18 Managing Insect Pests of Rice in Africa

Francis E. Nwilene,[1]* Souleymane Nacro,[2] Manuele Tamò,[3] Philippe Menozzi,[4,5] Elvis A. Heinrichs,[6] Abdoulaye Hamadoun,[7] Dona Dakouo,[2] Cyrille Adda[4] and Abou Togola[4]

[1]*Africa Rice Center (AfricaRice) Nigeria Station, Ibadan, Nigeria;* [2]*Institut de l'environnement et des recherches agricoles (INERA) Station de Farako-Bâ, Bobo-Dioulasso, Burkina Faso;* [3]*International Institute of Tropical Agriculture (IITA), Cotonou, Benin;* [4]*Africa Rice Center (AfricaRice), Cotonou, Benin;* [5]*Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), UR 102, Montpellier, France;* [6]*University of Nebraska, Lincoln, Nebraska;* [7]*Institut d'économie rurale Centre régional de recherche agricole (IER/CRRA), Sikasso, Mali*

Introduction

The major insect pests of rice in Africa include stem borers, African rice gall midge and termites (Nacro *et al.*, 1996; Nwilene *et al.*, 2008a). Pests cause considerable crop losses in the field and in storage. It is estimated that each year insects destroy between 10% and 30% of all food produced in Africa (Oerke, 2006; Pimentel, 2007; Dhaliwal *et al.*, 2010). The estimates of rice yield loss due to insects in Africa range between 10% and 15% (IRRI *et al.*, 2010). The major insects and associated damage differ regionally, by country and by rice variety, and in some years may exceed 90% (Youdeowei, 2004; FAOSTAT, 2006). Rice grain losses caused by pest damage contribute to rural poverty and food insecurity in Africa. The prevention of pest-induced food crop losses at pre- and postharvest stages is an integral part of the Millennium Development Goal (MDG) to ensure food security and poverty reduction (von Braun *et al.*, 2003). In the search for sustainable management options to increase food security, an overall challenge is to increase yields and decrease losses during production and harvest without harming the environment and resource base for future generations of farmers and consumers. As such, integrated pest management (IPM) plays a key role in the context of sustainable agricultural development, by reducing crop losses and thereby increasing productivity while minimizing environmental contamination and health hazards. Integrated pest management has evolved from pesticide-abatement strategies into analytical approaches to understand pest status within production systems in order to make informed decisions on appropriate management options that incorporate social, economic, gender and environmental issues. This chapter discusses pre- and postharvest insect pests in rice and reviews approaches to reduce quantitative and qualitative losses incurred along the rice value chain, in the context of a

* Corresponding author: f.nwilene@cgiar.org

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rapidly growing demand for rice in sub-Saharan Africa and the increased risk of pest outbreaks due to climate change.

Pre- and Postharvest Insect Pests

Dipterous and lepidopterous stem borers are among the most economically important pests of rainfed upland, rainfed lowland and irrigated rice in Africa (Nwilene *et al*., 2006, 2009a). The larvae of stem borers cause significant yield loss during the vegetative and reproductive stages by producing 'deadhearts' and 'whiteheads', respectively, which prevent panicle development (Brenière, 1983). The most important species reported on rice in Africa are: stalk-eyed flies, *Diopsis* spp. (Diptera: Diopsidae); African white borer, *Maliarpha separatella* (Lepidoptera: Pyralidae); African yellow stem borers, *Scirpophaga* spp. (Lepidoptera: Pyralidae); African striped stem borers, *Chilo zacconius* and *C. diffusilineus* (Lepidoptera: Pyralidae); pink stem borers, *Sesamia* spp. (Lepidoptera: Noctuidae); and African rice gall midge (AfRGM), *Orseolia oryzivora* (Diptera: Cecidomyiidae). All are indigenous to Africa, except for *M. separatella*, which also occurs in Asia (Table 18.1). Damage by AfRGM is different from other stem borer species, because the larvae attack the growing points of rice tillers in the vegetative stage (seedling to panicle initiation). Infestation of a tiller prevents panicle production and results in the development of a tubular gall – also known as 'onion leaf' or 'silver shoot'. Other insect pests prevalent in Africa

Table 18.1. Key pre-harvest insect pests across major rice-growing environments in Africa.

Upland	Hydromorphic	Rainfed and irrigated lowland
Pink stalk borer, *Sesamia calamistis*	African rice gall midge, *Orseolia oryzivora*	African rice gall midge, *Orseolia oryzivora*
Pink stalk borer, *Sesamia nonagriodes botanephaga*	African yellow stem borer, *Scirpophaga melanoclista*	African yellow stem borer, *Scirpophaga melanoclista*
Pink stalk borer, *Sesamia n. penniseti*	African yellow stem borer, *Scirpophaga subumbrosa*	African yellow stem borer, *Scirpophaga subumbrosa*
Pink stalk borer, *Sesamia poephaga*		Pink stalk borer, *Sesamia calamistis*
African striped stem borer, *Chilo zacconius* and *C. diffusilineus*		Striped stem borer, *Chilo zacconius* and *C. diffusilineus*
African white borer, *Maliarpha separatella*		African white borer, *Maliarpha separatella*
Stalk-eyed fly, *Diopsis longicornis*, *D. apicalis*, *D. collaris*	Stalk-eyed fly, *Diopsis longicornis*, *D. apicalis*, *D. collaris*	Stalk-eyed fly, *Diopsis longicornis*, *D. apicalis*, *D. collaris*
		Caseworm, *Nymphula depunctalis*
Termites		
Leaf-feeding beetles – Ladybird beetle (*Chnootriba similis*), Flea beetle (*Chaetocnema* spp.), grasshoppers – Short-horned grasshoppers (*Oxya* spp.), Meadow grasshoppers (*Conocephalus* spp.), sucking bugs, etc.	Leaf-feeding beetles – Ladybird beetle (*Chnootriba similis*), Flea beetle (*Chaetocnema* spp.), grasshoppers – Short-horned grasshoppers (*Oxya* spp.), Meadow grasshoppers (*Conocephalus* spp.), sucking bugs, etc.	Vectors of *Rice yellow mottle virus*: leaf feeding beetles – Ladybird beetle (*Chnootriba similis*), Flea beetle (*Chaetocnema* spp.), grasshoppers – Short-horned grasshoppers (*Oxya* spp.), Meadow grasshoppers (*Conocephalus* spp.), sucking bugs, etc.
Grain-sucking bugs – Stink bug (*Aspavia armigera*), Bean bug (*Riptortus* spp.), Green stink bug (*Nezara viridula*) and Head bug (*Mirperus* spp.)	Grain sucking bugs – Stink bug (*Aspavia armigera*), Bean bug (*Riptortus* spp.), Green stink bug (*Nezara viridula*) and Head bug (*Mirperus* spp.)	Grain sucking bugs – Stink bug (*Aspavia armigera*), Bean bug (*Riptortus* spp.), Green stink bug (*Nezara viridula*) and Head bug (*Mirperus* spp.)

include termites, caseworms, vectors of *Rice yellow mottle virus* (RYMV; see Séré *et al.*, Chapter 17, this volume), and grain-sucking bugs.

The vast majority of insects that are pests of stored grain belong to just two orders: Coleoptera and Lepidoptera (Reed, 2010). According to their pest status, they can be divided into two groups: primary and secondary storage insect pests. Primary storage pests are able to destroy stored rice (paddy or milled grains) independently. They are responsible for severe losses of stored rice and other cereals in Africa. Secondary storage insect pests can only attack grains that have been damaged by primary insect pests (Table 18.2). Most of the storage pests have been dispersed across the world by international trade (Youm *et al.*, 2011) and lead to quantitative and qualitative losses, as well as price reduction in most African markets. A quantitative loss of 18% was reported on farmers' stored rice in Benin over 4 months of storage (Togola *et al.*, 2010). The quantitative loss was estimated on damaged and undamaged grains collected from farmers' stored paddy grains. The damage is higher when the storage exceeds 4 months, due to the high reproduction rate of these insects and their short life cycle of just 45 days (Togola, unpublished data). Moreover, these pests produce heat and moisture and contaminate rice grain with their waste products and secretions (Walker and Farrell, 2003). The damaged grains are inappropriate for trade, or for use as food or seeds.

Managing Insect Pests

Varietal resistance

Resistant and tolerant rice cultivars play an important role in the reduction of yield losses due to insect pests and assessment of different rice varieties for insect resistance is an integral component of pest management. Because of its unique advantages (e.g. generally compatible with other control measures), host-plant resistance is a key component in the integrated control of rice insect pests in Africa. Success in identifying resistant material depends to a large extent on the ability to adequately evaluate germplasm and improved genotypes. Screening germplasm under artificial and natural pest infestations is essential for identifying better sources of resistance to major insect pests of rice. Knowledge of the mechanisms and factors contributing to host-plant resistance to insects is useful in selecting suitable criteria and breeding methodology for the genetic improvement of rice plants for insect resistance. Some of the factors associated with resistance, such as silica content and longer internode elongation in *Oryza sativa* varieties, can be used as 'marker traits' to screen and select for resistance to pests. Considerable progress has been made by the Africa Rice Center (AfricaRice) in the development of NERICA varieties that combine the high yield potential of Asian rice (*Oryza sativa*) with many useful traits from the African cultivated

Table 18.2. Key postharvest insect pests of stored paddy and milled rice in Africa.

Main species	Order (Family)	Status
Rice weevil, *Sitophilus oryzae* and Maize weevil, *Sitophilus zeamais*	Coleoptera (Curculionidae)	Primary pests of rice (paddy and milled grains)
Lesser grain borer, *Rhizopertha dominica*	Coleoptera (Bostrichidae)	Primary pest of rice (paddy and milled grains)
Angoumois grain moth, *Sitotroga cerealella*	Lepidoptera (Gelechiidae)	Primary pest of rice (paddy grain)
Red flour beetles, *Tribolium castaneum* and *T. confusum*	Coleoptera (Tenebrionidae)	Primary pest of rice (paddy and milled grains)
Rice moth, *Corcyra cephalonica*	Lepidoptera (Pyralidae)	Secondary insect pest of rice (paddy and milled grains)
Merchant grain beetle, *Oryzaephilus mercator*	Coleoptera (Sylvanidae)	Secondary insect pest of rice (paddy and milled grains)
Rust-red grain beetle, *Cryptolestes ferrugineus*	Coleoptera (Cucujidae)	Secondary insect pest of rice (paddy and milled grains)

species (*Oryza glaberrima*). Today, there are both upland and lowland NERICA varieties and traditional *O. sativa* varieties that are resistant or tolerant to some key pests of rice in Africa. Systematic evaluation of rice germplasm for AfRGM resulted in identification of over 50 primary sources of resistance among *O. glaberrima* and traditional *O. sativa* varieties (Nwilene *et al*., 2002). Several gall-midge-tolerant rice varieties (e.g. NERICA-L 19, NERICA-L 49, Cisadane, BW 348-1, Leizhung) have been developed and released for commercial cultivation in Africa. Nwilene *et al*. (2009b) identified anti-xenotic and antibiotic traits associated with resistance to AfRGM in some of these rice varieties, but the traits have yet to be utilized in breeding. The quantitative trait loci (QTLs) or genes conferring resistance to AfRGM have also been identified from (*O. sativa* × *O. glaberrima*) crosses, ITA306 × TOS14519 and ITA306 × TOG7106. Some progress has also been made in identifying suitable upland NERICA varieties (NERICA 1, 2, 5, 7 and 14) that are resistant or tolerant to rice stem borers (Rodenburg *et al*., 2006; Nwilene *et al*., 2008b). Some NERICA varieties (NERICA 5, 14, 18) are suitable for cultivation in termite-prone areas of north-central Nigeria (Agunbiade *et al*., 2009). Crop improvement programmes need to place emphasis on developing germplasm with multiple resistance to key insect pests using biotechnological tools (e.g. marker-assisted selection), because there are often two or more stresses in most rice production environments in Africa.

Bt-rice

Rice transformation with a *Bt*-gene (delta-endotoxins from *Bacillus thuringiensis*) was first targeted against Asian yellow stem borer (YSB, *Scirpophaga incertulas*), Asian striped stem borer (*Chilo suppressalis*) and leaffolder (*Cnaphalocrocis medinalis*) in Asia. Genetically modified rice plants (*Bt*-rice) resistant to striped stem borer, leaffolders and other insects have been developed (Fujimoto *et al*., 1993; Chen *et al*., 2005a), and two *Bt*-rice varieties (Huahui 1 and Xianyou 63) were authorized for marketing especially in China, in 2009 (Chen *et al*., 2011). Review of the literature on the entomological situation of *Bt*-rice in Asia and the current rice insect pest status in Africa led to the conclusion that, in the current state of knowledge, it seems inappropriate to introduce *Bt*-rice to control the diversity of rice insect pests in Africa (Silvie *et al*., 2012). Moreover, the high diversity of insects found on rice in Africa (including Madagascar) militates against the use of *Bt*-rice due to the problem of resistance and that the toxins only affect a small number of stem borer species (van Rensburg, 2007). Response to the toxins may be quite different from one species to another. The introduction of *Bt*-rice in Africa is currently inappropriate because most African countries have no containment facilities to test transgenic rice for insect resistance. Regulatory frameworks are needed that promote quality control and informed use of transgenic crops and plant protection products.

Field-level integrated pest management

A majority of smallholder farmers in Africa rely on their traditional knowledge to manage pest problems, mainly by the use of botanical pesticides (Mugisha-Kamatenesi *et al*., 2008). Apart from the traditional use of local herbs as biopesticides, indigenous knowledge systems also promote the use of sustainable soil and crop management practices which indirectly favour biologically-based pest regulation by natural enemies (Kuponiyi and Bamigboye, 2009). However, in a period of unprecedented change, farmers find that their indigenous knowledge provides only limited guidance. For farmers to more effectively manage pests on an ecological and sustainable basis, they need a combination of indigenous and scientific knowledge. The success of pest management programmes will depend largely on how well farmers understand and combine knowledge of biological and ecological processes with their own farming experiences. There is a growing realization that future agricultural growth hinges on smallholder farmers, who must be knowledgeable and exposed to a learning process that involves continuous field observation, agroecological analysis and management practices under local conditions, and that enhances decision-making capacity. A widespread constraint to the development of improved control methods is farmers' lack of information on the behaviour and reproductive cycles of target pests. When farmers misidentify the causes of damage observed in their fields, they may spray an insecticide to combat a pest when the damage is not caused by a pest. Also, by the time a pest is observed, it may be too late to do much about it except maybe spray with an insecticide. This is often the case in Africa. The smallholder farmers need to be taught to target the life-cycle stage that is susceptible to control measures. This is an example of how knowledge can benefit smallholder farmers and help protect rice from insect attacks. The farmer field school for IPM is an innovative model for community-based farmer education that uses non-formal or 'discovery learning' methods (William and Garba, 2011). The participatory learning and action-research (PLAR) for integrated rice management developed by AfricaRice may also serve as a vehicle to reach out to farmers, because it is a bottom-up social learning process to promote technological change through improving farmers' capacity to exchange knowledge, experiences and practices, to better observe, analyse and take appropriate decisions for action, and to get organized for action. Through the PLAR process, groups of farmers are able to find adaptive responses to site-specific problems and make the best use of available resources and local knowledge as well as research-based understanding of underlying processes (Defoer *et al.*, 2009; Defoer and Wopereis, chapter 31, this volume).

Landscape-level integrated pest management

There is considerable evidence that as agricultural production systems are intensified by increased use of external inputs to increase yield, and structural changes occur at landscape level, they tend to lose biodiversity and become destabilized, with increased frequency and extent of pest outbreaks (Swift *et al.*, 1996; Knops *et al.*, 1999). However, we know relatively little about the ecological mechanisms that result in this destabilization, or how important natural enemy diversity is in maintaining pest-control functions. In West Africa, for example, there is good circumstantial evidence that heavy infestations of AfRGM have become more common since the 1970s, with outbreaks associated with rice–rice double cropping and increases in nitrogen fertilizer application (Williams *et al.*, 1997). Studies in West Africa have also shown that the abundance of generalist herbivores and predators is positively correlated with weed biomass, whereas specialist herbivore abundance is positively correlated with rice biomass (Afun *et al.*, 1999). Understanding the complexity of these interactions and determining the positive and negative effects of intensification on the functioning of the different components of crop-associated biodiversity is essential for future development of sustainable production technologies.

The overall strategy in insect pest management for rice is to use a holistic 'plant health' approach, which should ideally start from considering soil-health aspects. A healthy plant might tolerate a higher population of noxious insects, while a carefully managed soil should provide improved ecosystem services such as beneficial organisms able to attack herbivores. Because of poor rotations, overuse of chemical pesticides, and inappropriate agronomic practices, soils might lose their ability to provide these important services, and hence need to be supplemented with appropriate amendments. For instance, the use of mycorrhyzal or endophytic fungi increases plants' ability to withstand attacks by pathogens, nematodes and insect pests (Secilia and Bagyaraj, 1992; Tian *et al.*, 2004). Also, complex interactions between soil fertility, insect attack and parasitoids have been documented in cereals such as maize (Chabi-Olaye *et al.*, 2005).

At the landscape level, the importance of alternative host plants both as an off-season resource for the different rice pests, but also as refugia for natural enemies cannot be overemphasized. Some studies in West Africa have identified possible innovations in this regard. For instance, AfRGM is attacked by parasitoids such as *Platygaster diplosisae* and *Aprostocetus procerae* in rice-production systems (Nwilene *et al.*, 2008c). However, the level of parasitization is low because the parasitoid populations build up too late to prevent heavy AfRGM infestation. Meanwhile, a related gall midge (paspalum gall midge, PGM, *Orseolia bonzii*) that forms galls on *Paspalum* grass is an important alternative host for the two parasitoids of AfRGM. Hence, habitat manipulation to increase the carry-over of parasitoids from PGM (which does not attack rice) to AfRGM, such as dry-season cultivation to encourage *Paspalum scrobiculatum* abundance early in the wet season, could improve the natural biological control of AfRGM. Similarly, ecological engineering using push–pull approaches, such as the one developed for maize in East Africa (Khan *et al.*, 1997), could be modified against cereal stem borers in West Africa, and particularly those attacking rice. Here the challenge is not just technical: any innovations requiring additional farmer inputs, such as seeds of companion crops and labour, need to be tested for their economic profitability and socio-cultural acceptability in West Africa. As shown in the next section, more complex management options require a robust linkage to and integration with available indigenous knowledge. The next challenge facing the development and deployment of ecosystem services is to use modern tools in population genetics to assess the presence of locally distinct populations of both rice pests and their natural enemies. Molecular markers can be used to characterize pest populations and to gather detailed information about their specific location and migration, as well as those of locally available and introduced beneficial organisms. These data, combined with ecological and biological characteristics, are critical for more appropriate targeting of biological control interventions (Agunbiade *et al.*, 2012).

Postharvest integrated insect pest management

Postharvest IPM begins with good postharvest handling and management practices right from the field to the storage environment. The prerequisites and options for good storage pest management include: (i) harvesting on time; (ii) maintenance and protection of the site and storage environment from birds, rodents and the weather (controlling grain and air moisture), and basic hygiene using thermal disinfestation of the site by solar heat or treatment with traditional additives; and (iii) commodity management (cleaning and drying of appropriate packaging facilities) using hermetic storage (pits or metal drums) or treatment with synthetic insecticides/pesticides. Because of the danger of pesticides affecting the quality of rice stored for human consumption, research has made it possible to develop alternative measures to minimize pesticide risks to human and agroecosystem health. Plant products such as botanical extracts, essential oils and vegetable oils are being explored as potential pest management tools because they are not toxic to plants, are systemic, biodegrade easily and stimulate the host's metabolism (Dubey *et al.*, 2008). These measures need to be explored more effectively in order to preserve the quantity and quality of stored rice in Africa. Moreover, technologies such as rendering males infertile by using ultraviolet rays, pheromone traps and baits can be explored as future options to manage postharvest insects. Finally, quarantine measures should be rigorously applied in order to minimize the dispersion of invasive pests across national borders.

Climate Change and Pest Movements

Dwindling and erratic rainfall patterns, rising air temperature and extreme heat are having an impact on the spatial and temporal distribution and proliferation of insect populations. This may alter host plant–insect interactions and will thus require new IPM strategies. Climate change can increase the risk of pest outbreaks leading to greater yield losses with inherent negative consequences for food security in Africa. The current distribution and shifts in the relative importance of major pests of rice and their natural enemies in the upland–lowland rice agroecosystem continuum needs to be established using the phenology models and risk maps in geographic information systems (GIS). Parasitoids – the key natural enemies of the most important pests of rice – depend on a series of adaptations to the ecosystem and physiology of their hosts and host plants for survival and are thus likely to be highly sensitive to changes in environmental conditions. Climate change affecting pest and natural-enemy profiles might disrupt *Bt*-crops, increase the number of pest generations, prompt immigration of new invasive species, and enable existing species to expand their ranges (Chen *et al.*, 2005b). It is likely that insect management strategies developed in the past will also be affected by changes in climate. Thus, better knowledge and understanding of pest behaviour and actual farmer practices under different projected scenarios are needed to adapt existing or develop new IPM technologies to respond to possible threats resulting from climate change. There is, therefore, a need to test and disseminate a set of monitoring and forecasting tools, including simulation models to national-programme scientists, and decision makers in IPM research and extension. It will also be useful to document how farmers adapt their insect pest management strategies to climate change.

In the warm and humid tropics of Africa, various species of insects remain active year-round and populations fluctuate according to the availability of food plants, presence of natural enemies and environmental conditions. For example, in the humid forest zone of Nigeria, AfRGM persisted through the short dry season on ratoons of cultivated rice at a rainfed site and on dry-season crops at an irrigated one. In contrast, at rainfed sites in the moist savannah zone the pest survived the longer dry season on the perennial wild rice *Oryza longistaminata*, while ratoons and volunteers of *Oryza sativa* provided 'bridges' between the wild host and wet-season rice crops (Williams *et al.*, 1999). Some pests of rice known to be restricted to the lower part of the slope are gradually moving to the upper portion. The reason for this sudden movement pattern is unknown. In order to aid pest-management decision making and understand spatial dynamics of pests in agroecosystems, including cultivated and non-cultivated areas, we need to build new tools for tracking insect movement in Africa. Such tools can be used to forecast infestation risks, target geographical variations in biotype and movement of insect vectors from alternative host plants to rice and vice versa, and target better management of pests at hot-spot locations and agroecosystems in cultivated lands. Some of the available new tools that can be used are: (i) stable isotopes (of hydrogen, carbon, etc.); (ii) phytochemical markers (gossypol, tomatine, etc.); and (iii) bacterial molecular markers.

Stable isotopes represent a powerful tool to determine the trophic (with carbon or nitrogen isotopes) or geographic origin (with hydrogen or oxygen isotopes) of any animal (Hood-Novotny and Knols, 2007; IAEA, 2009). Although they require costly equipment for analysis (gas chromatography/mass spectrometry), their use is growing, and the cost of the analyses is decreasing. In entomology, stable hydrogen and carbon isotopes have been used to track migrations of monarch butterfly (*Danaus plexippus*) in the USA (Hobson *et al.*, 1999). In France, Ponsard *et al.* (2004) showed that stable carbon isotopes are indicators of the photosynthetic type (C_3 or C_4) of the host plants of *Ostrinia nubilalis*, regardless of the feeding habits and metabolism intensity of adults. Analysis of the isotopic composition of stable isotopes of hydrogen can reveal the movements of animals such as fish and birds (Hobson and Wassenaar, 2008). This tool, which is being widely used in ecology, has been used on the Lepidoptera *D. plexippus* (Hobson *et al.*, 1999) and *Helicoverpa armigera* (Menozzi *et al.*, 2007) to determine the geographical origin of migratory adults.

Detection of plant-specific compounds in adult tissues is an excellent indicator of a larval feeding source. Orth *et al.* (2007) designed a test to detect gossypol, a cotton-specific alkaloid, as well as cotinine, a metabolite of nicotine, in the adipose tissues of *Heliothis virescens* moths. Coupled with the analysis of the carbon isotopic composition, the analysis of ingested gossypol gave better understanding of the trophic origin of *Helicoverpa zea* adults collected in pheromone traps (Head *et al.*, 2010).

Another technique for decoding the migration and geographical origin of an insect is **bacterial molecular markers**. This technique has been used to determine the geographic origin of fish (Le Nguyen, 2008a) and collected fruits (Le Nguyen, 2008b). For insects, analysis of bacterial communities is still in its infancy. The advantage is that the technique is applicable to every insect and does not require any background knowledge on the bacterial flora hosted by the target insect. The analysis of the bacterial flora on or within an insect using molecular markers to locate the geographical origin of the insect is an innovative approach. Insects harbour endosymbiotic bacteria such as *Buchnera* and *Wolbachia*, or Enterobacteriaceae such as *Citrobacter freundii* and *Klebsiella proteus* (Carletto *et al.*, 2008). There may be other bacteria hosted by the insect that might be specific to a given location. The technique most commonly used for insects is polymorphism analysis of 16S rDNA V3 region of bacterial communities by PCR (polymerase chain reaction) using the technique DGGE (denaturing gradient gel electrophoresis) by means of primers common to many bacteria. This technique has been used to identify the habitats of *Aedes albopictus* and *Ae. aegypti* (Zouache *et al.*, 2010), *Anopheles stephensi* (Rani *et al.*, 2009) and the carabid *Poecilus chalcites* (Lehman *et al.*, 2009).

Some rice pests, such as *Chilo zacconius* and AfRGM, can have alternative host plants (grasses, sorghum, wild rice). These tools can be useful to know their trophic and geographic origin with the aim of better pest control.

New Approaches to Characterization of Rice Pest Constraints and Quantification of Yield Losses

An individual crop stand is usually not exposed to a single organism, but rather to multiple harmful ones (pathogens, insect pests, weeds, etc.). It is then more relevant to consider injury profiles rather than individual injuries. In order to characterize patterns of rice cropping practices and injuries, key concepts and approaches have been developed in tropical Asia based on 'injury profiles' and 'production situations' (Savary *et al.*, 2000a). 'Injury profiles' are defined as a given combination of injury levels caused by a range of pests during a crop cycle, while a 'production situation' is considered as the physical, biological, social and economic context in which agricultural production takes place. Characterization of injury profiles in relation to production situations has the potential for developing pest management strategies that can be adapted throughout the region rather than being site-specific. Some injuries or their combinations have a stronger or weaker yield-reducing effect depending on the level of attainable yield, i.e. the yield performance of a crop that has not been exposed to yield-reducing factors, especially pests (Savary *et al.*, 2000b). While the information gathered pertains to the individual field, analysis of the data should aim at conclusions that have relevance to the region. The fact that a particular injury prevails in nearly all sites or seasons is not necessarily an indication of its importance. By contrast, some injuries may occur sporadically and cause considerable yield reductions. A combination of information on occurrences of injuries (through surveys) and on experimental measurement of yield losses they may cause is necessary to assess the importance of a given injury (Savary *et al.*, 2000a). Such a combination provided quantitative background to set priorities for rice pest management in Asia (Savary *et al.*, 2000b). This is a powerful tool to analyse yield losses at large scales. Survey data provide information on the occurrence of pests and diseases, while experiments quantitatively highlight their impact in terms of yield loss (Savary *et al.*, 2006). For example, RICEPEST, a simulation model of rice yield losses, enables the simultaneous handling of production situations and injury profiles, as well as the modelling of management strategies (Willocquet *et al.*, 2002). These concepts, approaches and models could be adapted to rice cropping under African conditions.

Conclusions

Insect pests, diseases and weeds inflict enormous losses to rice production in Africa. If rice production is to keep pace with increasing demand, effective and sustainable management strategies are urgently needed to tackle these important biotic constraints. Sustainable and efficient pest management practices require scientific expertise to develop, through research, the various IPM strategies (insect resistant or tolerant rice varieties, biological control, crop management practices and substitution of inorganic pesticides with biopesticides) and to effectively disseminate these technologies to farmers for adoption. Marker-assisted selection and other biotechnological techniques are providing new ways of manipulating plant resistance to insect pests. Efforts by AfricaRice to develop the interspecific hybrid progenies combining the hardiness of African *Oryza glaberrima* with the high productivity of Asian *Oryza sativa*, using embryo-rescue and double-haploidy, have paved the way for improving the resistance of rice varieties to stresses such as rice stem borers and other insect pests. Biological control shows great promise for regulating damaging populations of rice-feeding insects in Africa. For example, there is an abundance and diversity of natural enemies (parasitoids, predators and pathogens) in West African rice ecosystems and natural biological control is playing a major role in managing pests. Thus, every effort should be made to conserve and enhance the activities of natural enemies. High levels of natural biological control seen in Africa may be due to the low use of natural-enemy-destroying pesticides, where the incidence of pest resurgence, which is currently in the crisis stage in Asian rice, has not been experienced.

Some important available natural enemies (e.g. *Platygaster diplosisae* and *Aprostocetus procerae* reported to be effective against AfRGM, *Cotesia sesamiae* and *Xanthopimpla stemmator* against rice stem borers, *Metarhizium anisopliae* against termites) and plant products (such as azadirachtin [neem] and nicotine against stem borers and termites) have not been packaged commercially for use by smallholder farmers. There are no commercial biocontrol laboratories in Africa, whereas over 400 biocontrol laboratories exist in India to cater for the location-specific needs of farmers. There is a need to develop private–public partnerships with biological control/biopesticide producers for the development, scaling up and commercialization of technologies.

Rice IPM development in Africa is confronted by many challenges, such as national government policies that result in a lack of trained rice scientists to develop IPM components and the absence of effective information- and technology-dissemination programmes. Consequently, the IPM packages that have been developed are reaching only a few farmers and are having little impact at the farm level. The adoption of IPM technologies is low in Africa as a result of socio-economic, institutional and policy constraints. The lack of appropriate institutional technology-transfer mechanisms is a critical impediment to increased application of IPM. It has become increasingly evident that future agricultural growth hinges on African smallholder farmers, who must be knowledgeable in all aspects of rice production, including the management of pests. It is thus important that agricultural technology dissemination activities be upgraded and receive high priority in the national budgets of African countries, and not be dependent on external resources, if we are to reduce rural poverty and achieve food security and sustainable rural livelihoods in Africa.

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