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Assessing the long-term welfare effects of the biological control of cereal stemborer pests in East and Southern Africa: Evidence from Kenya, Mozambique and Zambia

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ABSTRACT

The International Centre of Insect Physiology and Ecology (*icipe*), undertook a biological control (BC) programme for control of stemborers from 1993 to 2008, to reduce cereal yield losses due to stemborer attack in East and Southern Africa. The programme released four biological control agents—the larval parasitoids *Cotesia flavipes* and *Cotesia sesamiae*, the egg parasitoid *Telenomus isis* and the pupal parasitoid *Xanthopimpla stemmator*—to control the economically important stemborer pests *Busseola fusca*, *Chilo partellus* and *Sesamia calamistis*. Two of the natural enemies that were released got established and spread to many localities in the region. This study adopted the economic surplus model based on production, market and GIS data to evaluate the economic benefits and cost-effectiveness of the programme in three countries—Kenya, Mozambique and Zambia. Findings show that the biological control intervention has contributed to an aggregate monetary surplus of US$ 1.4 billion to the economies of the three countries with 84% from maize production and the remaining 16% from sorghum production. The net present value over the twenty years period was estimated at US$ 272 million for both crops and ranged from US$ 142 million for Kenya to US$ 39 million for Zambia. The attractive internal rate of return (IRR) of 67% compared to the considered discount rate of 10%, as well as the estimated benefit–cost ratio (BCR) of 33:1, illustrate the efficiency of investment in the BC research and intervention. The estimated number of people lifted out of poverty through the BC-programme was on average 57,400 persons (consumers and producers) per year in Kenya, 44,120 persons in Mozambique, and 36,170 persons in Zambia, representing an annual average reduction of poor populations, respectively of 0.35, 0.25 and 0.20% in each of the three countries. These findings underscore the need for increased investment in BC research to sustain cereal production and improve poor living conditions.

1. Introduction

In East and Southern Africa (ESA), cereals, especially maize [*Zea mays* L.] and sorghum [*Sorghum bicolor* (L.) Moench] are among the most important field crops that commercial and small-scale farmers grow (Karanja et al., 2003; Taylor, 2003). These food grains are used to a large extent for subsistence and represent an important calorie intake source for poor rural farm families (IITA, 2013); however, biotic and abiotic problems constrain their production. Among the biotic constraints, insect pests represent an important challenge, and lepidopteran stemborers are the major injurious pests that occur when maize and sorghum are cultivated (Kfir et al., 2002; Polaszek, 1998; Songa et al., 2001). Field infestation of stemborers ranges from 30% to 100%, and the resulting yield loss may reach up to 88% (Kfir et al., 2002; Seshu

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Reddy, 1990; Youdeowei, 1989). In Kenya, the estimated yield loss due to stemborers is equivalent to KShs 7.2 billion (US$ 90 million) annually (EPZA, 2005). Odendo et al. (2003) examined the economic value of loss due to stemborers and found that the average loss in maize was 14%, and ranged from 11% in the highlands to 21% in the dry areas. An extrapolation to the Kenyan national production in maize revealed that about 0.44 million tonnes valued at US$ 25–60 million, which is enough to feed 3.5 million people per annum are lost. Other estimates on four seasons of crop loss gave 13.5%, equivalent to quantity loss of 0.4 million tonnes, which is worth US$ 80 million (De Groote et al., 2011), which corroborates the economic importance of stemborer pests.

Integrated pest management (IPM) including chemical and cultural controls was among the management strategies (Polaszek, 1998). However most of them had a lower adoption rate due to constraints associated to their use that make them impracticable and unattractive to farmers (van den Berg et al., 1998). The use of synthetic insecticides is associated with potential threats such as pest resistance, adverse effects on non-target organisms, hazards of pesticide residues, limited success in application, insecticide overuse, and application of insecticide mixtures (van den Berg and Nur, 1998; Varela et al., 2003). Even though insecticides are effective in managing stemborers in commercial agriculture, many resource-poor farmers cannot afford them. Considering these constraints, and the potentially negative impact of chemical control on human health and the environment, biological control is the appropriate method of control. Classical biological control involves introducing an exotic natural enemy, such as a predator or parasitoid, into a new environment where it did not exist (Lazarovitz et al., 2007). Because of its self-perpetuating characteristic and no additional investment, classical biological control (BC) remains an appropriate strategy of pest control for resource-poor farmers (Hajek, 2004; Kipkoech et al., 2009).

Since the early 1990s, the International Centre of Insect Physiology and Ecology (*icipe*) has made important progress in exploring the suitability and effectiveness of pest management using natural enemies. In partnership with national agricultural research systems (NARS) and universities, *icipe* implemented the biological control (BC) of stemborers through different projects by releasing natural enemies in the major maize and sorghum producing areas in East and Southern Africa (Omwega et al., 2006). Following the introduction of natural enemies, post-release surveys and studies were carried out, reporting establishment, acceptable levels of parasitism and decrease in stemborer densities (Bonhof et al., 1997; Cugala and Omwega, 2001; Cugala et al., 2006; Emana et al., 2002; Jiang et al., 2006, 2008; Odendo et al., 2003; Omwega et al., 1997, 2006; Seshu Reddy, 1998; Sohati et al., 2001; Songa et al., 2001; Zhou et al., 2001). Almost all the studies emphasized the first biological control agent that was released, *Cotesia flavipes (Cameron)* and focused on its short-term assessment (10 years after release), but economic assessments on the real social advantage were not carried out. Kipkoech et al. (2006) to some extent assessed the economic advantages of the natural enemies released using cost–benefit analyses based on yield loss reduction and predictions of parasitism levels and pest densities. The latter ex-ante study lacked results from exclusion experiments, which help in strengthening impact evaluations. Moreover, it was limited to the coastal region of Kenya, yet Omwega et al. (2006) had demonstrated the dispersal of the natural enemies to a wider area in East and Southern Africa.

To fill the knowledge gap regarding the long-term advantages of the biological control intervention, this research sought to assess the ex-post impact on social welfare in Kenya, Mozambique and Zambia. The specific objectives of this study were to: (i) estimate the social gain from the BC implementation and its distribution among consumers and producers, (ii) establish the effect of the intervention on reducing poverty, and (iii) determine whether the investment in BC research was socially worthwhile.

2. Background

2.1. Stemborers

Due to their feeding on plants during their larval stage, stemborers cause important physical and economic damage on cereal crops. Studies have revealed the presence and high diversity of stemborer species in East and Southern Africa (Le Ru et al., 2006a,b; Matama-Kauma et al., 2008; Moolman et al., 2014; Ong'amo et al., 2006), but the most economically important species are the crambid *Chilo partellus* (Swinhoe), and the noctuids *Busseola fusca* (Fuller) and *Sesamia calamistis* Hampson (Kfir et al., 2002; Ong'amo et al., 2006). A summary of their main characteristics is presented in Table 1.

2.2. Biological control

2.2.1. Definition and examples of BC implementations

Biological control is recognized as an ecosystem service of immense economic value (Jonsson et al., 2014). According to the International Biological Programme (1964–1974), biological control denotes the use of living organisms in the control of a pest or use of biota to control biota (Simmonds, 1967). DeBach and Rosen (1991) defined biological control as the use of predators, parasitoids, nematodes, and pathogens to maintain the population of a species at a lower density than would occur in their absence. Lazarovitz et al. (2007) defined biological control as managing a pest by deliberate use of living organisms.

Using this principle, many pest management programmes have been implemented. Well-known examples include control of water hyacinth with the release of *Neochetina* species (*Neochetina eichhorniae* (Warner) and *N. bruchi* (Hustache)) in Benin and East Africa (De Groote et al., 2003), control of the cassava mealybug

Table 1
Origin, infested crops, damages and distribution of the most economically important stemborers.

Stemborer	Origin	Crop infested	Damage on crops	Distribution
Chilo partellus (Swinhoe) (Lepidoptera: Crambidae)	Exotic (Accidentally introduced into Africa through Malawi during the 1920s)	Maize, sorghum, rice, sugarcane	Leaf damage, deadheart, direct damage to grain, increase susceptibility to stalk rot and lodging	East and southern Africa in warm and low altitudes
Busseola fusca (Fuller) (Lepidoptera: Noctuidae)	Indigenous to Africa	Maize, sorghum, millet	Feed on stem and leaves	Sub-Saharan Africa, in cool high altitude area in eastern Africa
Sesamia calamistis (Hampson) (Lepidoptera: Noctuidae)	Indigenous to Africa	Maize, sorghum, finger millet, rice, sugarcane	Attack a number of young stems, feed on stem	Sub-Saharan Africa, prevalent in medium and low altitude areas