Journal of
Agricultural, Food, and Environmental Sciences ISSN 1934-7235
Volume 1, Issue 2, 2007

Integrated pest management for African bollworm (*Helicoverpa armigera* (Hubner) in Botswana: review of past research and future perspectives

Motshwari Obopile, Lecturer/Entomologist, Department of Crop Science and Production. Botswana College of Agriculture, Private Bag 0027, Gaborone, Botswana. **mobopile@bca.bw**

Keatametse T. Mosinkie, Research Entomologist, Department of Agricultural Research, Private Bag 0033, Gaborone, Botswana. keatametsem@yahoo.com

Abstract

African bollworm or Old World bollworm (*Helicoverpa armigera* Hubner, Lepidoptera: Noctuidae) is an extremely polyphagous and major pest of many crops in Botswana. The damage to most crops results in reduction of yields. *H. armigera* is estimated to cause yield loss of 15 to 30% on sorghum in Botswana. Despite its importance, research on *H. armigera* has not been carried out in Botswana since 1979. This paper reviews the research on management of *H. armigera* that was undertaken in Botswana from the late sixties to late seventies (1967 to 1979). The research focused on developing various pest management methods that would be packaged into an integrated pest management strategy to manage *H. armigera* in field crops. The major findings were that microbial control (using nuclear polyhedrosis virus and *Bacillus thuringiensis* Berliner), enhancing natural enemies, cultural control and the use of insecticides had potential in management of *H. armigera.* These findings are discussed in comparison with other studies done in Asia, Australia and other parts of Africa where African bollworm is a major pest of field crops. The primary objective of this paper is to review the research that had been undertaken on *H. armigera* in Botswana and propose future research needs and directions.

Keywords: *Helicoverpa armigera,* parasitism, nuclear polyhedrosis virus, bioecology

Introduction

The African bollworm (*Helicoverpa armigera (*Hubner) Lepidoptera: Noctuidae) is an important pest of many crops in Botswana (Ingram et al., 1973, Roome, 1976, Munthali et al., 2004) and in many parts of the world (Zalucki et al., 1986, Sharma, 2001). It is reported to attack more than 60 plant species belonging to more than 47 families (Zalucki, 1994). *H. armigera* is distributed eastwards from southern Europe and Africa through the Indian subcontinent to Southeast Asia, and thence to China, Japan, Australia and the Pacific Islands (Reed and Pawar, 1982). *H. armigera* is recorded as a pest of virtually all field and horticultural crops (Jallow et al., 2004). It has been reported as a major pest of cotton, sorghum, maize, sunflower, groundnuts, cowpea, tomato and green pepper (Ingram et al., 1973, Roome, 1976, Munthali et al., 2004). The infestation by *H. armigera* on these crops is largely restricted to one stage in host-plant development. On cotton, damage is characterized by feeding activity on flower buds, flowers and cotton bolls. On maize, the larvae initially feed on the silk and later penetrate the tips of ears while in sorghum they damage developing grain from the milk to soft dough stages. On sunflower levels of infestation vary between localities and seasons, sporadically reaching epidemic proportions (Du Plessis, 1997). Small *H. armigera* larvae usually occur during the budding stages of sunflower and feed mainly on bracts (Du Plessis and van den Berg, 1999). In cowpeas, the larvae of *H. armigera* feed on flowers and bore into developing pods.

The direct damage to flowers and fruiting structures by larvae cause great losses in most crops. It causes an estimated loss of over US$2 billion annually in the semiarid tropics, despite US$500 million worth of pesticides applied for controlling this pest (Sharma, 2001). On sorghum *H. armigera* is estimated to cause yield loss of 15 to 30% in some years in Botswana (Gibbon et al., 1974). Despite the fact that *H. armigera* is an important economic pest of many crops in Botswana, research was only undertaken from the late sixties to late seventies (1967 to1979). During this period research was conducted by scientists funded mainly by Overseas Development Administration (ODA), now known as Department for International Development (DFID). At the end of the project when most scientists returned back to their countries there were few local scientists trained to carry out entomological studies in Botswana. Research work that followed at the end ODA project focussed on stemborers and sugarcane aphid with virtually no work done on African bollworm.

In this paper we review the research that had been undertaken on *H. armigera* in Botswana and present our perspectives on future research needs and directions for sustainable management of African bollworm. The past research focused on developing various pest management methods that would be packaged into an integrated pest management strategy to suppress population of *H. armigera* in field crops. The major findings were that microbial control, using nuclear polyhedrosis virus (NPV) and *Bacillus thuringiensis* Berliner*,* enhancing natural enemies and the use of insecticides suppressed the population of *H. armigera.* Most of the information is in the form of annual reports with limited access and this review intends to provide these results to the scientific community. Considering the importance of *H. armigera* in food crop production, we propose that more work need to be done on *H. armigera* to supplement past results. The use of various management methods like NPV, conservation of natural enemies, host plant resistance, cultural control (tillage, trap cropping and planting date) and minimum use of insecticides need to be packaged into an integrated pest management strategy against *H. armigera.* The move to revive research on *H. armigera* is supported by the fact that more farmers are now engaged in large-scale cotton, sorghum and sunflower production in Botswana, which are major hosts of African bollworm. There is also a relatively increased critical mass of crop protection scientists in Botswana who can carry out such research.

Monitoring and bioecology

The population dynamics of *H. armigera* was monitored by light trap placed at Sebele Agricultural Research Station (24^{o} 34' 34" S 25^{o} 56' 56" E) near Gaborone, Botswana from 1970 to 1975. The light trapping records of *H. armigera* moths collected are presented in Figure 1. The traps were set to determine times of emergence and periods of peak abundance to use as forecasting systems. The trends in the population dynamics of *H armigera* show the peak of emergence of overwintering generation in September. This peak is then followed by several more or less discrete periods of flight activity culminating in major peaks of adult activity in February, March, April and May (Anonymous, 1979). Similar trends were observed in Australia where abundance of *H. armigera* adults showed two distinct phases; an initial period of rapid recruitment in spring, creating a peak in November, followed by two to three subsequent, generally larger, generational peaks (Duffield and Steer, 2006). This is the period when many crops are still in the fields therefore available for damage by larvae of *H. armigera.* The major peaks coincide with period of higher availability of food from early-planted crop therefore posing problems to these crops. *H. armigera* adults are highly mobile, and adult movements occur on several spatial scales; between fields, between areas within a region, and between regions (Farrow and Daly, 1987). High population of *H. armigera* is associated with season of high rainfall. Early planted crops following good early rains and late planted crops following poor early planting rains suffer light attack by African bollworm while late planted crops following good early rains suffer heavy damage.

Diapause in H. armigera

H. armigera undergoes diapause as pupae in the soil. It exhibits a facultative pupal diapause, which depends on temperature and photoperiod (Kurban et al., 2005). The pupal diapause of *H. armigera* is also regulated by environmental cues during the larval stage (Roome, 1979; Qureshi et al., 2000), Shimizu and Fujisaki, 2002). Over-wintering pupae have the ability to delay normal development for a very long time, until temperature increased and plant growth renewed. Pupae formed under low temperature and short day length respond differently compared to those formed under high temperatures and long day length (Anonymous, 1975). The pupal day length is reported to have an effect on diapause and pupal period (Anonymous, 1979, Kurban et al., 2005). Minimum pupal mortality of over-wintering pupae can range between 50-80%. Abundant food supply during the wet seasons increases plant growth which favours the development of large populations of *H. armigera.* These variations in crop and insect phenologies have positive implications for cultural control methods. If all crops are cleared possibly in

April, this can reduce diapause in croplands, thereby reducing number of moths that will emerge during the cropping season.

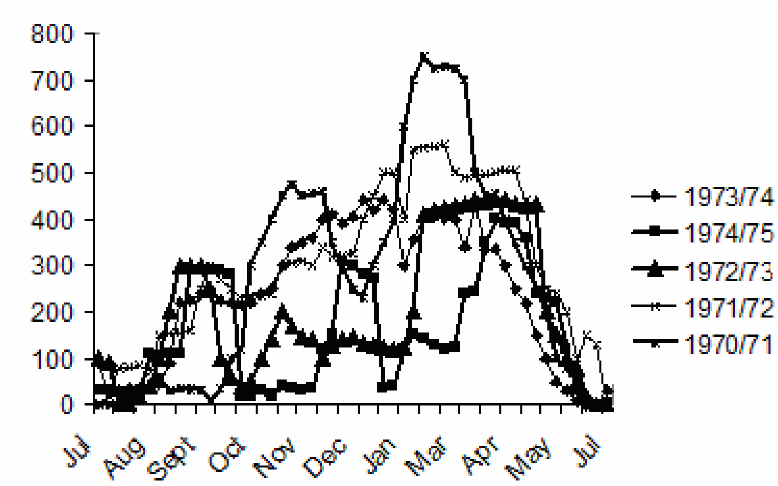

Figure 1**.** Annual flight patterns of *H. armigera* moth from 1973 to 1975 (Anonymous, 1975 and 1976).

Female oviposition and crop phenologies
Females oviposit at night and fecundity is high, with up to 3000 eggs reported from a single female (Shanower et al., 1999). Roome (1975) showed that female of *H. armigera* oviposited eggs between 2000hrs to 2300hrs. From here until 0200hrs, both the females and males started been inactive. The males usually fly above the crop in a purposeful manner from 0200hrs to 0400hrs. At this time the females remain stationary, released pheromone and then mated. Oviposition preference is reported to differ with crop species (Rajapakse and Walter, 2007). Host plants did not significantly influence the chance of a female moth being mated, despite substantial variation in moth abundance between the crops. Oviposition on all crops was found to be correlated with flower production but the level of oviposition depended on the coincidence between flower production and the state of fertility of the African bollworm population (Roome, 1975).

Female oviposition on cotton was found to be initiated by first flowering (bud formation) (Anonymous, 1975). After the first flowering, infestation by *H. armigera* did not correlate well with the flowering of cotton but followed more closely with the adult flight patterns. On legumes, cereals and sunflower, oviposition occurred mainly at early flowering and fell rapidly with the ripening of crop (Roome 1975, van Den Berg and Cock 1993). On maize egg density was greatest at tasselling and insecticides were recommended to be applied at tasselling and silking stage to reduce infestation. The initiation of oviposition in sorghum is suggested to be due to separation in the time of flowering of the main stem and the flowering of the tillers. Oviposition was heaviest on newly emerged sorghum flowers, and decreased rapidly as the anthers opened and was never observed on maturing crops (Anonymous, 1976, van Den Berg and Cock 1993).

Pest management methods
African bollworm is estimated to cause high yield loss on crops in some years in Botswana (Gibbon et al., 1974). Direct damage to flowering and fruiting structures by larvae, and extensive insecticide spraying result in low yields and high control costs (McGahan et al., 1991). Increased resistance to insecticides in *H. armigera* (McCaffery, 1998) has led to a renewed interest in developing alternatives to insecticidal control, such as ecologically based management methods and the development of resistant genotypes. Roome (1975a) reported that the control of *H. armigera* on crops that were grown for subsistence in Botswana could not support the cost of chemical control. Research efforts in Botswana focused on developing alternative control methods that included cultural control, biological control (parasitoids and insect pathogens) and use of resistant varieties.

Use of Pathogens

The microbial control methods that were studied and found effective against *H. armigera* were the use of nuclear polyhedrosis virus (NPV) and *B. thuringiensis*. Roome (1975b) tested a commercial preparation of NPV and *B. thuringiensis* against *H. armigera*. A single application of NPV at 200 LE Ha^{-1} mixed with 100 LE Ha^{-1} of 0.6% molasses (1 LE = 6 x 10^9 occlusion bodies per mL (OBs) gave season-long control on sorghum (Daoust and Roome, 1974). The results showed that NPV was as effective as a standard insecticide in reducing yield loss on sorghum due to damage by African bollworm. Neither the commercial preparation of NPV from *Heliothis zea* nor the *B. thuringiensis* preparation was as effective as the local NPV virus*. H. armigera* larval infestation was reported to rarely last for more than 30 days on sorghum (Roome, 1975b). The long survival of NPV on sorghum (80 days) indicated that a single application of NPV was adequate to protect the crop for a growing season. However the efficacy of NPV control on cotton was not as impressive as in sorghum. Recent work by Moore et al., (2004) in South Africa also showed that NPV has potential in management of African bollworm on citrus trees.

Use of parasitoids

Although parasitoids and predators can not be relied upon for total control of *H. armigera* in unsprayed fields, to understand their role is an essential component in the development of integrated pest management in cropping systems where *H. armigera* is an important pest (van den Berg and Cock 1993). Studies on the effects of natural enemies on life histories of *H. armigera* in Botswana focused on monitoring parasitism of eggs and larvae by parasitoids. Parasitism averaged 30.9% for the period of November to April and reached 50% in December in 1970 and 1971 cropping season (Fig. 2) (Anonymous, 1975). Parasitism of larvae collected from crops in 1968 to1969 averaged up to 50% on sorghum, 28% on sunflower, 49% on cowpeas and 76% on cotton. This level of parasitism is higher when compared to the results from East Africa where the level of parasitism was generally low (<5%) or absent (van den Berg et al., 1993). This showed that the use of parasitoids had a potential role in management of African bollworm. Several parasitoids were reared from *H. armigera* in Botswana on different crops as shown in Table 1. *Palexotista sp.nr. lax* Curran, *Trichogramma* spp*.* and *Prestomerus* spp*.* were the most effective parasitoids.

Roome (1971) suggested that increasing plant diversity by intercropping crops carrying nectars, such as cowpea or cotton with cereals could enhance effectiveness of parasitoids. Van den Berg and Cock, 1993 reported that when different host plants of *H. armigera* are planted in adjacent plots, or interplanted, *H. armigera* (and natural enemy) numbers on a crop are influenced by neighbouring crops, both directly and indirectly. Direct influences include preference for one crop over the other by ovipositing moths and the movement of larvae and natural enemies between interplanted crops. Indirect influences arise when *H. armigera* infestation on one crop is influenced by the population build-up or mortality level on neighbouring crops.

Although not reported in Botswana, predators have been reported as major factors in mortalities of *H. armigera* in cotton agro-ecosystems in South Africa and in smallholder crops in Kenya. In South Africa the average daily predation rates of 37% and 30% of bollworm eggs and larvae respectively were found in exclusion experiments in absence of insecticides (Van Hamburg and Guest, 1997). In Kenya the main predators of *H. armi*gera were anthocorids and ants. The anthocorids species were *Orius thripoborus* (Hesse), *Orius tantillus* (Motschulsky) *Orius albidipenrzis* (Reuter), *Cardiastethus exiguous* (Poppius), *Cardiastethus* sp. and *Blaptostethus* sp. The ant species were *Pheidole* spp. and *Myrmicaria* spp (Van den Berg and Cock 1993). In South African the mirids were the dominant predators and were represented by a number of unidentified species feeding on bollworm eggs and a *Campylomma* sp., which also predated on red spidermites. The next most abundant predator group was the Anthocoridae (Hemiptera) which was represented by *Orius thripoborus* and an *Orius* sp. followed by a variety of spiders, coccinellids (mainly *Scymnus moreletti*, *Hippodamia varigata*, *Cheilomenes propinqua*, *Exochomus flavipes*, *Lioadalea flavomaculata),* ants (*Dorylus spp. Pheidole* spp.), chrysopids, and staphilinids (Van Hamburg and Guest, 1997).

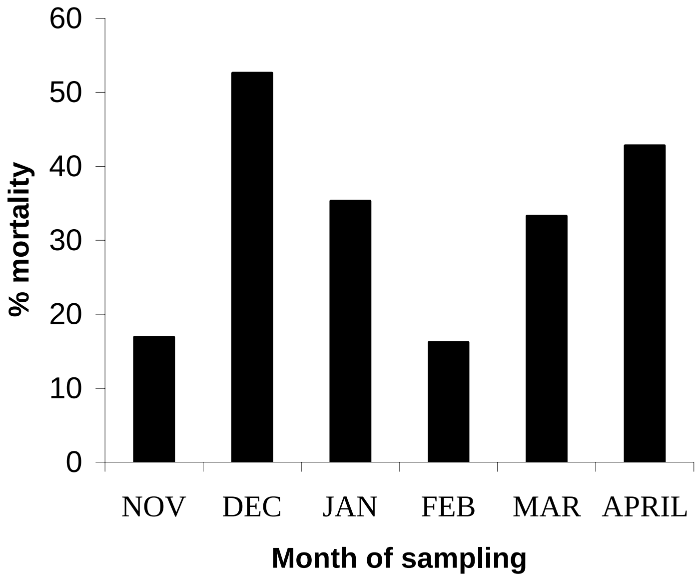

Figure 2. Percentage mortality of *H. armigera* due to parasitoids during 1969 to 1971 (Anonymous 1975).

Table 1. Percentage parasitism of *H. armigera* by various parasitoids on field crops.

Species	Stage	Sorghum	Cowpea	Sunflower	Cotton
Trichogramma spp.	EP	15.2	7.4	1	34.4
Telonomus spp	EP	0	0	0	1.0
Chelonus versalis Wilkn	LP	1.5	0	0	0.8
Apateles spp	LP	0.8	0	0.9	3.3
Pristomerus spp	LP	1.8	0	0.5	17.3
Charops spp	LP	0	0	0	2.7
Nemorea capensis R.D.	PP	2.9	0	0	0
Palexorista sp. Nr. Laxa Curran	PP	16.1	4.4	29.5	2.0
Goniophthalmus halli Mesnil	PP	0	0.6	0.5	0
Paradrino halli Curran	PP	0.6	2.7	0	0

Source: (Anonymous, 1975) EP = egg parasitoid, LP larval parasitoid, PP= pupal parasitoid

Use of cultural methods and resistant varieties

Increasing difficulty in controlling *H. armigera* on cotton in recent years has heightened the need to develop and adopt alternative, non-chemical pest management techniques. An alternative, and often complementary, strategy for management of *H. armigera* is the control of overwintering pupae through the practice of pupae busting which has been used in several cropping areas (Fitt et al., 1993; Murray et al., 1995, Duffield, 2004). Ploughing in of late maturing crops in winter increase the mortality of any pupae formed in cropland by exposing them to heat and predation. The other cultural control method is early planting which avoids the seasonal peaks of population that occur late February to March thereby avoiding very heavy larval infestations and reducing the over-wintering population. At this time the infestation is mainly eggs and young larvae which are easier to control.

Sustainable IPM will also need considerable input from the plant themselves (Fitt, 2000). Through conventional breeding some cotton varieties with tolerance to *H. armigera* have been introduced into commercial varieties (e.g. okra leaf types) in Australia (Wilson, 1994). However the use of host plant resistance has not been fully developed due to limited breeding programs in cotton, but resistant varieties can provide a more resilient plant background for pest management (Bottrell et al., 1998). Varieties of sorghum were evaluated for resistance to *H. armigera* in Botswana. The parameters that were measured included survival, developmental time and pupal weight. All varieties tested were susceptible to damage by *H. armigera*. However the lowest survival of larvae was recorded on variety Segaolane (Anonymous, 1976). Susceptible crops are thought to attract *H. armigera* adult and that once in the crop females are possibly trapped by physiological cues of the plants. The effect of physiological cues on host choice has not been fully investigated and is a possible area of future research.

Use of insecticides

Experiments carried out during the 1970s in Botswana to determine the most effective insecticides against *H. armigera* on cotton, sorghum and cowpea showed that carbaryl was the most effective insecticide. The compounds tested were DDT, endosufan, monocrotophos, tetrachlorvinphos and carbaryl (Ingram, 1971). Carbaryl was therefore recommended as a single insecticide for use in cotton against *H. armigera* using 85% dispersible powder at 100g per 18 litre of water and applied by knapsack sprayer (Ingram, 1971). It was recommended that the insecticides should be applied when 70-80% of crop is flowering. A sequential sampling graph was drawn up for cotton. Decision to apply insecticides depended on random counts of eggs and larvae which were plotted on the graph. The counts were recommended such that if a number of larvae or eggs rise above a certain level on the upper limit of the graph, spraying would be commenced. In intensive production systems especially of cotton, pesticides are the method for pest management that represent a significant component of production costs (Fitt 2000). Over reliance on pesticides is not sustainable and brings with it considerable economic, ecological problems from pesticide resistance in key pests, and environmental concerns arising from residues in soil and water and drift of pesticides into non-crop environments. Because of continuous and indiscriminate use of insecticides to minimize the damage caused by *H. armigera,* it has developed high levels of resistance to conventional insecticides (Kranthi et al., 2002). As a result of evolution of insecticide resistant populations of *H. armigera*, farmers at times resort to frequent use of insecticide mixtures (Sharma and Pampapathy, 2006). The crucial need to reduce dependence on pesticides to control *H. armigera* is strong (Fitt, 2000).

Future research needs and directions

Although the research findings on management of *H. armigera* in Botswana were promising they were not implemented on farmers' fields at the completion of the projects. In order to achieve an acceptable and cost effective method of *H. armigera* control, a new system of integrated crop management strategy must be developed. The strategy should consider the cropping systems currently used in smallholder field crops and large scale production systems. In Africa and many parts of India agricultural landscape is highly fragmented, and many alternative crop hosts of *H. armigera* are cultivated alongside each other and in many cases intercropped in the same field. Increased habitat diversity is often advocated as a means to enhance biological control in agroecosystems. This could be achieved through intercropping or companion planting of particular plants with the crop of interest to act as trap crops for key pests, or to provide alternative prey or nectar sources to maintain populations of beneficial organisms (Wratten and van Emden, 1995). Cultural control tools such as trap cropping seek to exploit specific biological or ecological traits of the target organism. For example, companion or strip cropping is aimed at exploiting pest preferences for certain stages, cultivars or species of host plants.

An important area of research, beyond simply minimising the use of pesticides should be to identify means to conserve, augment or manipulate beneficial populations. Conservation of natural enemies requires considerable ecological understanding of their seasonal phenology, habitat and prey requirements, while augmentation will employ mass releases of natural enemies. The parasitoids of *H. armigera* were found to be effective in Botswana but they were not enhanced to test their effectiveness in management of *H. armigera*. Further research on natural enemies and their effectiveness is critical for implementation of a biological control method in an integrated pest management programme. Little work has been conducted in Africa on NPV isolates except in Botswana by Rome (1976) and recently by Moore et al., (2004) on tomato and citrus trees in South Africa. The use of Nuclei polyhedrosis virus (NPV) need to be revisited and tested on farmers' fields to demonstrate the usefulness of this technology to the farmers. This will require isolation of the NPV from local population or source a commercial one if readily available. Most of the insecticides (e.g. DDT) that were recommended based on the past research are no longer in use or restricted. The current pest management option for *H. armigera* in Botswana is the use of insecticides, mainly pyrethroids. The recommendations are generally based on information from manufacturers of insecticides or on recommendations from other countries. Many insecticides came into the market since the research was undertaken; therefore there is a need to evaluate them and develop economic thresholds (ETs) for management of *H. armigera.* Developing economic injury levels (EIL) and economic threshold is a prerequisite in decision making process on when to apply insecticides in a cost effective and environmentally friendly manner.

The development of EILs and ETs and their implementation will require monitoring the population of the *H. armigera* through intensive sampling programme. Scott et al., (2005) showed that adult moth movement differs from season to season, highlighting the importance of studies in groups such as the Lepidoptera extending over consecutive years, because short-term sampling may be misleading when population dynamics and migration change so significantly. There is a need to undertake population monitoring as a forecasting tool in major cropping areas because some factors that influence population dynamics of *H. armigera* may have changed over the years. There have been new varieties, which were released since the research was done, therefore their performance under infestation *H. armigera* need to be tested together with those, which showed some level of resistance in the past. Cultural control methods that showed effectiveness need to be demonstrated in farmers' fields so that they can be adopted by farmers to manage H*. armigera.* For these proposed research activities to be sustainable there is a need to have a strong collaboration between the institutions that are involved in agricultural research especially Botswana College of Agriculture and the Department of Agricultural Research.

Conclusion

This review has established that no research has been conducted in Botswana on *H. armigera* since 1979. After this period there has been large scale production of field crops in Botswana especially in Pandamatenga and the Tuli Block in northern and eastern regions respectively. Therefore there is a need to revive research on *H. armigera* in order to compliment results obtained from past research. The research should centre on developing an integrated pest management program with emphasis on pest population monitoring, enhancing natural enemies, use of pathogens of *H. armigera,* host plant resistance, cultural methods, and minimal use of insecticides.

Acknowledgments

We thank the Department of Agricultural Research for allowing us to use the reports in their library.

References

Anonymous. 1975. Annual Report 1969-1971. Government Printer, Gaborone, Botswana.

Anonymous. 1976. Annual Report 1971-1973. Government Printer, Gaborone, Botswana.

Anonymous. 1979. Annual Report 1973-1975. Government Printer, Gaborone, Botswana.

Bottrell, D. G., P. Barbosa, F. Gould. 1998. Manipulating natural enemies by plant variety selection and modification; a realistic strategy? Ann. Rev. Entomol. 43: 347-367.

Daoust, R. A., R. E. Roome. 1974. Bioassay of a nuclear-polyhedrosis virus and *Bacillus thuringiensis* against the American bollworm, *Heliothis armigera*, in Botswana. J. Invertebr. Pathol., 23: 318-324.

Du Plessis, H., J. Van den berg. 1999. African bollworm-a pest of grain crops (ARC-LNR). Crop protection series number 16.

Du Plessis, H. 1997. Feasibility of chemical control of the African bollworm on sunflower in South Africa. African Crop Science Journal, 5: 47-53.

Duffield, S. J. 2004. Evaluation of the risk of overwintering *Helicoverpa* spp. pupae under irrigated summer crops in south-eastern Australia and the potential for area-wide management. Annals of Applied Biology, 144: 17-26,

Duffield, S. J., A. P. Steer. 2006. The ecology of Helicoverpa spp. (Lepidoptera: Noctuidae) in the Riverina region of south-eastern Australia and the implications for tactical and strategic management. Bulletin of Entomological Research, 96: 583–596.

Farrow, R. A., J. C. Daly. 1987. Long-range movements as an adaptive strategy in the genus Heliothis (Lepidoptera: Noctuidae): a review of its occurrence and detection in four pest species. Aust. J. Zool., 35: 1-24.

Fitt, G. P. 2000. An Australian approach to IPM in Cotton: integrating new technologies to minimize insecticide dependence. Crop Prot. 19: 793–800.

Fitt, G. P., D. A. H. Murray, M. Dillon, J. C. Daly. 1993. Overwintering *Heliothis* pupae and the importance of cotton stubble cultivation. Australian Cotton Grower 14, 50–52.

Gibbon, D., R. Gladden J. Harvey, K. Hubbard, R. E. Roome, K. E. Flattery, D. Legg, C. Neeteson, and P. Whiteman. 1974. Dryland crop production in Botswana: A review of research, 1968 to1974. Gaborone, Botswana. Ministry of Agriculture.

Ingram, W. R. 1971. The use of carbaryl as an alternative to DDT for the control of *Heliothis armigera* (Hb.) in the field crops in Botswana. In Proceedings of the Cotton Insect Control Conference, 24 - 27 March 1971, Blantyre, Malawi.

Ingram, W. R., N. S. Irving, and R. E. Roome. 1973. A handbook on the control of Agricultural pests in Botswana. Government Printer, Gaborone, Botswana.

Jallow, M. F. A., J. P. Cunningham, M. P. Zalucki. 2005. Intra-specific variation for host plant use in Helicoverpa armigera (Hubner) (Lepidoptera: Noctuidae): implications for management. Crop Prot. 23: 955–964.

Kranthi, K. R., D. R. Jadhav, S. Kranthi, R. R. Wanjari, S. S. Ali, D. A. Russell. 2002. Insecticide resistance in five major insect pests of cotton in India. Crop Prot. 21: 449–460.

Kurban, A., Yoshida, H., Izumi, Y., Sonoda, S. and Tsumuki, H. 2005. Pupal diapause of *Helicoverpa armigera*: sensitive stage for photoperiodic induction. Appl. Entomol. Zool. 40: 457–460

McCaffery, A. R. 1998. Resistance to insecticides in heliothine Lepidoptera: a global view. Philos. Trans. R. Soc. London Ser. B 353: 1735–1750.

McGahan, P., R. J. Lloyd, K. P. Rynne. 1991. The cost of *Helicoverpa* in Queensland crops. In: Twine, H., Zalucki, M. P. (Eds.), A Review of Heliothis Research in Australia. Conference and Workshop Series QC91006. Queensland Department of Primary Industries, Brisbane, Australia, pp. 11–28.

Moore, S. D., T. Pittaway, G. Bouwer, J. G. Fourie. 2004. Evaluation of Helicoverpa armigera Nucleopolyhedrovirus (HearNPV) for Control of Helicoverpa armigera (Lepidoptera: Noctuidae) on Citrus in South Africa. Biocontrol. Sci. Techn., 14: 239-250.

Munthali, D. C., M. Obopile, D. M. Modise, M. E. Madisa, P. Malope, B. C. Kwerepe, and V.E. Emongor. 2004. A guide to commercial production of selected vegetables in Botswana. Printing and Publishing Company, Gaborone, Botswana.

Murray, D. A. H., Marshall, J., Lloyd, R. J. 1995. Cultivation leaves overwintering pupae out in the cold. Australian Cotton Grower. March–April, 16–18.

Qureshi, M. H., T. Murai, H. Yoshida, H. Tsumuki. 2000. Populational variation in diapause-induction and–termination of Helicoverpa armigera (Lepidoptera: Noctuidae). Appl. Entomol. Zool. 35: 357–360.

Rajapakse, C. N. K., G. H. Walter. 2007. Polyphagy and primary host plants: oviposition preference versus larval performance in the lepidopteran pest *Helicoverpa armigera.* Arthropod-Plant Interactions, 1:17–26

Reed, W., Pawar, C. S. 1982. *Heliothis*: a global problem. In: Reed W, Kumble V (eds) Proceedings of the international workshop on *Heliothis* management. ICRISAT Centre, Patancheru, pp 9–13

Roome R. E. 1970. Report of the Entomological Team: in Annual Report of Research Section 1968-1969, Government Printer, Gaborone, Botswana.

Roome R. E. 1971. Field studies of the biology of *Heliothis armigera* (Hb.) (Lepidoptera: Noctuidae) in Botswana. In Proceedings of the Cotton Insect Control Conference, 24 - 27 March 1971, Blantyre, Malawi.

Roome, R. E. 1979. Pupal diapause in Heliothis armigera (Hübner) (Lepidoptera: Noctuidae) in Botswana: its regulation by environmental factors. Bull. Entomol. Res. 69:149–160.

Roome, R. E., R. A. Daoust. 1976. Survival of the nuclear polyhedrosis virus of *Heliothis armigera* on crops and in soil in Botswana. J. Invertebr. Pathol., 27(1):7-12.

Roome, R. E., 1975a. Control of *Heliothis* on subsistence crops in Botswana. Mededelingen van de Faculteit van Landbouwwetenschappen, Rijksuniversiteit te Gent, 40 (2): 267-282.

Roome, R. E. 1975b. Field trials with a nuclear polyhedrosis virus and *Bacillus thuringiensis* against larvae of *Heliothis armigera* (Hb.) (Lepidoptera, Noctuidae) on sorghum and cotton in Botswana. Bull. Entomol. Res., 65(3): 507-514.

Scott, K. D., N. Lawrence, C. L. Lange, L. J. Scott, K. S. Wilkinson, M. A. Merritt, M. Miles, D. Murray, G. C. Graham. 2005. Assessing Moth Migration and Population Structuring in *Helicoverpa armigera* (Lepidoptera: Noctuidae) at the Regional Scale: example from the Darling Downs, Australia. J. Econ. Entomol.,98: 2210-2219.

Shanower, T. J. J. Romeis, E. M. Minja. 1999. Insect pests of pigeon pea and their management Annu. Rev. Entomol. 44:77–96

Sharma, H. C. 2001. Cotton bollworm/legume pod borer, Helicoverpa armigera (Hubner) (Noctuidae: Lepidoptera): biology and management. Crop protection compendium. International Crops Research Institute for the Semi-Arid Tropics

Sharma, H.C., G. Pampapathy. 2006. Influence of transgenic cotton on the relative abundance and damage by target and non-target insect pests under different protection regimes in India. Crop Prot. 25: 800–813

Shimizu, K., K. Fujisaki. 2002. Sexual differences in diapause induction of the cotton bollworm, *Helicoverpa armigera* (Hb.) (Lepidoptera: Noctuidae). Appl. Entomol. Zool. 37: 527–533.

Van den Berg, H., M. J. W. Cock. 1993. Stage-specific mortality of *Helicoverpa armigera* in three smallholder crops in Kenya. Journal of Applied Ecology, 30: 640-653.

Van den Berg, H., M.J.W. Cock, G. I. E. K. Oduor, Onsongo. 1993. Incidence of *Helicoverpa armigera* (Lepidoptera: Noctuidae) and its natural enemies on smallholder crops in Kenya. Bull. Entomol. Res. 83:321–328.

Van Hamburg, H., P. J. Guest. 1997. The Impact of Insecticides on Beneficial Arthropods in Cotton Agro-Ecosystems in South Africa. Arch. Environ. Contam. Toxicol. 32: 63–68.

Wilson, L. J., 1994. Resistance of okra-leaf cotton genotypes to two-spotted spider mites (Acari: Tetranychidae). J. Econ. Entomol. 87: 1726-1735.

Wratten, S., H. F. van Emden. 1995. Habitat management for enhanced activity of natural enemies of insect pests. In: Glen, D.M., Greaves, M.P., Anderson, H.M. (Eds.), Ecology and Integrated Farming Systems. John Wiley, Chicester, pp. 117-145.

Zalucki, M. P., D. A. H. Murray, P. C. Gregg, G. P. Fitt, P. H. Twine, and C. Jones. 1994. The biology and ecology of *Helicoverpa armigera* (Hubner) and *H. puctigera* (Wallengren) in the inland of Australia: larval sampling and host plant relationships during winter and spring. Aust. J. Zool., 34: 779-814.

Zalucki, M. P., G. Daglish, S. Firempong, and P. H. Twine. 1986. The biology and ecology of *Helicoverpa armigera* (Hubner) and *H. puctigera* Wallengren (Lepidoptera Noctuidae) in Australia: what do we do? Aust. J. Zool., 34: 779-814.