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Host-plant resistance and biopesticides: ingredients for successful integrated pest management (IPM) in Australian sorghum production

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Abstract. There are two major pests of sorghum in Australia, the sorghum midge, *Stenodiplosis sorghicola* (Coquillett), and the corn earworm, *Helicoverpa armigera* (Hübner). During the past 10 years the management of these pests has undergone a revolution, due principally to the development of sorghum hybrids with resistance to sorghum midge. Also contributing has been the adoption of a nucleopolyhedrovirus for the management of corn earworm. The practical application of these developments has led to a massive reduction in the use of synthetic insecticides for the management of major pests of sorghum in Australia. These changes have produced immediate economic, environmental and social benefits. Other flow-on benefits include providing flexibility in planting times, the maintenance of beneficial arthropods and utilisation of sorghum as a beneficial arthropod nursery, a reduction in midge populations and a reduction in insecticide resistance development in corn earworm. Future developments in sorghum pest management are discussed.

Sorghum cropping in Australia

Grain sorghum, *Sorghum bicolor* (L.) Moench (Gramineae), is the most important summer cereal in Australia. The grain is used mainly for feeding stock, whereas the stubble is grazed. Between 400 000 and 600 000 ha are grown annually with production varying between ~500 000 and 1.5 million t. Approximately 70% of the crop is grown in central and southern Queensland, with the remainder in northern New South Wales.

Sorghum pests

More than 20 insects attack sorghum in Australia, of which the most important are the sorghum midge, *Stenodiplosis sorghicola* (Coquillett), and the corn earworm, *Helicoverpa armigera* (Hübner) (Passlow *et al*. 1985).

Larvae of four species of false wireworms, *Gonocephalum carpentariae* (Blackburn), *Gonocephalum macleayi* (Blackburn), *Pterohealus alternatus* Pascoe and *Pterohealus darlingensis* Carter, attack the germinating seed and initial growing shoots and roots. Adult false wireworms eat seedlings as they emerge from the soil and together with cockroaches (*Calolampra* spp.) and crickets [*Lepidogryllus* spp. and *Teleogryllus commodus* (Walker)], occasionally cause problems in the Central Highlands area of Queensland. Losses may be widespread and severe. Ants (*Pheidole* sp.) occasionally cause losses by harvesting planted seed. The black field earwig *Nala lividipes* (Dufour) creates some problems in the heavier black alluvial soils. The cutworm *Agrotis infusa* (Boisduval) rarely causes widespread losses, but isolated heavy infestations do cause damage. Two species of armyworm, *Pseudaletia convecta* (Walker) and *Pseudaletia separata* (Walker), attack leaves.

The corn aphid *Rhopalosiphum maidis* (Fitch) is universally associated with sorghum production in Australia. On occasion, enormous numbers are found on plants in the vegetative stage within the plant whorl. It is also an occasional pest of sorghum panicles. Honeydew excreted by the aphid causes sticky grain, which interferes with harvesting and grain handling (Spackman and Murray 1982). In warm humid tropical and coastal areas, the larvae of two species of moths, the sorghum head caterpillar *Cryptoblabes adoceta* Turner and the yellow peach moth *Dichocrocis punctiferalis* (Guenee), occasionally attack heads in the soft-dough stage and up until close to harvest.

The Rutherglen bug *Nysius vinitor* Bergroth was not included as a pest of sorghum by Passlow *et al*. (1985); however, in recent years the bug has been increasingly important, with large numbers of nymphs infesting panicles during the post-flowering stage and consequently it is now listed as a sorghum pest (Franzmann 2007). Feeding by the bugs on seeds results in reduced seed yield and quality.

Four species of locusts, the migratory locust *Locusta migratoria* (Linnaeus), the Australian plague locust *Chortoicetes terminifera* (Walker), the spur-throated locust *Austracris guttulosa* (Walker) and the yellow-winged locust *Gastrimargus musicus* (Fabricius), may cause severe damage in plague years.

Sorghum midge

The sorghum midge is probably the most important insect pest of sorghum worldwide (Young and Teetes 1977). It is a common pest wherever sorghums are grown between latitudes 40°N and 40°S (Harris 1985), and is the major sorghum pest in Australia (Passlow *et al*. 1985). Henzell *et al*. (1996) estimated that its annual cost to production in Australia was AU$10 million.

During the warm months of the year adult midge emerge from infested sorghum spikelets early in the morning. They mate and females fly to flowering sorghum and lay eggs within the

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spikelets. Most of the adults live for only 1 day. Damage results from the larva feeding on the caryopsis, which fails to develop into grain. The life cycle occupies about 3 weeks.

As winter approaches most individuals go into diapause (hibernation) as fully developed larvae in infested spikelets. As temperatures rise in spring and after a period of rain the diapausing larvae commence to develop and emerge (Franzmann *et al*. 2006). After one or two generations developing on the weed Johnson grass [*Sorghum halepense* (L.) Pers.], the midge attack flowering grain sorghum (Lloyd *et al*. 2007).

Management of sorghum midge – past history

Until the 1980s, sorghum midge was managed by manipulation of planting time, elimination of and isolation from alternative hosts, agronomic practices that ensured as even a flowering as possible, and insecticide treatment when necessary (Passlow 1973). Management today is centred on the growing of midge-resistant hybrids.

Midge-resistant sorghum

The development of midge-resistant sorghum, which we have in Australia today, began at Texas A&M University, USA, in the early 1970s, when Johnson *et al*. (1973) reported the discovery of useful and usable resistance.

A breeding program using this germplasm started at the Queensland Department of Primary Industries in 1975 (Henzell *et al*. 1980). Page (1979) demonstrated resistance to sorghum midge in this material in Australia. In cage tests Franzmann (1993) showed that the resistance was due to difficulty in laying eggs (ovipositional antixenosis) whereby the females died before all their eggs were laid (Franzmann 1996) and consequently fewer spikelets were infested per laying female.

Although the mechanism of resistance in commercial hybrids in Australia is principally ovipositional antixenosis, since the mid-1990s research has been conducted to isolate and incorporate an antibiosis mechanism of resistance into the Australian public breeding program (Hardy *et al*. 2001). The results of this search led to the selection of one new source of antibiosis-type midge resistance (MR). This resistance source is currently being incorporated into the Queensland Department of Primary Industries & Fisheries breeding program. The resistance was first discovered by researchers at the International Crops Research Institute for the Semi-arid Tropics, within an Indian land race line DJ6514, and has been deployed successfully in Indian grain sorghums (Sharma 1985).

The incorporation and commercialisation of MR in Australian grain sorghum is now nearly two decades old, and the history to date almost solely involves the commercialisation of the ovipositional-antixenosis resistance mechanism.

The first commercial midge-resistant hybrid was marketed in Australia in 1986. This first hybrid was a very poor agronomic type with a low level of resistance. However, a few hybrids of good agronomic type and possessing low to moderate levels of resistance (×2–4, i.e. a level two to four times that of a midge-susceptible hybrid) were available by 1992.

In response to the emergence of midge-resistant hybrids, commercial seed companies agreed that the level of resistance should be calculated for each commercial hybrid. This led, in 1993, to the formation of a unique partnership between the Queensland Department of Primary Industries and commercial seed companies to test all commercial hybrids to determine their level of MR. All commercial hybrids were tested repeatedly in a series of field trials to determine their relative levels of resistance. At the time a range of resistance levels between 1 and 7 was found. Since 1993, all commercial grain sorghum hybrids have been entered into the scheme and stamped with a MR rating of 1–7 after being tested against a series of control hybrids, which were rated between 1 and 7 in 1993 (Franzmann *et al*. 1996*a*).

However, by 2002–03 several hybrids were commercialised with MR ratings greater than 7. Subsequently, the midge-tested scheme was reviewed and expanded in 2003 to incorporate a new suite of highly midge-resistant hybrids (Hardy 2007). A new testing method was put in place to enable the MR rating scheme to more accurately rate hybrids with resistance levels equal to and above a new 8 MR standard hybrid. Any hybrids that recorded resistance levels above the 8-rated hybrid were assigned a new ‘open ended’ top MR rating of 8+. Such hybrids have been shown to be ‘practically immune’ to economic damage under most midge pressures in Australia.

Management of sorghum midge – the present

Currently over 99% of the grain sorghum crop in Australia has at least some level of midge resistance. All current commercial hybrids have a MR rating of 3 or more, most between 4 and 6. This high level of adoption and the elimination of low-rated MR hybrids has resulted in spraying for midge control being now extremely rare, with less than 5% of the crop being treated, whereas before the mid-1990s, 30–40% of the crop was sprayed (Hardy 2007).

Three species of parasitoids (Hymenoptera) have been recorded attacking midge larvae in Australia (Passlow 1958; Lloyd *et al*. 2007). Although the parasitoids don’t prevent damage by the larvae they parasitise, they can reduce midge populations in a crop (Franzmann *et al*. 1989) and consequently lower midge numbers attacking later-flowering crops in the local area. Reduced spraying for midge control greatly increases survival of parasitoids.

The overwhelming success of the commercialisation of MR hybrids means that most growers do not monitor their crops for midge for much of the growing season. Spraying crops for midge during the first half of summer is now a rarity. However, if midge are present, a simple formula is available to calculate an economic spray threshold.

Franzmann *et al*. (1986) determined the relationship between numbers of female midge laying eggs on panicles and resultant yield loss on midge-susceptible sorghum and used this value to construct a formula to determine the requirements for insecticide treatment (the economic threshold) (Franzmann *et al*. 1992). For midge-resistant sorghum, the economic threshold is increased by the factor of their midge resistance: 1–7 for most hybrids. In the case of 8+ hybrids the factor used is equal to or above 8. The MR rating is incorporated into a simple formula together with average yield loss per visiting female sorghum midge per day, the current sorghum price, the density of flowering plants and the cost and residual life of the insecticide used for control.

Apart from the universal use of midge-resistant hybrids at planting, there are several management practices that sorghum growers also use to avoid midge attack and lessen damage.

Early planting (before mid-November) to avoid midge attack (Franzmann *et al*. 2006) is an effective tactic to manage sorghum midge. Avoidance of midge attack may provide the added benefit of helping to increase longevity of effective host-plant resistance by lessening midge exposure to resistance factors.

Eliminating alternative hosts that serve to enhance the midge population increase in spring (Lloyd *et al*. 2007) lowers the chance of rapid build up of high midge populations in the area. Because populations usually increase by a factor of ~10 with each generation (Franzmann *et al*. 1989), panicles flowering about one generation time (3 weeks) after the commencement of flowering are at great risk of being attacked by high populations. Consequently, crops are managed to ensure as even a flowering as possible.

Corn earworm

Corn earworm is an important pest of many crops in Australia, including cotton and grains (Wardhaugh *et al*. 1980; Zalucki *et al*. 1986; Fitt 1994). It has been estimated to cost the Australian sorghum industry AU$14 million annually in control costs and production loss (Adamson *et al*. 1997).

On sorghum, female corn earworms lay eggs on panicles before flowering. Eggs hatch in 3–4 days and developing larvae feed initially on anthers and later on developing seeds. Larval development through 6 instars takes 18.5 days at 24.6°C (Twine 1978) and the larvae leave the plant and pupate in the soil. Adult moths emerge ~16 days later. The whole life cycle occupies ~7 weeks.

Pupae forming in autumn enter a diapausing or overwintering phase (Wilson *et al*. 1979; Kay 1982) and emerge as moths the following spring (October–November). Overwintering provides the main mechanism to convey insecticide resistance from one season to the next (Daly and Fitt 1990).

Management of corn earworm

More than 85% of the eggs laid on individual sorghum panicles by corn earworm are laid in the 3-day period before the commencement of flowering (Teakle *et al*. 1985; Franzmann 1986). Thus there is a close synchronisation between larval development and panicle development; larvae are usually in the 2nd or 3rd instar when panicles have just completed flowering. As no damage is done to developing seeds until larvae are in the 4th instar (Franzmann 2004), assessment of infesting populations and decisions on treatment may be withheld until the end of flowering. Withholding possible insecticide treatment allows for natural mortality factors to operate on the eggs and early instars. This mortality tends to be high. Generally, egg parasitism of corn earworm on sorghum panicles on the Darling Downs is usually above 60% and is often above 90% (Parker and Scholz 2004). Greater than 90% egg parasitism has been recorded in the Lockyer Valley (Franzmann 1986). Prior to the release of *Trichogramma pretiosum* Riley on the Darling Downs in 1995, *Trichogrammatoidea bactrae* Nagaraja was the dominant species of egg parasitoid (Scholz 1990). In a survey of the Darling Downs during 2003, *T. pretiosum* accounted for 98.6% of all parasitised eggs on sorghum (Parker and Scholz 2004). One of the most common biocontrol agents attacking corn earworm larvae on sorghum is the parasitoid *Microplitis demolitor* (Wilkinson), which oviposits into 2nd or 3rd instars (Seymour 1991). Parasitism of corn earworm larvae by *M. demolitor* on the Darling Downs is often 30–50% of moderate infestations of two to four larvae per panicle (D. A. H. Murray, unpubl. data). In a 5-year survey of overwintering *H. armigera* pupae in sorghum, 35% were parasitised by the larval-pupal parasitoid *Heteropelma scaposum* (Morley) (Lloyd *et al*. 2008).

In addition to these parasitoids, predators also take their toll. The egg predator *Orius tantillus* (Motschulsky) is common in flowering sorghum panicles (B. A. Franzmann, unpubl. data). Larval cannibalism is also an important mortality factor (Twine 1971; Twine *et al*. 1983).

Twine and Kay (1982) reported studies examining the relationship between corn earworm larval numbers and grain loss in sorghum and their results have been used as the basis for calculating treatment thresholds (Franzmann *et al*. 1992). The threshold formula has been modified recently following the results of further studies on midge-resistant open-panicled hybrids (Franzmann 2004). During its development, one larva is responsible for the loss of 2.4 g of grain.

When synthetic pyrethroids were first registered in 1978, they were spectacularly effective against *H. armigera* on sorghum. Resistance to synthetic pyrethroids was first reported in 1983, and resistance diminished performance to critical levels in most areas (Forrester *et al*. 1993). Synthetic pyrethroids applied for sorghum midge control inadvertently selected for pyrethroid resistance in *H. armigera*. Resistance also developed to endosulfan and carbamates (Gunning *et al*. 1992, 1996; Gunning and Easton 1994; Gunning 1995). Quick, easy and effective control with conventional synthetic insecticides was unreliable.

Corn earworm nucleopolyhedrovirus (NPV) is very effective on sorghum (Teakle *et al*. 1983, 1985; Murray *et al*. 2001), and in recent years much developmental work on the use of NPV against corn earworm on sorghum has been carried out (Murray *et al*. 2001). Consequently, NPV is now used almost exclusively for corn earworm control in sorghum. Less than 5% of the treated crop area is currently treated with synthetic insecticides.

For successful development in larvae infected with NPV, *M. demolitor* requires a 3-day advantage (Murray *et al*. 1995), so when using NPV, the recommendation is that assessments of populations be made 3 days after flowering. An alternative view is that NPV sprays may be applied during flowering as larvae are easier to kill when smaller (Franzmann *et al*. 1996*b*) and it matters little which organism does the killing. Also, there may be little point in saving *M. demolitor* for the next generation in that crop, as generally only one generation of corn earworm would develop on panicles in most crops. However, *M. demolitor* may be useful for biological control of later generations of corn earworm in other crops. Additionally, early NPV applications create the opportunity for an epizootic to occur from the first larvae killed (Teakle *et al*. 1985).

There are times when larvae are too large to target with NPV, and in such cases it is necessary to apply a more robust option. Methomyl has been the standard insecticide in such cases. Spinosad is now registered on sorghum but it has not been widely adopted, due largely to the excellent performance of NPV when correctly timed and its lower cost. Spinosad is relatively safe to most beneficial arthropods, although high toxicity against Hymenoptera could be an issue in sorghum where parasitoids are potentially very important.

Although no studies have been published for the particular situation of corn earworm on sorghum in Australia, the reduction in insecticide application for midge increases the survival of natural enemies for corn earworm, and hence increases levels of mortality in corn earworm populations.

Management of other pests

The size of the population of soil insects attacking seed and seedlings can be monitored by the use of germinating seed baits (Robertson and Simpson 1989) and control applied if required. Cultural controls are important. The ground should be prepared so that germination is as even and rapid as possible. The use of press wheels reduces damage (Radford and Allsopp 1987). About 80% of sorghum seed in Australia is treated with either imidacloprid or thiamethoxam before sale; however, if required, most soil insects can be controlled by application of insecticides at planting.

Clean fallowing before planting and weed control around the field perimeter at least 1 month before planting reduces the risk of damage from cutworms. If larval populations cause economic damage then spot treatment of affected areas when larvae are active is usually effective.

Both the yellow peach moth and the sorghum head caterpillar are managed by the growing of sorghum hybrids with open panicles, as hybrids with open heads are less infested than tight-headed hybrids. If larval infestations are such that control is warranted, then cost-effective chemical control is available.

Natural enemies are very important in reducing panicle infestations by the corn aphid (B. A. Franzmann, unpubl. data). The most important are a few species of ladybirds and larvae of two species of hoverflies (B. A. Franzmann, unpubl. data). Biological control of the corn aphid has been boosted in recent years by the establishment in Australia of two new control agents: the parasitoid *Lysiphlebus testaceipes* (Cresson) (Carver and Franzmann 2001) and the ladybird *Hippodamia variegata* (Goeze) (Franzmann 2002).

The reasons for more reported infestations of Rutherglen bug in recent years are uncertain, but one suggestion is that spraying for midge and corn earworm with broad-spectrum insecticides previously killed bugs. Synthetic pyrethroids remain the most cost-effective control treatment, but because of their disruptive nature, should only be used when absolutely necessary. There is a need for well-defined thresholds. High numbers of adults (>100/panicle) during anthesis have been shown to significantly reduce yield (M. Miles, unpubl. data), but further studies are required to investigate yield damage relationships for populations consisting mostly of nymphs during grain fill.

Benefits of a new IPM

A revolution has taken place in sorghum pest management and production in Australia. Dramatic changes have been made over the past 10 years. The changes have produced both immediate and flow-on benefits to sorghum and other field-crop production generally.

Economic, environmental and social benefits

When midge attack sorghum in economically damaging numbers, chemicals are targeted at females before they oviposit. However, effective chemical control of sorghum midge is difficult and under high continuous pressure, is prohibitively expensive and unlikely to succeed. A new population of ovipositing females attack each day, and as residual control provided by the insecticide reduces progressively, its efficacy is negligible by 3–5 days, making repeat applications necessary at 3–5-day intervals. However in hybrids with only moderate levels of resistance, insecticide applications are much more effective and economic control is easier to achieve (Franzmann 1996).

Spraying for midge control is now extremely rare. The annual cost of midge to the sorghum industry is currently estimated to be less than AU$1 million (A. T. Hardy, unpubl. data). Consequently, the obvious impacts of midge resistance are the economic and environmental benefits of reduced insecticide application for midge control.

The adoption of midge resistance is providing a measure of social benefit for sorghum growers and their communities. Reduction in spraying in the vicinity of farming communities enhances their quality of life. Sorghum growers can now be assured that devastating crop losses from sorghum midge are a thing of the past. Growers also have improved confidence that grain delivered to feedlots is free of chemical residues.

Flexible planting times

The practice of early, uniform planting of the sorghum crop has often been reported as an effective means of midge avoidance (Atherton 1941; Teetes 1985). Prior to the availability of midge-resistant hybrids, growers planted early to avoid damaging midge populations. If conditions for planting were unsuitable in spring, later-planted crops (flowering in late summer) usually suffered huge yield losses from extreme midge attack.

With the use of hybrids with high levels of midge resistance, growers now have much greater flexibility in planting time and can make use of rainfall events to plant at times that in the past would almost surely have led to complete crop failure due to midge attack.

Maintenance of beneficial arthropods and utilisation of sorghum as a beneficial-arthropod nursery

The literature is replete with articles detailing the adverse effects of insecticide application on beneficial arthropods, which provide some biological control of pest arthropods. Insecticides registered for midge control are broad spectrum in their action, killing not only midge, but beneficial arthropods as well. With reduced spraying for midge control, these beneficial arthropods, which attack not only the midge but corn earworm and the corn aphid, are not adversely affected.

NPV sprays affect only larvae of corn earworm and closely related species. They have no effect on beneficial arthropods. Sprays of NPV are applied to more than 95% of the area treated for control of corn earworm on sorghum. With a marked reduction in spraying for midge control and the use of NPV for corn earworm control, sorghum may now function as a nursery for beneficial arthropods for later sorghum crops, and other crops in proximity to sorghum. Farmscaping, which involves the use of sorghum as a source of beneficial arthropods to enhance biological control in the farming system (cotton, grains) is being investigated. Results are promising. A study in 2004–05 found that yield from unsprayed conventional cotton, growing adjacent to sorghum, was equivalent to the yield from isolated conventional cotton sprayed seven times (B. C. Scholz, pers. comm.).

Sorghum crops, untreated with synthetic insecticides, are seen as a sink for *H. armigera* because of the high levels of mortality in all the immature stages. Maelzer and Zalucki (1999) showed a strong negative effect of sorghum area and production on the size of the subsequent *H. armigera* population in northern New South Wales, suggesting that sorghum is a sink. Indeed, as part of an area-wide management strategy, some growers on the Darling Downs are treating subeconomic corn earworm infestations on sorghum with NPV to reduce the overall local population size.

Reduction in midge populations

Franzmann and Zalucki (1993) carried out a computer simulation study on the effect of growing midge-resistant sorghum on midge populations. Output from the simulation indicated that the use of extensive sowings of midge-resistant hybrids should generally lower the overall midge population. For example, in one simulation when growing a midge-susceptible sorghum, the population multiplication rate was 55 in the first season. When a highly resistant sorghum was simulated the multiplication rate was reduced to less than one, and consequently the population could be expected to actually decrease. An overall smaller midge population would be of benefit in lessening the frequency of occurrences when midge would have to be controlled by spraying.

Reduced insecticide resistance development in corn earworm

Midge sprays target the ovipositing females that attack during flowering. Panicles in flower also harbour corn earworm larvae. Insecticide applications against sorghum midge coincidentally give some control of corn earworm, but unfortunately they also expose corn earworm to selection for resistance (Forrester *et al.* 1993). Across the sorghum-growing regions of Australia, *H. armigera* is now resistant to several major insecticide groups, including those used for midge control (Forrester *et al.* 1993; Gunning and Easton 1994; Gunning *et al.* 1996).

Fewer sprays for sorghum midge control removes a large portion of the selective pressure on corn earworm resistance development, and should reduce the chance of exacerbating further insecticide resistance. Results of resistance monitoring have indicated a recent stabilisation or decline in resistance levels for most conventional insecticides (Rossiter *et al.* 2007). This not only benefits sorghum growers requiring control of corn earworm, but the benefit will flow to other crops attacked by corn earworm.

Further developments in sorghum pest IPM

Research over the past 30 years formed the basis for the development and enhancement of midge-resistant sorghum, and its use and exploitation in sorghum IPM. Research is continuing in several areas.

Sorghum breeders are attempting to raise the level of midge resistance and broaden the genetic base by incorporating the antibiosis mechanism of resistance into commercial hybrids. One such hybrid with a low level of antixenosis and a high level of antibiosis has been released and others are nearing release. Research results (A. T. Hardy, unpubl. data) show that it is possible to double, and even triple, the level of midge resistance by incorporating antibiosis into current hybrids.

Molecular markers for midge resistance are being developed to allow efficient, effective and rapid selection, and speed up the breeding process (Tao *et al*. 2003; Hardy and Jordan 2006). Gene cloning of the antibiosis gene or genes is also being attempted to give researchers a complete understanding of the resistance mechanism and its stable deployment within commercial hybrids.

The use of NPV for corn earworm control has been extensively developed and improved (Murray *et al*. 2001). The current registered rate of Vivus Gold® (Helicoverpa NPV, Agbiotech Australia, Richmond, NSW) at 375 mL/ha costs about AU$20.00. Many growers have used lower rates (200–250 mL/ha) with great success, and application via ground rigs using banded sprays over crop rows can further reduce spray costs.

Research and development on the production of *in vitro* NPV has shown promise; and initial tests of *in vitro* NPV indicate it to be equivalent to a commercial *in vivo* NPV (Murray *et al*. 2001).

Conclusion

The development and implementation of midge-resistant sorghums in Australia has helped establish one of the few examples of successful use of host-plant resistance, and its integration into a pest-management system. Midge-resistant sorghums have facilitated the development of IPM in sorghum. The success in sorghum has greatly contributed to the promotion and adoption of the principles of IPM in other crops. The story is often used as an example when describing an IPM system.

The use of midge-resistant hybrids to manage sorghum midge and the use of a NPV against corn earworm has made a major impact on the cultural, biological and insecticidal control methods of the major pests of sorghum production in Australia. These management practices are offering a 'clean green' product to the market place and meeting the requirements of economic, environmental and social sustainability now and in the future.

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