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IMPACT OF IPM STRATEGIES FOR CONTROL OF BORER PEST AND INFLUENCE ON YIELD AND QUALITY OF SUGARCANE CROP

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Abstract: The sugarcane borer is a major pest that significantly impacts sugarcane yield and quality, resulting in considerable economic losses globally. This review examines the extensive damage caused by the borer, which includes reduced biomass and sugar yield, as well as compromised quality of the harvested cane. The borer's infestation disrupts the plant's vascular system, diminishing photosynthetic efficiency and increasing disease susceptibility. These disruptions lead to lower sucrose content and purity in the cane juice, adversely affecting sugar extraction processes. Furthermore, this paper evaluates various integrated pest management (IPM) strategies, including biological control, chemical treatments, and cultural practices, assessing their effectiveness in controlling borer populations and mitigating damage. The review synthesizes findings from field studies and experimental research, emphasizing the importance of sustainable pest management practices to maintain high sugarcane yield and quality. The necessity for ongoing research and the development of innovative IPM solutions is highlighted to support the resilience and productivity of the global sugar industry. This comprehensive analysis underscores the critical role of effective pest management in safeguarding the future of sugarcane cultivation.
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Introduction

Sugarcane is an important commercial crop but at the same time it is capital, labor and irrigation intensive crop. Sugarcane is the basic raw material for jagery making which is important for cottage industries. Sugarcane is a traditional food crop being used for centuries as a feedstock for sugar production (Ferreira *et al*.,2018). Its systematic use for this purpose dates back more than 2,000 years in Pakistan and from there, it spread in the tropical and subtropical areas around the world, being cultivated today in more than 100 countries. Since those days, the selection process was aiming at plants with higher sucrose content and was based on natural crossing of wild species. (Priya *et al.,2023)*

Sugarcane is a major economic crop in many countries such as Brazil, India, China, Thailand, Pakistan and Mexico. Sugarcane is not only an important source of raw material for sugar and food production but also a source of eternal fuel production. In Brazil, the first plants were brought by the Portuguese in 1515 and the first mill was erected in the coast of São Paulo in 1632 but it took quite a few decades to become an established crop near Olinda in the state of Pernambuco (Rossato *et al*.,2019). Diatraea saccharalis and D. flavipennella are the main sugarcane borers that invade the sugarcane plantation and need to be considered in Brazil. However, only invasion of D. saccharalis can be found in all regions of Brazil. In Brazil, it occurs in all regions and is considered one of the major pests of sugarcane crops (Bhatt *et al.,*2022). Finally, several well-organized breeding programs were created around the world to provide sugarcane varieties richer in sugar resulting, by the end of the nineteenth century, in the so-called noble canes that are in the base of most present time breeding programs. In the processing of the sugarcane, firewood was normally used to supplement bagasse as fuel to satisfy the process heat demand. Ethanol was produced in some cases using the exhausted or final molasses, a residue from the sugar production process, for beverages or industrial use (Li *et al.,*2024).

In Pakistan and other cane sugar-producing countries, such as India and Guatemala, the surplus power generation by the sugarcane mills is becoming an irreversible trend, greening the country energy matrix and representing an important source of revenues for the mills (Pene *et al.,*2019). On the biofuels side, USA and Brazil represent 88 % of the world ethanol production, using corn and sugarcane as feedstocks, respectively; other countries, like Colombia, India, and Thailand, are also producing ethanol from sugarcane in large scale. Out of 120 nations nearly 65 nations produced from sugarcane, nearly 40 are from sugar beet and 10 are from both (Bhatt *et al.,*2021).

Numerous numbers of sugarcane borers are noticed in India, each borer was differing by its feeding nature. Borers mostly attack the economic part of sugarcane which leads to reduction in cane yield whereas yield loss due to early shoot borer, internode borer, top shoot borer, stalk borer and Gurdaspur borer were 22-33, 34.88, 21-37, 33 and 5-15% respectively whereas reduction in sugar recovery due to early shoot borer, internode borer, top shoot borer, stalk borer and Gurdaspur borer were 12, 1.7-3.07, 0.2-4.1, 1.7-3.07 and 1.5-2.5%, respectively (Ebrahimifar *et al.,*2023).

The top ten nations, which produced two-thirds of total sugar worldwide is tabulating. Sugarcane is coming under worthy agricultural crops, which have special contributing for energy, refuel and chemical Synthes (Bhatt *et al.,*2022). The sugar industry contributes around Rs. 4 billion under the head of excise duty. The industry directly employs over seventy-five thousand people, including managers, technicians, engineers, financial experts, skilled and unskilled workers. The sugar industry holds a relatively important position in agriculture, agribusiness and food consumption (Kuniata *et al.,*2019). In agribusiness, sugar is second in total sales after textiles. To the consumer, sugar is an essential commodity like vegetable ghee or flour. Because of the size of the sugar industry and its importance to the consumer, sugar is subject to a number of policies and government interventions. Invasion of sugarcane borer can cause damage to both sugarcane plantations and related food processing and eternal industries (Fahmy *et al.,*2021).

Sugarcane is the second largest cash crop of Pakistan and is being cultivated on 0.966 million hectares contributing around 3.6 % of Gross domestic production (GDP) (15). Sugarcane currently accounts 4.8% of cropped area and 11% value added of the total crops (12) (Srikanth *et al.,*2022). The sugar industry plays a pivotal role in the national economy of our country. Sugarcane provides sugar, besides biofuel, fiber, organic fertilizer and myriads of byproducts/co-products with ecological sustainability (Priya *et al.,*2023*)*. Molasses is the cheapest feed stock for the distilleries. The bagasse has been accepted as a viable alternative raw material to wood in the paper and pulp industry. The industry contributes around 4 billion rupees under the head of general sales tax and other indirect taxes levies to the Govt. (13). The industry employs over one million people, including management experts, technologists, engineers, financial experts, in addition to skilled and unskilled work force. Sugar industry contributes substantially to the rural economy as the mills are located in rural areas (Zeng *et al.,*2020).

According to the Federal Bureau of Statistics Report 2011-12, sugarcane was grown on an area of 1.046 million hectares. The cultivated area of sugarcane was about six percent greater than the previous year 2010- 11 (988 thousand hectares). Sugarcane production in the year 2011-12 was 58.038 million tons against 55.309 million tons for the year 2010-11. This indicates an increase of about 5 % in production during 2011-12 (Showler, A. T. 2019). The main factors contributing to the increase in agricultural production are profitable market prices and the use of more agricultural inputs. In Pakistan, farmers are being encouraged to grow more sugarcane as there is high demand of sugar due to population growth. However, the decline in yield of cane (kg/ha) between years 2010-11 and 2011-12 caused a reduction in sugarcane production (Sallam *et al.,*2021). The flood of 2010 enhanced soil fertility for much of the sugarcane growing area in Pakistan and as a result can yield (kg/ha) was about 7 % higher in year 2010-11 compared with 2011-12 (Singh *et al.,*2020).

According of province of Khyber Pakhtunkhwa Bureau of Statistics, annual agricultural statistical data indicate that there were 107 thousand hectares of sugarcane in the province in year 2012-13, an increase of 1 % over the previous year. Sugarcane production in the Khyber Pakhtunkhwa province has therefore increased in-significantly from 4.684 million tons in 2011-12 to 4.770 million tons in 2012-13 (Naveen *et al.,*2019).

Top ten countries Sugarcane production and consumption

No.	Country	Production	Consumption	Contribution of Sugar Production
1-	Brazil	38.87	10.60	20.28
2-	India	32.44	26.50	16.93
3-	European Uinon	21.15	18.80	11.03
4-	China	10.25	15.70	5.34
5-	Thailand	13.73	2.63	7.16
6-	USA	8.39	11.18	4.37

7-	Mexcio	6.32	4.59	3.29
8-	Pakistan	7.42	5.40	3.87
9-	Russia	6.50	6.16	3.39
10-	Australia	4.70	10.1	2.45

Factors Affecting of Sugarcane Production

The factors were highly significant at 5% level for the sugarcane production cost. The cost of land preparation, FYM, seed, irrigation, urea, DAP, seed and its application, and weeding were set in the econometric model (Wei *et al.,*2021).

In cost of DAP, the regression coefficient of cost of DAP was positive (0.22510), which implied that 1% increase in the use of DAP would increase the returns by 0.2% holding other factors constant. This co-efficient was significant indicating that revenue increased significantly due to moderate use of DAP increased the profit effecting. The estimated co-efficient was significant, indicating that the cost of DAP significantly influenced the sugarcane revenue due to moderate use of DAP (Da Silva Fernandes Souza *et al.,* 2024).

In cost of Urea, the regression coefficient of cost of urea was positive (1.93717), which implied that 1% increase in the use of fertilizer would increase the returns by 1.9% holding other factors constant. This co-efficient was significant indicating that revenue increased significantly due to moderate use of urea increased the production effecting incline in the revenue The estimated co-efficient was significant, indicating that the cost of urea significantly influenced the sugarcane revenue due to moderate use of urea. (Qamar *et al.,*2021).

Estimated value of coefficient and related statistics of Cobb-Douglas Production function of sugarcane production

Variables	Coefficient	Std Error	T- Value	P- Value
Cost of Urea	1.93717*	0.28503	6.80	0.0000
Cost of DAP	0.22510*	0.02658	8.47	0.0000
Cost of land preparation	0.86008*	0.03899	22.06	0.0000
Cost of Irrigation	0.08484*	0.01507	5.63	0.0000
Cost of FYM	-0.07020*	0.02047	-3.43	0.0007
R-Squared	0.9249	------	-------	-------
Adjusted R-Squared	0.9235	------	-------	-------
Resid. Mean Square (MSE)	0.48495	------	-------	-------
Standard Deviation	0.69638	------	-------	-------

5% level of significance

Species of Sugarcane Borer

One notable sugarcane borer belongs to the genus Chilo, which is classified under the Crambidae and was previously categorized under Pyralidae. Species within the genus Chilo initiate damaged by causing 'dead-heart' in sugarcane shoots and subsequently feed on the internal stem tissue. These damages result in a significant reduction in sugarcane yield, potentially leading to total crop failure (Geetha *et al.,*2018).

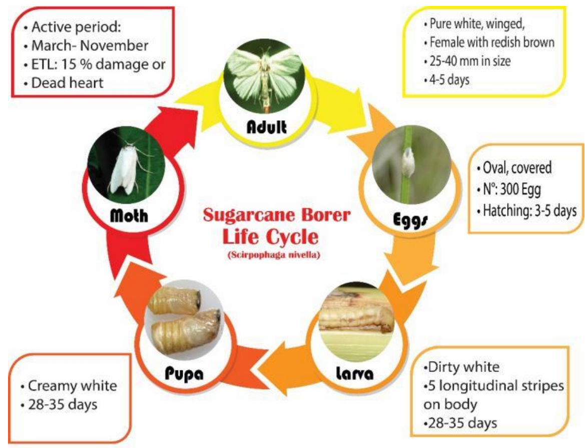
Chilo infuscatellus, commonly referred to as the early shoot borer, causes damage to the crop in its early stages, leading to a subsequent reduction in yield. This species can survive year-round in mild climate. Another significant sugarcane borer in this genus is the internode spotted borer (Chavan *et al.,*2021).

Chilo sacchariphagus, known for typically attacking plants aged 3–7 months. The third species, C. venosatus, is also a noteworthy sugarcane borer, contributing to substantial economic losses. The fourth species, C. tumidicostalis, primarily inflicts damage to the crop after internode formati. The fifth species, stalk borer C. auricilius, has young larvae that bore into shoots and canes by cutting holes and forming galleries in the stalk. Concerning borers within the Diatraea genus, their primary impact is on sugarcane in the Americas (Wang *et al.,2018).*

Diatraea saccharal is a prominent pest prevalent in the Western Hemisphere. Additionally, species like D. albicrinella, D. busckella, D. tabernella, D. centrella, D. indigenella, D. lineolata, D. considerate and D. magnifactella have been documented as sugarcane attackers. The pink borers species in the Sesamia genus led to a significant reduction in sugar recovery. Among these species, Sesamia cretica and S. nonagrioides are widely distributed in all sugarcane growing areas, infesting sugarcane at all stages of growth. S. grisescens, on the other hand, can cause substantial damage to sugarcane in a few countries (Tomaz *et al.,*2018). Additionally, larvaes of S. inferens bore into the aboveground parts of sugarcane seedlings. S. nonagrioides, also known as the corn borer, is another species within the Sesamia genus that causes severe damage to sugarcane (Reagan *et al.,2019)*. Apart from the borer species from Chilo, Diatraea and Sesamia, some species of other genera also attack sugarcane. For example, larvaes of Argyroploce schistaceana inflict damage to both underground and surficial parts of sugarcane, causing a significant increase in population density and ultimately resulting in losses in cane yield and sugar.

Life Cycles of Sugarcane Borer and bioecology:
Top borer of sugarcane:

Scientific Name of top borer is Scirpophaga nivella belong to family of Pyralidae and order is Lepidoptera. Feeding of top borer of sugarcane is India, Pakistan, China, Formosa, Japan, Philippines, Thailand, Bangladesh, Indonesia, Laos, Cambodia, Vietnam, Burma and Taiwan. Adult insects are Pure white, winged. Female with reddish brown anal hair tuft 25-40 mm in size and about 4-5 days. Females lay eggs in sensitive petioles and succulent leaves, with the bulk of eggs placed in the midrib tissue's undersurface. Eggs are bright and translucent, with a somewhat oval form. Egg incubation time ranged from 3 to 5 days. Pupa is Brownish and about 7-10 days. Nymph takes 6 to 22 days to complete four instars and become adult. The life cycle of female complete within one month period (Paudel *et al.*,2021).



Mode of Damage caused by top borer of sugarcane:

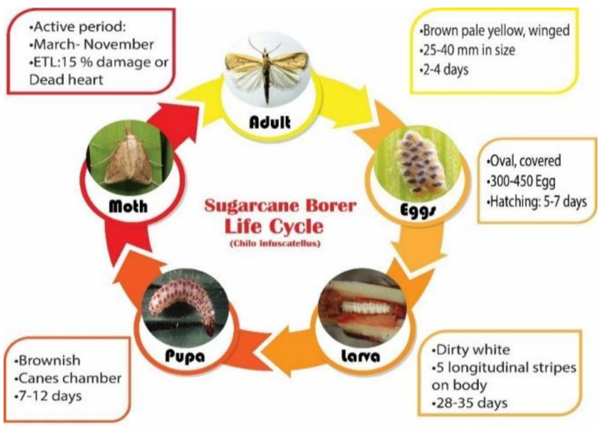
Caterpillar feeds on top portion that attack on different broods. Dead heart in grown up canes, which cannot be easily pulled, dead heart reddish brown in color, parallel row of shot holes in the emerging leaves and red tunnels in the midribs of leaves, bunchy top appearance due to the growth of side shoots (Kuniata., *et al.,*2019)

Controls of top borer sugarcane:

It can be controls by both non chemical and chemical methods. By non-chemical methods top borer of sugarcane can be control by removal of sugarcane tops and dead hearts during Dec to Feb and fed to cattle. Attacked shoots must be cut at ground level and use of sharp spike for killing. Use of light traps and pheromones traps and adult moth and larvae destruction. Use of egg parasitoid, Trichogramma chilonis, larval and pupal parasitoids and Isotima sp. By non-chemicals top borer of sugarcane can be controlled by using some chemicals such as Carbofuran (Furadon/Sunfuran/Curator 3G) 10-15 Kg/acre, Diazinon (Basodin 10G) 10Kg/acre and Cartap (padan 4G) 13-15 Kg/acre (Ruhela *et al.,*2021).

Stem borer of sugarcane:

Scientific name of stem borer of sugarcane is Chilo infuscatelus belong to family of Pyralidae and order is Lepidoptera. Feeding of stem borer of sugarcane is India, Pakistan, China, Formosa, Japan, Philippines, Thailand, Bangladesh, Indonesia, Laos, Cambodia, Vietnam, Burma and Taiwan. Adult insect is brown pale yellow in color, have both winged and about 25-40 mm in size and about 2-4 days. Females lay eggs in sensitive petioles and succulent leaves, with the bulk of eggs placed in the midrib tissue's undersurface. Female lays about 300 to 450 eggs and their hatching time period are 5-7 days. Eggs are bright and translucent, with oval and covered form. Larva is Dirty white have 5 longitudinal stripes on body and have 2-3 dark spots on their white-yellow forewings. Caterpillars have dark-brown to black heads, with five purple-brown longitudinal stripes along their greyish-white bodies. Active period of sugarcane stem borer is March- November and their ETL is 15 % damage or dead heart (Zhang *et al.,*2019).



Mode of Damage caused by stem borer of sugarcane:

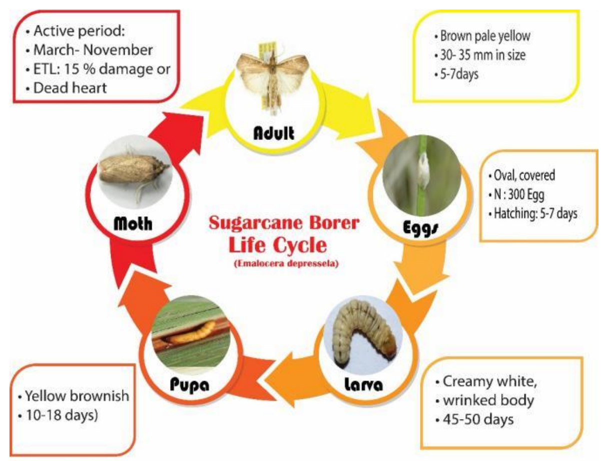
Caterpillar feeds and destroy 20% shoots annually. Dead heart shows in 1-3 months old crop, which can be easily pulled out. Caterpillar bores into the central shoot and feeds on the internal tissue cause Dead heart. Rotten portion of the straw-colored shoot emits an offensive odor. A number of bore holes at the base of the shoot just above the ground level (Achadian *et al*.,2023).

Control of sugarcane stem borer:

Sugarcane stem borer can be controlled by boht non chemical and chemical methods. By using non chemical methods of stem borer controlling is removal of sugarcane tops and dead hearts during Dec–Feb. and fed to cattle. Early sowing i.e. before middle of March. Use of different resistant varieties. Plough stubbles during Nov-Feb when larvae are hibernating. Attacked shoots must be cut at ground level and use of sharp spike for killing. Use of light traps and Pheromone traps. Use of egg parasitoid, Trichogramma chilonis and larval and pupal parasitoids Isotima sp. By chemical methods stem borer can be controlled by using different chemicals such as use of Carbofuran 10-15 Kg/acre, Diazinon 10Kg/acre and Cartap 13-15 Kg/acre (Nibouche *et al.,* 2019).

Root borer of Sugarcane:

Scientific name of root borer of sugarcane is Emalocera depressela belong to family pyralidae and order is Lepidoptera. Feeding of root borer sugarcane is India, Pakistan, mostly Barani areas and host ranges is besides Sugarcane, Sarkanda, Baru and other grasses. Adult is Brown pale yellow and about 30- 35 mm in size and about 5-7days. Females lay eggs in sensitive petioles and succulent roots, with the bulk of eggs placed in the midrib tissue's undersurface. Female lays about 300 to 350 eggs and their hatching time period are 5-7 days. Eggs are bright and translucent, with oval and covered form. Larva is creamy white, wrinkled body with transverse groove and over winter in stubbles of sugarcane. The larval duration is 21-27 days and it pupates inside the cane. The complete life cycle is 35-40 days. Dry sugarcane tops are produced due to the attack during July to September and large patches of dried canes appear due to its attack. Hitching time is 45-50 days. Pupae is yellow brownish and have 10-18 days. ETL of root borer is15 % damage/ and dead heart (Viswanathan *et al.,2021).*



Mode of Damage caused by root borer of sugarcane:

Very early observations on damage indicate that root borer attacks sugarcane in the early stages when the crop is 2-4 months old and causes damage throughout the year. Dead hearts are produced in the young crop which, though resemble those produced by shoot borer, cannot be pulled out (Gupta, & Paul 2023).

Control of root borer:

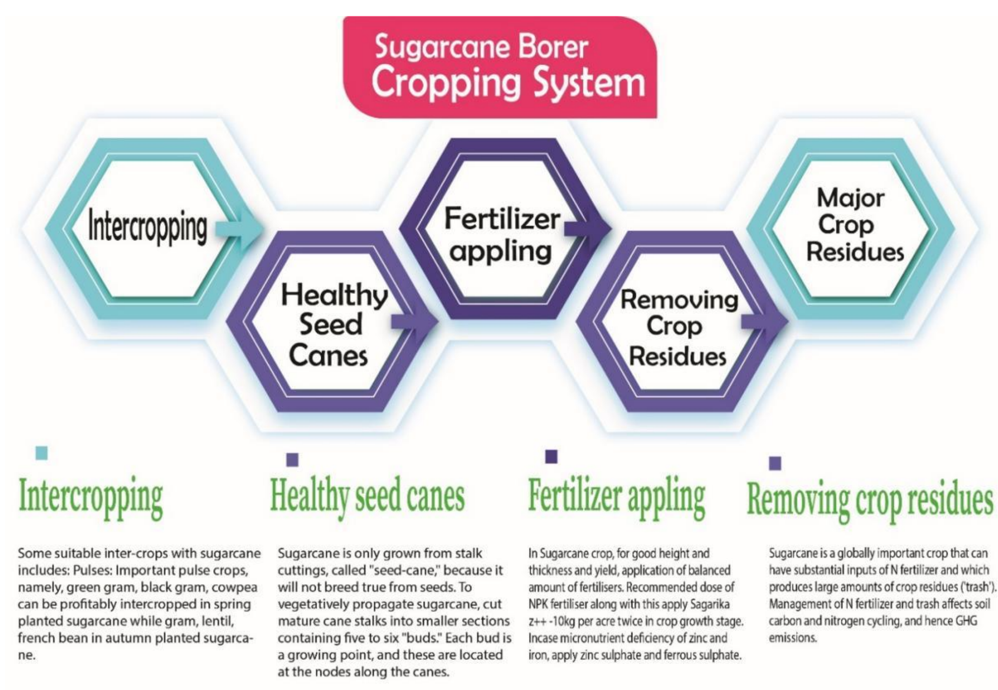
Root borer of sugarcane can be controlled by both chemical and non-chemical. By using non chemical root borer can be controlled by removal of sugarcane tops and dead hearts during Dec–Feb and fed to cattle. Early sowing i.e. before middle of March. Use of different resistant varieties. Plough stubbles during Nov-Feb when larvae are hibernating. Attacked shoots must be cut at ground level and use of sharp spike for killing. Use of light traps and Pheromone traps. Use of egg parasitoid, Trichogramma chilonis and larval and pupal parasitoids Isotima sp. By chemical methods stem borer can be controlled by using different chemicals such as use of Carbofuran 10-15 Kg/acre, Diazinon 10Kg/acre and Cartap 13-15 Kg/acre (Van Antwerpen *et al.,2022).*

Integrated pest management (IPM) control on sugarcane bores

Integrated pest management (IPM) is an ecological strategy for pest control designed to suppress pest populations below the economic threshold level (ETL) (Abinaya *et al.,* 2023). Presently, IPM systems for managing the sugarcane borer encompass the manipulation of cropping system, the use of chemical pesticides, behavioral manipulation, biological control, and the selection of resistant varieties (KUMAR *et al.,*2023)

Cropping system

The cropping system have long been acknowledged as the fundamental line of defense against pests in sugarcane cultivation practices (Sallam *et al.,*2021). These practices encompass intercropping, planting clean seed canes, the removal of crop residues and damaged plants, fertilization, the manipulation of planting dates, and other specific tillage methods (Raza *et al.,*2019). Intercropping is a valuable cultivation practice that can reduce pest damage, while simultaneously increasing income (Sanghera *et al.,*2023). However, it is important to avoid intercropping sugarcane with similar crops from the same family, Graminae, such as maize, sorghum and rice, to prevent the spread of pests between these crops (Nikpay *et al.,*2020). Alternatively, intercropping sugarcane with legumes such as soybean, mung bean, green manure crops, peanut, as well as vegetables such as tomatoes, hot peppers and cabbage, can establish an ecological balance conducive to the survival of natural enemies, thereby enhancing pest contorting the risk of pest infestation and enhancing both cane yield and quality. It is imperative to refrain from using canes sourced from fields severely impacted by pests (Ragunathan *et al.,*2020). Moreover, common practices such as pre-harvest burning and the timely mechanical removal of borer-infested shoots or egg masses have been widely employed to curtail in-field pest populations and minimize damage. The application of silicon (Si) fertilizer has proven effective in mitigating borer infestations by delaying the penetration of early instar larvaes into the stalks, resulting in increased larval mortality and reduced weight lost (Devi *et al.,*2023). Additionally, the choice of planting date can significantly impact D. saccharalis populations in sugarcane, with early-planted sugarcane displaying greater susceptible to borers, consequently leading to heightened infestations (Singh, D. P. (Ed.) 2023).



Chemical pesticide control

When the level of economic injury reaches 6–12% of damaged internodes for D. saccharalis, the necessity for action and the application of insecticides is recommended. Novaluron, an inhibitor of chitin synthesis, has demonstrated noteworthy reductions in D. saccharalis infestations, resulting in a 6.3–14.5-fold decrease in bored internodes (Wilson *et al.,2022).* Moreover, the pyrethroid gamma-cyhalothrin has proven effective in safeguarding sugarcane against D. saccharalis infestations. In studies conducted in Louisiana, insecticides such as Esfenvalerate, Cyfluthrin + Azinphos-methyl, Lambda cyhalothrin, Tebufenozide and Esfenvalerate + Acephate have demonstrated efficacy against D. saccharalis (Sharma *et al.,*2020). Particularly, they have shown a strong fit for the chemical management of the pest. Similarly, insecticides such as Clofenamide, ß-cyfluthrin, Novaluron and Chlorantraniliprole have proven effective in reducing D. saccharalis injury, achieving reductions ranging from 39.1 to 99.4%. Chlorantraniliprole and Flubendiamide have demonstrated high effectiveness in the management of E. loftini (Umar *et al.,*2021). In China, insecticides including Carbofuran granules and Bisalfap granules have been extensively employed for controlling sugarcane borer. Granular pesticides such as Sevidol granules, Lindane and Carbofuran have been utilized for controlling of the early shoot borer, C. infuscatellus, a significant pest in the sugarcane fields of Tamil Nadu, India (Dwivedi *et al.,*2023).

Behavioral manipulation

Considering the potential adverse effects of pesticides, behavioral management and biological control are regarded as alternative supplementary technologies for controlling sugarcane borer (Matti & P. V, 2021). Insects respond to a variety of chemical cues, including pheromones employed for mate attraction and allelochemicals used to locate host plants and identify plants under attack by herbivores. The utilization of sex pheromones serves as a valuable method for monitoring moth population levels of borers, providing essential information for timing insecticide applications and diminishing the fertility of wild females through mating disruption techniques (Roldán *et al*.,2020). The complexity of insect pheromones necessitates careful consideration of the formulation employed, particularly for successful trapping (Sandhu *et al.,*2020). For instance, the pheromone of C. infuscatellus has been identified as Z-II hexadecenol and Z-II Hexadecenal. While the sex pheromones of C. venosatus consist of a mixture of major components (Z13–18:AC, Z11–16:AC, and Z13–18: OH), only one sex pheromone component (Z11–16: OH) has been identified from C. infuscatellus. Pheromonetrapping techniques have proven successfully in detecting the presence of C. sacchariphagus (Sturza *et al.,*2020). Bojer in sugarcane in Mozambique sugarcane fields. The female sex pheromone of the sugarcane borer, C. sacchariphagus, comprises two compounds, (Z)-13-octadecenyl acetate (I) and (Z)-13-octadecen-l-ol (II). Traps baited with combinations of these components successfully captured male C. sacchariphagus moths, with the 7:1 ratio performing similar to a virgin female moth (Trials 1980). In field trials, a blend of (Z)-8-tridecenyl acetate, (Z)-9-tetradecenyl acetate and (Z)-10-pentadecenyl acetate in an 8:4:1 ratio proved highly attractive for trapping male C. auricilius (Mejía *et al*.,2020). Studies have showed that a combination of (Z)9-tetradecenol with (Z)-9-tetradecenyl acetate, with the most effective composition being 75:25, as an enticing attractant for male S. cretica. In Guangxi, China, control experiments utilizing the sex pheromone of C. infuscatellus on 5333 ha of sugarcane fields achieved a control effect of 82.48%, with the rate of attacked plants being less than 5% (Subiyakto *et al.,* 2023).

Biological control

In Integrated Pest Management (IPM) strategies for sugarcane borers, biocontrol plays a pivotal role. Biocontrol agents mainly encompass entomopathogenic microorganisms, parasitoids and natural enemies (Bezerra *et al.,*2021). Entomopathogenic microorganisms, encompassing bacteria, viruses, fungi, have found commercially applications as biological agents. Notably, among bacteria, Bt (B. thuringiensis) stands out as a well-known classical biological agent (Boonyaprapasorn *et al.,*2024). In South Africa, novel control strategies for E. saccharina have been developed using the sugarcane endophyte Gluconacetobacter diazotrophicus carrying Bt cry1Ac genes. Glasshouse trials revealed that sugarcane treated with Pseudomonas fluorescens carrying the Bt gene exhibited increased resistance to E. saccharina damage compared to untreated sugarcane (Garcia *et al*.,2024). In field trials, B. thuringiensis Berliner reduced D. saccharalis damage by up to 75%, although it has not yet been adopted for commercial production (Ruhela *et al.,*2020). The field of entomopathogenic fungi has emerged as a promising avenue for researching the biological control of insect pests in sugarcane plants. The entomopathogenic fungi Beauveria bassiana and Metarhizium anisopliae have displayed significant potential as biocontrol agents against the sugarcane borer, D. saccharalis (Zhou, Y. 2024). Field experiments conducted in Brazil showed that the application of M. anisopliae resulted in a commendable mortality rate of above 50% for D. saccharalis. Similarly, in India, M. anisopliae exhibited efficacy against C. indicus. Eight strains of M. anisopliae displayed high virulence against C. venosatus in China. Furthermore, M. anisopliae has demonstrated potential as a pathogen for S. inference (Rodrigues *et al.,*2021). In India, B. bassiana caused mortality rates of 69% to 76% in C. infuscatellus larvae. Laboratory studies have also indicated the pathogenicity of B. bassiana against S. inferens and S. grisescens. Other entomopathogenic fungi such as Hirsutella nodulosa, Isaria tenuipes, and I. farinosa. Cordyceps species have been studied on D. saccharalis, S. inferens and C. indicus, E. saccharina. Biological control through predation by natural enemies plays a significant role in managing sugarcane borers (Riffel *et al.,*2021). Predators such as ants, earwigs, ground beetles, spiders, wireworms, lady beetles, mites and soldier beetles are considered crucial in controlling sugarcane borers in Louisiana (Joseph *et al.,*2022). The red imported fire ant (Solenopsis invicta) emerges as a dominant natural enemy of D. saccharalis in Louisiana sugarcane fields. Pheidole spp. ants also serve as abundant predators on sugarcane borers. Spiders (Araneae) play a significant role as egg predators of D. saccharalis and hold second importance within the natural enemy complex (Silva *et al.,*2020). Fluctuations in biological control can arise due to geographical and seasonal variations, along with the presence of hyperparasitoids, which may undermine the effectiveness of this strategy. Moreover, the environmental instability of entomopathogenic microorganisms hinders their augmentative use in controlling sugarcane borers. Therefore, further in-depth research is still required in this field to achieve widespread application (Munira *et al.,*2020).

Parasitoids on sugarcane borers

NO.	Parasitioids	Borer Species	Borer life Stages	References
1-	Goniozus natalensis	Eldana saccharina	Larvae	Hearne et al. (1994)
2-	Lydella minense	Diatraea spp.	Larvae	Vargas et al. (2015)
3-	Xanthopimpla stemmator	E. saccharina, C. sacchariphagus	Pupa	Conlong (1994)
4-	Cotesia flavipes	Diatraea spp.	Egg and larvae	Parra et al. (2014)
5-	Telenomus busseolaes	S. Intacta, C. sacchariphagus	Egg	Qin et al. (2018)

Sugarcane Borer diseases detection

At present, Sankaran et al. used image method to calculate chickpeas seed size, and the result was highly correlated to the ground-truth data, with a correlation coefficient of 0.90, and the method also can be adapted for similar seed types (Li, A. 2024). Szczypiński evaluated the effectiveness of identification of barley varieties based on image-derived shape, color and texture attributes of individual kernels, with such analytical methods mainly as reduction of feature space dimensionality, linear classifier ensembles and artificial neural networks, and the barley varieties identification effect is better (Thilagavathi *et al.,2020).* At present, the sugar cane detection was mainly concentrated in fungi disease sugarcane leaf lesions and a variety of sugarcane shoots, internodes recognition study (Atheeswaran *et al.,*2023). In terms of sugarcane diseases, this study mainly concentrates on the sugarcane borer disease detection by the SVM classifier. Detected the sugarcane borer disease has an important economic value (Usman *et al.,*2020). First, used visual detection can replace manual detection, reduce capital investment and improve detection accuracy. Second, it can be combined with precut cutting machine to select the good seed and form the cutting - selecting automation, which can meet the needs of sugarcane precutting planter and improve the efficiency. Third, it can improve technological progress and lead the development of relevant technologies in this field (Kristini *et al.,2023).* For example, the design of precut cutting machine (automation or manual cutting), the design of storage and transportation equipment after the selection of sugarcane seed, and so on (Cruz *et al.,*2023). The process of sugarcane seeds image processing follows that, first of all, according to the characteristics of the sugarcane borer diseases were showed in the sugarcane image, the minimum average grey value and the corresponding minimum grey value as the classification features (Narmilan *et al.,*2022). And then, the grid search and the cross-validation method were used to select the regularization parameters C and kernel function parameter σ. According to the request of planting sugarcane, we should avoid select the parameter which has a relationship with low recognition rate for sugarcane diseases. Therefore, in this study, sugarcane borer disease as the main factors and disease-free as the secondary factors when choose the parameter. Finally, the detection purpose of sugarcane with disease and disease-free was realized (Verma, & Singh, 2024).

Sugarcane diseases and their control:

Sugarcane Smut:

This disease is mostly caused by the fungus Ustilago scitaminea. It can be characterized by normally whiplike surely sorus-bearing structures. Slender stalks, remarkably small narrow leaves and size variation are also its characteristics. After 2-5 months of cultivation, the diseased plant attain smut whip and shoot affects earlier. Globally, the most cane production affected by smut. Sucrose level, yield and juice quality is greatly affected due to sugarcane smut disease (Nalawade *et al.,*2022).

Control:

1. Rouging: remove or destroy soil before inserting the whip.
2. Plant deadly stems.
3. Hydrothermal treatment for 30 minutes at 52°C before planting.

Red Rot disease:

Cane erythema is caused by the fungus Glomerella tucumanensis. Red rot appears on the stem or spots with red spots and white centers and is recognized as a bundle of red blood vessels. Red rot is transmitted mainly from contaminated plant debris in the pores of water and soil. Agricultural and moisturizing agents, which typically infect insects, especially stems and termites, fungi and secondary invaders, accelerate the development of the disease red blood cells reduce sucrose in infected plants and increase processing costs due to impurities in the sap, while red artillery significantly reduces the germination rate of infected plants for planting (Viswanathan, 2021).

Control:

1. Planting resistant varieties.
2. Loosen the injured mass during the growing season.
3. Protect the weed less field and avoid planting in contaminated fields where plants were previously affected.
4.3 years of soybean harvesting practice (without grain).
5. A grid of healthy plants. It is necessary to remove dirt that indicates redness at the edges of the wound or part of a node or hole in the stem.

Sugarcane mosaic virus disease:

Sugarcane mosaic virus disease has been identified as one of the most important and deadliest pipe diseases in the world. SCMV is transmitted by mechanical ways and aphids. Diagnostic symptoms include young leaf spots and bright green or yellow-green leaf spots (Gitonga, 2021).

Control:

1. Plant-resistant varieties
2. Equalize systematically contaminated stocks by season.
3. Get rid of aphids and alternatives such as ivory, corn and sorghum.
4. Healthy plants should be selected

Sugarcane leaf blast:

Sugarcane leaf eruption caused by the fungus Paraphaeosphaeria michotii. This is a mild disease that survives straw and leaf debris. It attacks both leaves and stems. It affects leaf leaves, initially forming long yellow narrow spots with long axes parallel to the vessels. Spots can merge, and all leaves are red, dry and die from top to bottom (Indhumathi *et al.,*2022).

Control:

The best way to control this disease is to use only resistant varieties of a desire plant.

Curvularia leaf spot disease:

It is believed that the disease is a leaf region caused by Curvularia lunata. The initial symptom is a slight pale-yellow ribbon lesion on the first five leaves. Red changes occur around the lesion, and the affected tissue eventually dies (Limtong *et al.,*2020).

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