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Variation, biology and potential management strategies of banana weevil (*Cosmopolite sordidus* Germar) in Tanzania

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Abstract

Banana weevil (*Cosmopolite sordidus* Germar: Coleoptera) is an important insect pest of the genus *Musa* and has been regarded as a major factor causing about 30% of yield loss and farm abandonment in Tanzania. Despite of the agricultural importance, there is limited understanding of the variation and their causes, biology and management strategies of the banana weevil in the country. Thus, this review describes the causes, biology and identifies potential management strategies so that banana growers can not only increase their understanding on the pest-plant relations but also on possible options for managing banana weevil in Tanzania.

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Introduction

Banana weevil (*Cosmopolite sordidus* Germar: Coleoptera) is an important insect pest of the genus *Musa* (abaca, banana, plantain), *Ensette* and manilla hemp (Kiggundu *et al.,* 2007; Gokool *et al.,* 2010; Dahlquist, 2008; Bortoluzzi *et al.,* 2013; Dassou *et al.,* 2015; Hölscher *et al.,* 2016). It is found throughout tropics, subtropics and almost major banana producing regions around the world (de Graaf, 2006; Dahlquist, 2008). This insect pest has been regarded as a major factor in decline and disappearance of East African Highland Banana (EAHB) in Western Tanzania resulted to replacement of annual crops, brewing or dessert bananas (Rukazambuga *et al.,* 1998; Gold *et al.,* 2006; Mgenzi *et al.,* 2006; Kiggundu *et al.,* 2007; Aby *et al.,* 2015a). Banana farmers in Tanzania have been reported to rank it as first key banana insect pest (Nkuba *et al.,* 2015). Also, banana weevil has been attributed to banana yield loss of 30% and farm abandonment at Muleba district, Kagera region of Tanzania (Gold *et al.,* 2002). Other regions in Tanzania reported to be highly infested by banana weevils include Arusha, Kilimanjaro, Mbeya and Morogoro (Bujulu *et al.,* 1983; Gold *et al.,* 2001; Rannestad *et al.,* 2011). Despite of the agricultural importance of banana weevils in the country, there is limited understanding of the biology and management strategies of the banana weevil which is mainly due to challenges related with its distribution systems and high expenses in the banana faming systems in Tanzania (Rannestad *et al.,* 2013). Thus, this review describes the variation and causes, biology and potential management strategies so that banana growers can not only increase their understanding on the pest-plant relations but also on possible options for managing banana weevil in Tanzania.

Causes of weevil variation in the banana farming systems

There are different factors that influence weevil prevalence such as feeding materials, altitude, rainfall distribution, temperature, banana cultivars and volatiles, soil status and types, banana management practices and farming systems (Uronu and Cumming, 1983; Njau *et al.,* 2011; Rannestad *et al.,* 2011; Mwaitulo *et al.,* 2011; Were *et al.,* 2015).

Presence of banana residues or debris, tissues, fresh and decomposing materials normally serve as food sources and oviposition sites for banana weevils (de Graaf *et al.,* 2008; Mwaitulo *et al.,* 2011; Were *et al.,* 2015). They also provide shelters which harbor them (Nwosu, 2011). Mwaitulo *et al.* (2011) and Tinzaara *et al.* (2015) reported that fresh and decomposing banana residues produce kairomones which attracts weevil adults and aggregates them.

Banana weevils are very sensitive to dry environments while adequate moisture conditions encourages their activity and population growth (Gold *et al.,* 2006; Gokool *et al.,* 2010). Although their population present throughout the year but they prevail much during rainy seasons (Njau *et al.,* 2011). In Tanzania, high banana weevil population reported to be observed during rainy season in Kagera region (Uronu and Cumming, 1983).

Development and growth of weevil life cycle of banana weevil is related to temperature (Gold and Messiaen, 2000). Temperature reported to influence weevil activity (Gokool *et al.,* 2010). At a temperature below 12°C, weevil eggs fail to develop, and in combination with altitudes of above 1600 masl, their prevalence is insignificant. Njau *et al.* (2011) explained that a high temperature range of 25-30° C favour growth of the weevil population.

Research studies showed that prevalence of banana weevils has inverse relationship with altitude. At high altitude, their population is unimportant and vice versa (Njau *et al.,* 2011; Wachira *et al.,* 2013). In East Africa, banana weevils are not in high numbers at an attitude beyond 1500 meter above sea level (Njau *et al.,* 2011). Higher weevil damage were observed on local matooke banana types produced in regions with altitudes range of 1000-1200 masl than to exotic cultivars produced in regions with altitudes beyond 1500 masl damage (Tushemereirwe *et al.,* 2001).

Some banana systems reported to influence weevil population while others not (Wortmann and Sengooba, 1993; McIntyre *et al.,* 2001; Zake, 2015; Rukazambuga *et al.,* 2002; de Oliveira *et al.,* 2017).

McIntyre *et al.* (2001) reported that weevil population to banana plants were not affected by the three leguminous crops *Canavalia ensiformis, Mucuna pruriens and Tephrosia vogelii* when intercropped with banana in Uganda. In Tanzania, the banana-bean farming system did not reduce the weevil population in banana (Gold *et al.*, 1998). Ouma (2009) reviewed that weevil damage and infestations in banana plantation monocultures is more or less similar as in the banana-beans system.

Banana, coffee and hot pepper (*Capsicum sp.)* farming systems reported to have suppress weevil population in Mpigi district of central Uganda (Zake, 2015). Also, Ouma (2009) reviewed that banana-millet farming suppressed the weevil population. A study by Rukazambuga *et al.* (2002) in Uganda reported that banana-finger millet (*Eleusine corocana*) system diminished the weevil population but contributed to banana stress and stunting due to water and nutrient competition.

In Tanzania, trials on effects of banana-sweet potatoes on banana weevil population produced mixed results. In these studies, weevil population was reduced but caused banana stunting due to intercropping competition (Gold *et al.,* 2001). Generally, some banana farming systems were reported to produce mixed effects on both weevil population and banana plants, but there is lack of information which counteract these negative effects. Hence, more studies are needed to establish on how to eliminate the negative effects which affects banana plant physiology.

Biology of banana weevil

Banana weevil is characterized by a K-selected life cycle, low fecundity and slow population growth (Night *et al.,* 2010; Shukla, 2010; Rannestad *et al.,* 2011; Rannestad *et al.,* 2013). Adult female has low oviposition rate of 1-4 eggs per week. It lays egg singly in the cavity mined on the base of the banana plant, corms, crop residues, interleaf sheaths and stems (Night *et al.,* 2010; Dassou *et al.,* 2015; Uzakah *et al.,* 2015). Upon hatching, larvae penetrate into banana corms, pseudostems and true stems (de Graaf, 2006; Kiggundu *et al.,* 2007; Rannestad *et al.,* 2013). The larvae is the main destructive stage which results multiple galleries within banana corms during feeding (Akello *et al.,* 2008; Ocan *et al.,* 2008; Dassou *et al.,* 2015; Hölscher *et al.,* 2016; Maldonado *et al.,* 2016). The banana weevil adults are nocturnally active, sedentary, free living and measure 10-15 mm with fully second wings but rare or never observed to fly (Gold *et al.,* 2006; Dahlquist, 2008; Shukla, 2010; Rannestad *et al.,* 2011). Male secret six-specific detected compounds of aggregation pheromone, which is attractive to both sexes, with sordinin as a main component while female secret sex pheromone (Reddy *et al.,* 2008; Reddy *et al.,* 2009; Uzakah *et al.,* 2015). They are closely related and attracted to the host plants by volatiles, kairomones produced from fresh and decomposing banana materials (Rannestad *et al.,* 2011; Tinzaara *et al.,* 2015). The adult stage is the least destructive stage compared with larval stage, having long life span of up to 6 months, two to four years and feeds on banana debris, rotting banana tissues and sometimes on young suckers (Night *et al.,* 2010; Shukla, 2010; Mwaitulo *et al.,* 2011;Rannestad *et al.,* 2011; Were *et al.,* 2015). Under dry substrates, weevils die within 3-10 days while under soil moisture conditions without food, their survival period is ambiguously reported to be 2-6 and 4-17 months (Gold *et al.,* 2001; de Graaf, 2006). The restricted amount of host plant tissues trigger migration of the most weevils possibly searching for oviposition sites and food sources (Umeh *et al.,* 2010; Rannestad *et al.,* 2011; Rannestad *et al.,* 2013). The weevil growth stages such as eggs, larvae and pupae take place within banana plants and crop debris and usually complete its life cycle in a period of 5-7 weeks under tropical conditions (Gold *et al.,* 2006; Kiggundu *et al.,* 2007; Night *et al.,* 2010; Shukla, 2010; Mwaitulo *et al.,* 2011; Rannestad *et al.,* 2013; Hasyim and Hilman, 2015; Uzakah *et al.,* 2015).

Banana farmers reported to have limited knowledge on weevil biology with variations in their understanding. Some farmers don't recognize it, some fail to correlate weevil life cycle stages and other believe that larvae is destructive than adult and other belive vice versa (Ssennyonga *et al.,* 1998; Okech *et al.,* 2006).

This raise concerns in terms of their management to banana farming systems. To fullfill this, Tanzania extension services required to disseminate avalaible information to banana farmers to creates awareness in terms of its identification, population action threshold (5 adult weevils/trap, de Oliveira *et al.,* (2017), symptoms, damage and management startegies. This can be achieved through diffferent approaches like seminar and demostration studies to creates awareness regarding to the pest.

Species of banana weevil

There exist two known species of banana weevils namely; *Cosmopolites sordidus* Germar 1824 and *Cosmopolites pruinosus* Heller (Zimmerman, 1968a; de Graaf, 2006). *C. sordidus* Germar 1824 has numerous synonyms such as banana beetle, banana corm borer, banana root borer, banana weevil, black banana borer, rhizome weevil, plantain black weevil and many common names.

The name "banana root borer" raise confusion due to neither the larvae nor the adults attacks banana roots (de Graaf, 2006). *C. pruinosus* Heller is an important pest and has been considered to be a banana secondary pest in some countries such in Borneo, the Caroline Islands, Micronesia and Philippines (Zimmerman, 1968a; Zimmerman, 1968b). These two banana weevils have a very similar morphology with their distinctive features founded in the nature of pruinosity on the dorsum and the elytral striae (Zimmerman 1968; de Graaf, 2006). Although banana weevil *C. sordidus* reported to be an insect pest attacking banana in some regions of Tanzania, but still there is limited information on its prevalence and distribution across different banana farming systems in Tanzania. More studies are recommended to gain knowledge on the status of this destructive insect pest in different banana farming systems of Tanzania.

Symptoms and their effects on banana plants

The banana weevil is monophagous with its host range restricted to genera *Musa* and *Ensette* (Gold *et al.,* 2006; Mwaitulo *et al.,* 2011). It attacks all banana plant varieties and at all growth stages (Gold *et al.,* 2006; Reddy *et al.,* 2008; Reddy *et al.,* 2009). Its corm damage interferes with root initiation and development, water and nutrient uptake (Akello *et al.,* 2008; Night *et al.,* 2010; Maldonado *et al.,* 2016). The infested plants exhibit symptoms of leaf chlorosis, reduced sucker vigour and number, weak plants, low fruit bunch weight, premature plant death, stunted growth and delayed flowering and fruit maturation (Hayim *et al.,* 2009; Njau *et al.,* 2011; Rannestad *et al.,* 2013). Serious weevil damage causes toppling and snapping of the pseudostems at the base, particularly during windstorms and plant death (Night *et al.,* 2010; Sadik *et al.,* 2010; Rannestad *et al.,* 2013). Banana weevil is associated with yield losses of up to 100% in severely infested fields and can cause total crop failure (Reddy *et al.,* 2009; Sahayaraj and Kombiah, 2010; Omukoko *et al.,* 2014; Aby *et al.,* 2015a; Tinzaara *et al.,* 2015; Carval *et al.,* 2016; Maldonado *et al.,* 2016). Regarding to the weevil symptoms to be familiar, de Graaf (2006) reviewed that these symptoms are said to be similar with banana root nematodes symptoms**.** In view of the above, research efforts aiming at distinguish weevil symptoms from nematodes symptoms should be undertaken.

Current management strategies

Banana weevils can be managed through different strategies such as biological, chemical, cultural, botanical and host resistance (Sahayaraj and Kombiah, 2010; Nwosu, 2011; Tinzaara *et al.,* 2015; Maldonado *et al.,* 2016).

Biological control

Biological techniques include classical biological control, endemic natural enemies, secondary host association and microbes (Shukla, 2010; Mwaitulo *et al.,* 2011; Fancelli *et al*, 2013; Hasyim and Hilman, 2015). Beneficial insects of myrmicine ants *Tetramorium guineense* Nylander and *Pheidole megacephala* Fabricius have been reported to be effective in banana weevil in in some countries such as Cuba (Hasyim and Hilman, 2015).

Laboratory evaluation carried out by Hasyim and Hilman, (2015) showed promising control potential of two predators staphylinid *Belonochus ferrugatus* (Erichson) and histerid *Plaesius javanus*. The Jepson's beetle, *P. javanus* larvae and adults seemed to cause high mortality rate to weevil eggs and pupae (Hasyim, 2009; Hasyim and Hilman, 2015). Other succesiful control strategies has been achieved by using entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* and Entomopathogenic nematodes (Shukla, 2010; Fancelli *et al*, 2013; Omukoko *et al.,* 2014; Hasyim and Hilman, 2015). In Tanzania, study by Mwaitulo *et al.* (2011) showed that weevil control by using Entomopathogenic nematodes (EPNs) in the genera *Heterorhabditis* and *Steinernema* (Rhabditida) provided promising banana weevil control measure. The approach seemed to be good for sustainable production system and can contribute for agricultural sustainability compared with the chemical control. This approach is believed to be cost-effective to small-scale farmers in terms of purchasing and maintaining them in the field (Fancelli *et al*, 2013; Tinzaara *et al.,* 2015).

However, limited reports are available on wide application under field conditions and evaluation of entomopathogens (biological agent) in the tropical farming system (Sadik *et al.,* 2010; Omukoko *et al.,* 2014). Research studies need to be conducted on myrmicine ants especially *Pheidole megacephala* Fabricius and Entomopathogenic nematodes of genera *Heterorhabditis* and *Steinernema* reported to be available in East Africa (Rhabditida) in banana farming systems (Bonhof *et al.,* 1997; Mwaitulo *et al.,* 2011). These should center on their field performance and distribution systems to the small scale banana farmers forming large proportion of banana industry in East Africa.

Chemical control

Chemical controls include application of insect pesticides such as aldicarb, carbofuran, chlorpyrifos, cyclodiene, dusband, furadan, organophosphates and pirimiphos-ethyl (Aba *et al.,* 2011; Marilene *et al.,* 2013; Bwogi *et al.,* 2014; Carval *et al.,* 2016).

Use of these chemicals can results in high mortality of the banana weevil population and perceived by banana farmers as fast acting, manageable and effective (Aby, 2015; Tinzaara *et al.,* 2015). However in Tanzania, chemical application in banana weevil control is challenged by complex un-described banana distribution patterns in different farming systems and high cost (Bujulu *et al.,* 1983; Rannestad *et al.,* 2013).

Use of chemicals such as dieldrin, endosulphan and fenitrothion against banana weevil infestation in Tanzania has been reported with little success (Bujulu *et al.,* 1983). However, Chemical control is reported to provide short-time solution to the banana weevil problems while its long-time application resulted to development of banana weevil resistance (Gokool *et al.,* 2010; Bortoluzzi *et al.,* 2013; Bwogi *et al.,* 2014; Aby *et al.,* 2015a). Moreover, chemicals are less available, more toxic in terms of human health hazards and environments unfriendly due to destroying non-targeted beneficial natural insects (Sadik *et al.,* 2010; Bwogi *et al.,* 2014; Aby, 2015b; Tinzaara *et al.,* 2015). Sole chemical approach is basically effective due to result high death rate but it has limited information on application combination with other strategies. To reduce chemical applications but maintain their effectiveness, research studies should focus on integration of chemicals and non-chemical strategies to control banana weevils in the country.

Cultural control

Cultural controls involves cleaning planting material, practicing crop sanitation, corm paring, intercropping systems, mulching and pseudostem trapping (Okech *et al.,* 2006; Akello *et al.,* 2008; Dahlquist, 2008; Sahayaraj and Kombiah, 2010; Mwaitulo *et al.,* 2011; Aby *et al.,* 2015a ; Carval *et al*,. 2016). Some banana farmers in Tanzania have been reported to apply these cultural control strategies (Mgenzi *et al.,* 2006). Commonly practiced cultural method include cleaning planting materials involves corm paring and dipping it in hot water of 52-55°C for 15-27 minutes to kill the present eggs and larvae (Gold and Messiaen, 2000; Shukla, 2010).

Tenkouano *et al*, (2006) pointed that sucker sanitation can be achieved through treatment with either hot water at 52°C in 20 minutes or boiling water of 100°C in short time of 30 seconds.

Cultural technique also involves use of good non-infested banana planting materials (tissue culture) in cleaned farms. Materials replanting in the previously infested fields with old corms is strictly not recommended unless destroyed. Rather than using weevil-free planting materials, Tanzanian small-scale farmers are often reported to use the suckers from their neighbor fields which in turn seemed to increase weevil problem (Mwaitulo *et al.,* 2011). Practicing crop sanitation measures involving destroying of infested old corms, pseudostems and crop residues materials after harvesting aiming to remove oviposition sites have also been used (Shukla, 2010; Jallow *et al.,* 2016). It has been accompanied with allowing three months for the weevil population to die out. For instance, the study by Okech *et al.* (2006) reported that high crop sanitation reduced weevil and their damage compared with banana farms of low to moderate crop sanitation. It also contributed to production of larger bunch weights with >20 kg compared to about 12 kg. Although crop sanitation has been reported to be beneficial in different regions, banana farmers in Tanzania reported to practice it less (Mgenzi *et al.,* 2006).

Another important technique that has proved to be effective includes trapping of adults using systematic traps of pseudostem, corm disc (disc on stump/Columbian trap), pheromone (sordinin or cosmolure), cheese, modified roof tile, wedge and inoculated trap (Rannestad *et al.,* 2013; Aby *et al.,* 2015a; Jallow *et al.,* 2016; Queiroz *et al.,* 2017). Pseudostem traps can be treated with chemical like Confidor (imidachloprid), Baythroid (cyfluthrin) and Karate (lambda-cyhalothrin) (Gokool *et al.,* 2010). They are good for monitoring weevil population and can be applied to two weeks before replacing with new ones (Jallow *et al.,* 2016). Pheromone traps have been reported to be far better 5-10 and up to 18 times compared with pseudostem traps in Costa Rica and Uganda respectively (Gokool *et al.,* 2010). Its trapping performance has been reported to be higher during dry reasons than in rain seasons (Jallow *et al.,* 2016).

One other important cultural practice involves the use of mulching techniques. A study by Gold *et al.* (2006b) reported that application of banana mulches as one of crop management practice favor weevil population build-up as they provide organic matters and preserving soil moisture. However, this approach has been reported to be unable to manage banana weevil (Mgenzi *et al.,* 2006; Akello *et al.,* 2008; Sadik *et al.,* 2010; Tinzaara *et al.,* 2015). Cultural control strategies seems to correspond friendly with environmental and human health, but in country, there is limited information especially modified cultural strategies such as inoculated and pheromone (sordinin or cosmolure) traps. Therefore, intensive application of these strategies need to be exploited by farmers and hence extension service agents required to extend outreach programs to them to address the problem.

Botanical control techniques

Several plants such as *Azadrachta indica, Tephrosia vogelii, Tagetes erecta, Phyotolaca dodecandra, Ricinus communis* and *Nicotiana tabacum* have been tested for controlling banan weevil (Sahayaraj and Kombiah, 2010; Shukla, 2010; Bwogi *et al.,* 2014). Neem seed powder (rich in azadrachtin) has been reported to have insecticidal effects and thus to have ability to decrease weevil infestation (Sahayaraj and Kombiah, 2010). A study in Tanzania by Mgenzi *et al.* (2006) pointed out that neem seed powder produced promising results on weevil control. Dipping of young suckers in 20% neem seed solution during planting helped to repel weevil adults and thus reduced oviposition and their attacks (Shukla, 2010). Umeh *et al.* (2010) pointed that neem mulch leaf have insecticidal effects which managed to suppress banana weevil population in plantain and banana in Nigeria. Similarly a study by Bwogi *et al.* (2014) in Masaka and Mpigi districts of Uganda pointed that mixture of extracts from *Tephrosia*, tobacco and *Phytolaca* together with animal urine and ash produced similar positive management effects on banana weevil population in levels similar with synthetic chemicals of Carbofuran and Dusband. Botanical pesticidal plants may provide instant accessible pesticides to the farmer's and hence their promotion should be encouraged.

Host plant resistance

This technique involves using resistant cultivars with detrimental effects on weevil physiology. Its mechanisms include antibiosis, antixenosis (non-preference), corm hardness, host plant tolerance, plant antifeeds, extending larval mortality as well as extending larval development and growth (Kiggundu *et al.,* 2007; Night *et al.,* 2010; Arinaitwe *et al.,* 2015; Valencia *et al.,* 2016). Antibiosis is concerned with plant defense by affecting larval performance negatively by secreting sap and latex, corm hardness, antifeedants, toxic secondary plant substances and nutritional deficiencies and hence result weevil death (Kiggundu *et al.,* 2007). Antixenosis contributes resistant cultivars to deter weevil attacks through non-preference of larval and adult feeding as well as female oviposition. However, antibiosis has been reported to be important to weevil resistance mechanism rather than antixenosis due to cultivar non-discrimination behavior of the female oviposition (Sadik *et al.,* 2010; Night *et al.,* 2010)**.** Nevertheless in Tanzania, the East African Highland banana (the commonest cultivars) have been reported to be highly susceptible to weevil attacks (Night *et al.,* 2010; Sadik *et al.,* 2010; Shukla, 2010). Antibiosis seemed to provide plant self-protection against banana weevil but has less information. More research studies required to be conducted on banana plant secretions mainly toxic secondary plant substances.

Conclusions and research gaps

This review has highlighted the biology of weevils, causes of weevil variation in the banana farming systems and a number of banana weevil management strategies such as biological, chemical, cultural, botanical and host resistance. Of the methods, this review article recommends a combination of all except synthetic chemicals. More sustainably biological and host plant resistance can be the best options, however studies are needed to explore how these options can be developed.

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