Identifying the Right Plants for Diverse Biocontrol Agents in Tropical Smallholder Bean Farming Systems

Mkenda, P.A.[1,2], P.A. Ndakidemi[2], P.C. Stevenson[3,4], S.E.J. Arnold[2,3], S.R. Belmain[3], I. Darbyshire[4] and G.M. Gurr[5]

[1]Department of Biosciences, Sokoine University of Agriculture, P.O Box 3000, Morogoro, Tanzania.
[2]Department of Sustainable Agriculture, Biodiversity and Ecosystems Management, Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania.
[3]Natural Resources Institute, University of Greenwich, Chatham Maritime, Kent, ME4 4TB, United Kingdom.
[4]Royal Botanic Gardens, Kew, Richmond, Surrey, TW9 3AE, United Kingdom.
5School of Agricultural and Wine Sciences, Charles Sturt University, Orange, NSW 2800, Australia.

*Corresponding author Email: mayoprisca@sua.ac.tz

Abstract

Biocontrol agents such as predators, parasitoids and pathogens potentially regulate crop pests populations. The agents feed directly on the pests, oviposit in the pest body or cause disease in the pest. While biocontrol has become a commercial enterprise in temperate horticulture, there is much less information on the biocontrol agents present in smallholder agricultural systems in the tropics and little knowledge about the importance of plant diversity in supporting their biocontrol activities. A standardized botanical survey walk combined with observations of plant-insect interactions was conducted on field margin vegetation of 24 smallholder fields of common beans (Phaseolus vulgaris L.) in three elevation zones of a tropical ecosystem. Sweep nets were also used to capture the biocontrol agents and stored in 70% ethanol for detailed taxonomy where identification in the field was not possible. A wide range of biocontrol agents interacting with the field margin plants, particularly flowering forbs were revealed. The most preferred field margin plants were Ageratum conyzoides, Commelina benghalensis, Pennisetum purpureum, Panicum maximum and Tripsacum sp. The most common biocontrol agents found to interact with the field margin plants were spiders (Araneae), long-legged flies (Dolichopodidae), predatory and parasitic wasps (Ichneumonids and braconids), hoverflies (Syrphidae) and assassin bugs (Reduviidae). Preferences of the biocontrol agents to certain plant species were similar across all three zones, indicating the importance of such plants in terms of food resources, shelter or nesting sites. The preference of the biocontrol agents to some plant species indicates the need to identify the specific benefits of these species to the biocontrol agents to determine whether non-crop habitat manipulation might enhance natural pest regulation.

Keywords: Natural enemies, habitat manipulation, crop pest regulators, margin plants, tropical ecosystem.

Introduction

Semi-natural habitats around tropical smallholder agricultural lands consist of diverse plants, useful in the provision of food resources, habitats, nesting sites and refuge sites to biocontrol agents. These agents may be predators, parasitoids or pathogens that are responsible for natural pest regulation. Some of the semi-natural habitats within the cropping landscapes that have been reported from various studies to be useful in enhancing biocontrol agents include field margins/hedgerows, woodland or shrubland and grassland (Holland *et al.,* 2017). Field margin vegetation is one of the common features around smallholder tropical farming systems responsible for

enhancing populations of biocontrol agents. They can effectively promote more diverse biocontrol agent assemblages when there is also reduced pesticide use, tillage and enhanced crop cover compared with a conventionally managed crop (Vickery *et al.,* 2009). Field margin habitats provide food, nesting sites, overwintering sites, shelter and hosts to various predators and parasitoids which facilitates their enhanced biological control services in agro-ecosystems (Bianchi *et al.,* 2006; Gurr *et al.,* 2003; Landis *et al.,* 2000, Ramsden *et al.,* 2014). Many European nations and other developed countries have established these semi-natural habitats within the agricultural lands through agri-environment schemes to enhance biodiversity for various ecosystem services (Carvell *et al.,* 2007; Field *et al.,* 2007; Walker *et al.,* 2007; Scheper *et al.,* 2013). Non-crop habitats around croplands are more florally diverse, less disturbed and relatively permanent compared with the cropland. Generally, the presence of diverse plants within arable lands significantly influences the abundance and diversity of biocontrol agents regardless of the area of the non-crop habitat (Knapp & Řezáč, 2015; Pluess *et al.,* 2010; Jung *et al.,* 2008).

Biocontrol agents are enhanced by timely accessibility of prey as a food resource, floral resources as additional food, as well as shelter habitats and overwintering sites in case of disturbances (Ramsden *et al.,* 2014). Usually, biocontrol agents move from the field margin plants to the field crop during the growing season when there are abundant food resources and later back to the margin plants when the resources are scarce or due to agronomic disturbances (Girard *et al.,* 2011). Therefore, agricultural lands may be an unwelcoming environment for the biocontrol agents due to ecological simplification of the land with limited semi-natural habitats. Monoculture cropping systems together with the intensive application of agrochemicals in conventional farming are considered detrimental practices to many beneficial insects including the biocontrol agents in the field. The presence of semi-natural habitats within the agricultural lands provide suitable sites for the biocontrol agents and other beneficial insects to hide during farming disturbances like pesticide application, tillage, crop harvesting and other unfriendly farming practices. This highlights the importance of field margin plants in enhancing the population of the biocontrol agents where they act as refuge sites for the biocontrol agents to recolonize the cropland after disturbance.

Understanding the field margin plant species and various benefits provided by these features around arable fields is particularly important for their proper management. Some field margin plants are also reported to be the source of insect pests in the field through the provision of similar resources such as food and shelter. Drosophila suzukii and Stictococcus vayssierei are among the most reported pest species with several non-crop host plants along the field margin (Arnó *et al.,* 2016; Kenis *et al.,* 2016; Diepenbrock *et al.,* 2016; Tindo *et al.,* 2009). The information that a particular field margin plant may be more preferred by the insect pests is very useful for proper identification and management of the margin plants.

The smallholder agricultural lands of tropical ecosystems are largely heterogeneous and naturally surrounded by diverse field margin plants. However, these features around smallholder fields are highly used for feeding animals, as field boundary and sometimes for firewood (Elisante *et al.,* 2019) with limited research information on the role of these margin plants to the population of biocontrol agents. The intention of integrating agronomic and biodiversity objectives may widely be achieved through field margin establishment and management. Identification and maintenance of field margin plants within the smallholder tropical agricultural land is a potential measure towards enhancing the population of predators and parasitoids together with other beneficial insects. This study surveyed the field margin plant species available within the smallholder bean farming systems of tropical climate in Moshi rural district to evaluate the relationship between the margin plants and biocontrol agents. Specifically, the study focused on; i) identification of field margin plants in smallholder bean fields across elevation zones and ii) to assess the interaction between the biocontrol agents present in smallholder bean

fields and the margin plants. The study sought to test the following hypothesis; i) The biocontrol agents in smallholder bean fields interact with the margin plants ii) Some field margin plants are more preferred by the biocontrol agents across elevation zones.

Materials and Methods

Study Sites

The study sites were located across three agricultural zones in Moshi rural district, Kilimanjaro region. The three zones were classified based on the elevation to understand the effect of elevation on field margin vegetation and their influence upon biocontrol agents for wider application in the tropical areas where zonation do exists (Bussmann, 2006; Seo *et al.,* 2008). The three elevation zones also differed in terms of climate, land use management and farming practices (Ensslin *et al.,* 2015; Soini, 2005), which may consequently influence the vegetation diversity and biocontrol agents present. The low zone was between 800 to 1000 m asl, the mid-zone was between 1001 to 1500 m asl and the high zone was between 1501 to 1800 m asl. The annual rainfall ranged between 600 to 2000 mm (increasing with elevation). In the high zone, the study sites comprised Mbahe village (3.23 ºS, 37.50 ºE) which is located in the Marangu Mangharibi ward. The mid-zone covered Mieresini village (3.33 ºS, 37.53 ºE) whereas the low zone covered Kilimo Makuyuni village (3.40 ºS, 37.55 ºE). All the sites were smallholder fields of common beans (*Phaseolus vulgaris*). The assessment was done under their normal farming practices but without pesticide application.

Sampling design

The study involved 24 smallholder bean fields in all three elevation zones. In each zone, 8 bean fields were purposively sampled based on the size and length of the field margin vegetation. The length of the field margin vegetation chosen was at least 50 m.

Data collection

Assessment of the specific interaction between the field margin plants and the biocontrol agents was done through a standardized survey walk where the bean field and the margin meet, along 50 m long. Constant observation of any biocontrol agent found on plants within 1m of the researcher was done for three hours, from 9.00 am to 12.00 noon, when the insects were more active (Montgomery *et al.,* 2021). Both the biocontrol agents and the plant species found interacting were recorded. The observed biocontrol agents were counted together as either visiting or feeding the plant or resting on it and it was not necessary for the biocontrol agent to be on the flower part. The insect identity and the plant with which it interacted were recorded in each case to identify the most preferred field margin plants by the biocontrol agents in each zone.

The biocontrol agents were captured using a sweep net and stored in 70% ethanol where identification in the field was uncertain. The margin plants found to interact with the biocontrol agents were collected for herbarium specimen where identification was impossible in the field. The collected biocontrol agents were identified based on morphological features at the life sciences laboratory, Nelson Mandela African Institution of Science and Technology (NM-AIST), Arusha, with further support from Tropical Pesticides Research Institute (TPRI), Arusha. The collected herbarium specimens were sent to TPRI and Royal Botanic Garden, Kew in the UK for identification.

Data analysis

Network graphs were constructed from the collected data using the R program (R Core Team, 2018), version 3.5.1. Bipartite package (Dormann, *et al.,* 2008) was used to draw the networks via RStudio. To minimize complexity in the network graphs, only interactions that occurred more than 10 times between the biocontrol agents and the margin plants were included in the networks.

Results

A total of 39 plant species (Table 1) were found interacting with different biocontrol groups for over 10 times (Figures 1, 2 and 3).

Table 1: Surveyed field margin plant species in three elevation zones of Moshi rural district

Label	Plant species	Location
1	*Centella asiatica*	High and mid zones
2	*Oxalis corniculate*	High and mid zones
3	*Commelina benghalensis*	High, mid and low zones
4	*Drymaria cordata*	High zone
5	*Conyzae bonariensis*	High zone
6	*Asystasia mysorensis*	High and mid zones
7	*Ageratum conyzoides*	High, mid and high zones
8	*Richardia scabra*	High, mid and low zones
9	*Sporobus pyramidalis*	High zone
10	*Galingsoga parviflora*	High, mid and low zones
11	*Bidens fondosa*	High zone
12	*Bidens pilosa*	High and mid zones
13	*Cyperus rotundas*	High and low zones
14	*Persea americana*	High zone
15	*Tripsacum sp*	High zone
16	*Desmodium uncinatum*	Mid zone
17	*Digitaria velutina*	Mid and low zones
18	*Neonotonia wightii*	Mid and low zones
19	*Pennisetum purpureum*	Mid and low zones
20	*Senna spectabilis*	Mid zone
21	*Achyranthes aspera*	Mid zone
22	*Sida rhombifolia*	Mid and low zones
23	*Cynodon dactylon*	Mid zone
24	*Panicum maximum*	Mid and low zones
25	*Desmodium intortum*	Mid and low zones
26	*Hyparrhenia rufa*	Mid zone
27	*Amaranthus hybridus*	Mid zone
28	*Lantana camara*	Mid zone
29	*Emilia discifolia*	Mid zone
30	*Morus australis*	Low zone
31	*Thevetia peruviana*	Low zone
32	*Euphorbia heterophylla*	Low zone
33	*Tridax procumbens*	Low zone
34	*Leucas martinicensis*	Low zone
35	*Euphorbia hirta*	Low zone
36	*Indigofera trita*	Low zone
37	*Acacia tortilis*	Low zone
38	*Gynandropsis gynandra*	Low zone
39	*Launaea cornuta*	Low zone

Identified field margin plants supporting biocontrol agents in the high elevation zone (1501 to 1800 m asl)

The biocontrol agents that were found to interact with the field margin plants more frequently in the high zone were spiders, long-legged flies, predatory wasps, parasitic wasps, hoverfly and tachinid fly (Fig. 1). Spiders were found to interact mostly with creeping plant species such as *C. benghalensis*, *D. cordata* and *C. asiatica* and few non-creeping plants like *A. conyzoides* and *C. bonariensis*. Long-legged flies highly interacted with Guatemala grass (*Tripsacum* sp.) while predatory and parasitic wasps were mostly interacting with A. conyzoides compared with other plant species. Similarly, hoverfly interacted more with A. conyzoides and to some extent with *D. cordata.* Lady beetle is one of the biocontrol agents that was observed to have very low interaction with the margin plants. Generally, the most preferred field margin plants to the biocontrol agents in the high zone were Tripsacum sp, *A. conyzoides* and *C. benghalensis*.

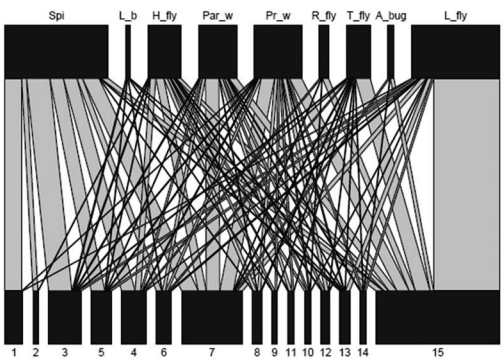

Figure 1: Bipartite network graph between biocontrol agents and field margin plants in the high elevation zone in Northern Tanzania

Each bar in the upper row represents biocontrol agents (Spi = spider, L_b = lady beetle, H_fly = hoverfly, Par_w = parasitoid wasps, Pr_w = predatory wasps, R_fly = robber fly. T_fly = tachinid fly, A_bug = assassin bug, L_fly = long-legged fly) and each numbered bar in the bottom row represents field margin plant species (Table 1). The width of the bars is proportional to the number of interactions.

Identified field margin plants supporting biocontrol agents in the mid-elevation zone (1001 to 1500 m asl)

In the mid zone, hoverflies, spiders and predatory and parasitoid wasps and assassin bugs were the most dominant biocontrol agents and were found to interact with several plant species. *A. mysorensis* was the most dominant species in the mid-zone but not attractive to biocontrol agents. Instead, similar preferences of the biocontrol agents toward certain plant species were observed in mid-zone as was found in the high zone. Spiders were most often interacting with *N. wightii* and *C. benghalensis,* which are mostly climbing and creeping plant species, respectively, compared with other plants. Predatory wasps were highly interacting with *A. conyzoides* as in high zone, followed by *B. pilosa* and *P. maximum*. Hoverfly and parasitic wasps had diverse interactions with several plant species including *B. pilosa* and *P. maximum*, while assassin bugs were more specific to *S. rhombifolia*. Long-legged flies were less abundant in mid-zone as compared with the high zone, thus their interaction with field margin plants in the mid-zone was not so strong (Fig. 2).

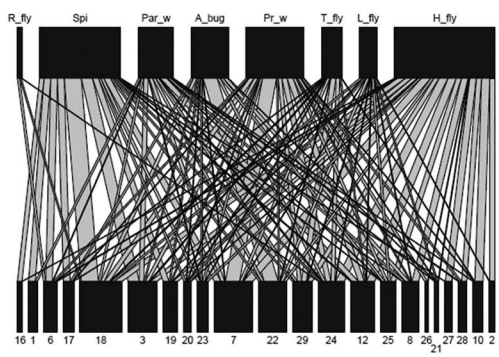

Figure 2: Bipartite network graph between biocontrol agents and field margin plants in the mid-elevation zone in Northern Tanzania

Each bar in the upper row represents natural enemies (R_fly = robber fly, spi = spider, Par_w = parasitoid wasps, A_bug = assassin bug, Pr_w = predatory wasps, T_fly = tachinid fly, L_fly = long-legged fly, H_fly = hoverfly) and each numbered bar in the bottom row represents

field margin plant species (Table 1). The width of the bars is proportional to the number of interactions.

Identified field margin plants supporting the biocontrol agents in the low elevation zone (800 to 1000 m asl)

Pennisetum purpureum, *P. maximum*, *R. scabra*, *B. pilosa* and *E. heterophylla* were the common margin plants in the low zone (Fig. 3). The interactions between the biocontrol agents and the margin plants were so diverse compared with mid and high elevation zones due to the existence of less abundant but diverse weed species. *A. conyzoides* and *C. benghalensis* which were the most abundant weeds in high and mid-elevation zones were less abundant in low elevation zone. Hoverfly and predatory wasps were the most abundant biocontrol agents with a high preference for *E. heterophylla* and *B. pilosa*. Only a few long-legged flies were present in the low elevation zone with a high preference to *P. maximum* which is also a grass species as Guatemala grass which was the most preferred in the high zone. Other biocontrol agents were less abundant with no strong interaction with particular plant species.

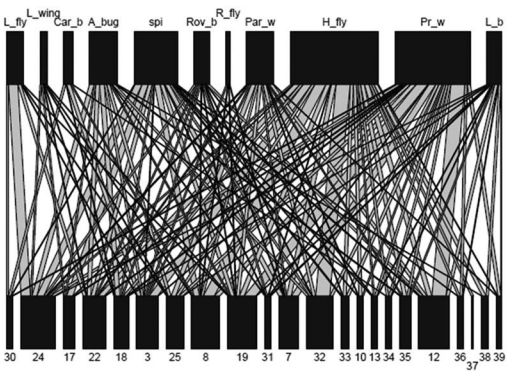

Figure 3: Bipartite network graph between biocontrol agents and field margin plants in the low elevation zone in Northern Tanzania

Each bar in the upper row represents biocontrol agents (L_fly = long-legged fly, L_ wing = lacewing, Car_b = carabid beetle, A_ bug = assassin bug, spi = spider, Rov_b = rove beetle, R_fly = robber fly, Par_w = parasitic wasps, H_fly = hoverfly, Pr_w = predatory wasps, L_b = lady beetle) and each numbered bar in the bottom row represents field margin plant species (Table 1). The width of the bars is proportional to the number of interactions.

Discussion

The biocontrol agents showed similar preferences to certain field margin plants across the three elevation zones. Predatory wasps, parasitic wasps and hoverflies were highly interacting with *A. conyzoides* in all three zones, justifying the importance of this plant to biocontrol agents regardless of elevation. Most creeping and climbing plants were found to support several ground-dwelling biocontrol agents due to their potential in providing microhabitats with increased vegetation complexity. *D. cordata* and *C. asiatica* both of which are creeping plant species are reported to harbour several biocontrol agents especially spiders (Mukti *et al.,* 2014; Sadof *et al.,* 2014; Withaningsih *et al.,* 2018) as also observed in the high zone. Likewise, in the -mid-elevation zone spiders were more interacting with *N. wightii* and *C. benghalensis* which are mostly climbing and creeping plant species, respectively, compared with other plants. These weed plant species are among the most reported plants of agricultural importance within the smallholder farming communities of Africa (Hillocks, 1998).

A. conyzoides is one of the known plant species with several floral visitors searching for pollen and nectar (Amaral *et al.,* 2013; Lin *et al.,* 1993; Ngongolo *et al.,* 2014), signifying its importance as a food resource to beneficial insects around agricultural land. A. conyzoides, and B. pilosa promote the survival and activities of predators (Amaral *et al.,* 2013). Assassin bugs were highly attracted by *S. rhombifolia*, and according to Cruz *et al.* (2013), it is among the spontaneous plants in agroecosystems that harbour predatory mites and other several species important in natural pest control. It can therefore be considered as a potential field margin plant for enhancing the beneficial insects within the smallholder farming systems. *Tripsacum* sp is a commonly known fodder plant in tropical countries including Tanzania due to its high nutritive values (Singh, 1999). The study reports an additional benefit of this

plant to harbour biocontrol agents particularly long-legged flies in smallholder agricultural ecosystems.

Most of the field margin plants that show a strong interaction with the biocontrol agents have been reported by other studies to potentially enhance their population through the provision of alternative food resources, nesting sites and refuge sites. For example, *R. scabra* and other several margin plants are reported as useful in maximizing multiple ecological services (Olson & Wäckers, 2007). *Panicum* spp. and other grass species are highly used in the construction of beetle banks (Hopwood *et al.,* 2016) and as fodder for animals (Fernandes *et al.,* 2014). The study revealed additional benefits of these grass species in harbouring biocontrol agents around agricultural lands. Lady beetles were very abundant in the field but very few along the margin plants, and this is supported by Olson and Wäckers (2007) who also found the abundance of ladybeetle to increase from the margin towards the field centre. They are known to prefer floral resources only when their host insect pests, particularly the aphids are scarce (Hatt *et al.,* 2017; Lundgren, 2009).

The relative importance of field margin vegetation and other non-crop features in enhancing biocontrol activities around agricultural lands may vary dramatically due to several factors. The efficiency of the biocontrol agents in pest regulation is influenced by their dispersal ability between the margin plants and cropland (Fischer *et al.,* 2013), intraguild predation (Martin *et al.,* 2013) as well as the qualities of resources from the margin plants (Arnó *et al.,* 2016; Kenis *et al.,* 2016; Robinson *et al.,* 2002; Tindo *et al.,* 2009). Inconsistent responses of the biocontrol agents and insect pests to the surrounding landscape composition is also reported by Karp *et al.* (2018). This signifies the need for more studies to understand when habitat manipulation and management represent the win-win situation.

Conclusion

Network analysis informs that many of the biocontrol agents interacts with diverse weed plants, including several species with pesticidal or medicinal properties (e.g. *A. conyzoides, Bidens* sp., *Tithonia diversifolia*, and Ocimum gratissimum). Other plants like C. benghalensis, *C. asiatica*, *T. luxum*, *P. purpureium*, *N. wightii, R. scabra* and *E. heterophyla* were also preferred by several predators and parasitoids. Many of these plants have a longer flowering season than the crop itself so play a role in supporting biocontrol communities, as well as conferring further ecosystem services. However, the promotion of these species should proceed with care and sensitivity as many are introduced exotics from other tropical biomes. Farmers should be encouraged to observe and identify the best field margin vegetation for enhancing the beneficial insects with proper field margin management practices to ensure a high population of beneficial insects within the cropland. Addressing all these will enable movement towards a more environmentally sustainable crop production system.

Acknowledgements

The authors are grateful to the District Executive Director of Moshi rural District Council for granting the permission to conduct the research. Thanks to the agricultural extension officers and the smallholder farmers in Moshi rural district for their full participation in the study. The authors acknowledge the management of the Tropical Pesticides Research Institute (TPRI) for their kind support during the identification of plants and insects. This work was funded by Darwin Initiative grant (DI22-012) through Darwin Initiative project and McKnight Foundation grants through Charles Sturt University in Australia.

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