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Current control methods for diamondback moth and other brassica insect pests and the prospects for improved management with lepidopteran-resistant Bt vegetable brassicas in Asia and Africa

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ABSTRACT

The diamondback moth (DBM), *Plutella xylostella* (L.), remains a major pest of brassica crops worldwide. DBM has been estimated globally to cost US$ 1 billion in direct losses and control costs. Chemical control of this pest remains difficult due to the rapid development of resistance to insecticides and to their effect on natural enemies. These problems are especially severe in South Asia and Africa where lack of knowledge, limited access to newer and safer insecticides, and a favourable climate result in DBM remaining a serious year-round pest which substantially increases the cost and uncertainty of crop production. Despite these problems, application of synthetic insecticides remains overwhelmingly the most common control strategy. Biologically-based efforts to control DBM in Africa and Asia have focused strongly on parasitoid introductions. However, despite the identification and deployment of promising parasitoids in many regions, these efforts have had limited impact, often because farmers continue early-season spraying of broad-spectrum insecticides that are lethal to parasitoids and thus exacerbate DBM outbreaks. A significant driver for this pattern of insecticide use is the presence of aphids and other pests whose appearance initiates inappropriate spraying. Despite often extensive training of producers in farmer field schools, many growers seem loath to discard calendar or prophylactic spraying of insecticides. The introduction of an IPM technology that could replace the use of broad-spectrum insecticides for DBM and other key Lepidoptera is crucial if the benefits of parasitoid introduction are to be fully realised. The deployment of DBM-resistant brassicas expressing proteins from *Bacillus thuringiensis* could help to break this cycle of insecticide misuse and crop loss, but their deployment should be part of an integrated pest management (IPM) package, which recognises the constraints of farmers while addressing the requirement to control other Lepidoptera, aphids and other secondary pests.
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1. Introduction

Globally, cabbage (*Brassica oleracea* var. *capita*) is grown on 3.1 million ha and cauliflower (*B. oleracea* var. *botrytis*) and broccoli (*B. oleracea* var. *italica*) on 983,000 ha (estimate excludes Chinese cabbage (*Brassica campestris*)) (FAOSTAT, 2007). In Africa and Asia, cabbage remains a very important crop for smallholder farmers, providing income and nutrition and enabling small farms to remain financially viable, especially in the rapidly growing peri-urban farming sector. Diamondback moth (DBM), *Plutella xylostella* (L.), has for many years been considered to be the most important pest of cabbages and other brassica crops worldwide (Talekar and Shelton, 1993; Shelton, 2004), costing up to 1 billion US$ per year in damage and control costs (Javier, 1992). The origin of this very widely quoted figure is unclear. However given that a more recent estimate for the costs to India alone for DBM control was US$ 168 million per annum (Sandur, 2004), the earlier global estimate may be reasonable.

The DBM problem is usually most severe in the tropics and subtropics where year-round brassica cultivation and a life cycle as short

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as 14 days make this pest a continuous threat to production. This continuous cultivation and short life cycle can result in more than 25 generations of DBM a year being exposed to the synthetic insecticides routinely used by growers. This high level of selection pressure and the high fecundity of DBM are key factors which have contributed to this species developing resistance to a wide range of insecticides in the field (Wright, 2004), including novel insecticides such as spinosad and indoxacarb (Zhao et al., 2002, 2006) as well as some strains of the bacterial insecticide, *Bacillus thuringiensis* (Shelton et al., 2007). The rapid evolution of resistance to insecticides makes DBM particularly challenging to control in a sustainable fashion.

This problem is especially acute for poorer farmers in Asia and Africa, who lack access to up-to-date knowledge and the newest insecticides and so tend to rely heavily on and overuse older, more toxic, broad-spectrum insecticides (Rauf et al., 2004; Badenes-Perez and Shelton, 2006). Even at the first International DBM Workshop, held in 1986, it was reported that in Southeast Asia, brassica farmers had already experienced a long history of DBM resistance to insecticides as a result of spraying as frequently as three times a week (Ooi, 1986). Resistance to the older organophosphates and organo-chlorine insecticides was addressed by the widespread adoption of pyrethroids in the early 1980s, but by the mid-1980s, widespread control failures of these insecticides were reported (Rushtapkornchai and Vattanatangum, 1986). This pattern of introduction and failure of insecticides continues today because of the widespread lack of adoption of any insect resistance management (IRM) strategy by farmers (Wright, 2004; Mau and Gusukuma-Minuto, 2004). The introduction of new chemistries such as spinosad, avermectin, fipronil, indoxacarb, etc. have offered DBM control tools with different modes of action but, despite attempts at grower education, a pattern of frequent non-rotational use of insecticides (every 3–5 days) combined with year-round growing continues, in many areas of Asia to drive the resistance process (Amit et al., 2004). Even in East Africa, where resistance to insecticides such as pyrethroids has appeared somewhat later than in Southeast Asia, growers routinely use weekly applications of insecticides (Oduor et al., 1997; Cooper, 2002). Thus insecticidal control of DBM by farmers in Asia and Africa is frequently characterised by overuse, with little regard to recommended IPM practices and is seen as both increasingly expensive and uncertain.

This overuse of synthetic insecticides is not merely symptomatic of DBM control difficulties in the tropics but is seen by some as a major factor in elevating the pest status of DBM. Many studies have indicated that early application of non-selective insecticides such as pyrethroids is an important initiating factor in subsequent DBM outbreaks (Talekar and Shelton, 1993). This relationship is usually interpreted as a direct result of these chemicals impacting natural enemies of DBM (Talekar et al., 1992; Furlong and Wright, 1993; Xu et al., 2001) and application of these chemicals certainly results in dramatically reducing parasitoids (Shepard and Schellhorn, 1997; Kfir, 2004). Over the last twenty years, much effort has been devoted to developing IPM management strategies for DBM in the tropics (Talekar and Griggs, 1986; Talekar, 1992; Endersby and Ridland, 2004) but crop losses continue and insecticide misuse remains widespread (Wright, 2004). DBM remains a pervasive and intransigent pest of brassica production and has proved difficult and expensive to manage using either synthetic insecticides or biological control alone (Shelton, 2004).

A promising alternative to conventional insecticides is the deployment of insect-resistant crops derived from genetic engineering (GE). The development of GE technologies and, in particular, the ability to incorporate genes for the production of *Bacillus thuringiensis* (*Bt*) insecticidal proteins has enormously boosted our capacity to generate new insect-resistant crop lines that can be incorporated into IPM programmes (Romeis et al., 2008).

It therefore seems appropriate to examine whether the deployment of *Bt* brassicas might enable us to improve DBM management and overcome some of the problems that have impeded the development of effective and environmentally acceptable IPM for this and other key brassica pests.

2. Brassicas in Asia

Asia is the largest vegetable production area in the world. In China, cabbages and cauliflower are grown on 2,175,800 ha; in India there are 232,800 ha of cabbage and 278,800 ha of cauliflower, and in Bangladesh cabbage is grown on about 14,000 ha with a similar area devoted to cauliflower. In Indonesia, cabbages are grown in an area of 57,000 ha (FAOSTAT, 2007). Throughout Asia, the most important brassicas are Chinese cabbage, head cabbage, Chinese kale and cauliflower (*all B.oleracea*), produced predominantly by smallholder farmers. The crop production areas in many parts of South Asia have traditionally been in the highlands, but recently there has been some increase in production in lowlands during the cooler dry season.

In Asia it has generally been reported that DBM is the main pest in almost all production areas. In India, Sandur (2004) found that DBM was identified as the major pest (92% farmers), with reported losses of up to 50%, although other estimates of losses show a somewhat lower range, e.g. 5–14% (Badenes-Perez and Shelton, 2006). Aphids (*Brevicoryne brevis*, *B. brassicae*, *Myzus persicae* and *Lipaphasis erysimi*) seem to be less important in Asia with between 8% and 24% of farmers reporting them as a major pest in a survey in India (Badenes-Perez and Shelton, 2006). Other Lepidoptera can be locally or seasonally serious, including *Helcoverpa armigera* in India, *Hellula undalis* and *Crocidolomia pavonana* (=*binotalis*) in the Mekong basin, Malaysia, South Asia, and Indonesia (SAVERNET, 1996; FAO, 2000; Sandur, 2004). *Pieris rapae* can also be an important pest in cooler highland areas (Lim et al., 1997; FAO, 2000). In Indonesia, the main pests are DBM and *C. pavonana* (60–75% of farmers recorded them as severe) with *H. undalis* (20–40% of farmers) and *Agrotis* (20–35% of farmers) as important subsidiary pests (Rauf et al., 2004). In China, *Spodoptera* spp. and *Pieris* spp. are also important (Liu et al., 2004) and striped flea beetles (*Phyllotreta striolata*) can be very damaging in lowland areas.

2.1. Insect management in Asian brassicas

In the sub-tropics and tropics of Asia, most farmers rely on the use of synthetic insecticides for controlling insect pests in brassicas, primarily DBM, *Spodoptera* spp., *Pieris* spp. *H. undalis*, *C. pavonana* and flea beetles (Talekar and Shelton, 1993; Wright, 2004). Farmers in Malaysia, India and Indonesia often spray up to eleven types of insecticides per season, with spray intervals of sometimes two to three days (Rauf et al., 2004; Sandur, 2004; Wright, 2004; Mazlan and Mumford, 2005). Calender spraying and mixing of highly toxic cocktails with older insecticides are widespread practices in Asia (Harris, 2000; IPM-DANIDA, 2004; FAO, 2005; Williamson, 2005).

Subsequently, a high level of resistance to insecticides has been developed by DBM in some major brassica production areas including India, the Cameron Highlands of Malaysia and Thailand. This has resulted in the rapid adoption of new insecticide products by farmers as soon as they become available (Mohan and Gujar, 2002; Wright, 2004). However, the rapid, widespread and often exclusive use of newer insecticides is usually followed by the rapid evolution of resistance (Amit et al., 2004). In South Asia for example, substantial resistance to new insecticides has appeared within as little as two years of first use (Wright, 2004) and in Hawaii after only 30 months (Mau and Gusukuma-Minuto, 2004). There is frequent "burn out" of new products (e.g. spinosad, avermectin and indoxacarb) in the intensive brassica production areas such as Cameron Highlands of Malaysia and in Thailand (Wright, 2004).

However, it should also be borne in mind that the picture for synthetic insecticide control is not that of abject failure as painted by some proponents of biological control. It is more a case that insecticidal control of DBM continues, but at a higher cost to farmers, attended with greater uncertainty, and accompanied by increased environmental contamination and human health problems (IPM-DANIDA, 2003, 2004).

3. Brassicas in Africa

A wide variety of brassica crops are grown in Africa (Table 1), though kales and cabbages are generally the most important crops in terms of quantity of production. Precise data is not easy to come by except where focused studies have been carried out, e.g. Kenya and Ghana. In Kenya the estimated annual production of brassicas is 550,000 tons, with 95% of the production in the highlands on 35,000 ha (FAOSTAT, 2007). In East Africa, about 90% of the brassica production is by smallholder growers on plots of 0.1–0.5 ha and this probably applies to other regions of sub-Saharan Africa (SSA), although in South Africa larger scale commercial production is also important (Kfir, 2004). Brassicas are particularly important in the peri-urban farming sector in East Africa (Oruku and Ndun'gu, 2001) as they are key components of the local diet and nutritionally very important for poorer people who cannot afford alternative vegetables. Kales in particular are a major item in the local diet and are an important smallholder subsistence crop in Kenya, Ethiopia, Zimbabwe and Mozambique (Löhr and Kfir, 2004).

The production of cabbage and open-leaf kales for local markets and regional trade is predominant, although commercial production of spinach, broccoli and pak choi for export is increasing, especially in Kenya and Tanzania (Nyambo and Löhr, 2005). Production is mainly confined to the cooler wet seasons but there are areas where dry season production is practiced, for example, in export operations that may continue year-round. While the highlands remain the focus of production, some production has started in semi-arid lowlands (Nyambo, 1995).

In Ghana and Benin, production of cabbages for the peri-urban market is very important, with production concentrated in the lowland zones during the wet season when pest pressure is low (Cherry, 2004). In West Africa, as a whole, brassicas are important vegetables grown in an area of 13,900 ha with annual production of 140,500 tons (FAOSTAT, 2003).

Table 1
Types of Brassicas grown in Africa (Source: Cumbi and Ernesto, 2002a; Sibanda et al., 2000; Massomo et al., 2005; Sithole, 2005; Ssekyewa, 1995; Mingochi et al., 1995; Nyambo, 1995; Rossbach et al., 2005; James et al., 2006; Sall-Sy et al., 2004; V. Umeh, pers. comm.; K. Diarra, pers. comm.).

Cabbage (*B. oleracea* var. *capitata*)	Benin, Cameroon, Ethiopia, Kenya, Malawi, Mozambique, Nigeria, Senegal, South Africa, Tanzania, Uganda, Zambia, Zimbabwe
Kale (*B. oleracea* var. *acephala*) (choumollier)	Ethiopia, Kenya, Tanzania, Zambia, Zimbabwe
Ethiopian cabbage (*B. oleracea* var. *carinata*)	Ethiopia, Zambia
Cauliflower (*B. oleracea* var. *botrytis*)	Kenya, Tanzania, Uganda, South Africa, Zambia
Chinese cabbage (*B. campestris* var. *chinensis*)	Kenya, Nigeria, Tanzania, Uganda, Zambia, Zimbabwe
Rape (*B. napus*)	Malawi, South Africa, Zambia, Zimbabwe
Brussels sprouts (*B. oleracea* var. *gemmifera*)	Zambia, Zimbabwe
Broccoli (*B. oleracea* var. *italica*)	Kenya, Zambia, Zimbabwe
Portuguese cabbage (*B. oleracea* var. *Tronchuda)*	Mozambique

3.1. Insect management in African brassicas

A detailed study of farmers in Kenya indicated that aphids (97%) and DBM (75%) are the major insect pest threats to kale, a pattern similar to that reported for cabbages, where 89% of farmers reported aphids as problems and 69% DBM (Oruku and Ndun'gu, 2001). However, other authors have stressed the pre-eminence of DBM, with aphids as a secondary, early-season pest in Kenya (Kibata, 1997) and East Africa (Nyambo and Löhr, 2005). In addition other species, including the cabbage looper (*Trichoplusia ni*) and cutworms (*Agrotis* spp.), are reported as pests by up to 60% of farmers in Kenya. *H. undalis* is reported as a major caterpillar pest in Mozambique (Chitio, 1995), Zambia (Mingochi et al., 1995) and Zimbabwe (Sithole, 2005). *C. pavonana* is locally important in Tanzania (Nyambo, 1995) and in Malawi and Zimbabwe, the Bagrada bug (*Bagrada hilaris*) is also frequently reported as a problem (Seif and Löhr, 1998). Aphids (*B. brevis, M. persicae* and *L. erysimi)* are serious pests of brassicas not only because they cause direct damage but also because they are vectors of important viral diseases such as turnip mosaic virus and cauliflower mosaic virus (Cooper, 2002; Spence et al., 2007). Outside Eastern and Southern Africa, data on pest importance is sparse but in Ghana and Benin, DBM was again reported as the dominant pest of crucifer production (Goudegnon et al., 2004). *H. undalis* and *B. brassicae* are additional major insect pests limiting cabbage production in Benin (James et al., 2007).

The use of synthetic insecticides for DBM control in Africa is reportedly characterised by such practices as mixing, calendar spraying and the use of unregistered and fraudulent products of poor quality (Williamson, 2003). Surveys in a number of countries including Kenya and Zimbabwe (Oruku and Ndun'gu, 2001; Sithole, 2005) have shown that there is an overwhelming reliance on broad-spectrum insecticides (pyrethroids, organo-phosphates, and carbamates), often applied weekly or biweekly (Table 2). In addition, the quality of applications is often poor or ineffective (Cooper, 2002). Reliable figures on the exact cost of DBM control, like those on damage, are hard to come by in most of Africa. In Kenya, studies suggest some 30% of production costs are for insecticides and their application, but this can range widely from 25 to 65% (Oruku and Ndun'gu, 2001). Currently, most farmers use the same broad-spectrum insecticides for the control of both aphids and DBM, which may occur and be treated simultaneously, so costs are hard to partition between the two. A major issue in addressing DBM

Table 2
Pesticides used for brassica pest control in Africa (Source: Cumbi and Ernesto, 2002b; Chitio, 1995; Mohammed et al., 2006; Rossbach et al., 2005; Sithole, 2005; Williamson, 2005).

Synthetic pyrethroids	
Cypermethrin, Deltamethrin, Permethrin	Cameroon, Kenya, Malawi, Mozambique, Tanzania, Uganda, Zambia
Lambda-Cyhalothrin	Ethiopia, Kenya, Tanzania, Zimbabwe
Carbamates	
Carbofuran	Kenya, Malawi
Carbaryl	Zimbabwe
Organo-phosphates	
Dimethoate, Phenthoate	Cameroon, Kenya, Malawi, Mozambique, Tanzania, Uganda, Zimbabwe
Chlorpyriphos, Profenofos	Tanzania, Uganda
Malathion	Uganda, Zimbabwe
Organo-chlorines	
Endosulfan	Mozambique, Tanzania

control relates to the body of scientific opinion (Kfir, 2003) and some data (Cooper, 2002) indicating that serious outbreaks in Africa occur following applications of broad-spectrum insecticides for aphid or cutworm control, although other researchers report that applications of insecticides did not result in increased attack by DBM (Oduor et al., 1997). While this resurgence pattern may not be consistent in all areas, it is probable that in any effective DBM management programmes using DBM-resistant plants, the issue of controlling these other pests without exacerbating the DBM problem will be important for ensuring farmer satisfaction.

4. IPM programmes for DBM

The use of IPM for controlling DBM has long been recognised as the way forward from the pure dependence upon synthetic insecticides (Talekar and Griggs, 1986). The key components in IPM (host plant resistance, preservation and augmentation of natural enemies, introduction of appropriate parasitoids and predators, use of pathogens, manipulation of insect/host semiochemistry, cultural manipulation, the use of selective insecticides and improved spray application) have all been developed and utilised with varying degrees of vigour and success (Shelton, 2004). In the search for an alternative to the "chemical treadmill" approach to managing DBM and brassica pests, several major IPM initiatives in Asia and Africa have pursued biological control programmes. A series of major international workshops on DBM management have been concerned with developing the use of parasitoids, pathogens and natural enemies for DBM IPM (Talekar and Griggs, 1986; Talekar, 1992; Sivapragasam et al., 1997; Kirk and Bordat, 2004; Endersby and Ridland, 2004; Shelton et al., 2008).

4.1. IPM programmes for brassicas in Asia

There have been major IPM programmes focussed on natural enemy conservation and parasitoid introduction, as discussed by Talekar and Shelton (1993) and Shelton (2004). In Asia, AVRDC has been the leading institution, heading a series of international networks dedicated to brassica IPM. The Asian Vegetable Network (AVNET) included Indonesia, Malaysia, Philippines and Thailand and was established in 1989 with AVRDC and national agricultural research system partners funded by the Asian Development Bank. This included an IPM programme for DBM centered on biocontrol with parasitoids and the use of environment-friendly insecticides, mainly *Bt* formulations. The role of natural enemies, if allowed to flourish, in controlling DBM populations has been well documented and it has been demonstrated that these can be important in reducing damage although variability of impact is an issue requiring further study if their role is to be harnessed reliably (Furlong et al., 2004).

Mass rearing facilities have been set up for the parasitoids *Diadegma semiclausum*, *Cotesia plutellae*, *Diadromus collaris and Trichogrammatoidea bactrae* (AVRDC, 1993). All four parasitoids were released in pilot sites in the mid-highlands in Indonesia and they became established temporarily. In Malaysia, *D. semiclausum* and *D. collaris* were released in the Cameron Highlands. *D. semiclausum* became established in the Cordilleres Highlands in the Philippines and *C. plutellae* was released in lowland fields in Batangas and Laguna. In Thailand, *C. plutellae* and *T. bactrae* were released in lowland areas of Amphur, Sarapee and Chiang Mai. Training of extensionists and farmers was also included in the project (AVRDC, 1993). Subsequently, this parasitoid release approach was extended to several other Asian countries (Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka) under a new network, the South Asian Vegetable Research Network (SAVERNET), which included the introduction of improved cabbage and cauliflower germplasm into the programme (SAVERNET, 1996).

The FAO 'Inter-Country Programme (ICP) for the Development and Application of Integrated Pest Management in Vegetable Growing in South and Southeast Asia' started in 1996 and the second phase ended in 2007. The programme focused on the Greater Mekong Sub-region and covered Cambodia, Laos, Thailand, Vietnam and Yunnan Province in southern China. Other member countries were Bangladesh, Indonesia and the Philippines. The focus has been on extensive training of farmers in IPM through traditional training and, from 1996, in the FAO-led farmer field school (FFS) initiative on vegetable IPM (FAO, 2005).

There have been a series of IPM initiatives focussed on DBM implemented in Asia since the early 1970s. Malaysia started brassica IPM programmes much earlier than the neighbouring countries and DBM was the focus in the 1970s with the introduction of *D. semiclausum*, *D. collaris* and *Oomyzus sokolowskii.* However the impact was initially limited, as many farmers continued spraying synthetic insecticides (AVRDC, 1993). Farmers were forced to change their methods because high insecticide residue levels in cabbages led to a ban by neighbouring countries on cabbage imports from Malaysia. The use of *Bacillus thuringiensis* (*Bt*) products, based upon *Bt kurstaki*, in the late 1980s and early 1990s was initially met with a high level of adoption by farmers in the Cameron highlands (Wright, 2004). As farmers turned to *Bt* products and the use of synthetic insecticides declined in this area, *D. semiclausum* became well established and the dominant parasitoid species (Ooi, 1999). That was ten years after its first introduction to the Cameron Highlands, but the continuing intensive use of synthetic insecticides prevented it from having a major impact on DBM before the widespread adoption of *Bt* products by farmers (Ooi and Lim, 1989). However, continuous use of *Bt* without adherence to any IRM strategy rapidly resulted in the appearance of resistance to *Bt* in the 1990s (Syed, 1992) and this is now widespread in Malaysia (Wright, 2004).

As part of the SAVERNET programme in South Asia, farmers were advised to use *Bt* instead of broad-spectrum synthetic insecticides and an initial decline in insecticide use led to a limited establishment of the exotic parasitoids in some areas (SAVERNET, 1996). Parasitoids, mainly *D. semiclausum* and *C. plutellae*, were released in pilot sites in highland areas of India (Ooty, Tamil Nadu and Himachal Pradesh) and Nepal (Baktapur, Khumaltar and Suryaleinayark). Surveys revealed that some of the parasitoids were already established in other regions. For example, *C. plutellae* and *D. collaris* were found in cabbage and cauliflower in Bangladesh. *D. semiclausum*, *D. collaris*, *C. plutellae* and *O. sokolowskii* were recorded in Taxilla in Pakistan. However, the full potential impact was never achieved, because many farmers continued applying insecticides or, after having used *Bt* for a period, returned to broad-spectrum insecticides (Ooi, 1997). The common problem in all these countries was the lack of understanding by farmers as to how natural enemies work. Additionally, the local extension systems did not always have the capacity to support and sustain the IPM approaches (Sivapragasam, 2004). Subsequently, resistance to *Bt* caused farmers to regress to synthetic insecticides. Another issue for IPM programmes was that cheap illegal imports of insecticides have entered many Asian markets on a large scale and farmers tend to purchase these cheap products, undermining planned IRM and IPM strategies (Sivapragasam, 2004).

In Indonesia, an IPM programme for Brassicas has been underway since 1989 using FFS to improve control of DBM and *C. pavonana* (Rauf et al., 1993). However, a survey in 2004 in West Java showed that, despite up to 25% of farmers having received IPM training, insecticide applications were still intensive and only 5–10% of farmers used IPM practices and/or *Bt*. Projects aimed at encouraging farmers to adopt improved IPM in China have shown that farmer-adapted IPM utilising scouting, thresholds and biological insecticides could reduce chemical use with little risk of crop loss and that farmers could be trained to adopt them in project areas (Liu et al., 2004), although it was stated that expansion of this on a wide scale would require significant impetus from supporting policy and legislation changes to reduce reliance on pesticides and to ensure that farmers get access to the necessary supporting expertise. Strategies to conserve biological control in brassicas have been developed and tested in Korea and shown to be cost effective (Furlong et al., 2008). Interestingly in this case the main control agents were the generalist predators rather than the parasitoids.

In summary, parasitoid-based IPM has been introduced on a large scale in a number of major highland production centres in South Asia, often supported by FFS training of substantial numbers of farmers. Investigation of the impact and adoption of these brassica IPM programmes are "significantly lacking" (Sivapragasam, 2004). Some follow-up surveys suggest that few farmers stick with IPM, and the continuing widespread use of broad-spectrum insecticides reduces the impact of parasitoids, and DBM populations remain high (Ooi and Lim, 1989). There is a clear need to understand better why farmers fail to adopt, or regress from, IPM. In lowland brassica locations there has been even less success, as *C. plutellae* when released fails to reduce DBM populations sufficiently, even in the absence of synthetic insecticides (Talekar, 2004). In both highland and lowland systems, therefore, there is a great need to improve brassica IPM by introducing new tools, of which insect-resistant crop varieties might be an example.

4.2. IPM programmes for brassicas in Africa

Africa has a long history of brassica cultivation of traditional local species and varieties (Schippers, 2000) and perhaps an equally long acquaintance with DBM. The rich parasitoid fauna of DBM in some parts of Africa has indeed led to the suggestion that DBM is itself of Southern African origin (Kfir, 1998). However, the reported indigenous parasitoid fauna (Table 3) is very limited in other important African brassica regions such as the Kenyan highlands, where only three species were naturally recorded and observed parasitism rates were low (Löhr et al., 2007).

Vegetable IPM programmes have only recently been established in Africa as compared to Asia. DBM work has concentrated on the introduction of new parasitoid species and strains and on promoting the conservation of natural enemies to support both introduced and endemic natural enemies, along the lines previously piloted in Asia (Löhr et al., 1998). In Africa, the International Center for Insect Ecology and Physiology (ICIPE) has led regional IPM initiatives through programmes such as the GTZ 'IPM Horticulture' project 1994–2000 and the 'Biocontrol of DBM in East-Southern Africa' project started in 2000. Major initiatives by ICIPE and KARI have involved introducing *D. semiclausum* from AVRDC in 2001 for highland production in East Africa and *C. plutellae* from South Africa for lowland production. *D. semiclausum* established and spread successfully in Kenya, Uganda and parts of Tanzania (Gichini et al., 2008). *C. plutellae* established in Uganda, but repeated releases in Kenya did not lead to an establishment (Nyambo et al., 2008).

Table 3
Main parasitoids of diamondback moth in Africa (Kfir, 1998; Goudegnon et al., 1999; Ayalew et al., 2004; Goudegnon et al., 2004; Nagawa, 2003; Sall-Sy et al., 2004; Sithole, 2005; Rossbach et al., 2005; Seif and Löhr, 1998; Smith and Villet, 2004; Löhr et al., 2007; Mingochi et al., 1995; Chitio, 1995).

Species	Countries
Oomyzus sokolowskii	Benin, Cameroon, Ethiopia, Kenya, Senegal, South Africa, Tanzania, Uganda, Zimbabwe
Diadegma mollipla	Cameroon, Kenya, Malawi, South Africa, Tanzania, Uganda, Zimbabwe
Diadegma semiclausum	Kenya, Tanzania, Uganda
Diadegma sp.	Ethiopia
Cotesia plutellae	Benin, Ethiopia, Kenya, Senegal, South Africa, Tanzania, Uganda, Zambia, Zimbabwe
Diadromus collaris	South Africa, Zambia, Zimbabwe
Apanteles sp.	Ethiopia, Kenya
Brachymeria sp.	Kenya, Senegal, South Africa, Uganda, Zimbabwe
Apanteles litae	Senegal
Bracon hebetor	Mozambique
Agathis sp.	Mozambique

Field releases of *D. semiclausum* at trial sites in the Kenyan Highlands have been very promising with a 50% reduction in DBM damage and up to 50% of farmers having ceased spraying for DBM (Löhr et al., 2007). However there is still a need to treat for aphids, the second most important pest in Kenya. The full impact on brassica cropping is also complex. One economic analysis showed that while farmers in areas with parasitoids used 34% less insecticides, they also generated less revenue than farmers using insecticides in areas without biological control, an intriguing result that may have been related to lower productivity seen in areas adopting biological control (Jankowski et al., 2007). However, control success in East Africa seemed very promising and there were plans to extend this introduction approach to highlands in other African countries such as Burundi, Malawi, Mozambique, Zambia, Zimbabwe and Rwanda, but funding constraints have prevented any start in realising this programme (B. Löhr, pers. comm.). The scope for expanding this introduction approach across Africa is additionally limited in some cases by national regulations, which do not permit the introduction of exotic parasitoids, e.g. in Ethiopia.

4.3. Bt and IPM

A major tool in many IPM programmes has been the promotion of sprayable *Bt* formulations, based upon *Bt kurstaki* and *Bt aizawai* as the insecticides of choice for DBM and other defoliating Lepidoptera. As these formulations are highly specific and were initially very effective, without any impact on natural enemies, they would seem ideal as a component of DBM management. However, unlike most synthetic insecticides, *Bt* spray residues on the plant must be consumed by DBM larvae to be effective and residues break down quickly (2–3 days), so this often results in frequent applications, which is both expensive and arguably contributes to resistance development (Shelton et al., 2007).

Most formulations are spore-crystal mixtures containing a mixture of toxins (*Btk:* Cry 1 Aa, Cry 1Ab, Cry 1Ac, Cry 2a2A and Cry 2B; *Bta*: Cry 1Aa, Cry 1Ab, CryIC, Cry ID and Cry 2B toxins) (Heckel et al., 2004), although the mix of toxins in a product can vary depending on the isolate from which it was derived. *Bt* formulations are more expensive than many broad-spectrum insecticides so it is mainly resistance to the older, cheaper synthetic insecticides that has driven up-take of more selective agents such as *Bt* in brassica-growing areas of Asia. Products based on *Bt kurstaki* (*Btk*) and *Bt aizawai* (*Bta*) have been widely used in Southeast Asia but there has been little or no systematic adoption of IRM strategies even in areas like the Cameron highlands ($<$25%) by farmers (Wright, 2004). As a result, *Btk* resistance was documented for Malaysia from 1990 (Syed, 1992), which led to a subsequent switching to *Bta* and avermectin. Resistance to these ingredients soon followed in Malaysia (Iqbal et al., 1996). Resistance to various strains of *Bt* also occurred in Thailand and China where *Bt* formulations were used intensively (Liu et al., 1996; Perez and Shelton, 1997; Wright et al., 1997). The use of sprayed *Bt* formulations is recorded in Africa but, as this is relatively expensive, its use is limited and resistance against sprayed *Bt* has not been reported yet.

With hindsight, this pattern, which so closely mirrors the experience with DBM and synthetic insecticides, should have been an obvious outcome of overreliance on a single type of control product. However, it was presumed that *Bt*, having been used for two decades without reported resistance, was "naturally resistance proof" and its deployment as part of an IRM strategy was unnecessary, a fallacy that should be taken as a salutary warning against reliance on unproven assertions (Tabashnik, 1994; Tabashnik et al., 1998).

4.4. Other biological IPM approaches

The use of entomopathogens for DBM control has been reviewed by Wilding (1986) and more recently by Cherry et al. (2004). A number of pathogens infecting DBM have been identified. There are several viruses including a DBM granulovirus (PlxyGV), a DBM NPV (Kariuki and Macintosh, 1999), and a DBM cypovirus. Trials of the PlxyGV in Asia (Su, 1991; Talekar, 1996) and Africa (Grzywacz et al., 2004) indicate that PlxyGV has some promise as a biological pesticide for DBM but no commercial products have yet been registered outside China (sun and Peng, 2007).

Several fungi, including *Beauveria bassiana*, *Metarhizium anisopliae* and *Paecilomyces fumosoroseus*, have also been evaluated as insect biocontrol agents in brassica systems. Most of these fungi have been evaluated for use as direct replacements for synthetic insecticides rather than as inoculative agents for classical biological control. The International Institute of Tropical Agriculture (IITA) has screened two entomopathogenic fungi, *B. bassiana* and *M. anisopliae*, for their virulence to DBM and these have shown promise in field trials (James et al., 2007). At least one product containing *B. bassiana* as the active ingredient in an oil-based suspension concentrate formulation is registered for use against DBM in India. Fungi from the entomophthorales, such as *Zoophthora radicans*, have been known to be an important population control factor for DBM, especially in rainy periods (Wilding, 1986). However, difficulties in production, storage and application have made using *Z. radicans* as an inundative insecticide impracticable (Lacey et al., 2001). These issues have led to research on DBM control with *Z. radicans* being focussed on auto-dissemination rather than direct spraying (Vega et al., 2000). While the use of *Z. radicans* for DBM control is the subject of much active research (Furlong and Pell, 1997; Vickers et al., 2004), practical commercial exploitation has not yet been achieved. The use of entomopathogenic nematodes for DBM control has also been evaluated (Baur et al., 1997; Mason and Wright, 1997), but issues such as short UV persistence and the need for high relative humidity appear to be significant constraints with currently available formulations. Microsporidian parasites are recorded as widespread among DBM in the field (Canning et al., 1999), but their impact on DBM fitness is complex (Schuld et al., 1999) and development of these agents as commercial controls remains at a very early stage.

Overall, while there has been a body of research on developing and evaluating entomopathogens for DBM control in recent years, this has not changed the conclusions of Cherry et al. (2004) that their role has "not dramatically changed since the earlier reviews of Wilding (1986) and Talekar and Shelton (1993), and that entomopathogens have yet to take centre stage in DBM control".

The use of pheromone mating disruption as an IPM strategy has a long history (Cardé and Minks, 1995) and there have been a number of studies evaluating this approach against DBM in both Asia and Africa (Ando et al., 1979; Chisholm et al., 1984; Ohbayashi et al., 1992). Trials in the USA showed that control could only be achieved by using very high application rates of >250 g ha^{-1} (Mitchell et al., 1997), which could not be considered commercially viable (Talekar and Shelton, 1993). Subsequent trials in the USA and Kenya were not able to show that the use of pheromones provided any significant level of control (Schroeder et al., 2000; Downham, 2001).

Other IPM approaches to DBM control that have been promoted include the use of local botanical concoctions (chilli–garlic, Mexican marigold) and non-conventional pesticides (e.g. wood ash and fermented cow urine) for DBM control. These have been promoted in Kenya, but positive results could not be confirmed in controlled trials (Cooper, 1999). The organic farming sector in particular has promoted the use of botanicals such as neem (*Azadirachta indica*) (HDRA, 2000). Neem has been particularly promoted for DBM control, with both leaf and seed extracts are reported as showing promise in African trials (Schmutterer, 1992). A GTZ-funded IPM project in Tanzania from1992 to 2002 promoted the use of neem seed cake to control DBM and *H. undalis* on brassicas (Foerester et al., 2001). While results are reported as being more consistent with neem than with some other botanicals, and immediate use by trained farmers reached 65%, wide scale adoption by farmers post-project has not yet been determined (Foerester et al., 2001). There is also a significant question surrounding the supply of neem for large scale use in brassicas. Application rates are often high, requiring 0.5–2 kg of seed formulation or 10–20 kg fresh leaves per ha, and major sources of insecticidally-effective neem are generally in coastal regions far from the main highland brassica production areas. Another botanical insecticide is pyrethrum (*Chrysanthemum cinerariaefolium*) itself, but, although Kenya is a major producer of natural pyrethrum, East African farmers hardly use it (Birech et al., 2006).

A major drawback which both entomopathogens and botanicals share with *Bt* is that, while some of these agents are highly effective against DBM, most fail to adequately control aphids that are the major secondary pest and vectors of brassica plant viruses.

4.5. Area-wide management of DBM

Because DBM can be highly mobile, this presents challenges for its management on a local and area-wide basis. Long distance movement of DBM has been well documented and includes instances of inter-continental movement (see Ridland and Endersby, 2008 for a recent review of the literature on DBM movement patterns). Using knowledge of weather patterns and atmospheric fronts, trajectory models have been used to predict potential migration events and to allow early warnings to growers. However, because of the difficulty in convincing one set of growers to use tactics that will prevent an insect's movement into another area, early warnings are likely to be the best outcome from such knowledge. However, on a regional level, other strategies can provide more direct benefits. Shelton et al. (1996) have shown that DBM can be easily transported from one area to another on cabbage transplants. This is often accompanied by resistance to insecticides to which they were challenged in their original site, thus causing considerable problems to growers who purchase the infested transplants. Having this knowledge has allowed transplant growers and those who purchase their transplants to enter into a dialogue about appropriate control strategies and expectations.

Within a region, studies have shown that if adequate resources are available for DBM populations on a year-round basis, they tend to have limited movement, as has been demonstrated in Hawaii. Such lack of mixing of populations can lead to problems. For example, when resistance to a particular insecticide begins because of frequent and widespread use of a product, it will be difficult to avoid large crop losses and restore the efficacy of the chemical unless there is an agreement among growers in that region to temporarily remove that product as part of a regional IRM program. This was done in Hawaii when resistance to spinosad occurred (Zhao et al., 2002). However, for long-term sustainable management of DBM it has become evident that a landscape perspective must be developed. Such a perspective will require knowledge of the local and regional movement patterns of DBM, implementation of crop diversity and rotation strategies, and reliance on multiple tactics including biological control and insecticide resistance management strategies (Hoy et al., 2007).

5. Potential role of insect-resistant brassicas

Host plant resistance should be the foundation for pest management, but in many cases there is no suitable resistant germplasm (Kennedy, 2008). This is especially true for two of the largest and most damaging orders of insects, Lepidoptera and Coleoptera. Although considerable effort has focused on breeding lepidopteran resistance in brassicas (Eigenbrode et al., 1990), traditional breeding efforts have not been successful. Particularly in the developing countries of Africa and Asia, control of DBM is onerous and demanding, especially for poorer farmers who lack access to the resources, new technologies and knowledge needed to reliably control the ravages of this pest. Without resistant germplasm, history tells us that growers will continue to rely on insecticides as their main control strategy. In developing countries, heavy reliance on insecticides has particular concerns in vegetables such as brassicas because they are generally frequently treated by resource-poor farmers who lack adequate education about pesticides and protective equipment. Environmental and human safety is greatly compromised in the present management system for brassicas that relies so heavily on traditional insecticides, especially in developing countries. This suggests that there is a "clear and present need" for additional pest management technologies and that plant resistance should be an essential element, especially in developing countries.

The experiences in developing countries with GE crops have been rapid. In 2008, there were more developing (15) countries planting GE crops than developed (10) countries (James, 2008). Only one country in Africa grew GE crops in 2007 (South Africa), but this increased to three in 2008 with the addition of Burkina Faso and Egypt. As developing countries develop their biosafety laws and regulations and gain experiences with existing GE insect-resistant crops (cotton and maize), it is more likely that they will adopt *Bt* brassicas when they become available.

Growers in developing and industrialised countries want pest management tactics which are easy to implement and less labor-intense (Shelton, 2007). The development and deployment of insect-resistant brassicas should help meet those goals and become an essential new tool for brassica IPM initiatives. Plant material with reliable endogenous resistance to DBM would, at a stroke, cut farmers' need to apply the broad-spectrum chemicals whose continued use has so frequently prevented introduced and endemic natural enemies from achieving their full impact (Nyambo and Löhr, 2005). The deployment of insect-resistant brassicas would seem to have the most potential impact in lowland cropping systems where parasitoid options are weak (Talekar, 2004) but also have great potential in highlands where the promotion of parasitoid-based IPM is most advanced but adoption lags.

In the last decade, the deployment of GE insect-resistant crops such as cotton, in places like India, has transformed crop production by increasing yields and incomes while reducing very significantly the historic misuse of environmentally damaging synthetic insecticides (Gujar et al., 2007; Gruère et al., 2008). Worldwide, the only *Bt* crops currently on the market are *Bt* cotton and *Bt* maize. First introduced in 1996, by 2007 they were grown on 46 million ha in 23 countries (James, 2008). *Bt*-transgenic cotton plants in China have been reported to provide a 60–80% decrease in the use of foliar insecticides, amounting to about 15,000 tons of chemicals (Pray et al., 2001; Huang et al., 2003), a similar result to that identified by a recent review of the impact of *Bt* cotton in India (Qaim et al., 2008). In Australia, since their introduction in 1996, an average of 56% reduction in the use of foliar insecticides has been reported (CSIRO, 2003). The deployment of insect-resistant *Bt* varieties has reduced the total world use of insecticides by an estimated 14% (Phipps and Park, 2002). More recently Brookes and Barfoot (2008) estimated a decrease in active insecticidal ingredients of 22.9% for cotton and 5% for maize. In addition, Brookes and Barfoot (2008) report that the use of Bt cotton and maize reduced the environmental impact quotient (EIQ), which integrates the various environmental impacts of individual pesticides into a single "field value per hectare" (Kovach et al., 1992) by 24.6% and 5.3% in cotton and maize, respectively.

Zilberman et al., (2007) have explored the wider impact of agricultural biotechnology on yields, risks and biodiversity and have concluded that the current GE crops have significant potential to increase economic welfare in low income countries. Clearly appropriate introduction mechanisms are necessary to maximise farmer and consumer benefits and ensure sustainability. A number of initiatives such as the USAID Agricultural Biotechnology Support Programme II/Mahyco programme on Bt brinjal (eggplant) and the CIMBAA initiative on Bt brassicas (see below) are exploring these options.

Given the success of Bt cotton (Naranjo et al., 2008) and *Bt* maize (Hellmich et al., 2008) as elements in IPM programs, there would also seem to be great opportunities for direct economic benefits from *Bt* cabbage and cauliflower in developing countries (Shelton et al., 2008). In fact, research over the last 15 years has provided empirical evidence of the benefits of controlling DBM with *Bt* plants and the compatibility of such plants with important biological control agents such as *Diadegma insulare* (Chen et al., 2008). However, given the proven ability of DBM to evolve resistance to *Bt* in the field, it is important that any such material be optimised for resistance management. Dual *Bt* gene broccoli transformations, utilising two non-cross-resistant Bt genes against DBM, have proven to be very successful for resistance management in long-term greenhouse studies (Zhao et al., 2003) and such *Bt* brassicas have proven more sustainable than foliar sprays of *Bt* (Shelton et al., 2008). To maximise the effectiveness of dual gene plants, the proteins that they express should ideally be unused or very little used in sprayed formulations to date, and the genes incorporated into the plants should be closely linked to avoid accidental separation by breeders. Such an approach is currently the basis of an international public–private partnership collaboration focused on bringing DBM-resistant cabbage and cauliflower to Africa and Asia for testing and evaluation (Shelton et al., 2008, Russell et al. 2008). This programme, the Collaboration on Insect Management for Brassicas in Asia and Africa (CIMBAA) has been running since 2005 and utilises pyramided *cry1Ba2* and *cry1Ca4* Bt genes whose products are active against DBM. Transformed cabbage and cauliflower lines have been selected in screen-house trials in India and are being challenged with the key lepidopterous pest species. Work with purified Cry1B and Cry1C protein on insects in India, USA, Indonesia, Taiwan and Australia has showed excellent efficacy against the key pests DBM, *C. binotalis* and *H. undalis* and good efficacy against *Pieris* species. The caterpillars of the noctuid moths *Spodoptera litura* and *Helicoverpa armigera* are less susceptible to these proteins (Shelton et al., in press). Currently these two species are minor pests in the complex in most places and at most times but it remains to be seen what might happen if the insecticide pressure on cabbage and cauliflower was reduced.

The risk of resistance development is a serious concern with Bt plants as it has been with insecticides. The first controversial reports of resistance to field deployed Bt plants was in *Helicoverpa zea* from Bt cotton, after 10 years of use, in parts of the USA

(Tabashnik et al., 2008). The deployment of large areas of single Bt gene plants with limited effective refugia is suggested as the reason for resistance first appearing here. By pyramiding these particular *cry1B* and *cry1C* genes which code for proteins which are not substantial components in Bt sprays commercialised in India and which are not cross-resisted by DBM, the CIMBAA initiative expects to minimise the risks of resistance development, especially in a fragmented agricultural environment such as India containing many crop and wild alternate host plants. Tightly linking the genes on a single chromosome should prevent future breeders accidentally separating the genes and exposing them to selection separately. In fact DBM resistance to Cry1C has been shown to be polygenic (Zhao et al. 2000) and attempts to select simultaneous resistance to both proteins have not yet succeeded. However, experiments are underway to ascertain the prevalence, if any, of heritable simultaneous resistance to these insecticidal proteins in DBM in Indian populations. If resistance is found, its heritability and any fitness costs will be studied and the results fed into the Bt-Adapt simulation model (Kranthi and Kranthi 2004) which has been modified for diamondback moth, dual-gene Bt crops and the brassica cropping systems in India. This will be used to test scenarios for the minimisation of resistance development and feed into the stewardship strategy for these plants should they be released.

Concerns as to the potential for pollen flow from GE brassicas to conventional and organic crops and possibly to weedy relatives and are also being explored experimentally in India. The provision of pyramided Bt gene material in male sterile hybrids is one way to substantially reduce these real or perceived risks, given that seed production is in areas isolated from other brassica production, and that the hybrids will not produce viable pollen in the production areas. One potential drawback raised in connection with deploying GE and hybrid seed generally is that of negative impacts on local self selection and seed production by farmers, often perceived as a key to preserving crop diversity in developing countries (Borowiak, 2004). However, self production of seeds in practice may be negligible in major horticultural areas. Most premium cabbage and cauliflower seed used in India is currently imported as hybrids. In so far as cabbage seed is produced locally it is in specialist seed production areas in upland regions, allowing for vernalisation, and not by the crop producers in the plains. Cauliflower will flower in the plains where the marketed crop is grown but the proportion of farmer saved seed is negligible and declining, even in open pollinated varieties and the use of open pollinated varieties themselves is declining rapidly as the advantages of hybrid seed become more widely apparent. A survey in Kenya found that 98% of small farmers rely on seed bought from established seed suppliers (Oruku and Ndun'gu, 2001). This would indicate that seed delivery of new technology, even to smallholders in Sub-Saharan Africa, is a potentially viable mechanism for promoting adoption of a new IPM technology by brassica growers.

The importance for sustaining IPM of understanding farmer perceptions of control success and their rationale for decision-making has been highlighted previously (Sivapragasam, 2004). If farmers can be led to avoid the use of broad-spectrum insecticides, then the full pest control potential of parasitoids and natural enemies can be realised. There is a weight of scientific opinion that this would, in turn, greatly reduce pest pressure both from DBM and the many secondary pests, perhaps returning brassica production to the pre-synthetic insecticide paradigm when DBM was not a major economic problem (Talekar, 1996; Kfir, 2003).

Any successful IPM programme based upon deployment of insect-resistant planting material for brassicas will have to provide control not only for DBM but also for key early-season pests such as aphids and cutworms if it is to provide a solution acceptable to farmers on a wide scale. Failure to control these secondary pests would be very likely to result in farmers reverting to early application broad-spectrum pesticides, negating many of the potential economic and environmental benefits of crops resistant to pest lepidoptera. Currently no suitable genes delivering proteins for control of sucking pests have been incorporated into commercially available plants (Kennedy, 2008). Thus, in the absence of Bt-based resistance to these non-target pests, the impact of DBM-resistant material is most likely to be optimised if it is deployed as part of an IPM system with components for the control of these other major pests, e.g. aphids, flea beetle, etc. Depending on the timing within the season and location, there may be potential for the enhanced control of secondary pests by beneficial organisms if the insecticidal applications for the key lepidopteran pests are no longer applied. This is under study in India now.

One promising approach to the control of early-season sucking pests, which is already proven in brassica systems, is the use of insecticidal seed coatings (Walsh and Furlong, 2008). In cotton in India this has been shown to substantially delay the first application of insecticides for controlling sucking pests in cotton, and was a key component in delaying early application of broad-spectrum insecticides by farmers (Kannan et al., 2004). However, cabbage and cauliflower are transplanted crops and aphids are not always only an early-season pest and the period of efficacy of insecticidal seed treatments is limited. In some areas, for example South India, the great majority of brassica producers buy seedlings as plugs for transplanting. Where this situation pertains, systemic insecticidal seed treatment coatings may be transplanted with the plant, or insecticides may be applied as a root/soil drench with neonicotinyls or other materials at or after transplanting. These options and the persistence of their effects are being explored now in field trials in India.

Krishna and Qaim (2007) explored the likely benefits of public private partnerships for the delivery of GM vegetables in India in the context of the Bt brinjal currently being considered for commercial release. Their conclusion was that there was ample latitude in 'willingness to pay' to allow all parties (farmers, seed producers and consumers) to benefit substantially from the introduction of these technologies. The same authors explored consumer attitudes towards GM food and pesticide residues in India though a consumer study in four urban areas (Krishna and Qaim, 2008). They found 60% of consumers accepting GM insect-resistant vegetables at current prices and most consumers accepting the technology if insecticide residues and vegetable prices were reduced by the technology. Interestingly those most aware of the problems of insecticide residues on vegetables were also those most opposed to the introduction of GM insect-resistant vegetables, even although residues would be reduced. This nervousness in respect to GM crops in better-educated consumers to some extent mirrors findings in Europe and elsewhere and the actual consumer response remains to be seen when these materials reach the market.

In conclusion, the deployment of effective and durable insect-resistant brassicas in Africa and Asia within an effective IPM context would be a major contribution to efforts to advance the adoption of rational biologically-based and durable IPM in brassicas. This would have substantial positive impacts, promoting agricultural productivity and human nutrition without the deleterious environmental and health consequences associated with the heavy dependence on synthetic insecticides that characterises current production systems. Efforts are underway to achieve these ends through a public–private, donor supported, partnership developing dual Bt gene cabbage and cauliflower for the developing world (Shelton et al., 2008, Russell et al., 2008).

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