Sustainable Control of Taro Beetles via Scoliid Wasps and *Metarhizium anisopliae*

F. O. Faithpraise, J. Idung, C. R. Chatwin, R. C. D. Young, P. Birch, H. Lu

***Abstract*—**Taro Scarab beetles *(Papuana uninodis, Coleoptera: Scarabaeidae)* inflict severe damage on important root crops and plants such as Taro or Cocoyam, yam, sweet potatoes, oil palm and coffee tea plants across Africa and Asia resulting in economic hardship and starvation in some nations. Scoliid wasps and *Metarhizium anisopliae* fungus - bio-control agents; are shown to be able to control the population of Scarab beetle adults and larvae using a newly created simulation model based on non-linear ordinary differential equations that track the populations of the beetle life cycle stages: egg, larva, pupa, adult and the population of the scoliid parasitoid wasps, which attack beetle larvae. In spite of the challenge driven by the longevity of the scarab beetles, the combined effect of the larval wasps and the fungal bio-control agent is able to control and drive down the population of both the adult and the beetle eggs below the environmental carrying capacity within an interval of 120 days, offering the long term prospect of a stable and eco-friendly environment; where the population of scarab beetles is: regulated by parasitoid wasps and beneficial soil saprophytes.

Keywords*—Metarhizium anisopliae*, Scoliid wasps, Sustainable control, Taro beetles, parasitoids.

I. INTRODUCTION

SCARAB beetles are widely distributed across the globe as illustrated by [1]. Some of the well-known beetles from the *Scarabaeidae* family, which are pests are: Japanese beetles, Dung beetles, June beetles, Rose chafers (Australian, European and North American), Rhinoceros beetles, Hercules beetles, Goliath beetles, Sweet potato beetles, Taro beetles (*Papuana uninodis*) [2], [3], [4].

As reported earlier in the background study in our previous work on the partial control of scarab beetles in [5]. Our goal in searching for a lasting solution to the devastating damage from the scarab beetles is an ongoing objective.

II. RELATED WORKS

The most notable research work on the existing bio-control agents for the *Scarabaeidae* family includes the use of: fungal, viral and bacterial pathogens and nematodes. Fungal control vectors include *Beauveria brongniartii* and *Metarhizium anisopliae* [6], [7]. *Baculovirus has* been used against *Oryctes rhinoceros* [8]-[10]. Fungi *Beauveria* spp. has been deployed against scarab grubs [11], [12]. Bacteria *Bacillus thuringiensis* and *Paenibacillus* have been applied against *Papuana uninodis* [13]. Nematodes (*steinernematids* and *heterorhabditids*) have been used against *Scarabaeidae larvae* and adult beetles [14]. The susceptibility of beetles to nematodes was confirmed in [15] and a plant pest detection and recognition system was proposed to validate the identification of the infected pest [16].

All the bio-control agents described above have shown a favorable and successful control ability but have not been adequate to deliver a lasting and permanent solution. To achieve an effective solution a Sustainable Control System which deploys scoliid wasps and the *Metarhizium anisopliae* fungus species, a beneficial soil saprophytes, is proposed.

III. MODEL, MATERIALS, AND METHODOLOGY

To achieve accurate results we have simulated a pest control experiment with the affected crop being Taro, a crop with very high economic value and an important food crop.

The target pest is the scarab beetle. The scarab beetle is chosen because of its destructive nature and its threat to communities that are dependent on root crops. The beetles sporadically attack young plants, tubers, ring bark young tea, cocoa, and coffee plants in the field and bore into seedlings of oil palm and cocoa [17]-[19].

The *Scoliidae* wasps are well known biological control agents as they are employed using different strategies to control the population density of crop pests as illustrated by [20]. They are also known as ground wasps, as they work their way through the soil, digging burrows in order to locate the prey, sting them (beetle larvae) and lay an egg on the paralyzed insect, they cover the burrow on their way out [21]. It has the ability to sting many grubs that never recover from the paralysis; it then lays a single mature egg on a few hosts, which hatch in about three days to continue their life cycle [22]. After hatching, the *Scoliidae* larva feeds on its host for approximately one to two weeks and then spins an underground cocoon [23] from which the adult wasp emerges in an average of about five weeks, the scoliid wasp lays eggs continuously for two months and has a life span of 4-5 months [24]-[26]. *Metarhizium anisopliae* is a fungus, which grows

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naturally in the soil with a long history of control of several insects species including beetles [27], thrips [28], mosquitoes [29] by acting as a parasite. *Metarhizium* species are soil saprophytes, which can be used as a biological control agent to maintain the population of insects; it is frequently found in agricultural fields [30]. The fungi survive better in association with plant roots [31]. Its prospect as a biological control agent is demonstrated for the control of the rhinoceros beetle [9], [32], [33], and it is the active ingredient of 'BIO 1020' and 'Met52'[34], an insecticide for the control of tuber flea beetles.

A. Mode of Operation of the Metarhizium anisopliae Fungus

The *Metarhizium anisopliae* fungus will usually germinate from the soil or from its host and grow a germ tube, which eventually ends in an appressorium. A piercing pin grows under the appressorium, which produces hydrolytic enzymes like proteases, lipases, chitinases, and via mechanical pressure penetrates the outer covering or skin entering into the blood containing body cavity (hemocoel) of the host. The single cells of the fungus, blastospores, bud off from the penetration structure, circulate in the insect hemocoel and multiply, thereby depleting the host nutrients. They also produce toxic compounds that suppress the hosts' immune system, thereby assisting in killing the host. Finally, after the host dies due to mycosis, the fungus will penetrate out of the skin and grow conidiophores, on which environmentally stable aerial conidia are produced. These conidia are passively disseminated into the environment and eventually infect new hosts" [27]. Any insects infected by the fungus species are easily recognized a few days after death, when the fungus grows out of the insects' skin and forms reproductive structures in the form of fungal hyphae that appear white but as conidia form and mature; they often take on a characteristic olive green colour, see Fig. 1. However, depending on the species and strain of *Metarhizium anisopliae* fungus, spores can range across several colours: from white to yellow to brown and green [35].

Fig. 1 Classes of insects affected by *Metarhizium anisopliae* fungal mycosis [27], [36]. The figure illustrates growth of the fungus on the skin of the insects some days after they are killed

The sustainable control concept provides a general opportunity for the control of all classes and species of *Scarabaeid*, as it is based on the interaction between the population of all species of adult Scarab beetles and its life cycle stages and the naturally beneficial insects scoliid parasitoid wasps and *Metarhizium anisopliae* fungus, a soil saprophytes as shown in Fig. 2, which illustrates the life cycle of a scarab beetles and the dynamic interaction between the pest population, the wasps and fungus. The blue arrows indicate the normal state flow of the life cycle of a scarab beetles, it demonstrates how the adult beetles lay their eggs, after a time, the eggs transform to larvae, which pupate and then turn into adult beetles. Once the scoliid wasps lay their eggs in the beetle larvae as indicated by the pink arrow, the reproductive life cycle of the beetles is disrupted as the beetle larvae produce scoliid wasps rather than turning into pupae and then into beetles. The pink arrows in Fig. 2 also show the dual attack of the *Metarhizium anisopliae* fungus on the larvae and the adult stages. After considering the lifecycles of the scarab beetles, the fungus and the parasitoid wasps; a model of the interacting populations was designed by using the following non-linear simultaneous ordinary differential equations. The equations can be interpreted by looking at Fig. 2, which illustrates the population dynamics in the habitat. Equations 1 to 5 provide a dynamic model of the evolving scarab beetle (Taro) life cycle stages, the scoliid wasps and the *Metarhizium anisopliae* fungus per square meter.

$$\frac{dN_b^e}{dt} = \beta_b N_b^h - \varepsilon_b N_b^e - m_b^e N_b^e \tag{1}$$

$$\frac{dN_b^l}{dt} = \varepsilon_b N_b^e - \lambda_b N_b^l - aN_b^l N_{lw}^s - \zeta N_b^l - m_b^l N_b^l \tag{2}$$

$$\frac{dN_{lw}^s}{dt} = \xi a \; N_b^l N_{lw}^s - p_{lm} N_{lw}^s \tag{3}$$

$$\frac{dN_b^p}{dt} = \lambda_b N_b^l - \rho_b N_b^p - m_b^p N_b^p \tag{4}$$

$$\frac{dN_b^h}{dt} = \{\rho_b N_b^p - \tau N_b^h - m_b^h N_b^h\}\left[N_b^h\left(\frac{K_b^h - N_b^h}{K_b^h}\right)\right] \tag{5}$$

where:

$N_b^h, N_b^e, N_b^l, N_b^p$ = Population density of taro beetles: adult, egg, larvae and pupae.

N_{lw}^s = Population density of Scoliid wasps

ζ, τ = *Metarhizium anisopliae* efficiency of killing the pest adult and larvae

K_b^h = Environmental carrying capacity of the adult Taro beetle.

$m_b^h, m_b^e, m_b^l, m_b^p$= taro beetles mortality rate: adult, egg, larvae and pupae respectively.

p_{lm}= Scoliid wasp mortality rate.

ξ= efficiency of turning the pest larva into Scoliid parasitic wasps

a = probability that a parasitoid wasps finds and parasitizes a larva prey

β_b= Number of eggs laid per day from the Taro beetle

ε_b= Fraction of eggs hatching into beetle larvae

λ_b= Fraction of beetle's larvae changing to pupae respectively

ρ_b= Fraction of pupae turning into adult Taro beetle

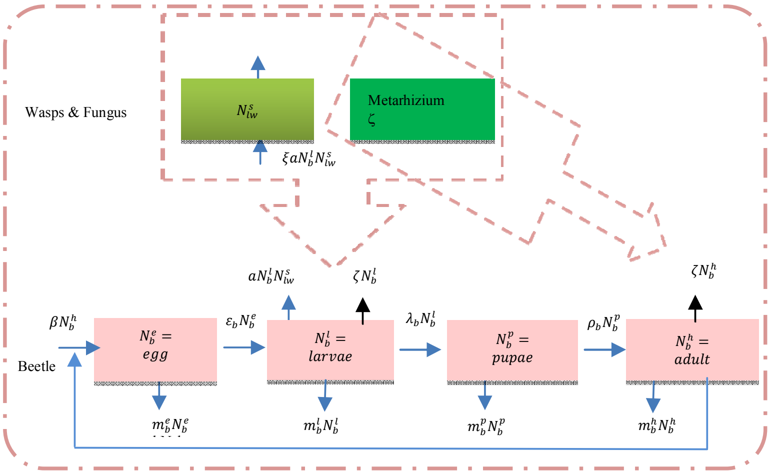


Fig. 2 Population dynamics schematic for wasp-beetle-fungus interaction model describing the detailed activities of how the wasps and fungus exercise control over the beetle population in its habitat

The proposed model consists of five simultaneous non-linear, ordinary differential equations (1) to (5), which are solved using a 4th order Runge–Kutta method as described by [37]-[40] and using the average life span of all the insect life cycle stages and their mortality rates as described in the previous works of [41]. The following results were obtained from the combination of the average life span of all the insects (pest and wasps). The Weibull probability distribution function was used to determine the various mortality rates of the pests and predators; for the detailed procedure refer to [42]. To determine the probability with which the parasitoid wasps locate and parasitize the host, we used a negative binomial distribution as demonstrated in [43].

IV. THE MODEL /EXPERIMENTAL RESULTS

The model of interaction between the Scarab beetles, the fungus and the parasitoid wasps considers an established infestation of Taro beetles with numerous populations of the adult, eggs, larvae and pupae. For this simulation model 5 taro adult beetles were used with an initial population of 60 eggs, 40 larvae and 20 pupae per square metre of taro cultivated field, the population density of the beetles' increases as illustrated in Fig. 3 with great damage to the taro field.

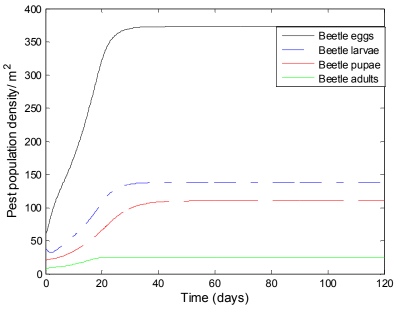
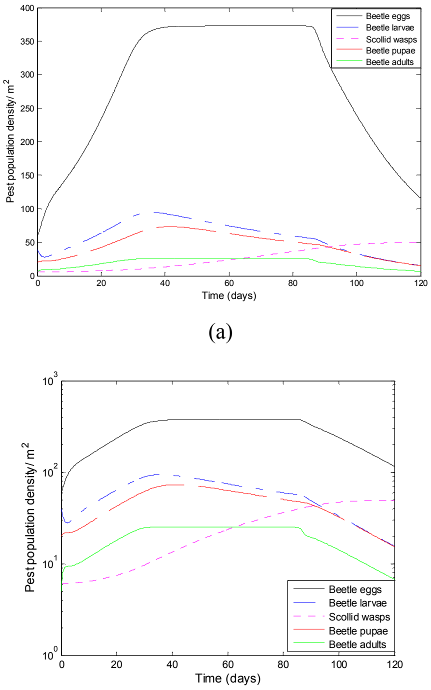


Fig. 3 Scarab beetles rate of increase in the absence of any control measure

In the absence of any control measure, as the *Metarhizium anisopliae* conidia is yet to be matured; the beetles reproduce and increase their population to 373 eggs, 138 larvae, 111 pupae and 25 adults, the adult population is only limited by the environmental carrying capacity, which was set to a value of 25.



(a)

(b)

Fig. 4 The effect of wasps & *Metarhizium anisopliae* fungus on scarab beetle infestation- (a) normal plot (b) semi-log view illustrating the control effect on the pest population

A. Control Strategy

To control the damage to the field, 6 scoliid wasps were introduced in the presence of matured *Metarhizium anisopliae* fungus in the infested habitat. Fig. 4 illustrates the result after a 120 day period.

The result of Fig. 4, illustrates the ability of the wasps and fungus to drive down the population density of the pest from the peak of 373 to 116 eggs, 94 to 15 larvae, 73 to 14 pupae and 25 to 7 adults from the 90th day, which adversely affected its egg production as most of the larvae were being killed by both the fungus and the wasps across the 120 day interval.

The results of Fig. 4, provides a satisfactory answer to our goal, as maximum control of the pest population was achieved. From the result of Fig. 4, we are optimistic of the long term effect of this combination, therefore a 1000 day simulation is illustrated in Fig. 5.

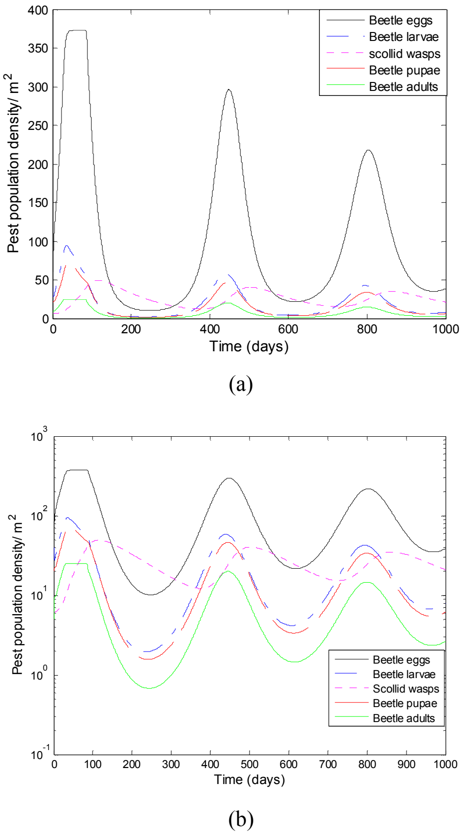


Fig. 5 The long term effect of beneficial insects and *Metarhizium anisopliae* fungus on the control of scarab beetles- (a) normal plot (b) semi-log view

The result of Fig. 5 shows the inability of the beetle population to reach the environmental carrying capacity as the maximum values observed across the 1000 day interval from the 200 days onwards was 295 eggs, 58 larvae, 44 pupae and 19 adults before the population was driven down to 37 eggs, 7 larvae, 6 pupae and 3 adults.

The result of Fig. 5 shows the sustainable control of the population of the adult beetles and its life cycle stages as the pest could not develop resistance to the fungal diseases over a long time period. The oscillatory variation of the insect population trend confirms the benefits of using a dual parasitoid approach exploiting the *Metarhizium anisopliae* fungus, as illustrated by [44].

V. RESULT ANALYSIS

The result of Fig. 3 shows that it is possible to have Scarab beetles outbreaks when an ecosystem is left unattended, as observed by the reproduction rate of the Scarab beetles on the taro corm field for an interval of 120 days. The population increased from an initial starting population of 60, 40, 20 and 5 for the egg, larvae, pupae and adults to a peak of 373 eggs, 138 larvae and 111 pupae and the adult population reached the environmental carrying capacity, rising from the initial 5 to 25 adult beetles in 24 days.

The result of Fig. 4 shows the control exhibited when the scoliid wasps and *Metarhizium anisopliae* fungus are introduced into the habitat, the population of the beetles larvae and pupae where under firm control. Furthermore, the effective control by the wasps and fungus combination reflected on the beetles egg population, whose population dropped to 116 eggs, as the adult population dropped from its environmental carrying to 7 adults.

The success of the above result motivated our quest to understand the long term effect of the combination as illustrated in Fig. 5. The results of Fig. 5 show the long term effect of the combination as the wasps and fungus regulate the population density of the pest preventing a pest outbreak for up to 1000 days.

We are able to illustrate the capability of the fungus *Metarhizium anisopliae* on the population density of the beetle adult and larvae combined with the scoliid wasps, which only attack the larvae stage of scarab beetles, therefore any larvae that escape attack will be caught after it undergo transformation to the adult stage, which will die during its search for food as the asexual conidia stick to its exoskeleton and germinate into a germ tube, which penetrates the skin of the beetle and enters into the body cavity as hydrolytic enzymes, which release toxic substances, which gradually kill the host due to mycosis. At the moment the host is confirmed dead, the fungus will pierce out of the integument and grow conidiophores, on which environmentally stable aerial conidia are produced. These conidia are passively disseminated into the environment and eventually infect new hosts as shown in Fig. 1.

The model demonstrates that both short term and long term control of the beetle population can be achieved given sufficient time. The use of pesticides has the tendency to cause pest outbreaks because, insecticides not only kill the pest but will completely eliminate the naturally beneficial wasps and soil saprophytes.

We therefore encourage the deployment of scoliid wasps in combination with *Metarhizium anisopliae* fungus, which can attack the adult beetles to force its population down as observed in the results.

VI. CONCLUSION

We have successfully reduced scarab beetle population to an economically acceptable threshold via the use of scoliid wasps and *Metarhizium anisopliae* fungus. We have also demonstrated the long term effect of establishing wasps and beneficial soil saprophytes which can occur when an environment is protected from the application of chemical pesticides. *Metarhizium anisopliae* fungus should be introduced alongside the cultivation of the root crops in order to get the asexual conidia matured before the beetles or pests invade the field. Also naturally beneficial insects in taro habitats should be encouraged as soon as a scarab beetle or larvae are sited. A procedure for scarab beetle management has been successfully designed and analysed, with the combination of scoliid wasps and *Metarhizium anisopliae* fungus providing an effective control approach.

We therefore recommend growing *Metarhizium anisopliae* fungus at the same time that the root crops are cultivated in order to arrest the effect of the invading pests of all kinds.

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