for area-wide control of sugarcane borers in Pakistan. Brighton Crop Protection Conference: Pests and Diseases - 1996: Volume 1: Proceedings of an International Conference, Brighton, UK, 18-21 November 1996, pp.385-388.

Avasthy PN (1967) Sugarcan pests in India and their control. PANS 13:111-117.

Avasthy PN, Tiwari NK (1986) Minor moth borers. In: Sugarcane Entomology in India (H. David, S. Easwaramoorthy and R. Jayanthi, eds), pp.165-191. Sugarcane Breeding Institute, Coimbatore, India.

Beccaloni G, Scoble M, Kitching I, Simonsen T, Robinson G, Pitkin B, Hine A, Lyal C (2003) (Editors) *The Global Lepidoptera Names Index (LepIndex)*. World Wide Web electronic publication. http://www.nhm.ac.uk/research-curation/research/projects/lepindex/search/detail.dsml [accessed on 30 May 2015]

Begum S, Anis SB (2014) Checklist of Indian Trichogrammatidae (Hymenoptera: Chalcidoidea). Int J ent Res 2(1):7-14.

Bhatt TA, Vyas ST, Mehta VR, Patel KK, Patel JM (1996) Natural parasitism in sugarcane root borer. Bharatiya Sug 22(3):37-39.

Box HE (1953) List of sugarcane insects. Commonw Inst Ent, London. l0lp.

CAB Thesaurus (2014) http://www.cabi.org/cabthesaurus/mtwdk.exe?k=default&l=60&w=146893&n=1&s=5&t=2 [accessed on 26 May 2015]

Cheema PS (1948) Differentiation between the sugarcane root borer and stem borer attack in early stages of crop growth as well as at harvest. Indian J Ent 10:130-131.

Cheema PS (1953a) Nature and extent of damage caused by the sugarcane root-borer, *Emmalocera depressella* (Swin.), in the Punjab. Indian J Ent 15(2):139-145.

Cheema PS (1953b) Studies on hibernation of sugarcane root borer, *Emmalocera depressella* Swinhoe. Indian Sug 3:103-106.

Das SB, Veda OP (2005) Record of sugarcane root borer, *Emmalocera depressella* (Swinhoe) in West Nimar Valley of Madhya Pradesh. Insect Envir 11(3):106.

Easwaramoorthy S, Santhalakshmi G (1993) Occurrence of *Beauveria bassiana* on sugarcane root borer *Emmalocera depressella* Swinhoe. J Biol Control **7**:47-48.

Easwaramoorthy S, Srikanth J, Santhalakshmi G (1996) Seasonal occurrence of the fungus *Hirsutella nodulosa* Petch and granulosis virus of sugarcane internode borer *Chilo sacchariphagus indicus* (Kapur). Entomon 214):205 - 209.

EPPO (2015) EPPO Global Database (available online). https://gd.eppo.int/taxon/EMMADE [accessed on 09 May 2015].

Fletcher TB (1932) Report of the Imperial Entomologist. Sci Rep Imp Inst Agric Res, Pusa, pp.87-92.

Gotterell GS (1954) Notes on insect injuries to crops in Afghanistan. Pl Prot Bull, FAO 2(4): 53-55.

Gupta BD (1953) Resume of work done under the insect pests scheme during 1946-47 to 1950-51. Indian Central Sugarcane Committee, New Delhi. 111p.

Gupta BD and Avasthy PN (1952) Biology of sugarcane borer, *Emmalocera depressella* Swinh., in the Uttar Pradesh. J agric Anim Husb UP 2:19-25.

Gupta KM, Singh B, Ganga Sagar (1966) Losses caused by root borer (*Emmalocera depressella* Swinh.) to sugarcane in Uttar Pradesh. Indian Sug 16(3):273-279.

Hari Chand, Anil Kumar, Dwivedi GP, Sudhir Paswan (2010) Incidence level of borer pests to promising clones/varieties of sugarcane in Bihar. Environ Ecol 28(3A):1855-1857.

Haris SM, Ahmad Z, (2002) Braconinae enemies of insect pests of rice in India (Hymenoptera: Braconidae). Bionotes 4(4):103.

Hayat M (1989) A revision of the species of *Encarsia* Foerster (Hymenoptera: Aphelinidae) from India and the adjacent countries. Oriental Insects 23:1-131.

Isaac PV (1936) Report of the Imperial Entomologist. Sci Rep Inst Agric Res, Pusa, 1933-34, pp.168-174.

Isaac PV (1937) Report of second entomologist (Dipterist) in charge, scheme for research on insect pests of sugarcane. Sci Rep Agric Res Inst, New Delhi, 1936-37, pp.175-177.

Isaac PV (1939) Report of the Second Entomologist (Dipterist) in Charge of Scheme for Research on Insect Pests of Sugarcane. Sci Rep Agric Res Inst, New Delhi, 1937-38, pp.129-131.

Isaac PV (1941) Report of the Second Entomologist (Dipterist) in Charge of Scheme for Research on Insect Pests of Sugarcane. Sci Rep Agric Res Inst, New Delhi 1939-40, pp.115-119.

Isaac PV and Misra CS (1933) The chief insect pests of sugarcane and methods for their control. Agric Livestock India 3(4):315-324.

Jai Rao K (1967) Trials with the Taiwan strain of *Lixophaga diatraeae* Tns in India. Technical Bulletin, Commonwealth Institute of Biological Control 9:25-29.

Jayanthi R, David H (1990) Root borer *Emmalocera depressella* (Swinh.) problem in south India – a current appraisal. Coop Sugar 21(11):807-810.

Jayanthi R, Salin KP (1993) Annual Report 1992-93. Sugarcane Breeding Institute, Coimbatore. pp. 64-65.

Jayanthi R, David H, Salin KP (1992) Annual Report 1991-92. Sugarcane Breeding Institute, Coimbatore. pp. 66.

Khan RM, Joshi HC (1969) Abnormal larval population of sugarcane root borer, *Emmalocera depressella* Swinh. (Pyralidae: Lepidoptera) in insecticide treated plots. Indian J Ent 31(2): 177-179.

Khan AR, Singh D (1942) Studies on “dead-hearts” caused by different species of sugarcane borers in the Punjab. Indian J Ent 4(1):77-85.

Khanna SS, Sharma SP (1969) Root borer, *Emmalocera depressella* Swinh, a serious pest of sugarcane in East U.P. Indian Sug 19:583-584,589.

Kumar A, Chand H, Dwivedi GP, Paswan S (2011) Comparative field efficacy of insecticides against *Emmalocera depressella* Swinhoe in sugarcane. J ent Res 35(1):35-37.

Kundu R, Saha SC, Majid MA, Abdullah M (1994) Preliminary studies to investigate the possible effects of soil properties on sugarcane rootstock borer infestation. Int J Pest Mgmt 40(3):266-269.

Mann RS, Suri KS, Sharma S (2006a) Population dynamics of insect pests of sugarcane in Punjab. Indian J Pl Prot 34(2):198-201.

Mann RS, Goyal G, Sharma B (2006b) The association between sugarcane root borer, *Emmalocera depresella* and wilt disease of sugarcane. Annual Meeting of the ESA 2006, December 10-13, 2006. Indianapolis.

Mrig KK, Chaudhary JP (1992) Comparative efficacy of carbofuran and phorate for the control of top and root borers in sugarcane ratoon. J Insect Sci 5(1): 57-61.

Mrig KK, Chaudhary JP (1993) Comparative efficacy of different insecticides, applied with different irrigation levels for control of sugarcane shoot & root borers. Coop Sug 25(1/2):33-37.

Mrig KK, Chaudhary JP, Mahla JC (1995) Effect of irrigation intervals on the incidence of shoot and root borers in sugarcane ratoon. J Insect Sci 8(2):188-191.

Nagarkatti S (1980) Trichogrammatid parasites of sugarcane borers in India - distribution and identification. In: Biological control of sugarcane pests in India, Sithanantham S, Solayappan AR (eds), pp.13-19. Tamil Nadu Cooperative Sugar Federation Ltd, Chennai.

Nagarkatti S, Nagaraja H (1977) Biosystematics of *Trichogramma* and *Trichograrnmatoidea* species. A Rev Ent 22:157-176.

Nagarkatti S, Nagaraja H (1979) The status of *Trichogramma chilonis* Ishii (Hym.: Trichogrammatidae). Oriental Insects 13(1-2): 115-118.

Nair KR, Prakash S, Nagarkatti S, Henderson MT (1971) A consolidated list of wild and cultivated plant species attacked by sugarcane borers in North India. Proc Int Soc Sugarcane Technol. Congr 14:435-439.

Narayanan ES (1938) A note on *Stenobracon deesae* (Cam.), a new parasite of the root-borer of sugarcane. Indian J agric Sci 8(2):215-216.

Pandya HV (1997a) Biological control of sugarcane pests. Coop Sug 28(9):684-686.

Pandya HV (1997b) Control of sugarcane borers, mealy bugs and scale insects in Gujarat. Coop Sug 28(10):745-746.

Pandya HV, Patel MB (2007a) Extent of damage of sugarcane borers in Gujarat. Indian Sug 57(5): 27-30.

Pandya HV, Patel MB (2007b) Effect of partitioned growth stage protection on incidence of sugarcane borers in Gujarat. Coop Sug 38(9):41-44.

Pandya HV, Patel CB, Patel MB, Patel JR, Radadia GG, Bhatt TA, Vyas ST, Mehta VR, Patel KK, Patel JM (1995) Incidence status of sugarcane borers in South Gujarat. Coop Sug 27(4):261-264.

Pandya HV, Patel CB, Patel JR, Patel MB, Patel KK, Patel JM, Mehta VR (1996a) Assessment of losses due to root borer in sugarcane. Bharatiya Sug 22(3): 19-20.

Pandya HV, Patel CB, Patel MB, Patel JR, Radadia GG, Bhatt TA, Vyas ST (1996b) Biology of sugarcane root borer. Coop Sug 27(12):915-918.

Pandya HV, Patel CB, Patel JR, Patel MB, Patel KK, Radadia GG, Mehta VR, Bhatt TA, Vyas ST, Patel JM (1996c) Study on population dynamics of sugarcane root borer. Bharatiya Sug 22(4):23-24.

Pandya HV, Patel CB, Patel JR, Patel MB, Patel KK (1996d) The problems of sugarcane borers in Gujarat, India. Coop Sug 28(4):293-294.

Pandya HV, Patel CB, Patel MB, Patel JR, Radadia GG, Bhatt TA, Vyas ST, Mehta VR, Patel KK, Patel JM (1996e) Association of root borer with wilt disease in sugarcane. Coop Sug 27(9):680.

Pandya HV, Patel CB, Patel KK, Patel JM, Patel JR, Patel MB (1998) Study on population dynamics of sugarcane root borer in Gujarat. Coop Sug 29(11):781-782.

Pannu BS, Verma KS, Dang YP, Chhillar BS (1990) Investigations on yellowing of sugarcane foliage. Indian Sug 40(6):417-419.

Patel CB, Pandya HV, Patel MB, Patel JR, Radadia GG, Bhatt TA, Vyas ST, Mehta VR, Patel KK, Patel JM (1996a) Varietal screening against sugarcane root borer. Bharatiya Sug 21(5):19-20.

Patel CB, Pandya HV, Patel MB, Patel JR, Radadia GG, Bhatt TA, Vyas ST (1996b) Screening of sugarcane promising varieties for susceptibility against root borer. Coop Sug 27(10):747-748.

Pruthi HS (1936) Report of the Imperial Entomologist. Sci Rep Agric Res Inst, Pusa, 1934-35, pp.141-152.

Pruthi HS (1937) Report of the Imperial Entomologist. Sci Rep Agric Res Inst, New Delhi, 1935-36, pp.123-137.

Pruthi HS (1940) Report of the Imperial Entomologist. Sci Rep Agric Res Inst, New Delhi, pp.116-133.

Pruthi HS (1941) Report of the Imperial Entomologist. Sci Rep Agric Res Inst, New Delhi, 1939-40, pp.102-114.

Pruthi HS (1946) Report of the Imperial Entomologist. Sci Rep Agric Res Inst, New Delhi, 1941-44, pp.64-71.

Pruthi HS, Narayanan ES (1938) A study of the behaviour of some common varieties of sugarcane in reference to the attack of borers at Pusa (Bihar) during 1935-36. Proc Nat Inst Sci India, 4(1):87-107.

Pruthi HS, Narayanan ES (1939) A statistical study of the loss caused by borers and termites to mature sugarcane at Pusa in 1935 and 1936. Indian J agric Sci 9(1):15-37.

Rahman KA (1941) Parasites of the insect pests of sugarcane in the Punjab. Indian J agric Sci 11(1):119-128.

Rahman KA and Singh D (1942) Studies on deadhearts caused by different species of sugarcane borers in the Punjab. IndianJ Ent 4:77-95.

Ramasubramanian T. and Srikanth J. 2015. Insecticides for the management of sugarcane pests in tropical India – an advisory for intelligent use. ICAR-Sugarcane Breeding Institute, Coimbatore, 21p. ISBN 978-81-926387-9-9.

Rana ZA, Mushtaq M, Mahmood K, Ahmad M (1992) Moth population fluctuation of sugarcane borers. J Agric Res (Lahore) 30(4):507-512.

Sardana HR (1993) Effect of root borer, *Emmalocera depressella* (Swinhoe) infestation on cane weight and juice quality. Pl Prot Bull (Faridabad) 45(4): 26-27.

Sardana HR (1994a) New record of parasite of sugarcane root borer, *Emmalocera depressella* Swinhoe. Bull Ent (New Delhi) 35(1-2):150-151.

Sardana HR (1994b) Spatial dispersion pattern of root borer, *Emmalocera depressella* Swinhoe in sugarcane. Crop Res (Hisar) 8(2):354-362.

Sardana HR (1995) Seasonal abundance of root borer, *Emmalocera depressella* Swinhoe on commercial varieties of sugarcane. Indian J Ent 57(2):135-140.

Sardana HR (1996a) Hibernation of sugarcane root borer, *Emmalocera depressella* (Swinhoe) in commercial cultivars in sub-tropics. Agric Sci Digest (Karnal) 16(2):78-82.

Sardana HR (1996b) Spatial distribution of eggs of root borer, *Emmalocera depressella* Swinhoe in sugarcane. Ann agric Res 17(2):143-147.

Sardana HR (1996c) Evaluation of insecticides against sugarcane root borer, *Emmalocera depressella* Swinhoe. Indian J Ent 58(2):165-167.

Sardana HR (1997a) Seasonal patterns of root borer *Emmalocera depressella* Swinhoe on sugarcane in India. Entomon 22(1):55-60.

Sardana HR (1997b) Occurrence of entomophagous fungi on sugarcane root borer, *Emmalocera depressella* Swinhoe. Ann agric Res 18(1):104.

Sardana HR (1997c) Transformation for egg counts of sugarcane root borer, *Emmalocera depressella*. Indian J Ent 59(4):343-346.

Sardana HR (1998a) Some observations on the biology of sugarcane root borer, *Emmalocera depressella* (Swinhoe). Ann Pl Prot Sci 6(1):66-69.

Sardana HR (1998b) Field response of sugarcane germplasm for multiple resistance to major borer pests in sub-tropics. Crop Research (Hisar) 15(1):115-118.

Sardana HR (1999a) Record of root borer, *Emmalocera depressella* on *Andropogon sorghum*. Indian J Ent 61(1):100-101.

Sardana HR (1999b) Field reaction of inter specific hybrids of sugarcane to major borer pests. Ann Pl Prot Sci 7(2):163-167.

Sardana HR (2000a) Efficacy of bioagents against sugarcane root borer, *Emmalocera depressella* Swinhoe. Insect Environ 6(3):102-103.

Sardana HR (2000b) Integrated management of sugarcane root borer, *Emmalocera depressella* Swinhoe. Coop Sug 32(4):271-274.

Sardana HR (2001a) Population dynamics of sugarcane root borer, *Emmalocera depressella* in Haryana. Ann Pl Prot Sci 9(2):315-316.

Sardana HR (2001b) Influence of summer inter-cropping on the incidence of root borer, *Emmalocera depressella* of sugarcane. Indian J Ent 63(1):49-51.

Sardana HR (2001c) Evaluation of a new insecticide Regent (Fipronil) against sugarcane shoot borer, *Chilo infuscatellus* Snellen and root borer, *Emmalocera depressella* Swinhoe. Pesticide Res J 13(1):74-78.

Sardana HR (2001d) Relative efficacy of bio-rational and chemical insecticides against root borer of sugarcane. Pesticide Res J 13(1):112-114.

Sardana HR, Misra A (2003) Influence of row spacing and companion cropping on the incidence of major sugarcane borers. Indian J Ecol 30(2):199-208.

Sardana HR, Singh N, Tirpathi BK (2000) Investigations on the relationship between root borer and wilt disease of sugarcane. Indian J Ent 62(1):11-17.

Saxena AP (1967) Biology of *Campyloneurus mutator* (Fabricius) (Hymenoptera: Braconidae). Tech Bull Commonw Inst Biol Control 9:61-72.

Saxena AP, Dayal R (1965) Efficiency of Cuban fly (*Lixophaga diatraeae* Tns.) against sugarcane borers. Indian Sug 15(2):83-86.

Singh PP, Kumar K (1979) Studies on the interaction between gamma-BHC and nitrogen application in sugar cane. Int Sug J 81(971):329-331.

Singh M, Madan YP (2001) Reaction of some sugarcane genotypes towards root borer (*Emmalocera depressella* Swinhoe) under natural conditions. Indian Sug 51(9):599-602.

Singh M, Chhilar BS, Madan YP (1996a) Biology of sugarcane root borer *Emmalocera depressella* Swinhoe. Indian Sug 45:12.

Singh M, Chhillar BS, Madan YP (1996b) Effect of some soil insecticides on the incidence of root borer (*Emmalocera depressella* Swinhoe). Indian J agric Res 30(3/4):143-151.

Singh M, Madan YP, Chhillar BS (2001) Incidence of root borer (*Emmalocera depressella* Swinhoe) in sugarcane genotypes. Agric Sci Digest 21(2): 131-132.

Singla ML, Duhra MS (1991) Sampling plan for estimation of damage by major sugarcane borers. J Insect Sci 4(1):76.

Srikanth J, Salin KP (2003) Ecological adaptability in augmentative biological control: a sugarcane perspective. Biological Control of Insect Pests, Ent. Res. Inst. Ser. No. 1. S. Ignacimuthu and S. Jayaraj (eds). pp. 332-340. Entomology Research Institute, Loyola College, Chennai, February 7-8, 2002.

Srikanth J, Easwaramoorthy S, Shanmugasundaram M, Kumar R (1999) Seasonal fluctuations of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) parasitism in borers of sugarcane and sorghum in Coimbatore, south India. Insect Science and its Application 19(1):65-74.

Srikanth J, Easwaramoorthy S, Santhalakshmi G (2001) Seasonal fluctuations of natural enemies of sugarcane shoot borer *Chilo infuscatellus* Snellen. Entomon 26(Spl. Issue):76-79.

Srikanth J, Geetha N, Kurup NK, Santhalakshmi G (2002) Density-dependent natural control of sugarcane shoot borer *Chilo infuscatellus* Snellen (Lepidoptera: Crambidae). In: Vistas of Entomological Research for the New Millennium, Proceedings of National Symposium, K.P. Sanjayan, V. Mahalingam and M.C. Muralirangan (eds), pp.119-122. G.S. Gill Research Institute, Chennai, December 28-30, 2000.

Srikanth J, Salin KP, Kurup NK, Subadra Bai K (2009) Assessment of the tachinid *Sturmiopsis inferens* as a natural and applied biological control agent of sugarcane shoot borer *Chilo infuscatellus* in southern India. Sugar Tech 11(1):51-59.

Srikanth J, Singaravelu B, Kurup NK, Mukunthan N, Santhalakshmi G, Nirmala R (2012a) Predators as natural and applied biocontrol agents of sugarcane woolly aphid *Ceratovacuna lanigera*: an appraisal. In: Proceedings of International Symposium on New Paradigms in Sugarcane Research, Viswanathan, R., Hemaprabha, G., Bhaskaran, A., Mohanraj, K., Jayakumar, V., Ramasubramanian, T. and Nair, N.V. (eds.), October 15-18, 2012. Sugarcane Breeding Institute (ICAR), Coimbatore, India, 396p.

Srikanth J, Singaravelu B, Kurup NK (2012b) Natural control of woolly aphid by *Encarsia flavoscutellum* prevents yield and quality loss in sugarcane. J Sugarcane Res 2(1):64-68.

Tanwar RK, Bajpai PK (1993) Relative abundance of borer species in relation to environmental factors at shoot stage of sugarcane. Indian Sug 43(4):243-248.

Viswanathan R, Malathi P, Sundar AR, Poongothai M, Singh N (2006) Current status of sugarcane wilt in India. Sugarcane Int 24(4):3-7, 12.