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Potential of *Lariophagus distinguendus* (Förster) (Hymenoptera: Pteromalidae) to suppress the maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) in bagged and bulk stored maize

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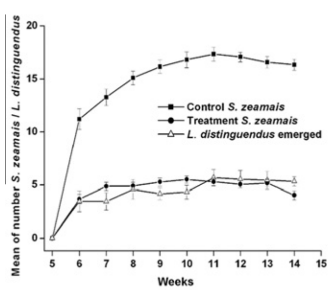
HIGHLIGHTS

- ▶ The parasitoid *Lariophagus distinguendus* suppressed *Sitophilus zeamais* in jute bags and bulk stored maize.
- ▶ The suppression of host in bulk maize was dependent on depths.
- ▶ Offspring of *L. distinguendus* were produced in jute bags and in bulk.
- ▶ The practical potential of using the parasitoid for biological control of *S. zeamais* was established.

GRAPHICAL ABSTRACT



The mean number and Standard deviation of adult *Sitophilus zeamais* and *Lariophagus distinguendus* adult progeny that emerged 6 to 14 weeks after start of oviposition of parental *Sitophilus zeamais* adults, release of *Lariophagus distinguendus* in week 4, beetle larvae exposed at depths from 20 cm–100 cm in grain column; n=3, 34 infested kernels per replicate, 25°C, 65-70% relative humidity.

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ABSTRACT

Grains are often stored in jute bags in developing countries, especially in Africa, as well as in small quantities in bulk. Parasitoids suitable for biological control of stored-product pests should be able to find their hosts in bulk grain or in jute bags over a certain distance in a warehouse containing stacks of bagged grain. The potential of using *Lariophagus distinguendus* for the biological control of *Sitophilus zeamais* was assessed in maize stored in jute bags and bulk grain. The ability of the parasitoid to penetrate the jute cloth and the grain mass and parasitize its host was studied under controlled conditions of 25 ± 1 °C and 65 ± 5% RH. Experiments were carried out in small 5-kg jute bags containing 28 d old *S. zeamais* larvae within infested maize kernels, and in cylinders filled with maize grains and containing caged hosts at different depths. *L. distinguendus* parasitized *S. zeamais* in the jute bags and in the storage cylinders at various depths. In the jute bag experiment, out of the 60 *L. distinguendus* adults released, a mean ± SD of 7.03 ± 1.78% and 6.34 ± 1.01% of the 40 females and of the 20 males released, respectively, entered the jute bags. Significantly, no differences were found between the female and male *L. distinguendus* that entered the bags. Mean reduction of *S. zeamais* in the jute bags by parasitoids was 81%. The parasitic wasps also significantly reduced the emergence of *S. zeamais* in bulk maize. At depths of 20–45 cm from the grain surface, mean reduction of *S. zeamais* was 74%, while from 95 to 100 cm, mean reduction was 34%. When results from depths lower than 50 cm were pooled and compared with pooled data from depths higher than 90 cm, there was a significant reduction in parasitism at depths of more than 90 cm. For depths below 50 cm a mean of 5.3 *L. distinguendus* adult offspring per cage emerged

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compared with a mean of 2.6 at depths of more than 90 cm. These results support the approach to utilize *L. distinguendus* as a component in the integrated control of *S. zeamais* in bagged or bulk stored maize.

1. Introduction

Globally, maize *Zea mays* L. is one of the major cereal crops. It is the second most important cereal crop in the world after wheat, contributing substantially to the total cereal grain production in the world economy as a trade, food, feed, and industrial grain crop (Pingali, 2001). Maize is the most consumed cereal in tropical Africa, however this crop is heavily devastated during storage by insect pests, especially *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). Insects contribute to contamination of food products through the presence of live insects, insect products such as chemical excretions or silk, dead insects and insect body fragments (Phillips and Throne, 2010). Paradoxically, tropical African countries are among the world leaders in food insecurity (Ngamo and Hance, 2007). Post harvest losses continue to undermine the food security and incomes of smallholder farmers in sub-Saharan Africa, threatening livelihoods of vulnerable households. Therefore the fight against hunger and poverty needs to be intensified if this Millennium Development Goal is to be realized in sub-Saharan Africa. Food security could be achieved by increasing agricultural productivity and reducing pre- and post-harvest crop losses. In tropical regions, farmers store 75% of maize after harvest (Kumar, 1991). Post-harvest losses to storage insect pests have been recognized as an increasingly important problem in the tropics (Markham et al., 1994; Abebe et al., 2009). The cosmopolitan maize weevil, *S. zeamais* is the most serious pest of maize in sub-Saharan Africa, where it is causing considerable economic losses of the crop (Obeng-Ofori et al., 1997; Nukenine et al., 2010). Within one maize kernel, several weevil larvae can develop and may cause complete loss of the maize. Damaged grain has reduced nutritional value, low percentage germination, reduced weight and lowered market value (Demissie et al., 2008).

Sustainable and effective methods for reducing *S. zeamais* damage are needed in developing countries to reduce food insecurity. Currently, control of *S. zeamais* populations around the world is primarily dependent upon continued applications of synthetic contact insecticides and fumigants, which are often the most effective treatments for the disinfestations of stored food, feedstuffs and other agricultural commodities from insect infestation. Although effective, their repeated use for decades has disrupted biological control by natural enemies and led to outbreaks of other insect species and sometimes resulted in the development of resistance, toxic residues in food with serious health hazards and pollution of the environment (Park et al., 2003; Obeng-Ofori, 2007; Ogendo et al., 2008; Mondal and Khalequzzaman, 2010). These problems have stimulated interest in the development of alternative strategies such as the use of natural enemies of pests that are less harmful to the consumer and the environment (Press and Mullen, 1992; Schöller et al., 2006).

Lariophagus distinguendus Förster (Hymenoptera, Pteromalidae) is a polyphagous ectoparasitoid parasitising larvae and pre-pupae of several beetle species that infest stored raw agricultural products and goods (Steidle and Schöller, 1997) including, amongst others: the rice weevil *Sitophilus oryzae* (L.) (Cline et al., 1985; Press and Mullen, 1992; Lucas and Riudavets, 2002), the granary weevil *Sitophilus granarius* (L.) (Ghani and Sweetman, 1955; Steidle and Schöller, 2002), the maize weevil *S. zeamais* (Wen and Brower, 1994), the lesser grain borer *Rhyzopertha dominica* (F.) (Ahmed, 1996; Menon et al., 2002), and the cigarrete beetle *Lasioderma serricorne* (F.) (Ahmed and Khatun, 1988). Preference studies have also been carried out with *L. distinguendus* showing that *Sitophilus* spp. are preferred hosts (Steidle and Schöller, 1997; Steidle et al., 2001, 2003).

During oviposition, females sting into infested grains with their ovipositor, paralyze the beetle larva and deposit an egg on it. The hatching parasitoid larva feeds upon the host larva within the infested seed (Hase, 1924; Steidle and Schöller, 1997). Males of *L. distinguendus* that encounter an unmated female perform a characteristic courtship behavior that has been described in detail (van den Assem, 1970). *L. distinguendus* was studied as a biological control agent against the granary weevil, *S. granarius* (L.), in grain stores (Steidle, 1998; Steidle and Schöller, 2002; Hansen and Steenberg, 2007). The ability for long-range host finding of this parasitoid mediated by volatiles has been shown (Steidle and Schöller, 1997).

Host finding is influenced by several factors in a cereal storage ecosystem. These factors range from environmental conditions (Hong and Ryoo, 1991) to host density and food availability (Steidle and Schöller, 2002). *L. distinguendus* is already used commercially in Central Europe to control of *Sitophilus* spp. in grain stores (Schöller, 2010), but not in tropical countries even though *L. distinguendus* was found in tropical Africa, Mexico and Costa Rica (Böye, 1988, 1990; Espinal et al., 1996). Because *L. distinguendus* has been shown to be effective against other *Sitophilus* spp., we evaluated the effectiveness and the development of management programs using this parasitoid for control of *S. zeamais* in bagged and bulk grain in developing countries.

This study investigated the host finding ability of *L. distinguendus* in small jute bags and model storage cylinders containing maize grains and the potential of the ectoparasitoid for biological control of maize weevils attacking durable stored products under tropical maize storage systems.

2. Materials and methods

2.1. Culturing of insects

Both insects were cultured in the laboratory maintained at a constant temperature of 25 ± 1 °C, 65 ± 5% relative humidity, and a photoperiod of 16 h:8 h (L:D). Adults of *S. zeamais* were taken from the permanent stock culture of the Institute for Ecochemistry, Plant Analysis and Stored Product Protection, Berlin, Germany. The strain of *S. zeamais* used is known to have been collected in a grain store in Berlin, Germany, in 1968 and it has been kept under laboratory conditions since then in the institute on maize at 28 °C and 65–70% RH. The "Berlin" strain of *L. distinguendus* was used in this study. This strain originated from dog food infested with *Stegobium paniceum* (L.) from a pantry in Berlin (Steidle and Schöller, 2002). It was subsequently reared on *S. granarius* and was obtained from Biological Consultants Ltd., Berlin, Germany. Maize weevils were reared by placing 50 unsexed adults in 250 ml glass jars containing 150 g of maize grains with a moisture content of 12–13%. The jars were covered with nylon mesh held in place with rubber bands. Parent adult weevils were removed after 14 days and weevils that subsequently emerged were collected and used for the various bioassays. This rearing procedure continued every 7 days in order to obtain weevils of known ages for the different experiments. To rear *L. distinguendus*, 50 newly emerged parasitoids were placed in 1 L glass jars