A NEW APPROACH FOR INTEGRATED PEST MANAGEMENT OF SUGARCANE IN PAKISTAN

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ABSTRACT

Conventional Integrated Pest Management (IPM) is mostly described as "a decision-making process using multiple pest management tactics to prevent economically damaging out-breaks while reducing risks to human health and the environment". Low-level IPM is the most often employed form, consisting of the most basic of IPM practices-scouting and insecticide applications according to economic thresholds. Some growers have progressed to medium-level IPM, the adoption of a few additional preventive measures, e.g. cultural controls and plant resistance, coupled with efforts to cut back on broad spectrum pesticide use in order to protect beneficial organisms. These IPM strategies are mainly targeted towards single pest species and do not consider all the pests in a specific agro-ecosystem. High-level or Bio-intensive IPM, is where multiple interventions are integrated in a bio-intensive approach targeting multiple pests. Bio-intensive IPM is based on holistic agro-ecosystem interactions, in which knowledge about insects, their symbionts, pathogens, natural enemies, plants, endophytes and interactions between all of these are combined to develop IPM in an area-wide, environmentally friendly manner. Reviewed here are advances in knowledge of, and of biotic interactions between direct, indirectand induced plant resistance, plant nutrition, habitat management, chemical ecology, natural enemies, soil-health, micro- organisms such as endophytic fungi and Wolbachia and phylogenetics and phylo-geography. All of these are potential building blocks of a bio-intensive IPM system under-construction at SRDB, SRI and MNSUAM. Also discussed are opportunities and challenges in these areas of research, considering bio-security threats to the Pakistan sugar industry and possible limitations in current sugarcane plant breeding material.

Keywords: *Chiloinfuscatellus*, IPM, Induced Resistance, Sugarcane, Pakistan, Direct and Indirect Resistance.

INTRODUCTION

SRI Faisalabad has been working to improve control of the sugarcane stem borer Chiloinfuscatellus (Snellen) since the early 2010s (Munir, 2014). A few cultural control measures and several less susceptible varieties have been developed against it (Munir, 2014). However, it still remains a pest throughout the sugar industry (Sikandar and Ahmad, 2021).

In order to build resilience

into the sugarcane agroecosystem, a refocusing of control efforts into a biointensive area-wide integrated pest management approach is necessarv (Klassen, 2005). Such an approach marries conventioncontrol options al with ecologically based new technologies such as delineation of within species populations, chemical ecology, stimulo-deterrent diversion (push-pull) and enhancement natural of enemies through habitat

management and good soil health practices, to produce sustainable IPM strategies applicable across large areas multiple involving stake (Conlong holders and Rutherford, 2009).There is also a need to refocus biosecurity build to again resilience to invasion into agro- ecosystems, rather than building walls around them.

IPM–From the bottom up

Plant resistance to pests and diseases can be linked to

optimal physical, chemical and biological properties of soil (Zehnder et al., 2007). 'Healthy' soil is described as having sufficient organic matter to support a high of animal diversity (arthropods, nematodesetc.) and microbial life. Soil can act as important reservoirs for a diversity of entomo fungi pathogenic & nematodes. as well as predaceous arthropods. which contribute can significantly to the regulation of pest populations.

Ninety percent of insect pest species spend at least part of their life cycle in soil. In addition. pests that occasionally come into contact with soil can be attacked by predators or become infected by entomo pathogens (Klingen et al., 2002). After the harvest of heavily infested sugarcane, the residual E. saccharina population from which infestation of the following ratoon crop can be expected is found in the sugarcane stubble at soil level and in the stool below ground.

minimizing compaction By and tillage, and by mulching and increasing organic soil scan support matter, populations increased of entomo pathogenic fungi, pathogenic entomo nematodes and predaceous arthropods such that these natural enemies of insects can be included in the suppression of pests in a conservation biological control strategy (Meyling and Eilenberg, 2007).

Direct and indirect hostplant resistance

Insect resistance in grasses is the result of many defense mechanisms that act in parallel to limit the damage of herbivore attacks. Many of these defense mechanisms based on are plant secondary metabolites. or defensive proteins that directly affect the herbivore due to their toxic, deterring or anti-nutritional properties.

Structural resistance also occurs. Keeping and Meyer (2002) have shown that resistance to E. saccharina can be enhanced using soilsilicon. applied which becomes incorporate in to the plant alongside lignin and fiber increasing resistance to penetration. These authors emphasize а relationship between nitrogen and silicon nutrition where by the ratio of these elements determined in leaf analyses can be used as an indicator of E. saccharina infestation risk. Keeping and Rutherford (2004)have reviewed mechanisms of resistance E. direct to saccharina. Two decades ago, a new type of defense mechanism, termed indirect defense, was first described in maize. Central to this type of defense is the release of a volatile plant SOS signal, a mixture of volatile secondary metabolites.

Plant volatiles are derived from complex biochemical processes and include fattyacid-derived products [methyl-jasmonate, cisjasmone, and green leaf volatiles (GLV) like hexenal

hexenyl-acetate]. and monoterpenes, sesquiter shikimicacidpenes, and derived products [e.g.methylsalicylate and indole] (Ferry et al., 2004). These can serve as signals, not only to attract predators and parasites of attacking herbivores, but they can also repel the herbivore itself, and they can elicit responses in neighbouring undamaged plants (De Moraes et al., 2001). The use of elicitors to directly activate or prime resistance shows much promise as an IPM tool (Zehnder et al., 2007).

Habitat management

Therefore, it is very important to understand the role of plants in managing in sect populations. An example comes from our experience control in trying to Ε. saccharina with indigenous association and new biological control agents.

Conlong *et al.* (2007) found that female *E. saccharina* moths will accept *Cyperus papyrus* and *Cyperus dives* as host plants in preference to the indigenous grass *Pennisetum purpureum*, with sugarcane being least preferred.

A preference was demonstrated by Keeping *et al.* (2007), that if given choice between older sugarcane & maize, *E. saccharina* would ovi position maize even if it were Bt maize.

Keeping *et al.* (2007) further showed that larval survival on

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this Bt maize was zero. A hierarchicalovi position preference (Thompson and Pellmyr, 1991) is suggested Southern African E. in saccharina females. with most ovi position found on or close to its indigenous sedge hosts, followed by indigenous and then grasses, sugarcane.

However, a large proportion of these eggs were not laid directly on the plants, but in crypticovi position sites in the of potential vicinitv host plants (Kasl, 2004; Barker, Egg dumping 2008). is highly behavior of poly phagous species (E. saccharina attacks species of the Cyperaceae, Typhaceae, Juncaceae and Gram in (Conlong, aceae 2001: and Conlong, Mazodze 2003), orin species associated with super abundant host plants.

These are both possibilities with E. saccharina in sugarcane and its cyperaceous hosts, as both occur hosts in large mono-specific essentially stands. Adult females therefore may not be particularly attracted by host or 'pull' plants in an IPM system and conversely they may be more strongly repelled by non-host or 'push' plants, since the presence of these could indicate that the insect had reached the edge preferred of the monospecific host plant stand.

Nevertheless, *E. saccharina* seems to have a hierarchical preference in choosing a host plant habitat to oviposit in,

i.e. Cyperaceae and maize, both of which have *E.* saccharina population controls in place; natural enemies in the Cyperaceae (Conlong, 1990, 1997, 2000) and genetically engineered Bttoxininmaize (Keeping *et al.*, 2007).

Further evidence to promote habitat management as a control option, demonstrated the repellent 'push' properties of the indigenous grass Melinisminutiflora Beauv. to cereal stem borers, and also its attractant properties to their parasitoids. М. minutiflora produces volatiles similar to damaged maize, even in the absence of pest damage to itself (Gohole et al., 2003).

In a glasshouse experiment SASRI, Xanthopim at (Thunberg) plastemmator (Hymenoptera: Ichneumonidae) parasitised more E. saccharina pupae in sugarcane in close proximity to this grass, than in sugarcane only (Figure 1) (Kasl, 2004). This suggests that the searching behaviour of the parasitoid was increased Melinis by volatiles.

The next phase in developing habitat management this approach for E. saccharina was to setup field trials using rows of *M. minutiflora* along either in irrigation or contour breaks as a repellentor 'push' plant. Ε. saccharina damage populations and were halved in field plots planted next to strips of M. compared minutiflora to control plots, suggesting that the pest was repelled by *Melinis* volatiles (Figure 2) (Barker *et al.*, 2006). Planting *Cyperus papyrus* as a trap, or 'pull' plant along drainage lines of selected sugarcane fields resulted in significantly reduced damage in the cane associated with it (Figure 3) (Kasl, 2004).

Based on the success of these trials. a farm-based management plan habitat has been devised, incorporating indigenous host plants and Bt maize as 'pull' plants for E. saccharina and M. minutiflora as the 'push' component. This biointensive approach has been expanded Biointo а intensive-PM plan, in corporating plant nutrition, soil health and the use of less susceptible sugarcane varieties.

An addeda spectto the plan is to plant buck wheat at the time of sugarcane planting. This is to attract adult parasitoids and predators into the sugarcane environment by providing a pollen and nectar source for their survival during periods of low host availability, much the same as advocated by Wäckers et al. (2005) and Zehnder et al. (2007) in their conservation biological control approach to enhance the activity of indigenous natural enemies.

Does sugarcane emit SOS volatiles when attacked by *E. saccharina*?

In contrast to the situation in the natural hosts of *E*.

negligible saccharina, parasitism has been recorded in sugarcane, even when this crop was planted adiacent to infested indigenous host plants with a bundant parasitoids present (Conlong and Hastings, 1984). Many introduced parasitoid shave also failed to colonise the sugarcane habitat (Conlong, 1997).

Using gas chromatography, Smith et al. (2006) showed volatile different emission patterns Cyperus between papyrus infested by Ε. saccharina and un-infested С. papyrus. Infested sugarcane was neither qualitatively or quantitatively different from un-infested sugarcane and both were different from C. papyrus (Figure 6). In addition, these authors showed that the Goniozusindicus parasitoid (Ashmead) (Hymenoptera: Bethylidae) was attracted to frass from E. saccharina that had fed on C. papyrus, and was not attracted to frass from E. saccharina that had fed on sugarcane. Adding this to the lack of parasitism recorded in sugarcane, even in the vicinity of natural host plants harbouring parasitoids, suggests that modern sugarcane genotypes may not attract natural enemies through the release of herbivore induced SOS volatiles, or that they may differ in the ability to do so.

Genotypic differences in plant volatile emission

The ability to mount indirect defence against *E*.

saccharina may have been lost in sugarcane as a result in advertently of concentrating on direct resistance in amono culture oriented plant breeding selection program. Besides this possibility, the release of volatiles plant is characterised bya large degree of genotypic variation plant species, within for example, maize genotypes their closest and wild relatives. Zea mays ssp. Parviglumis and Mexicana (collectively known as teosinte). show significant differences in emissions when attacked (Gouinguene et al., 2001; Degen et al., 2004).

An example of loss of indirect defence has been found below ground in maize. In response to feeding by the western rootworm, corn Diabrotica virgiferavirgifera (Coleoptera: (LeConte) Chrysomelidae), maizeroots (E)-b-caryophyllene release attracts the entomo that pathogenic nematode habditismegidis Heteror (Rasmann et al., 2005). Most North American maize lines not release (E)-bdo caryophyllene in response to rootworm attack, whereas many European lines and teosinte accessions do (Kollner et al., 2008).

The existence of genotypic differences in the emission pattern of volatile compounds for Kenyan *M. minutiflora* cultivars has also been demonstrated (Gohole*et al.*, 2003). The lack of response by *X. stemmator* in the presence of Australian *M.*

minutiflora again points to variability within this species (Figure 1). Australian *M. minutiflora*is extensively used for cattle fodder.

The strong od our of the plant can be carried through to milk and, because of this, there has been an extensive program to breed less volatile variety with similar nutritional quality. The volatile (s) that the parasitoid responded to in the African variety could have been bred out of the Australian variety.

Breeding for artificially primed and induced resistance

The loss of the ability to produce an SOS volatile and the observed genotypic variability in their production by maize points towards the exploitation of the phenomenon in sugarcane, by breeding varieties for enhanced attractiveness to natural enemies. This could be achieved through the application of an artificial elicitor followed by selection for enhanced direct and indirect resistance in а system that includes natural enemies.

Experimental application of elicitors is fairly simple and it worth trying to make is selections among plant breeding lines grown under the influence of plant defence elicitors, aiming for new cultivars optimized for artificially inducible resistance traits without significant yield penalty (Agrawal et al., 2002; Ahman, 2006). Historically, induced resistance research has mostly concentrated on direct activation where resistance is expressed in advance of challenge by the pest. The possibility of priming as a mechanism of protection has often been overlooked because it only becomes challenged apparent in plants. Priming equates to a 'heightened state of readiness', in that in the event of damage to a primed plant, resistance responses are faster and more intense (Conrath et al., 2006).

Direct activation of resistance best be employed might where the target pest is widespread and has An predictable outbreaks. example is the sugarcane thrips. Fulmekiolaserrata (Kobus) (Thysanoptera: Thripidae) that affects more than two thirds of sugarcane plants in a particular field at the same time. Outbreaks occur in summer with peaking numbers every January since the pest was first discovered on the African continent in 2004 (Way et al., 2006). Primed resistance would, however, be more suitable for *E.* saccharina. since much lower а proportion of plants is attacked and infestation stend to be patchy.

Ecology and phylo geography

The basic building block of IPM is stiller garded as ecology (Gurr *et al.,* 2003). In a study of *E. saccharina*, Conlong (2001) found behavioural, host plant and natural enemy differences in

population soccurring between South, Central and West Africa, with them seemingly coming together in Uganda.

The second fusing factors between different populations what otherwise of is amorphologically similar species made it an ideal can e for did at molecular systematic canalyses. Assefa using the (2006).et al. cytochrome oxidase subunit 1 (CO1) region of the mitochondrial genome, separated E. saccharina into three distinct groups (west, south and Ethiopian). Two of these groups (west and south) were found in Uganda. The CO1 genetic diversity between these groups was larger than that between recognised species within the genus Ostrinia (Lepidoptera: Crambidae) (Coatesetal., 2005). In other insects. unexpected mt DNA CO1 patterns have led to the discovery of cryptic species (Hebert et al., 2004; et al., 2007). Such diversity should encourage us to confirm covarving genetic. behavioural and ecological characteristics which would lend support to the notion that cryptic species exist within the Ε. saccharina complex.

In IPM programs which use classical bio-control as one of their management options, or translocation of natural enemies, these aspects can be enhanced by using such techniques to identify cryptic species, or populations of species most closely related to each other, so that more informed decisions can be made regarding natural enemy selection for use against pests. This applies not only to pest species, but also to parasitoids (Ngi-Song *et al.*, 1998).

Since 1992. surveys for indigenous parasitoids of E. saccharina in a variety of African habitats have been completed. Thirty species of larval parasitoids have been found in eight countries (Conlong, 2000). Several of have failed these to parasitise E. saccharina from South Africa due to incompatibility. For example, from West Africa. Descampsinasesamiae (Diptera: Tachinidae) larva eareen capsulated by E. saccharina (Conlong, 1997). Cotesiasesamiae (Cameron) (Hymenoptera: Braconidae) from South A fricaisalsoun successful as capsulated. sareen egg Further collections of parasitoids from Central Africa, where southern and western populations of E. could saccharinaco-exist, revealbiotypes of parasitoids that could be effective against this pest (Ngi-Song et al., 1998).

The interaction between *E. saccharina* and *Fusarium*

When E. saccharina bores in sugarcane, the tissue surrounding the boring becomes reddish discoloured often affecting а whole internode. Following on from this, and work of Schulthess et al. (2002), McFarlane et al. (2009) cultured numerous

Fusarium spp. isolates, from the red tissue surrounding *E. saccharina* borings, as well as from undamaged stalks as endophytes. Most of the isolates from borings were beneficial to *E. saccharina* in artificial diet in terms of larval survival and growth rate, and were attractive to neonatesinol factory choice assays.

A few of the endophytic isolates were antagonistic, with *E. saccharina* neonates repelled and growth retarded. Moths may also be attracted or repelled depending upon isolate. Ako *et al.* (2003) showed that West African *E. saccharina* females laid on average 32 eggs on maize stalks with *F. verticillioides* present as an endophyte, versus nine on stalks grown from fungicide or hot water treated seeds.

In integrated control an against Ε. approach saccharina, seed cane hot water treatment and/ or treatment with fungicides endophytic could reduce Fusarium colonisation by isolates beneficial to Ε. saccharina, thereby reducing the chance of infestation. Alternatively, the facilitation of endophytic colonization of sugarcane Fusarium by isolates antagonistic to E. saccharina could afford more sustainable and environmentally friendly protection from this stalk borer. Another approach could be to exploit the differences in volatiles repellent between and isolates attractive the in development of repellents and lures of use in the field.

CONCLUDING REMARKS

Khan et al. (1997a) described a 'push-pull' system effective against stem borers in This sugarcane. system the indigenous includes parasitoid Cotesiasesamiae as well as C. flavipes which were introduced against the Chilopartellus exotic (Overholt et al., 1997). C. phagus. sacchari now present in Mozambique, is being parasitised by both C. flavipesand X. stemmatoron larvae and pupae respectively in sugarcane. Ngumbi et al. (2005) showed C. flavipes females that respond to terpenoids and the green leaf volatiles which are released by maize plants damaged by C. partellus. This suggests that sugarcane may produce SOS volatiles in response to C. sacchariphagus.

There alternative are hypotheses to that of loss of ability to produce SOS volatiles. By boring the tops of stalks and leaf spindles in voung cane, volatile emission could be elicited bv C. sacchariphagus, whereas E. saccharina may avoid eliciting volatile emission by boring the bottoms of stalks in older cane. Another hypothesis is that the Fusarium associated with E. saccharina could interfere with the elicitation of volatile emission or change the composition emitted of volatiles. These possibilities worthy are of further investigation.

Nevertheless, a bio-intensive IPM strategy could be made more effective if the crop itself is capable of releasing appropriate SOS volatiles when attacked. Breeding varieties for enhanced attractiveness to natural potential enemies has if natural enemies are already habitat present in the management system. Goniozusindicus parasitises E. saccharina in C papyrus. It is also known to parasitise C. partellus (Keiji and Overholt, 1996) and has been found doingso in Sorahum arundinaceum growing in proximity to С. papyrus (Conlong, 1994; 1997). It is therefore possible that G. indicus could parasitise both C. sacchariphagus and E. saccharina in sugarcane. The same applies to the pupal parasiteX. stemmator.

Conlong et al. (2004) showed that some of the varieties with the highest direct resistance to E. saccharina were the most susceptible to C. sacchariphagus and viceversa. This has implications for variety choice in an IPM system designed to target both pests simultaneously, should С. sacchariphagus South African invade the industry. sugar Given increasing adoption of the 'push-pull' habitat management concept even in the absence of parasitoid activity against E. saccharina in sugarcane, and its success against C. partellusin maize, we are confident that 'pushpull' habitat management will also be effective against C. sacchariphagus.

The development of IPM strategies depends on a

sound understanding of the chemical ecology of pest interactions with sugarcane, natural enemies and the habitat. Modern IPM is not insect/plant only about interactions, it is about holisticagro-ecosystem interactions. which in increased knowledge about the environment. soils. plants, pathogens,

endophytes, symbionts and insects are all combined to provide effective crop protection in an environmentally friendly manner.

As knowledge about, and interactions between, induced plant resistance, chemical ecology, microorganisms such as endophytic fungi and Wolbachia. and phylo genetics phylo and geography of arthropods becomes easily available; it is hypothesized that these will become important components of bio-intensive AW-IPM, thereby minimizing the impacts of synthetic pesticides even more.

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