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# Advances in insect pest management technologies of agricultural crops: an integrated approach

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ABSTRACT

The paper presents a critique of advances and applications of technologies in the management of insect pests of agricultural crops. The management technologies discussed include; biological control, host resistance, use of genetic modification of crops, traditional pesticide materials, and legislative control. Further, the implications of each management technology to the welfare of the communities and the ecosystems in general are discussed. These are technologies which could form components in the Integrated Pest Management (IPM) approach to combating insect pests of crops. It is revealed from the analysis that when wisely employed, developments in pest management play a great role in increasing food security, environmental conservation, reduction of poverty and ultimately improving the peoples' quality of life.

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## Introduction

Insect pest infestations cause greater losses of agricultural products in developing countries thereby hindering agricultural development resulting in food insecurity. For crops in storage, insect infestations cause great losses given their low Economic Injury Levels (EIL) (FAO. 1996). In controlling crop losses the major thrusts reported in the advances of pest management mainly focus on field crops in farms amongst rural communities (Abate *et al.*, 2000; Chapman, 2000; Rugumamu, 2005). At international border posts of many countries, government agencies are also reported to enforce plant quarantine regulations as pest control measures.

In principle pest control measures have to be extended to various ecosystems and integrated into an operational system, be it large or small in scale, if they are to be effectively applied. The major objective of this paper is to present and critically analyse major advances in pest management technologies and their application in order to recommend wise uses in an integrated approach. Development and applications of technologies in the management of insect pests forms a sound basis for a better understanding of their contribution to the Integrated Pest Management (IPM) approach. The current thrust in pest management is on IPM, a domain of extension science referring to a management system that combines all economically, technically and ecologically applicable technologies to keep pest populations below those causing economic injury while minimizing unwanted side effects of the applied measures (Hill, 1987; Benbrook, 1996; Matteson, 2000; Neuenschwander *et al.*, 2003).

Timely application of control measures following fluctuations of pest populations in relation to their general equilibrium position, economic threshold and economic injury levels was illustrated by Hill (1987). Various scientific and technological discoveries and developments over time have been contributing vastly in managing insect pests and vectors of crop diseases particularly in farm fields at varying degrees. In this regard Chapman (2000) outlined landmark events in insect-related basic biology and applied entomology of the twentieth century in agricultural development (Table 1). The technological discoveries were in line with efforts to attain food security.

***Table 1: Major advances in insect pest management over time***

| Time | Development in pest control |
|---|---|
| 1920s – 1930s | Biological control campaign against prickly pear in Australia |
| 1940 | DDT first synthetic insecticide used |
| 1950s -200…. | Varietal resistance to insect pests broadly classified by Painter (1951) and Russell (1978).<br>Silent spring published.<br>Synthetic pyrethroids based on structure/activity relations.<br>Sterile male technique eliminates screw worm from most of North America.<br>IPM concepts established.<br>Transgenic cotton containing *Bacillus thuringiennsis* toxin commercially available.<br>More GMO crops developed (OFAB 2007-2008) |

Food security is conceived to be a situation in which people do not live in hunger or fear of starvation (FAO 2003). Around 852 million men, women and children worldwide are chronically hungry due to extreme poverty, while up to 2 billion people are intermittently food insecure due to varying degrees of poverty (FAO, 2003). According to FAO (1996), food security exists when all people, at all times, have access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. FAO is currently carrying out a Special Programme for Food Security (SPFS) assisting some governments replicate successful food security practices on a national scale. The SPFS also encourages investment in rural infrastructure, off-farm income generation, urban agriculture and safety nets. Noting that a household is the lowest level of community organization in Africa the above conception merits high consideration in this regard.

In Tanzania for instance, the overall policy in the food and agriculture sector is to achieve self-sufficiency in food and food security through increased food production as well as increased commodities for export and hence reduction of poverty (URT, 2005). It places emphasis on, among other things, food production and underscores the need to utilize science and technology in order to develop the agricultural sector and aiming at the maximization of productivity through introduction of improved scientific and technological initiatives in the use of appropriate seed varieties and better methods of food and crop processing, preservation and storage.

Scientific and technological initiatives generally encompass their relationship in pest management to produce desirable approach to solve problems of pest infestations in crops (Hill 1987). This paper reviews the different integrated pest management (IPM) strategies available and proposes a way forward in employing search practices under African agriculture.

## Insect Pest Infestations of Crops

The most important step towards controlling insects and minimizing losses is the correct identification and application of proven control measures. Bhatia (1976) advanced that the harvested crop is the net result of all prior production efforts and any subsequent losses incurred are absolute losses with no possibilities for compensatory action. It is imperative therefore, to develop effective management technologies against both field and stored pests especially in systems where rural livelihoods are based on agriculture. Cereals, pulses and root crops are commonly grown in almost all ecosystems in African. Maize, *Zea mays*, for example, is a staple food and cash crop grown and stored in almost all the regions of the tropics (Abate *et al.*, 2000). The recent technological development including the introduction of many new maize varieties to farmers have triggered the crop's propagation into highlands and mid-altitudes. In the early 1980s problems associated with maize and cassava production in some East and West African countries for instance, have been aggravated by the damage caused by the Larger Grain Borer (LGB), *Prostephanus truncatus* (Golob, 1988; Rugumamu, 2003).

Prevailing relative increases in crop yields have been facilitated partly by scientific and technological advances in breeding for genotypes of greater resistance to field pests and diseases and partly by application of modern farm practices and implements. However, Abate *et al.* (2000) noted that greater storage losses to insect pests may also result from some of the improved technologies. Some new crop varieties, however, are mostly susceptible to insects in farms and in storage. Arnason and Gale (1992); Rugumamu (2005) later demonstrated that some grain physical and chemical/nutritional characteristics incorporated during breeding could result into its susceptibility to insects in storage. It may be cautioned that whereas some measures have proved successful some other relief forms perpetuate famine. Following from the above, users should be cautioned given that some technological development efforts knowingly or unknowingly could aggravate socio-economic problems.

## Application of Industrial Chemical Pesticides

Historically, when synthetic chemical pesticides mostly the organochlorine group came into widespread use in the 1940s, they promised an era of abundant agricultural yields. However, Carson (1962), and Hill (1987) have their thoughts shared with Edward Groth who in his foreword in the book "Pest Management at the Crossroads" by Benbrook (1996) noted that it didn't take long to recognize that these miracle chemicals had costs and risks as well as benefits. The chemicals were highly toxic to most insects with control levels of 98 – 99% or even higher, broad spectrum and persistent thereby becoming unfriendly to the environment. Currently, control of insect pests is achieved by mainly the application of industrial pesticides (Kilimo/GTZ 1996; Golob, 2002) even though this strategy has several shortcomings, economically, technically and ecologically.

Insect Growth Regulators (IGR) and Juvenile Hormones (JH) are also included in the pesticides groups which are specific and have minimal disruptive effects on the environment. JH if applied to full-grown larva disturbs the process of metamorphosis and the insect dies as a deformed pupa/ adult (Chapman, 2000). Nonetheless IGRs are not as specific as JH but they interfere with cuticle formation at the time of ecdysis and hence killing the moulting larva.

Field evidence shows that, only rarely does industrial chemical application kill all the pests, and that the few which survive during successive generations develop slight genetic differences from the main stock of the insect species which become biotypes, usually giving serious problems as they develop resistance to the chemicals (Hill, 1987; Golob, 2002). Incidentally, Benbrook (1996) reports that genetic resistance to pesticides in pest populations and outbreaks of new pest problems when broad-spectrum insecticides remove natural checks and balances, have led to escalating dependence on pesticide use with no real decline in pest-induced crop losses. It is further urged that if not well monitored, continued additions of chemicals result into general ecological disturbance as well as causing residue in ecosystems. Edge and Schauber (2000); Fischel, (2005) report that toxicological experiments have showed that pesticides could cause cancer and birth defects awnd damage or interfere with nervous, endocrine, reproductive and immune systems in mammals.

Socioeconomic status in Africa has made the use of synthetic pesticides the lowest among all regions of the world (Sangodoyin, 1993). They are very expensive and most governments have reduced subsidy to farm inputs especially to pesticides (Arthur, 1996). Further, misuse of chemicals during application, non-availability when most required and incorrect timing of treatment given the low EIL of most crop pests, aggravate chemical control problems. In this regard, Benbrook (1996) lamented that many chemical pesticides cost comparatively little to use, in large part, because the risks and social costs associated with their use are not included in their price.

To this end, in Tanzania for example, a full-fledged Tropical Pesticides Research Institute (TPRI) was established in the 1970s with a purpose of institutionalizing a system for both research and regulation of pesticides in use in the country. It supervises and regulates the manufacturing, importation, distribution, sale and use of pesticides and to administer the regulations made under the Act establishing it (Kilimo/ GTZ 1996; Nakora, 2005). As argued by Carson (1962); Dendy *et al.*, (1991); Hodges (1994) and Arthur (1996), any rational decision on the use of chemical pesticides in pest management must be based on the cost–benefit analysis and environmental impact considerations. It is against this background that strategies for minimizing expenditure in pesticide use will be a factor to sufficient food supply, reinvesting of finances obtained from other sectors and last to the reduction of health hazards of the pesticides which in some cases are unauthentic.

## Biological Control of Insect Pests

Another important component of IPM in agriculture is biological control which, in a broad sense, includes all types of control involving the use of natural organisms which have a long history of evolution (Rees, 1988; Dick, 1990; Scholler *et al.*, 1997; van Emden, 1999; Neuenschwander *et al*., 2003). Biological control is the reduction of pest populations by natural enemies and typically involves an active human role. The enemies kill or debilitate their host and are relatively specific to certain insect groups. Conservation, classical biological control, and augmentation are three basic types of biological control strategies. The main attractions of this control are that it reduces the necessity of using chemical poisons and in its most successful cases gives long-term control from one introduction (van Emden, 1999). In this regard, biointensive IPM is advocated in agricultural systems. Benbrook (1996), however, emphasized that expanded reliance on biontensive IPM could work when far-sighted policies are in place from both government and private sector. Biological control is most effective against pests of exotic crops which often do not have their full complement of natural enemies in the introduced locality. On rare occasions, a local predator or parasite will successfully control an introduced pest.

*Terestriosoma nigrescens* Lewis, a predator was released and established as a natural enemy for the control of P. truncatus in some African countries including Kenya (Giles *et al.*, 1996; Meikle *et al.*, 2002; Holst and Meikle, 2003). However, initial studies on the impacts of this entomophagous insect to control the target insect have concentrated on observing its spread and the effects on loss reduction in experimental maize stores (Rees, 1988; Borgemeister, 2001). It may not be surprising now, however, if T. nigrescens has already been established in more African countries. Entomopathogenic fungi, Beauveris spp was reported to infect P. truncatus, S. zeamais, Tribolium spp, Carpophilus spp. in Kenya (Oduor *et al.*, 2000). Scholler *et al.*, (1997) report that protection by natural enemies should be taken much early during storage given the low EIL of infested stored crops.

A major limitation to this technology is that most predators are not host-specific and hence not particularly confined to any specific host (1988; Bottrell *et al.*, 1998). Further, the enemy requires longer periods to be effective. It is thus advanced that ecological research on specificity of agents to the pests may allow a wide introduction of more predators; pathogens; parasites and parasitoids of common insect pests as biological control measures. It is hence important to preserve natural enemies whenever possible and to facilitate their identification.

Male Sterilization Technique (MST) and use of pheromones are other biological methods of insect pest control. Male sterilization was first proposed in 1955 (Klassen and Curtis, 2005) and is effective when applied to restricted populations and also in species where females mate only once and unable to distinguish or discriminate against sterilized males. Recently, recombinant genetic technology has been applied to SIT and transgenic (GM) sterile males have been the focus of extensive research efforts (Morrison *et al*., 2010). Attractant pheromones are used in pest population monitoring so that control measures may then be exercised if necessary with precise timing. It should be appreciated moreover that aggregation pheromones could be employed in insect pest behavioural control where insects are induced to fly to inappropriate hosts.

***Genetic Modification of Crops for Pest Resistance:*** Over the last two decades major advances in the field of agriculture biotechnology and in particular recombinant DNA technology have enabled the production of crops that are insect pest resistant due to expression insecticidal proteins. The most studied and widely applied insecticidal protein in crops is the Bt toxin which is produced by the bacterium *Bacillus thirungiensis* (Cranshaw, 2003). The bacterium forms crystals of proteinaceous insecticidal δ-endotoxins (called crystal proteins or Cry proteins), which are encoded by cry genes. Using the recombinant DNA technology (rDNA) cry genes have been transferred into crops such maize (Bt maize) and cotton (Bt Cotton). It is reported that Cry toxins are effective against some insect species of the orders Lepidoptera, Diptera, Coleoptera, Hymenoptera and also Nematodes. Proponents of the rDNA technology (GM technology) list the following among benefits of using Bt crops; (i) reduced environmental impacts from pesticides, (ii) increased opportunity for beneficial insects (iii), Bt proteins will not kill beneficial insects, (iv) reduced pesticide exposure to farm workers and non-target organisms (Cranshaw, 2003; Federici, 2007 NewAfrican, 2009). Alongside the benefits the following potential risks are reported (i) invasiveness (ii) development of resistance to Bt – (iii) Cross-contamination of genes-whereby genes from GM crops can flow into related native species (Paalberg, 2006; Yarobe and Quicoy, 2004; Hosea *et al*., 2005).

Successful biological control are commonly permanent and also self-propagating and self-perpetuating and hence self-adjusting (Scholler *et al*., 1997; van Emden, 1999). Despite the importance the control, there can arise shortcomings, for example, most predators used to attack pests and vectors are not host-specific hence could attack beneficial organisms (van Emden, 1999). The genetically manipulated parasites or pathogens also when misused may result into undesirable consequences. In this regard, concern is usually expressed over the dual-use nature of biological agents due to the ease with which they could be directed to antagonistic use for biological warfare against crops and animals including humans.

## Host plant resistance in pest management

Resistant crop varieties are an aspect of pest control of great importance whereby plant breeding is a very specialized subject in its own rights and hence it is dealt with separately, not just within biological control (Hill, 1987). Varietal resistance to pests was broadly classified by Painter (1951) into three categories which are non-preference, antibiosis and tolerance. Hill (1987) further noted that, non-preference and/or antibiosis types of resistance have adverse effect on the bionomics of the pest by causing its death or decreasing the rate of its development and reproduction. Until recently, it was commonly believed that resistance of a crop variety could only be effective to a growing plant in the field.

It is emphasized by Bosque-Perez and Schulthess (1998) that host-plant resistance as a pest control method is environmentally safe, economically acceptable to farmers and most compatible with other components in IPM initiatives. Further, Bhatia (1976); Rugumamu (2006) reported resistant varieties as one of biological components in the IPM which could significantly reduce losses of agricultural crops. As a contribution to this control initiative, varying levels of resistance of some maize varieties to *P. truncatus* and *S. zeamais* were determined in the laboratory and in the farm stores studies by, among others Derera *et al.*, (2001); Rugumamu (2005), the findings indicate significant differences among the maize varieties tested according to statistical methods by Fowler *et al.* (1999) and Sokal and Rohlf (1998). These results did shed light to the importance of pursuing a search on resistance levels of many more maize varieties developed and grown by farmers in order to identify resistant varieties to the common insect pests.

Under subsistence food production, however, it has been noted that the availability of resistant varieties has, to some extent, failed to achieve a major impact (Mohamed and Teri, 1989; Hillocks, 1995; Abate *et al.*, 2000). This is reported to be a result of, first, local varieties were probably most resistant due to co-evolution and selection by farmers over many years; second, farmers in unstable and variable environments plant mixtures of varieties that are more able to respond to erratic rainfall, fluctuations in soil conditions and to pest and disease problems; and, third, breeding physical characteristics in varieties may have a detrimental effect on either palatability or cooking time or both and therefore unacceptable to farmers. However, given the potency of resistant varieties to insect pest control, it is recommended that deliberate effort by policy markers be directed towards dissemination of the knowledge to stakeholders, the smallholder farmers in order to enhance food security and poverty reduction.

Among the various methodologies currently used for assessing and determining varying resistance of crop varieties to insect pests are presented by Dobie (1977) and Rugumamu, (2006). These innovations are intended to positively contribute to the welfare by reducing food insecurity. Different crop varieties are produced in various breeding programmes and it is now known that some crop physical and chemical/nutritional characteristics could affect their susceptibility to insect attack and damage (Chapman, 2000; Aluja *et al.*, 2001). The methodologies for screening crops for resistance are in line with the need to monitor the possible misuse of breeding technologies which could lead to mass production and distribution of varieties with poor qualities leading to losses of higher magnitude.

## Application of Traditional Pesticides

Farmers' ingenuity in rural areas has enabled them, through time, to apply indigenous pesticide materials to protect crops (Rugumamu and Mtumbuka, 1998; Rutatora and Matee 2001). It is advanced by UNESCO (2002) that pest management practices in traditional African agriculture have a built-in mechanism in the overall crop production systems. It is acknowledged by Elwell and Maas (1996); Rutatora and Mattee (2001) among others, that the majority of smallholder farmers in most African countries employ only Indigenous Knowledge Systems (IKS) in their agricultural production processes.

It is reported that due to increased applications of chemical insecticides by some communities over the last few decades, some traditional methods of protecting stored seeds and food crops are being forgotten to the extent that some farmers are now unaware that traditional low-cost alternatives do exist. It is however cautioned by Golob (1988); Golob and Hanks (1990) that rampant claims of the effectiveness of traditional grain protectants need further research to establish their efficacy and full potential as well as any possible toxicological hazards associated with their use. The current emphasis upon IPM is, in effect, a reassertion of the need to put traditional good husbandry practices in place as a fundamental component of pest control (Haines, 1999; Abate *et al.*, 2000).

## Legislative Control

Legislative measures of pest control such as restrictions of movement of produce at entry points at international borders are usually enforced by state agencies as a pest control strategy (Golob, 1988). The programme for example is practiced in Tanzania and is adaptable as a model for other countries in Africa to prevent the exotic insect pest, *P. trucatus* infestations from spreading to neighbouring countries (FAO, 2003). The strategy, however, is reported to work with limited success given free movement of people in this global village.

## Way Forward

Based on the above analysis, it is concluded that development and applications of science and technology in insect pest management cannot be overemphasized. It is evident that when wisely used control strategies form components of IPM and the main advantages of various insect pest management technologies have been highlighted for increased agricultural production. It is, however recommended that extensive and in-depth multidisplinary research is essential in order to eliminate possible dual uses.

Although development of components of IPM was recommended over thirty years ago the thrust was on the effective uses of various control measures in farm field environments (Hill, 1987). Given the existing situation regarding insect infestations Adda *et al*., (2002) call for research in the field of IPM that will reduce reliance on only chemical. It is noted, however, that IPM strategies are specific to each pest, climatic conditions and other local factors. It is against this background that IPM requires multidisciplinary research, often years of it to develop successful IPM methods and unlike chemicals, once developed; IPM strategies cannot be packed and sold everywhere.

On another front, it is advanced here that instead of IPM "technology transfer" through training and visit (T&V) system, the "farmer first" paradigm of participatory non-formal education led by IPM extensionists in farmer field schools followed by community IPM activities is highly recommended. This approach emphasizes farmer-training-farmer and research by farmers (Meikle *et al.*, 2002; Scoones and Thompson, 2009). In essence, with well synergized IPM components, it would result in a total well being of crops and the ecosystem in which they grow. When scientific and technological advances are wisely applied in agricultural production systems in accordance with the knowledge on biological conservation, crop pest management and food security will be significantly promoted.

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