

JULIANA ANDREA MARTINEZ CHIGUACHI

**CONSERVATION OF NON-CROP PLANTS AS A MANAGEMENT
STRATEGY TO IMPROVE FUNCTIONAL BIODIVERSITY IN CHILI
PEPPER CROPS**

Tese apresentada à Universidade Federal de Viçosa, como parte das exigências do Programa de Pós-Graduação em Entomologia, para obtenção do título de *Doctor Scientiae*.

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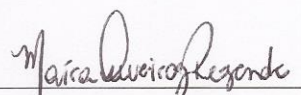
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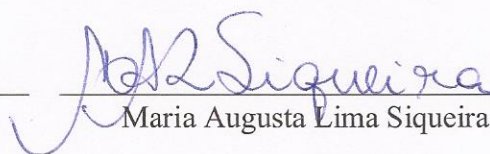
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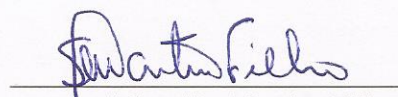
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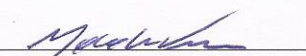
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*Aos meus pais Melva e Juan,
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e entender que com cada vôo empreendido ganhamos aprendizado.
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Sumário

Abstract	vii
Resumo	ix
Introdução Geral	1
Referências Bibliográficas	4
Chapter I	7
Effects of management practices used on chili pepper crops in the abundance of functional groups of arthropods.....	7
Abstract	7
1. Introduction	8
2. Material and methods.....	10
2.1. Field sampling.....	10
2.2 Statistical analysis	12
3. Results	13
4. Discussion.....	15
5. References	19
Chapter II.....	32
Response of coccinellids to the management of non-crop plants and to the availability of alternative foods in chili pepper crop.....	32
Abstract	32
1. Introduction.....	33
2. Materials and methods	35
2.1. Abundance of coccinellids on chili pepper crop.....	35
2.2 Laboratory experiments.....	37
2.2.1 Predators and prey rearing	38
2.2.2 Coccinellid predation on broad mites.....	39
2.2.3 Broad mite mortality from coccinellids.....	39
2.2.4 Survival of coccinellids feeding on broad mites and on non-crop flowers	40
3. Results	42
3.1 Abundance of coccinellids in chili pepper crop.....	42
3.2 Coccinellid predation on broad mites.....	43
3.3 Broad mite mortality from coccinellids.....	43
3.4 Survival of coccinellids feeding on broad mites and on non-crop flowers	43
4. Discussion.....	44
5. References.....	47

Conclusões gerais61

Abstract

CHIGUACHI, Juliana Andrea Martinez, D.Sc., Universidade Federal de Viçosa, March, 2018. **Conservation of non-crop plants as a management strategy to improve functional biodiversity in chili pepper crops.** Adviser: Madelaine Venzon. Co-adviser: Débora Pires Paula.

Management practices used within cropping systems play an important role in the ecosystem, because they can cause impacts on biodiversity. Practices such as the conservation of non-crop plants and the reduction of pesticides can favor populations of arthropods that perform functions within the agroecosystem, offering a greater availability of alternative resources. In this study, we carried out field and laboratory experiments. In fields of chili pepper, we evaluated in chili pepper fields the effect of three different management practices: (i) conservation of non-crop plants and non-application of pesticides, (ii) without non-crop plants and non-application of pesticides and (iii) conventional management (application of pesticides) on populations of different functional groups and on the abundance and diversity of insects of the family Coccinellidae. In the same crop system, we evaluated the abundance of Coccinellidae in relation to the abundance of prey potential and alternative resources available in the crop of chili pepper with and without the presence of non-crop plants. Additionally, in the laboratory, we evaluated the predation of first instar larvae of the coccinellid species *Eriopsis connexa* and *Harmonia axyridis* on broad mites as an alternative food. Also, we quantified survival of these species feeding on broad mites and on floral resources of *Ageratum conyzoides*, a non-crop plant commonly found in and around cropped areas. As results, we found that the management system with the conservation of non-crop plants and the non-application of pesticides positively affected the abundance of functional groups such as predators, parasitoids, pollinators and herbivores, as well as the abundance and diversity of coccinellid predators. Furthermore, different species of coccinellids were found with the highest relative abundance of *Scymnus rubricaudus*, *Brachiacantha groendali*, *Hyperaspis festiva* and *Cycloneda sanguinea*. Besides, we confirmed that the management of non-crop plants through their conservation favors the abundance of coccinellids in comparison to fields of chili pepper without non-crop plants. First instar larvae of *E. connexa* and *H. axyridis* fed on different stages of the broad mite. Both species increased survival when broad mites and floral sources of *A. conyzoides* were supplied together, but only *E. connexa* survived more days when only broad mites were supplied. However, none of the species

completed larval development. Therefore, management practices implemented in the chili pepper crop that aim to reduce the application of pesticides and to conserve the non-crop plants can contribute to an increase in biodiversity, improve the abundance and diversity of coccinellid predators, and provide alternative resources that favor survival of these predators.

Resumo

CHIGUACHI, Juliana Andrea Martinez, D.Sc., Universidade Federal de Viçosa, março de 2018. **Conservação de plantas espontâneas como estratégia para melhorar a biodiversidade funcional em pimenta-malagueta.** Orientadora: Madelaine Venzon. Coorientadora: Débora Pires Paula.

Práticas de manejo usadas nos sistemas de cultivos desempenham um papel importante dentro do ecossistema, pelos efeitos que podem causar à biodiversidade. A conservação de plantas espontâneas e não aplicação de pesticidas podem favorecer populações de artrópodes que exercem funções dentro do agroecossistema, oferecendo uma maior disponibilidade de recursos alternativos. Neste estudo, foram realizados experimentos de campo e de laboratório. Em campos de pimenta-malagueta, foi avaliado o efeito de três diferentes práticas de manejo nas populações de diferentes grupos funcionais e na abundância e diversidade de insetos da família Coccinellidae: (a) conservação de plantas espontâneas e a não aplicação de agrotóxicos; (b) sem conservação de plantas espontâneas e a não aplicação de agrotóxicos; e (c) manejo convencional (aplicação de agrotóxicos). Foi avaliado a abundância de coccinélídeos em relação a abundância de presas potenciais e recursos alternativos disponíveis no cultivo de pimenta-malagueta, com e sem presença de plantas espontâneas. Em laboratório foi avaliada a predação de larvas de primeiro instar das espécies *Eriopis connexa* e *Harmonia axyridis* no ácaro-branco (*Polyphagotarsonemus latus*). Além disso, a sobrevivência destas espécies foi avaliada na presença do ácaro-branco e recursos florais da planta *Ageratum conyzoides*, encontradas em áreas de cultivo. O sistema de manejo com a conservação de plantas espontâneas e a não aplicação de pesticidas afetou positivamente a abundância de grupos funcionais como predadores, parasitoides, polinizadores e herbívoros, assim como a abundância e diversidade de predadores coccinélídeos. Além disso, foram encontradas diferentes espécies de coccinélídeos com maior abundância relativa das espécies *Scymnus rubricaudus*, *Brachiacantha groendali*, *Hyperaspis festiva* e *Cycloneda sanguinea*. O manejo com a conservação de plantas espontâneas favoreceu a abundância de coccinélídeos em comparação com campos de pimenta-malagueta sem plantas espontâneas. Alimentos alternativos para os predadores foram encontrados nos campos de pimenta-malagueta como o ácaro-branco e recursos florais de plantas de *A. conyzoides*. Larvas de primeiro instar das espécies *E. connexa* e *H. axyridis* predaram diferentes estágios do ácaro-branco. Ambas as espécies aumentaram a sobrevivência quando o ácaro-branco e recursos florais

de *A. conizoides* foram fornecidos juntos, mas somente *E. connexa* teve maior longevidade quando apenas o ácaro-branco foi fornecido. No entanto, nenhuma espécie completou o desenvolvimento larval. Portanto, práticas de manejo implementadas na cultura de pimenta-malagueta que visem a reduzir a aplicação de pesticidas e principalmente conservar as plantas espontâneas contribuem para um aumento da biodiversidade, da abundância e diversidade de predadores coccinelídeos e fornecerem recursos alternativos que favoreçam a conservação destes predadores.

Introdução Geral

Um dos principais fatores que tem levado a mudanças no uso da terra é o crescimento da população humana, que por sua vez, tem levado a um rápido aumento na demanda por alimentos (Foley et al., 2005; Godfray et al., 2010; Lambin et al., 2011; FAO, 2017). Sistemas agrícolas tem se tornado altamente produtivos para satisfazer as necessidades globais por alimento (Samberg et al., 2016). No entanto, muitos agricultores implementam práticas como a simplificação do habitat, aumentando as áreas em monocultura e o uso de agrotóxicos (Emmerson et al., 2016). Porém, tais práticas tem causado problemas ao meio ambiente como a contaminação de água e ar, efeitos na fertilidade do solo (Matson et al., 1997; Stoate et al., 2009) e perda da biodiversidade (Tilman et al., 2001; Landis, 2017). Também podem causar efeitos negativos em diferentes grupos funcionais do ecossistema, entre eles predadores, parasitoides e polinizadores (Letourneau e Bothwell, 2008; Kremen e Miles, 2012), gerando impactos na eficiência dos serviços ecossistemicos como o controle biológico e polinização (Tscharntke et al., 2012).

Devido a isso, práticas para mitigar esses impactos, como evitar o uso de pesticidas (Tscharntke et al., 2012) e aumentar a diversidade de espécies de plantas, tem sido estudados (Landis et al., 2000; Gurr et al., 2003, 2017). Práticas como a conservação de plantas espontâneas, crescendo associadas nas entrelinhas ou adjacentes aos campos de cultivo (Altieri e Nicholls, 2004; Denys e Tscharntke, 2002; Skirvin et al., 2011) podem aumentar a abundância de polinizadores e seus serviços de polinização (Blaauw e Isaacs, 2014). Aumentam também a abundância e diversidade de inimigos naturais (Chaplin-Kramer et al., 2011), devido a variedade de recursos alimentícios que as plantas oferecem, como pólen, néctar, presas e hospedeiros alternativos, microclima moderado e refúgio para enfrentar condições adversas (Landis et al., 2000).

Inimigos naturais são beneficiados pelo consumo de fontes de alimento alternativo como pólen e néctar, que melhoram sua sobrevivência e fecundidade (Lundgren, 2009a; Gurr et al., 2017). Ao incrementar as populações de organismos benéficos no ambiente, maiores contribuições são realizadas para um eficiente controle biológico, pois na maioria dos casos existe uma correlação entre a abundância de inimigos naturais e a redução de organismos praga (Tscharntke et al.,

2007; Coll, 2009). Apesar do conhecimento da importância do manejo do habitat e o aumento da diversidade de plantas sobre as funções da biodiversidade (Bianchi et al., 2006; Chaplin-Kramer et al., 2011), ainda é necessário entender como as espécies e os grupos funcionais são afetados pelas práticas de manejo que são implementadas em campos de cultivos.

Inimigos naturais, como predadores generalistas, tem um papel importante dentro do ecossistema devido a uma ampla alimentação incluindo uma variedade de presas (Symondson et al., 2002). Entre esses predadores, a família Coccinellidae possui importantes agentes de controle biológico, devido principalmente a predação de pulgões (Obrycki et al., 2009), ácaros (Biddinger et al., 2009), cochonilhas, moscas brancas e psílideos (Hodek e Honěk, 2009). Contudo, estes predadores também usam outros alimentos alternativos como parte importante de suas dietas que normalmente são encontrados em condições de campo, como pólen, néctar, frutas, plantas e fungos (Lundgren, 2009b). O aproveitamento destes alimentos alternativos por predadores coccinélideos lhes permite a obtenção de fontes nutricionais e energéticas, reduzindo assim a mortalidade quando suas principais presas não estão disponíveis (Hodek e Evans, 2012). Estas fontes alternativas de alimento são proporcionadas principalmente pela diversificação do habitat devido a variedade de espécies de plantas que são encontradas oferecendo recursos florais e um ambiente que serve de refúgio para presas alternativas (Altieri, 1999; Landis et al., 2000). Por esse motivo, existe uma forte relação entre as populações de coccinélideos e o manejo do habitat (Woltz et al., 2012; Amaral et al., 2013). Entretanto, estes predadores são bastante complexos nos comportamentos de forrageamento e alimentação. É necessário entender melhor como os sistemas de manejo dos campos de cultivo principalmente pela diversificação do habitat e a disponibilidade de recursos encontrados podem afetar suas populações e características de vida.

Neste estudo foram realizados experimentos de campo e de laboratório. Os estudos de campo foram executados no sistema de cultivo de pimenta-malagueta (*Capsicum frutescens* L.). Esta cultura vem crescendo em diferentes regiões do Brasil como Goiás, São Paulo, Ceará, Rio Grande do Sul, e principalmente em Minas Gerais, onde tem uma maior importância socioeconômica (Rufino e Penteado, 2006), pois a produção em sua maioria é proveniente da agricultura familiar. Não obstante, o aumento das áreas para produção de pimenta-malagueta, geralmente, leva a uma

perda da biodiversidade e simplificação da matriz agrícola, o que facilita surtos populacionais de insetos que se tornam pragas na lavoura (Venzon et al., 2011). A produção de pimenta-malagueta enfrenta alguns problemas, entre eles o ataque de pragas como pulgões, ácaros, mosca branca e tripes, que agem em diferentes fases do ciclo da cultura (Venzon et al., 2006, 2011). O uso de agrotóxicos como método de controle, apesar de este ser um método pouco sustentável, é ainda bastante utilizado na cultura. Assim, práticas de manejo dos cultivos que visem ao controle preventivo e à redução dos impactos de organismos pragas e que aumentem a biodiversidade em função de melhores serviços para o ecossistema, são necessários.

Neste estudo o cultivo de pimenta-malagueta foi usado como modelo, sendo avaliado o efeito de três práticas de manejo nas populações de diferentes grupos funcionais, na abundância e diversidade de joaninhas predadoras da família Coccinellidae (inimigo natural de pulgões principal praga da pimenta) (capítulo 1). As práticas de manejo foram: (a) áreas com a conservação de plantas espontâneas; (b) áreas sem plantas espontâneas e (c) áreas com manejo convencional de pragas (com uso de agrotóxicos) e sem plantas espontâneas. Nos mesmos sistemas de cultivo, foi avaliada a abundância de coccinélídeos em relação a abundância de potências presas e recursos alternativos disponíveis no cultivo de pimenta-malagueta. Adicionalmente, foi avaliada a sobrevivência de larvas de primeiro instar das joaninhas predadoras *Eriopis connexa* e *Harmonia axyridis* alimentadas de ácaro-branco e de recursos florais da planta *Ageratum conyzoides*, uma das plantas encontradas com maior frequência em áreas de cultivo (capítulo 2). Desta forma visamos compreender melhor como as práticas de manejo usadas em cultivos de pimenta-malagueta podem afetar a diversidade de grupos funcionais e como a prática de conservação de plantas espontâneas pode contribuir com as populações de coccinélídeos predadores.

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Chapter I

Effects of management practices used on chili pepper crops in the abundance of functional groups of arthropods

Abstract

In agricultural systems, the management practices play an important role on functional biodiversity. Intensification of agriculture increases the use of pesticides and reduces vegetation diversity, impacting negatively the biodiversity, by reducing the abundance and diversity of functional groups that offer services to agroecosystems. Nevertheless, management practices such as conservation of non-crop plants associated with crop fields offer alternative resources to many arthropods, such as Coccinellidae, important natural enemies for several pests. In this study, we evaluated how management practices used in chili pepper crops affect the functional biodiversity and the abundance and diversity of predatory coccinellids. For this, three management systems were established: (a) fields with the presence of non-crop plants and without pesticides; (b) fields without non-crop plants and without pesticides; and (c) fields with conventional pest management (with pesticides) and without non-crop plants. The management system with non-crop plants positively influenced the abundance of functional groups such as predators, parasitoids, pollinators and herbivorous, as well the abundance and diversity of coccinellids. The species of coccinellids with higher abundance in the systems were *Scymnus rubricaudus*, followed by *Brachiacantha groendali*, *Hyperaspis festiva* and *Cycloneda sanguinea*. Our results indicated the importance of reducing intensive agricultural practices such as pesticide application and habitat simplification to increase biodiversity conservation and biological control.

Keywords: Biodiversity, predators, coccinellids, parasitoids, non-crop plants, pesticides

1. Introduction

Intensification of agriculture has been pointed out as one of the causes of losses in biodiversity (Benton et al., 2003; Kleijn et al., 2011; Landis, 2017). Pesticide use and monocultures are predominant practices in conventional agriculture and have deleterious effects on biodiversity. The growth of the human population has led to an increase in agricultural production, consequently increasing the use of pesticides for pest control (Oerke, 2006; Damalas et al., 2011; Popp et al., 2013; Pretty and Bharucha, 2015). In spite of this, in many cases, the effects on pest control have led to different outcomes and pest species have become resistant to many of these products (Pimentel, 2005; Whalon et al., 2008). In other cases, species that are considered pests reappear in places where insecticides have been applied (resurgence), or species that are not considered harmful increase in number and become pests (Devine and Furlong, 2007; Nicholls, 2008). In addition, the use of pesticides can cause indirect effects on populations of natural enemies by affecting their mobility and the ability to search and recognize the prey, reduction of prey, population growth and reproduction and, ultimately, by killing them (Cloyd, 2012).

Agriculture intensification also has headed to an alteration in the structure of habitat, generating homogeneous fields (Baessler and Klotz, 2006). That is, increasing monoculture environment for the simplification of vegetational diversity eliminating non-crop areas, scrubs and hedgerows (Benton et al., 2003). These simplification cause effects to habitats, due to the reduction of food resources and shelter sites available for natural enemies (Corbett and Rosenheim, 1996; Gurr et al., 2017), decreasing biodiversity, altering thus, negatively the abundance and diversity of natural enemies (Altieri, 1999). Consequently, reducing the biological control of pests (Andow, 1983; Thies and Tschardtke, 1999; Thies et al., 2011; Rusch et al., 2016). In contrast, heterogeneous, diverse or complex habitats enhance the biodiversity (Benton et al., 2003), increasing the populations of natural enemies by offering resources as pollen, nectar, shelter and alternative hosts (Landis et al., 2000). In this way, the adoption of agroecological practices that diversify the habitat have been proposed (Gurr et al., 2003, Norris and Kogan, 2000, 2005; Amaral et al., 2013), such as conserving of non-crop plants, growing associated in the rows or in edges of crop fields (Landis et al., 2000; Gurr et al., 2003). These practices favor the

diversity of plants and natural enemies (Landis et al., 2000; Gurr et al., 2003; Bianchi et al., 2006). By providing resources such as pollen and nectar, that enhances activity and performance of natural enemies, and by providing shelter, alternative hosts and oviposition sites in unfavorable conditions (Altieri, 1994; Landis et al., 2000, 2005). In addition, the coexistence of different species in the same habitat is promoted by increasing vegetational diversity (Janssen et al., 2007; Pell et al., 2008).

Diversified habitat plays an important role improving functional diversity, i.e. organism groups with same traits and function in the ecosystem (Tilman et al., 1997), such as predators, parasitoids and pollinators that offer ecosystem services (Costanza et al., 1997; Hassan et al., 2016). The study of these functional groups allows understand how changes in the habitat can affect the dynamics of the communities and their functioning in the ecosystem (Blondel, 2003).

Chili pepper (*Capsicum frutescens*) agroecosystem is economically important in different regions of Brazil, mainly for the family farming (Pinto et al., 2012). The crop is attacked by different herbivores such as aphids, mites, fruit borers, thrips and whiteflies that can cause negative impact to the production (Venzon et al., 2006, 2011). However, several natural enemies present in chili pepper crops may contribute to the regulation of these pest populations, such as Coccinellidae predators of aphids (Venzon et al., 2011). In spite of this, populations of these predators have been affected in their abundance and diversity by the intensive agricultural practices in crop fields (Grez et al., 2014).

We tested the hypothesis that no pesticide application and the conservation of non-crop plants help to improve functional biodiversity and the populations of coccinellid predators, by increasing their abundance and diversity in chili pepper fields. We evaluated three different systems of pepper cultivation: (a) fields with the conservation of non-crop plants and without application of pesticides; (b) fields without non-crop plants and without application of pesticides; and (c) fields with conventional pest management (with use of pesticides), and without non-crop plants.

2. Material and methods

2.1. Field sampling

The experiment was conducted in eight chili pepper fields (*C. frutescens*) in different small scale farms separated by at least 30 m. located in the municipality of Paula Cândido, state of Minas Gerais, Brazil (20° 52' 26" S, 42° 58' 48" W). In all fields, seedlings were transplanted in October 2015. Plants were spaced 1 m apart within a row and between rows. Each chili pepper field had 300 m² with 300 plants. Three management systems of chili pepper were evaluated: (a) fields of chili pepper with non-crop plants; (b) fields of chili pepper without non-crop plants (control); (c) conventional fields of chili pepper (chemical control of insects) and without non-crop plants. Initially, each management system consisted of three areas, but due to the lack of homogeneity of agricultural practices carried out, according to the previous design established, one conventional field was excluded.

The agricultural practices were similar among fields and based on family agriculture. Standard agricultural practices were used including organic and mineral fertilization. A compound fertilizer NPK (8:28:16) was applied at the rate of 100 g per plant at the time of transplanting. After that, 30 g of NPK (12:6:12) was applied per plant at intervals of 15 days, until 15 March 2016, when the plants were at fructification stage. In addition, foliar fertilizer (Platon-25/1m/L of water) was use in conventional fields.

In fields with non-crop plants and controls, farmers used cow urine (5%) as plant fertilizer (Oliveira et al., 2009) and it was applied to the soil two times after transplanting, at 15 days interval. It was also used as an alternative to pest control (Gahukar, 2013) and was sprayed in the foliage of plants every 15 days, but using concentration of 1%. The applications were performed at the end of the afternoon to avoid burning leaves. For the control of broad mites *Polyphagotarsonemus latus* (Banks) lime sulfur was used (Venzon et al., 2013), no other acaricides and insecticides were applied during execution of the experiment in these fields.

Fields with non-crop plants had a 3 m strip of such plants growing around their edges. Also, strips of 0.30 m of non-crop plants were kept between chili pepper rows.

This procedure was done after 90 days from planting, when the presence of these plants will interfere less on crop production (Reifschneider, 2000), taking into account that the chili pepper agroecosystem is generally characterized by the growth of non-crop plants of the Asteraceae family (Amaral et al., 2016, 2013; Salgado, 2014; Chiguachi, 2018). Nevertheless, the growth of these plants around each chili pepper plant was preventing by manual control every 20 days. Fields without non-crop plants were maintained with bare soil around and inside by using mechanic tools (e.g., hoe and rake), every 20 days, or when needed.

Fields with conventional management had intensive use of synthetic chemicals for control of pests and diseases. According to the farmers, this was done to prevent future infestations that would cause damage to production. This management was defined by the farmers and is the common practice in the region. There was no instruction on the correct use of insecticides because we wanted to show the effects of how is the reality use of these products. These fields were kept free of non-crop plants between chili pepper rows by using mechanic control. Around fields, edges were kept without non-crop plants by applying glyphosate (Roundup/5ml/L). During the experiment, farmers applied monthly the fungicide thiophanate-methyl (Cercobin 500SC/2ml/L), acaricide and insecticide abamectin (Vertimec 18 EC/1ml/L) and insecticide lambda-cyhalothrin (Karate 50 SC/1ml/L).

To evaluate functional diversity in chili pepper with different management systems, we sampled weekly all fields, starting on 17 February 2016 and lasting until 13 April 2016, totalizing nine sampling date. Samplings were done using a sweep net of 0.30 m diameter. In each field, we walked at constant pace along transect of 100 m and we swept the net back and forth through plants. Collected insects were transferred to plastic bags and taken to the laboratory, where they were separated and stored in 70% ethanol for further identification. Subsequently, the arthropods were separated into predators, parasitoids, pollinators, and herbivorous, identified at family level.

Additionally, because the coccinellids are the most important predators of aphids in chili pepper (Amaral et al., 2013), we want to know its abundance and richness the three management systems. For that, in addition to the collection with sweep net explained above where the coccinellids were separated we also collected

coccinellids by beating the chili pepper foliage over a white plastic tray (38.0 x 25.0 x 5.0 cm). The procedure was done before walking with the sweep net. In each field, sampling was done every week in 10 % of the plants (e.g., 10 plants/100 plants). After collection, coccinellids were individualized to vials with 70% ethanol, and taken in the laboratory of Entomology (EPAMIG) for identification. Coccinellids collected with both methods were reunited and identified at species level.

2.2 Statistical analysis

The effects of management of practices on the abundance (i.e. total number of individuals) of predators, parasitoids, pollinators and herbivorous, were analyzed by generalized linear models (GLM), assuming a Poisson distribution (count of arthropods collected by treatment field). The models were submitted to residue analysis to test the optimal adequacy of the error distribution and corrected for negative binomial when detected overdispersion of the data (Crawley, 2013). The significance of each term was assessed using Chi-square test, based on an estimated mean deviance parameter. Analysis of variance (ANOVA) was used to observe the effect of treatment in the abundance of arthropods. When significant differences were observed ($p < 0.05$), comparisons of means (considering the number of repetitions per treatment) were submitted to contrast analysis using the RT4Bio package.

Coccinellids collected by beating foliage over a collection tray and with sweep net were subjected to abundance assess (i.e. total number of individuals) and richness (i.e. total number of species) among the three management systems (non-crop plants, control and conventional), through generalized linear mixed models (GLMM), using a Poisson distribution (count of coccinellids collected by treatment field and sampling date). The collection dates were only considered as a random factor in the analysis. The significance of each term was assessed using Chi-square test, based on an estimated mean deviance parameter. Analysis of variance (ANOVA) was used to observe the effect of treatment in the abundance and species richness of coccinellid predators. When we analyzed the three management systems, a combination of treatments for the verification of the differences between the means (considering the

number of repetitions per treatment) was done through generalized linear models (GLM), using a Poisson distribution. To remove the effect of temporal pseudo repetition, caused by repeated collections in each area, the lme4 package was used. All statistical analyses were performed on platform R version 3.3.1. (R Core Team, 2017).

3. Results

A total of 1189 arthropod predators were collected in all sampling fields, and were significantly affected by the management system (Chi-square = 80.804, $df = 2$, $P < 0.0001$). Their abundance was higher in fields with non-crop plants, followed by fields without non-crop plants and no pesticides, and conventional fields (Table 1). There was no significant difference between the means of these last two treatments. Insects of the family Formicidae were the more abundant group of predators, mainly in fields with non-crop plants. They were followed by predators of the Coccinellidae (collected only with sweep net), which showed more abundance in fields with non-crop plants than in fields without non-crop plants and in conventional management fields. Syrphidae, Anthocoridae and Dolichopodidae were found in less quantity but their abundances were still higher in fields with non-crop plants than in the other management systems. Arthropods belonging to Order Araneae and Families Vespidae, Sphecidae and Forficulidae had the lowest abundance (Fig. 1).

A total of 1169 Hymenoptera parasitoids were collected in all the sampled fields, represented by ten families. The abundance of these parasitoids was significantly affected by the management system (Chi-square = 84.759, $df = 2$, $P < 0.0001$). Fields with the maintenance of non-crop plants had more parasitoids, followed by conventional fields and fields without non-crop plants (Table 1). The most abundant families of parasitoids found were Pteromalidae, Scelionidae and Platygasteridae with average of 5.7 ± 1.1 , 4.5 ± 1.0 and 4.3 ± 1.1 of individuals per field with non-crop plants, respectively. The majority of parasitoid families had high densities in fields with non-crop plants than in the other management systems, except Encyrtidae and Ceraphronidae that did not have a different abundance among the management systems.

The abundance of insect pollinators were positively affected by management

systems (Chi-square = 55.739, df = 2, $P < 0.0001$), being more abundant, with average of 1.2 ± 0.3 , in fields with non-crop plants. Only the families Halictidae, Apidae and Andrenidae were found.

Herbivores were affected by the management systems (Chi-square = 78.751, df = 2, $P < 0.0001$), being more abundant in fields with non-crop plants with average of 98.3 ± 14.7 . Families Cicadellidae, Chrysomelidae, Melyridae and Miridae showed the highest densities in fields with non-crop plants. Despite of this, from observations made in the fields, no damage was observed in the chili pepper crop. In contrast, insects of the family Aphididae, one of the main pests of chili pepper crop, were found and affected by the management system. They showed a higher abundance in fields with conventional management when compared to fields with non-crop plants and without non-crop plants.

The abundance of the family Coccinellidae (sweep net plus by foliage beating), in fields of chili pepper was affected by the management system (Chi-square = 92.273, df = 2, $P < 0.001$) and there was a significant difference in all cases: conservation of non-crop and conventional (Chi-square = 87.93, df = 2, $P < 0.0001$), conventional and control (Chi-square = 20.163, df = 2, $P < 0.0001$) and non-crop plants and control (Chi-square = 54.748, df = 2, $P < 0.0001$) (Fig. 2). Thus, the coccinellid population was more abundant in fields with non-crop plants with average of 6.5 ± 0.6 , followed by control with average of 2.7 ± 0.3 and by conventional fields with average of 1.3 ± 0.4 coccinellids per field. During experimental period, we observed that the abundance of coccinellids remained constant during most of the time in fields with non-crop plants, while in the other management systems it oscillated (Fig. 3).

The species richness also was affected by the management system (Chi-square = 9.628, df = 2, $P < 0.001$), and it was higher in fields with non-crop plants. There was significant difference between fields with non-crop and conventional (Chi-square = 9.2343, df = 2, $P < 0.001$); and there were no significant differences between conventional and control (Chi-square = 2.2022, df = 2, $P = 0.3325$), and non-crop plants and control fields (Chi-square = 3.1946, df = 2, $P = 0.2024$) (Fig. 4).

The coccinellid species with the highest abundance were *Scymnus rubricaudus*

(Casey, 1899), followed by *Brachiacantha groendali* (Mulsant, 1850), *Hyperaspis festiva* (Mulsant, 1850) and *Cycloneda sanguinea* (L.). *Harmonia axyridis* (Pallas) and *Diomus agapitus* (Gordon) were found only in fields with non-crop plants, and *Scymnus loewii* (Mulsant, 1850) was only found in fields without non-crop plants (Fig. 5).

4. Discussion

Our study revealed that the management practices, regarding the presence of non-crop plants, affected the abundance of functional arthropod groups in chili pepper. In general, abundance of these groups was higher in fields with non-crop plants and without pesticide use. Populations of predators and parasitoids were enhanced in these fields. These two groups are important because they can provide the ecosystem service of pest control (Costanza et al., 1997; Kremen and Miles, 2012). Another important group found in chili pepper fields were pollinators. Their abundance was higher in fields with non-crop plants without application of pesticides than in the other management systems. However, the low abundance and diversity of pollinator species found in all fields may be due to the collection method employed. Despite this, is important to highlight the relationship that has the conservation of non-crop plants in chili pepper crops with pollinating insects and the positive effects on chili pepper production (Oliveira 2014).

This study also showed how functional groups varied in their abundance depending on the management system. Generally, fields with non-crop plants and without application of insecticides had greater abundance of predators and parasitoids. This support studies that show that abundance of natural enemies increases in more diverse habitats (Bianchi et al., 2006; Gardiner et al., 2009a) and without application of pesticides (Bengtsson et al., 2005), promoting higher biodiversity. The low abundance of individuals found in functional groups such as predators, parasitoids and pollinators in chili pepper fields with practices as the application of pesticides can be explain by the susceptibility these groups have to the exposure of insecticides (Xu et al., 2001; Bommarco et al., 2011; Vanbergen and the Insects Polinators Initiative, 2013). The use of pesticides is not the only cause of the low abundance of functional groups; we found that the monoculture system without application of pesticides also reduced the abundance of these groups. This effect may

be due to lack of alternative resources available, refuge for overwintering, oviposition sites and moderate microclimate caused by habitat simplification (Altieri and Nicholls, 2004). Contrary to diversified habitat that by the maintenance of non-crop plants offer alternative resources such as pollen, nectar, alternative prey and host for natural enemies (Landis et al., 2000; Norris and Kogan, 2005; Gurr et al., 2017). This is because, non-crop plants usually have a diversity of flowers that provide nutritionally adequate food such as floral nectar and pollen that support survival and reproduction (Wäckers and van Rijn, 2012; Amaral et al., 2013), providing both energy and essential proteins for natural enemies (Wäckers et al., 2007). The availability of these resources in diversified habitats increases the abundance and diversity of populations of natural enemies, contributing to improve the control of pests (Bianchi et al., 2006; Gardiner et al., 2009a).

Here we also find high abundance and diversity of herbivores in the management system with non-crop plants, however, in personal observations no important damage to chili pepper crop was registered, perhaps due to the fact that the herbivores collected are not considered important pest of this crop. In many cases, non-crop plants provide shelter and resources serving as reservoir for herbivores (Norris and Kogan, 2000) and thus avoiding in some cases outbreak to the main crop (Risch, 1987). An important aspect of this study was the increase in the abundance of the family Aphididae in conventional fields, important pest of chili pepper crop (Venzon et al., 2006), even with the applications of insecticides. This may be explained because the application of insecticides causes disturbances to the ecosystem and generates different responses to those expected (Pimentel, 2005; Popp et al., 2013) and thus increase its population despite the application of the insecticide. Besides, the practices used in the region where the experiment was developed could also increase the abundance of the aphids due to the excessive and regular application of pesticides, not following the recommendation offered by professionals; and use of products not allowed for the chili pepper crop.

We found different predators groups and were more abundant in areas with the conservation of non-crop plants. These results confirm the positive and strong relationship between the abundance of predators and the diversity of plants (Dassou and Tixier, 2016) because the availability of floral resources, abundance of prey and moderate microclimate (Landis et al., 2005). In addition to shelter provisioning that reduces competition and intraguild predation (Finke and Denno 2006), allowing

coexistence among predatory species and promoting a better biological control of pests (Amaral et al., 2015).

In this study, we focused in predators of family Coccinellidae that are likely found in chili pepper crops (Amaral et al., 2013), and are important natural enemies of aphids (Obrycki et al., 2009), one of the major pest of chili pepper. The population of coccinellids was maintained higher in fields where the non-crop plants were present and lower in fields without non-crop plants and with spraying of pesticides. Probably, coccinellids were favored by the resources that different non-crop plants can offer for adults and larvae, as pollen and floral and extrafloral nectar (Burgio et al., 2004, Lundgren, 2009, Amaral et al., 2013), supplying nutrients and energy that contribute to an increase in their survival (Lundgren, 2009, Hodek and Evans, 2012). Similarly, studies have found that coccinellids are benefited by more diversified habitat, for example, conservation of native non-crop plant communities (Amaral et al., 2013), non-crop plants associated hedgerows (Burgio et al., 2004), and wildflower plantings (Blaauw and Isaacs, 2015).

The diversity of species was also favored by the presence of non-crop plants in chili pepper crop; we found with the highest relative abundance the species *Scymnus rubricaudus*, *Brachiacantha groendali*, *Hyperaspis festiva* and *Cycloneda sanguinea*. These species have been found in South America (Gordon et al., 2014; Resende et al., 2006; Harterreiten-Souza et al., 2012) and mainly *H. festiva* and *C. sanguinea* have been observed feeding on aphids (Resende et al., 2006). Thus, the maintenance of non-crop plants help to conserve the biodiversity of species and reduce ecological disturbances that can be caused by the invasion and domination of other species (Didham et al., 2007). Species of coccinellids respond differently according to the habitat composition to which they are exposed (Gardiner et al., 2009b). For example, studies have shown that native species increase in less disturbed habitats and on the contrary, exotic species reduce their populations (Greze et al., 2013).

Harmonia axyridis is a specie exotic considered highly competitive and its establishment is related to the decline of native species (Evans 2004; Harmon et al., 2007; Roy et al., 2012, Bahlai et al. 2015). Here this species only found in fields with non-crop plants although the abundance was relatively low, this can be explained by the low abundance of aphids found in all management systems. Since the presence and dispersion of *H. axyridis* is positively related to the prey availability as aphids (Brow et al., 2011). Despite the low abundance of this species in fields with non-crop

plants in this study we confirm there is a dynamic and diverse coccinellid populations mainly due to refuge provision that allows the coexistence between species by the reduction of intraguild predation (Osawa, 2011) and a greater availability of food resources that reduce competition between coccinellid predators (Amaral et al., 2015).

In this study, we found that chili pepper crop with a conventional management system had a negative impact on decreased abundance of different functional groups and on decreased of abundance and richness of coccinellids. This reflects how management practices in crops associated with the intensive use of pesticides to control pests and diseases can affect non-target arthropods (Biondi et al., 2012). Organisms such as parasitoids and predators can be exposed to intoxication when they come in contact with prey or floral resources contaminated with insecticides (Fernandes et al., 2010; Wang et al., 2008; Wanumen et al., 2016). Causing lethal (death) and sublethal effects by altering the reproduction, offspring, longevity and feeding behavior (Stark and Banks, 2003; Desneux et al., 2007; Cloyd, 2012). Finally, harming the attack and search behaviors of prey, decreasing their efficiency in biological control (Pimentel, 2005).

Our results demonstrate that diversified habitats with non-crop plants favor the abundance of functional groups that offer diverse services to the ecosystem, including biological control. This study is supported by “enemies hypothesis” which predicted that abundance of predators and parasitoids increase in diversified habitats (Root, 1973), showing a positive relationship between the increase in abundance and richness of natural enemies and the reduction of pest attack (Letourneau et al., 2009). Besides the conservation of non-crop plants the non-application of pesticides is necessary to increase the abundance of various functional groups, as well as the population of coccinellid predators important by offering services to the ecosystem mainly in biological control.

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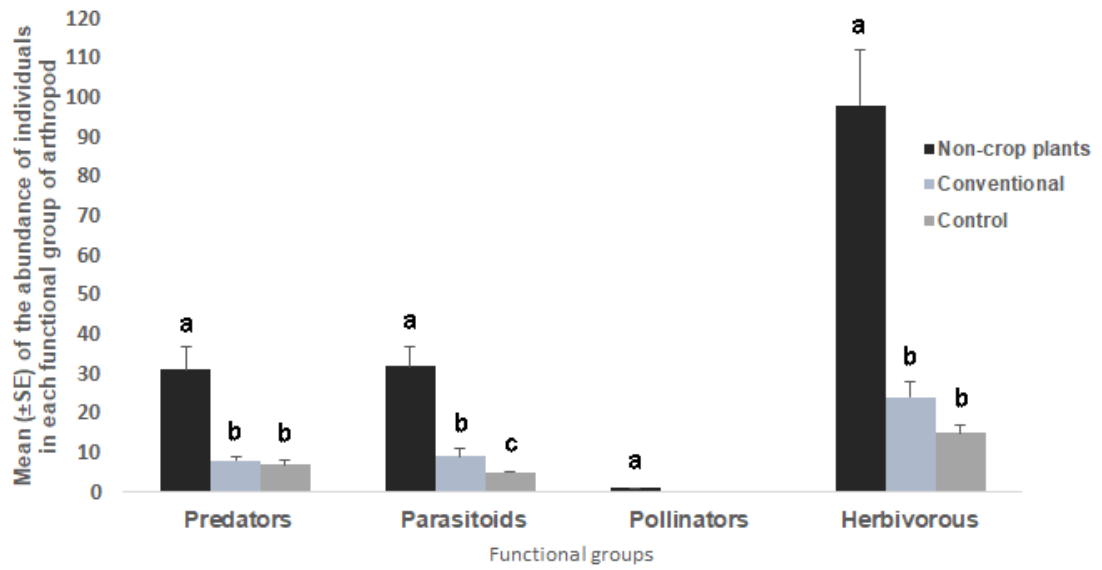


Figure 1. Mean (\pm SE) of the abundance of individuals in each functional group of arthropod collected with sweep net in chili pepper fields in Paula Cândido (Minas Gerais, Brazil), between February to April 2016, with different management systems: with non-crop plants (three sampling areas), conventional (two sampling areas), and without non-crop plants (three sampling areas), referred as control. Bars with different letters are statistically different from each other.

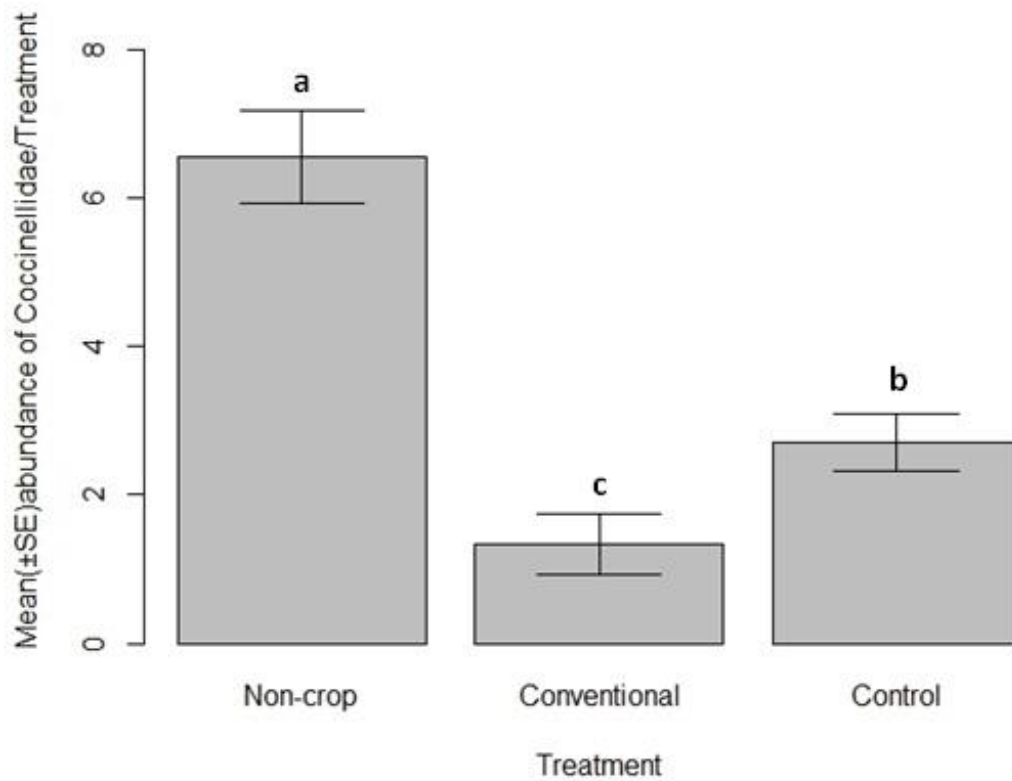


Figure 2. Mean (\pm SE) of the abundance of Coccinellidae collected in 30 chili pepper plants per field with plastic tray plus collections with sweep net in three fields with non-crop plants, two fields conventional and three fields without non-crop plants (control). Sampling was carried out weekly from February to April 2016, in Paula Cândido, Minas Gerais, Brazil. The abundance in fields of chili pepper was affected by the management system (Chi-squared = 92.273, df = 2, $P < 0.001$). Bars with different letters are statistically different from each other.

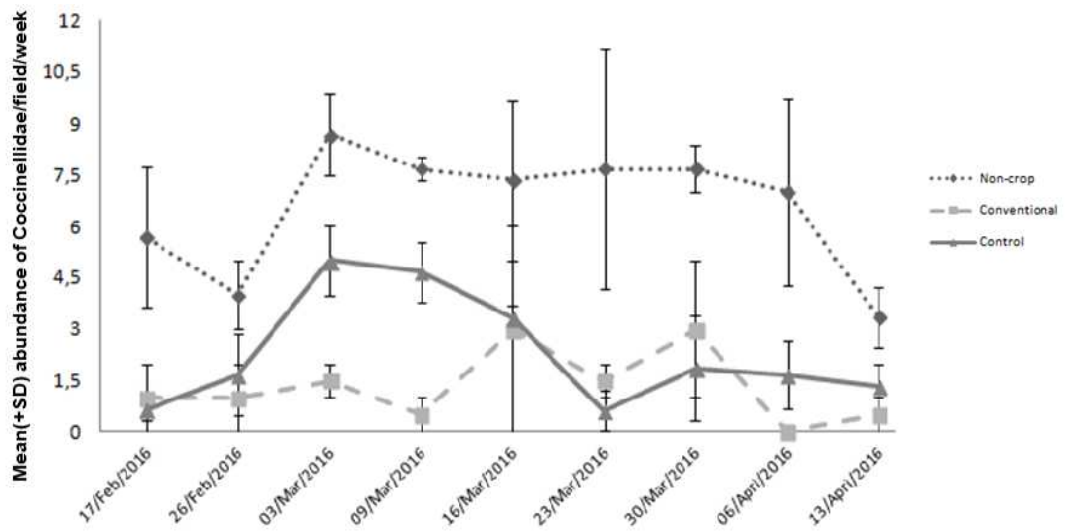


Figure 3. Mean (\pm SD) of the abundance Coccinellidae (per treatment per week sampled) collected in 30 chili pepper plants with plastic tray plus collections with sweep net in three fields with non-crop plants, two conventional and three fields without non-crop plants (control). Sampling was carried out weekly from February to April 2016, in Paula Cândido, state Minas Gerais.

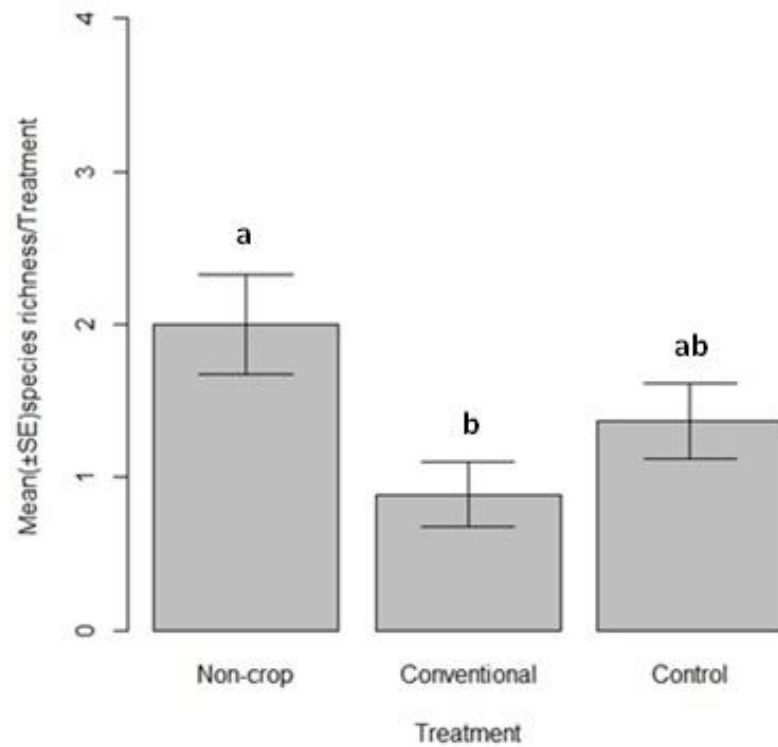


Figure 4. Mean (\pm SE) of species richness of Coccinellidae collected by field in 30 chili pepper plants with plastic tray per field plus collections with sweep net in three fields with non-crop plants, two fields conventional and three fields without non-crop plants (control). Sampling was carried out weekly, in Paula Cândido, state Minas Gerais, Brazil. The richness in fields of chili pepper was affected by the management system (Chi-square = 9.628, df = 2, $P < 0.001$). Bars with different letters are statistically different from each other.

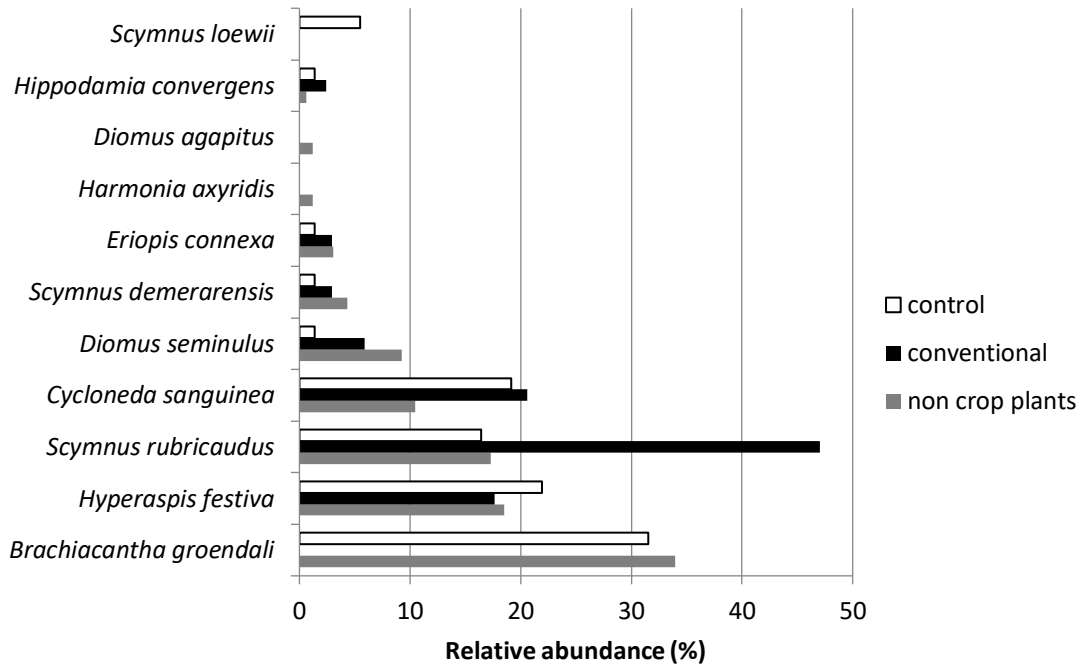


Figure 5. Species composition of the Coccinellidae community collected by field in 30 chili pepper plants with plastic tray per field plus collections with sweep net in found in three management systems (non-crop plants, conventional and without non-crop plants/control) in chili pepper from February to April 2016 in Paula Candido, Minas Gerais, Brazil.

Chapter II

Response of coccinellids to the management of non-crop plants and to the availability of alternative foods in chili pepper crop

Abstract

The conservation of non-crop plants associated with crops has been used as a strategy that can offer benefits to predator populations due to the provision of alternative resources and shelter. Predatory coccinellids feed mainly on aphids, but have been found in chili pepper fields co-occurring with high infestations of broad mites (*Polyphagotarsonemus latus*), and with low presence of aphids. In this work, we evaluated the abundance of Coccinellidae in relation to the abundance of potential prey and alternative resources available in the crop of chili pepper (*Capsicum frutescens*), with and without the presence of non-crop plants. We evaluated whether first instar larvae of *Eriopis connexa* and *Harmonia axyridis* feed on broad mites and alternative resources. The conservation of non-crop plants in chili pepper fields favored higher abundance of coccinellids. Alternative foods were found in the agroecosystem of chili pepper with non-crop plants, such as broad mites and floral resources of several non-crop plants. First instar larvae of both species fed actively on broad mites. The survival of *E. connexa* was greater when it fed only broad mites and when broad mites were offered together with flowers of *Ageratum conyzoides*; *H. axyridis* survived for more days only when it was fed with broad mites together with flowers of *A. conyzoides*. But none of the two species completed pre-imaginal development. In this way, the strategy of conservation of non-crop plants associated with chili pepper fields favors the abundance of coccinellids.

Keywords: *Eriopis connexa*, *Harmonia axyridis*, broad mites, *Ageratum conyzoides*, predation

1. Introduction

The growth of the population in recent years has led to the intensive use of the land to increase agricultural productivity (Tilman et al., 2011; Popp et al., 2013; Struik and Kuyper, 2017; Acevedo et al., 2018). Practices used to this aim have headed to the expansion of areas in monoculture, to the increase in use of inputs as fertilizers and pesticides (fungicides, insecticides, herbicides), and high-yielding varieties (Matson et al., 1997; Tilman et al., 2002; Pretty and Bharucha, 2014). The use of these practices causes strong impacts to the environment such as pollution of the air, water and soil (Stoate et al., 2009), and reduction of biodiversity (Benton et al., 2002, 2003; Landis, 2017). These are mainly due to the intensive use of pesticides to control one of the biggest problems of agricultural production, which it is the attack of pests, and are responsible to cause considerable losses to crops (Popp et al., 2013). However, the intensive use of pesticides has caused harmful effects, such as increased resistance, resurgence of pests (Nicholls, 2008) and mortality of natural enemies (Pimentel, 2005).

Habitat manipulation has been used as an alternative to mitigate disturbances in the environment and in arthropod populations (Landis et al., 2000; Jonsson et al., 2015). The use of alternative practices such as vegetational diversification, seek to increase the availability of resources to optimize the populations of natural enemies (Gurr et al., 2003, 2017; Tscharncke et al., 2007), which leads to an efficient biological control of pests (Bianchi et al., 2006).

Several strategies have been explored to obtain vegetational diversity, among them the conservation of non-crop plants growing as stripes, field margins or adjacent to crops (Schmidt et al., 2005; Amaral et al., 2013). This strategy has contributed to the increase in the availability of alternative resources such as pollen, nectar and alternative prey, refuge to face adverse conditions (Norris and Kogan 2005; Rodriguez-Saona et al., 2012), serve as reservoir for the early arrival of natural enemies and enhance pest suppression on crops (Bianchi et al., 2006; Macfadyen et al., 2015). Specifically, the availability of resources and alternative prey has increased the abundance and diversity of different natural enemies. Thus, pollen offers different nutrients such as proteins, amino acids and lipids, nectar (sucrose, glucose and fructose) and alternative prey supply energy (Lundgren, 2009a; Hodek and Evans, 2012). Moreover, these resources promote longevity and fecundity of

natural enemies (Gurr et al., 2017). Beneficial organisms such as predators have been reported to have a positive effect on their populations with increased habitat diversity (Purtauf et al., 2005; Burgio et al., 2006; Schmidt et al., 2008; Gardiner et al., 2009; Amaral et al., 2013, 2016). Mainly, generalist predators have responded positively to increase plant diversity due to their broad diet, adaptive behaviors and searching strategies (Symondson et al., 2002), supply of alternative resources (Landis et al., 2005), and refuge sites that reduce intraguild predation (Finke et al., 2006).

Predators of the family Coccinellidae are considered generalists due to their broad nutritional diet (Hodek and Honěk, 2009). Besides aphids, they can feed on other prey such as scales, mealybugs, psyllids, whiteflies and spider mites (Biddinger et al., 2009), as well as on plant resources such as nectar and pollen. They can feed on fungi and foliage of plants (Lundgren, 2009b). These alternative resources become important when the prey population is declined (Giorgi et al., 2009; Hodek and Evans, 2012). These predators use alternative foods that are more likely found in more diversified habitats, and they can improve reproduction, avoid mortality in the state of diapause (Lundgren 2009b), and increase survival rates, especially when floral resources are supplied (Amaral et al., 2013; Fonseca et al., 2017). Alternative prey can be used by coccinellids in their diets, for example, several Stethorini species are specialist predators of spider mites (Biddinger et al., 2009). Other Coccinellid species as *Coleomegilla maculata* (Rondon et al., 2004; Weber and Lundgren, 2009), *Eriopis connexa* (Germar), *Cycloneda sanguinea* (L.) (Venzon et al., 2009) and *Adalia bipunctata* (Robinson) also feed on spider mites as alternative food. When alternative prey and plant resources are offered together, predator fitness may be improved (Lundgren, 2009a). Nevertheless, the effect of diet on coccinellid populations depends on the quality and composition of the alternative resources offered (Lundgren, 2009b; Hodek and Evans, 2012).

In this study, we evaluated the abundance of Coccinellidae in relation to the abundance of potential prey and alternative resources available in the crop of chili pepper (*Capsicum frutescens*) with and without the presence of non-crop plants. The use of chili pepper was due to its economic importance to various regions of Brazil, mainly for small-scale family farming (Ohara and Pinto, 2012). Chili pepper is attacked by different species of pests that cause a negative impact on the crop (Venzon et al., 2006, 2011). Therefore, more sustainable practices to control pest are necessary. We investigated whether alternative prey and plant resources present in

the agroecosystem of chili pepper would play a role on survival of two common predatory Coccinellidae species: *Eriopis connexa* and *Harmonia axyridis*. *Eriopis connexa* is endemic of southern South America and *H. axyridis* (Pallas) is an invasive species native from Asia (Komai, 1956) and found in South America in 2001 (Almeida and da Silva, 2002). Both species are often encountered in the cropping system of chili pepper and are important predators of aphids and other chili pepper pests.

In addition to field studies, we performed laboratory trials to quantify the predation rate and survival of *E. connexa* and *H. axyridis* on broad mites (*Polyphagotarsonemus latus*) as possible alternative prey. We also evaluated the role on non-crop plants as a food resource for these coccinellids. We aimed to investigate whether: (i) abundance of Coccinellidae increases in relation to the abundance of potential prey and alternative resources available in the crop of chili pepper with and without the presence of non-crop plants; (ii) non-crop plants provide alternative prey and sources for the coccinellids; and (iii) first instar larvae of the coccinellids feeding on broad mites and other alternative resources enhancing their survival.

2. Materials and methods

2.1. Abundance of coccinellids on chili pepper crop

The abundance of coccinellid on chili pepper (*C. frutescens*) crop with presence/absence of non-crop plants was evaluated due to the importance of these predators as natural enemies of pests in this crop, mainly to control aphids (Venzon et al., 2011). Sampling were conducted in six chili pepper fields located in the municipality of Paula Cândido, State of Minas Gerais, Brazil (GPS coordinates 20° 52' 26" S, 42° 58' 48" W), from October 2015 to April 2016. Chili pepper seedlings were transplanted in October 2015. Each chili pepper fields had 300 m² and plants were spaced 1 m apart within a row and between rows.

The agricultural practices were similar among fields and based on small-scale family farming. Standard agricultural practices were used including organic and

mineral fertilization. The plants were managed using mechanic tools (e.g., hoe and rake), with minimal tillage. A compound fertilizer NPK (8:28:16) was applied at the rate of 100 g at the time of transplanting. After that, 30 g of NPK (12:6:12) was applied per plant at intervals of 15 days, until 15 March 2016, when the plants were at fructification stage. Due to infestation observed of broad mite *P.latus* was used to control lime sulfur at concentration of 1%, no other acaricides and insecticides were applied during sampling period. To confirm this infestation of broad mite in chili pepper plants, in each field 15 plants were selected randomly and 3 leaves from each plant were removed and placed in a paper bag and taken to the laboratory to be observed under the stereomicroscope (Zeiss-Discovery v8) and confirm if there was live mites.

Three fields of chili pepper were with presence of non-crop plants and three fields without non-crop plants. Fields with non-crop plants had a strip of 3 m such plants growing in their edges. Also, strips of 0.30 m of non-crop plants were kept between chili pepper rows. This procedure was done after 90 days from planting, when the presence of these plants will interfere less on crop production (Reifschneider, 2000). Nevertheless, the growth of these plants around each chili pepper plant was prevented by manual control every 20 days. Fields without non-crop plants were maintained with bare soil around and inside by using manual tools every 20 days or when needed.

To quantify the abundance of Coccinellidae, all fields were sampled weekly from 8 December 2015 and until 13 April 2016, totalizing 18 sampling date. Sampling was done in all fields by beating the chili pepper foliage over a white plastic tray (38.0 x 25.0 x 5.0 cm). In each field, sampling was done in 10% of the plants. After collection, coccinellids were transferred individualized to vials with 70% alcohol, and taken in the laboratory of Entomology (EPAMIG) for identification. In addition, coccinellid sampling was also done using a sweep net of 0.30 m diameter walking at constant pace along a transects of 100 m we swept the net back and forth through plants. Collected insects were transferred to plastic bags and taken to the laboratory, where coccinellids were separated from other insects and stored in 70% ethanol for further identification.

To identify alternative resources from non-crop plants the most abundant non-crop plant species in the three fields were quantified using a tape measure stretched in a line-transect of 20 m between chili pepper lines (adapted from Auld, 2009). The

tape measure was stretched in three randomly transects parallels inside each field. After that, every 2m of each transect a point was fixed. In each point, the plant inside a quadrat of 25 x 25 cm were counted and characterized (adapted from Amaral et al., 2013). Unknown plants were collected for later identification in laboratory. The non-crop plants were sampled three times during the execution of the experiment, on 4 February, 16 March and 18 April 2016. In total, 30 points for repetitions (3 fields with non-crop plants) totalizing 90 points per date/field for a total of 270 points during all experiment.

To verify the possible preys consumed by coccinellids in the chili pepper, a sampling was done using a sweep net of 0.30 m diameter. In each field, we walked at constant pace along a transect of 100 m and we swept with net back and forth through plants, collected insects were transferred to plastic bags and taken to the laboratory where the main prey consumed by coccinellids were only separated and identified.

Coccinellids abundance (i.e. total number of individuals including adults and larvae) was compared between fields with and without non-crop plants, through generalized linear mixed models (GLMM), using a Poisson distribution. The significance of each term was assessed using Chi-squared test, based on an estimated mean deviance parameter. To remove the effect of temporal pseudo repetition, caused by repeated collections in each area, the lme4 package was used. All statistical analyses were performed on software R version 3.3.1. (R Core Team, 2017).

2.2 Laboratory experiments

From the field observations, we have found that the period of higher abundance of coccinellids coincided with a period of higher broad mite infestation in chili pepper and low presence of aphids, the main prey of coccinellids. For this reason, we carried out feeding tests with broad mite as potential prey of coccinellid predators. The species used in the broad mite predation tests were *E. connexa* and *H. axyridis*, since they are predators commonly associated to the agroecosystem of chili pepper and feed on different insects and mites (Venzon et al., 2011, Amaral et al., 2013). In

addition, they were found during our sampling. Besides, they are easy to rear in the laboratory, which allow us to test our hypothesis.

2.2.1 Predators and prey rearing

Eriopis connexa and *H. axyridis* were obtained from an initial rearing of adults collected in the Vale de Agronomia of Federal University of Viçosa (UFV). Adult couples were kept in plastic containers of 500 ml and maintained at 25 ± 1 °C, 16:8 L:D and $65 \pm 5\%$ RH. The eggs laid by the females were separated and as soon as the larvae hatched, they were individualized in plastic containers of 10 ml. Larvae and adults were fed *ad libitum* with aphids (*Myzus persicae*), reared in a greenhouse on cabbage plants) and with eggs of *Anagasta kuehniella* (Zeller) (Lepidoptera: Pyralidae). Water was provided with a moistened cotton ball. Honey was provided only for adults in a thin layer on the inner walls of the plastic containers.

Broad mites *P. latus* were collected in the municipality of Paula Cândido (Minas Gerais, Brazil, 20° 52' 26" S, 42° 58' 48" W) from infested chili pepper plants in January 2016. They were rearing in bean plants that were obtained by sowing seeds in a commercial substrate (Tropstrato®, HT hortaliças, Brazil) inside plastic pots of two liters kept in a greenhouse for fifteen days. After that, infested plants were taken and kept in the laboratory. For the maintenance of mite rearing, new plants of beans were placed every week.

Aphids were collected from cabbage plants that were obtained by sowing seeds (Topseed®, cabbage seed) in a commercial substrate (Tropstrato®, HT hortaliças, Brazil) in polystyrene trays (67 x 34 x 5.5 cm and 128 cells), in a greenhouse. When seedlings had 45 days post-emergence, they were sown in a commercial substrate (Tropstrato®, HT hortaliças, Brazil) inside plastic pots of two liters, kept in greenhouse and were infested with aphids.

2.2.2 Coccinellid predation on broad mites

Predation rate of coccinellids was recorded for the first instar larvae of *E. connexa* e *H. axyridis*, obtained from the rearing previously established in the laboratory. As soon as the larvae emerged, they were individualized in plastic containers of 10 ml with a moistened cotton ball and left without food for 24 hours. Predation rate of first instar larvae was observed on arenas consisting of chili pepper leaf discs (3 cm in diameter) placed individually on a Petri dish (5 cm in diameter) filled with agar. Leaf discs were fixed on agar with their abaxial side up, since this side of the leaf is usually chosen for oviposition and feeding by *P. latus*. The agar around the leaf disc was cut and removed, and water was added later to hydrate the agar and prevent predator larvae and mites from escaping.

Each leaf disc received 100 broad mites of different stages including larvae and adults. First instar larvae of each coccinellid species were added individually to each arena. During a period of 10 minutes, each larvae was observed and its predation on the broad mite was registered with the aid of a stereomicroscope (Zeiss-Discovery v8). The number of mites that the larvae consumed completely was registered. For each species of coccinellid, 30 replicates were done. The means of predation rate were compared by the “t” test after verifying the heterogeneity of the variance.

2.2.3 Broad mite mortality from coccinellids

To evaluate whether predation of the coccinellid larvae would reduce *P. latus* population, we used chili pepper seedlings as arenas. They were obtained by sowing pepper seeds in a commercial substrate (Tropstrato®, HT hortaliças, Brazil) in polystyrene trays (67 x 34 x 5.5 cm and 128 cells), in a greenhouse. When seedlings had two pairs of true leaves (30 days post-emergence) they were used in the experiments. Each seedling was carefully inspected for arthropod presence with the aid of a stereomicroscope (Zeiss-Discovery v8). After that, each pepper seedling was conditioned in glass vials containing cotton with water to keep the seedling fresh. Each seedling was infested with 100 broad mite adults. Mites were transferred from infested bean leaves to seedling with the aid of a brush under the stereomicroscope (Zeiss-Discovery v8).

After the mites were transferred to the seedlings, newly hatched first instar larvae of *E. connexa* or *H. axyridis* from the laboratory colony, as explained above, were placed individually on each seedling. The infested seedling and the larvae were kept inside a plastic pot (500 ml). Predators were removed along with the seedlings from the plastic pot after 24 hours. The seedling were carefully inspected and the remaining mites were counted under the stereomicroscope (Zeiss-Discovery v8). A control treatment with only broad mites without predators was carried out in order to correct for broad mite mortality. A total of 64 replicates were done for *E. connexa*, 56 for *H. axyridis* and 64 for control treatment. The percentage of mortality due to predation for the first instar larvae of coccinellids was calculated using Henderson and Tilton formulae (1955). The “t”-test was used to compare the means of percentage of mortality of broad mites caused by predation of *E. connexa* and *H. axyridis* after verifying the heterogeneity of the variance.

2.2.4 Survival of coccinellids feeding on broad mites and on non-crop flowers

After observing that the two species of coccinellids tested were able to feed on the broad mite, we evaluated the effect of the broad mite as prey on the survival of the predators. Additionally, as we found a higher population of coccinellids in fields with non-crop plants, we also evaluated the role of such plant resource on their survival. One of the most common plant species found at the fields, *Ageratum conyzoides* (Table 1) was selected for this experiment. We quantified the survival of *E. connexa* and *H. axyridis* feeding on broad mites and on non-crop flowers of *A. conyzoides*, and on a mixed diet.

First instar larvae of each species were taken from rearing and individualized in plastic containers (10 ml) with a moistened cotton ball. After a period of 24 hours without food, larvae were used for the experiment. The following diets were offered to first instar larvae of *E. connexa* and *H. axyridis*: (i) 100 broad mites offered on chili pepper seedlings; (ii) 20 aphids (*M. persicae*) for *E. connexa* and 25 aphids for *H. axyridis* offered on chili pepper seedlings (numbers of aphids were decided in preliminary tests to avoid that larvae died due to starvation); (iii) flowers of *A. conyzoides* (six flowers); (iv) flowers *A. conyzoides* (six flowers) and 100 broad

mites offered on chili pepper seedlings; and (v) clean chili pepper seedlings (control).

Chili pepper seedlings were obtained by sowing seeds of *C. frutescens* in polystyrene trays (67 x 34 x 5.5 cm and 128 cells) with a commercial substrate (Tropstrato®, HT hortaliças, Brazil). Seedlings with two pairs of true leaves, approximately 30 post-emergence days, and free of arthropods were used in the experiments. For the infestation of chili pepper plants with the broad mites and aphids, a fine paintbrush was used. Broad mites and aphids were obtained from the previously established rearing as explained above.

In order to obtain flowers of *A. conyzoides* free of arthropods for the experiments, we collected plants in the field of the UFV and transplanted to plastic pots of two liters with a mixture of soil and commercial substrate. Pots were kept in a greenhouse and once plants had enough dried flowers, the seeds were taken and sowed in plastic pots of two liters with the same soil mixture. Plants were kept inside wooden framed cages covered with a fine mesh after 50 days post-emergence approximately, when they start flowering, they were used in the experiments. To carry out the experiments, the flower petioles were cut and formed branches (six flowers). They all observed under the microscope to ensure that they were free of arthropods.

Each replicate consisted of one larvae *E. connexa* or *H. axyridis* on a seedling of chili pepper, flowers or with both. For this, each larvae was individualize previously in plastic containers 10 ml with a moistened cotton ball and left without food for a period of 24 hours, after each larvae was placed on chili pepper seedlings, flowers or both mixed depending on the treatment. To keep fresh pepper seedling, branches of flowers or both, they were conditioned in glass vials containing cotton with water. Each glass vial plus the larvae was placed inside a plastic pot (500 ml) and closed with a voile cover. After 24 hours, survival and developmental stage of the each larva was evaluated. Alive larvae were transferred for the same treatment but with new chili pepper seedling, flowers of *A. conyzoides* or both, according to the treatment. A total of 30 repetitions per treatment were made and each one was observed until adult emergence or death of the insect.

Survival of coccinellids in the different diets were estimated by the Kaplan-Meier technique and compared using the log rank test (Kaplan and Meyer, 1958).

The Bonferroni method was used to correct the significance level for multiple comparisons (Miller, 1981).

3. Results

3.1 Abundance of coccinellids in chili pepper crop

The abundance of coccinellids in fields of chili pepper was affected by the management system (Chi-squared = 5.1433, df = 1, $P < 0.05$). Coccinellid predators were more abundant on fields with non-crop plants, showing an average of 5.5 ± 3.8 (SD) coccinellids for field per week sampled, than on chili pepper fields without non-crop plants, an average of 4.5 ± 5.6 (SD) coccinellids for field per week sampled. During the experiment, we observed a difference in the abundance of coccinellid from the beginning of collections until February 4 (Fig. 1A). During this period, a strong increase in abundance of the population was observed in both management systems. In spite of this, the abundance of coccinellids was higher in areas with non-crop plants.

During the sampling period, high infestations of chili pepper plants with broad mites were found in the fields between the end of December 2015 and beginning of February 2016 (Fig. 1B). It was necessary to control the broad mites through the application of lime sulfur (1%) sprayed on 14 January and 11 February 2016. This concentration was chosen because it kills the mites but is less harmful to the predators (Venzon et al., 2013). Spraying was performed at the end of the afternoon to avoid burning the leaves. Aphids were only detected in very low amount, in the total of the samplings, with an average 1.7 ± 1.92 (SD) and 1.6 ± 2.87 (SD) aphids per field of chili pepper with absence and presence of non-crop plants, respectively.

A total of 20 species of non-crop plants was found associated with chili pepper agroecosystem during the experimental period. The main species occurring were *Bidens pilosa*, followed by *Eleusine indica*, *Galinsoga parviflora* and *A. conyzoides* (Table 1).

3.2 Coccinellid predation on broad mites

First instar larvae of *E. connexa* and *H. axyridis* were observed to prey on broad mites. Larvae of *E. connexa* consumed an average of 3.0 ± 3.8 (SD) mites in 10 min and larvae of *H. axyridis* consumed an average of 1.7 ± 2.3 (SD) broad mites in the same interval. There was no significant difference between the two species in the predation rate of broad mites (t-teste = 1.5823, df = 48.218, p = 0.1201).

3.3 Broad mite mortality from coccinellids

Both coccinellid first instar larvae fed actively on broad mites. In 24 hours, *E. connexa* was responsible for an average mortality of $77 \pm 50\%$ (SD) of broad mites and *H. axyridis* first instar larvae caused an average mortality of $66 \pm 35\%$ (SD). There was no significant difference in the mortality of the broad mites caused by the two coccinellid species (t-teste = 1.36, df = 112.99, p = 0.1756) (Fig. 2).

3.4 Survival of coccinellids feeding on broad mites and on non-crop flowers

Survival of *E. connexa* differed among treatments (Chi-squared = 144, df = 4, p < 0.001). The highest survival was observed for larvae that fed on aphids (p < 0.0001) (Table 2). Survival of *E. connexa* in diets that contained broad mites was higher than on clean chili pepper seedlings and when only *A. conyzoides* flowers (p < 0.0001) (Fig. 3). The diet of *A. conyzoides* flowers together with broad mite increase significantly the survival of *E. connexa* when compared to only *A. conyzoides* flowers and clean chili pepper seedlings (p < 0.0001). The survival of predatory larvae did not differ when was offered only *A. conyzoides* flowers compared to only clean seedlings of chili pepper.

For *H. axyridis* the highest survival was observed on larvae that fed on aphids (Chi-squared = 127, df = 4, p < 0.001) (Table 3). Survival rate of *H. axyridis* in the diet that contained only broad mites was not significantly different from the diet with

clean chili pepper seedlings and when only *A. conyzoides* flowers were supplied ($p=0.161$) and ($p=0.0761$) respectively. There was no effect on survival when the diets were supplied separately. However, when broad mites and *A. conyzoides* flowers were offered together, there was an increase on survival of *H. axyridis* compared when only clean chili pepper seedlings, only *A. conyzoides* flowers ($p<0.0001$) or only broad mites were supplied ($p<0.01$). Thereby, both alternative food resources combined increased the survival of *H. axyridis* over each food resource separately (Fig. 4).

4. Discussion

The abundance of coccinellid predators was higher on chili pepper fields with the presence of non-crop plants, probably due to the availability of the resources offered by the non-crop plants integrated or associate with the crops, such as nectar, pollen, or alternative prey. Moreover, non-crop plants provide moderate microclimate and refuge from adverse conditions, such as environmental disturbances and the application of pesticides (Landis et al., 2000, Bianchi et al., 2006, Gurr et al., 2017). Previous studies also have found that management that promotes higher habitat heterogeneity favors the increase of populations of coccinellid predators (Amaral et al., 2013; Woltz and Landis, 2014, Yang et al., 2018) and other natural enemies (Norris and Kogan, 2005).

Here, we observed that from the middle to end of chili pepper season, the population of coccinellids were maintained higher in fields where the non-crop plants were present and lower in fields without non-crop plants. This confirmed that probably, coccinellids were favored by the resources that different non-crop plants can offer for adults, as pollen, floral and extrafloral nectar (Burgio et al., 2004; Lundgren 2009a; Amaral et al., 2013), supplying nutrients and energy that contribute to an increase in their survival (Lundgren, 2009b; Hodek and Evans, 2012). In addition, allowing to the coexistence of several species reducing intraguild predation (Osawa, 2011; Amaral et al., 2015). The most frequently non-crop plants found were *B. pilosa*, *G. parviflora* and *A. conyzoides*, belonging to the family Asteracea. These plants play an important role, serving as alternative host plants for insects (Norris

and Kogan, 2005). Besides, due to their floral attributes and the constitution of the nectar (Torres and Galetto, 2002), they are visited by a diversity of aphidophagous like coccinellids (Tschumi et al., 2016).

Differences were observed in the abundance of population of coccinellids during the beginning of collections until February 4, being this abundance high in both treatments (Fig. 1A), which coincided with the low availability of aphids (main prey) and with high infestation of one of the main pest of chili pepper crop, the broad mite *P. latus* (Venzon et al., 2011). This relationship led us to raise questions about which food the coccinellids were feeding on. We suggested that during this first period, coccinellids present in both fields might have preyed upon some alternative prey, such as broad mites, due to the scarcity of their main prey (aphids) in the crop. In addition, after application of lime sulfur (1%) to control broad infestation mite we observed that the mites were controlled and subsequently the population of coccinellids had a reduction. However, coccinellids population were maintained in chili pepper fields with both management systems, which would confirm that the used concentration of lime sulfur had low impact on these predators, as it had on Chrysopidae and Phytoseiidae predators (Venzon et al., 2013).

We observed in the laboratory experiments that *H. axyridis* and *E. connexa* had a positive response in the predation of different broad mite stages, which was unknown until now. First instar larvae of both species had a similar predation during the time that they were exposed to broad mites. The coccinellid *E. connexa* caused 77% and *H. axyridis* 66% of broad mite mortality after 24 hours showing a high efficiency in the population reduction of this mite. The close relationship between the body size of coccinellid predators and the size of the prey consumed may explain why first instar larvae (other instars were tested but not fed) of both species could feed efficiently in this small mite, thus supported for argument that body size is one of the main determinants of the capture efficiency of prey (Sloggett, 2008). This, highlighting the potential that first instar larvae of these species may have to reduce broad mite populations. There are references of coccinellids preying on spider mites but not on broad mites. For instance, *E. connexa* and *C. sanguinea* can feed on *Tetranychus evansi*, however, the efficiency in the predation was reduced by the webbing produced for this mite (Venzon et al., 2009). In addition, *Coleomegilla maculata* might prey on *Tetranychus urticae* (Koch), but in a lower rate, because it preferred to feed on the aphid *Aphis gossypii* (Glover) (Rondon et al., 2004). Some

clades of Coccinellidae, such as the Stethorini tribe, have been reported to be specialists on mites mainly of the Tetranychidae (Biddinger et al. 2009). For instance, larvae and adults of *Stethorus gilvifrons* Mulsant showed predation of all stages of *Oligonychus coffeae* (Nietner), however, adult females were more efficient in the predation of this mite (Perumalsamy et al., 2010). These results highlight the coccinellid predation on mites, despite of some mites not being their main prey.

To understand how the alternative prey, as broad mites and floral resources, could contribute to the survival of coccinellids, we performed evaluations with broad mites, and chose flowers of *A. conyzoides* taking into account previous results that showed the benefit of the floral resources of this plant in the survival of some predators (Amaral et al., 2013, Salgado, 2014). Furthermore, this plant was also found in this study associated with chili pepper fields. We found that the supply of mites as prey and floral resources did not allow the complete larval development of either coccinellid predators, but enabled them to survive for some time. Thereby, during this period of survival they can to found proper prey for completing larval development. Both foods can be considered a non-essential food with insufficient nutritional quality (Michaud, 2005). However, they might be considered alternative food because they only serve as a source of energy and help to prolong longevity in situations of lack of food (Hodek and Honěk, 2012). Preys considered non-essential play an important role in the feeding of coccinellids, because they sustain their populations and reduce their disappearance in different places when essential prey is scarce (Michaud, 2005).

Different survival patterns were observed in both coccinellid species. *Eriopsis connexa* had increased survival when the diet was supplied with only broad mites and when mixed *A. conyzoides* flowers and broad mites, but only flowers had no effect. *Harmonia axyridis* did not increase survival when single diet of only broad mites or only *A. conyzoides* flowers were offered, but did when broad mites mixed with *A. conyzoides* flowers were offered. These suggest that, there was a synergistic effect when the floral resources of *A. conyzoides* and broad mites were offered together for the first instar larvae of *E. connexa* and *H. axyridis* affecting positively their survival. Possibly when the diets were offered separately for both species of predators they detected a nutritional imbalance in each diet and by consuming both mixed diets they were able to compensate for the lack of nutrients (Mayntz et al 2005) improving survival. This could happen because plant and prey resources have

different chemical and morphological characteristics (Coll and Guershon, 2002); in addition, their nutritional values often are not sufficient for a suitable feeding when they are offered separately (Lundgren, 2009a). Thus becoming, the mixture of diets a complement to improve the fitness traits of predators (Oelbermann and Scheu, 2002; Messelink et al., 2008, Marques et al., 2015). These results coincide with studies that show that the supply of mites as only prey are not sufficient for reproduction and development of coccinellids, for example when development and reproduction of *C. maculata* was supplied only with *Tetranychus urticae* (Koch) compared to mix of synthetic pollen (Riddick et al., 2014). The responses obtained from both coccinellid species show also that their development can vary with the alternative resources offered (Lundgren, 2009b). For example, survival of *H. axyridis* decreased compared with the survival of native *C. sanguinea* when exposed the same resources provided by the non-crop plants (Amaral et al., 2013).

In our study, we demonstrated that both predatory coccinellids, a native and exotic, might be able to use alternative prey and floral resources. Our study revealed that the presence of non-crop plants associated with the chili pepper crop play an important role in the survival of coccinellids, increasing their abundance. Besides, it highlights that *H. axyridis* and *E. connexa* can feed on broad mites and the importance that alternative prey can have on the survival of the coccinellids, facilitating their conservation to increase natural pest control.

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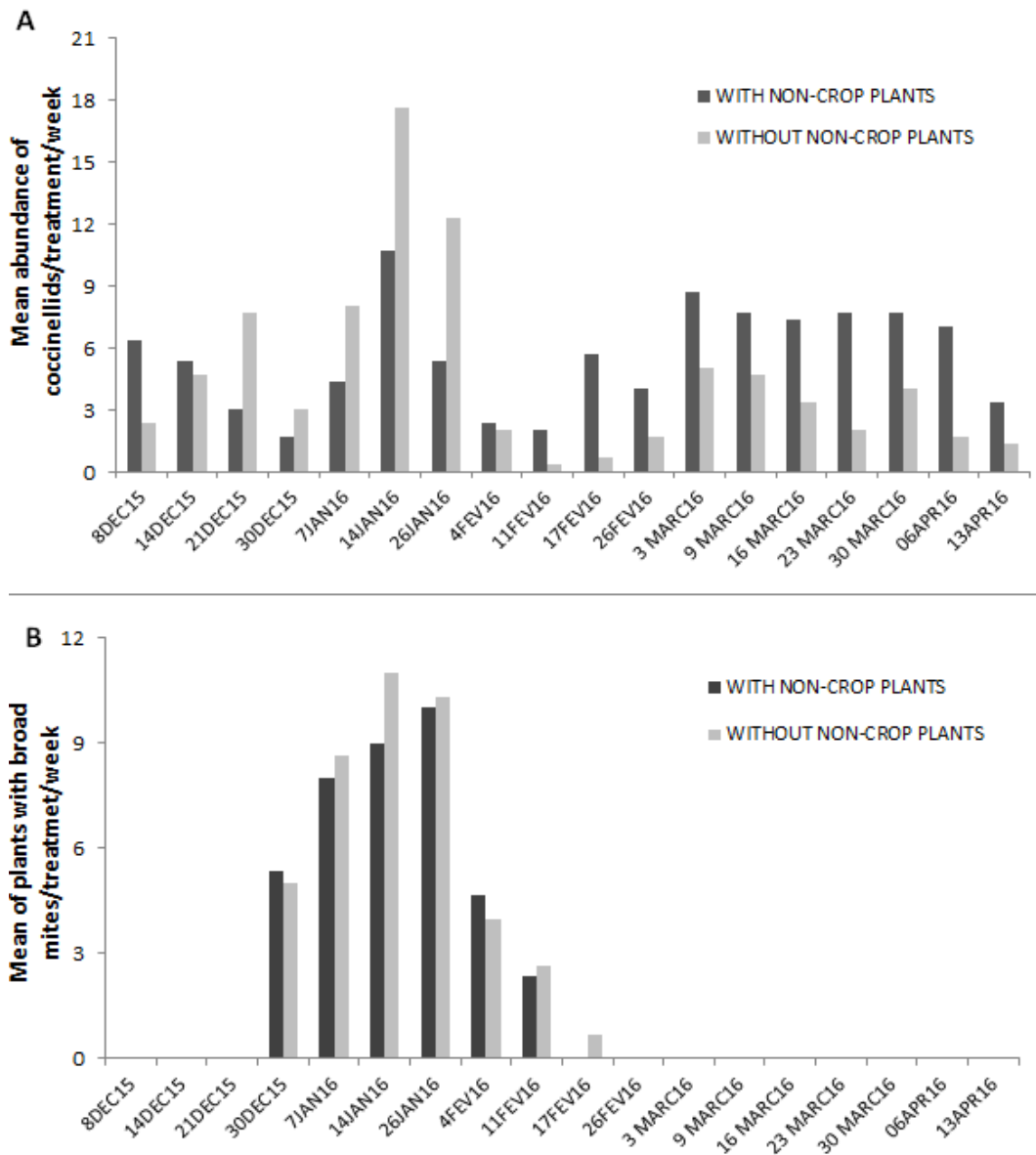


Figure 1. (A) Mean of the abundance of Coccinellidae predators collected field in 30 chili pepper plants per field with plastic tray plus collections with sweep net in three fields with non-crop plants and three fields without non-crop plants (control). (B) Mean of number of plants infested with broad mites (15 chili peppers plants sampled per field). Sampling was carried out weekly from December 2015 to April 2016. In Paula Cândido, state Minas Gerais, Brazil.

Table 1. Non-crop plants found in the three chili pepper fields sampled in Paula Cândido, state of Minas Gerais, Brazil. Plant species are presented in decreasing number found on 270 sampling points during the experiment.

Non-crop plants	Common name	Family	Number of sampled plants
<i>Bidens pilosa</i>	Hairy beggarticks	Asteraceae	20
<i>Eleusine indica</i>	Goosegrass	Poaceae	17
<i>Galinsoga parviflora</i>	Gallant soldier	Asteraceae	15
<i>Ageratum conyzoides</i>	Tropic ageratum	Asteraceae	14
<i>Cyperus rotundus</i>	Nut grass	Cyperaceae	10
<i>Leonurus sibiricus</i>	Honeyweed	Lamiaceae	10
<i>Commelina diffusa</i>	Climbing dayflower	Commelinaceae	9
<i>Digitaria horizontalis</i>	Jamaican crabgrass	Poaceae	8
<i>Emilia fosbergii</i>	Cupid's-shaving-brush	Asteraceae	7
<i>Amaranthus</i> sp.	Low amaranth	Amaranthaceae	6
<i>Ipomoea grandifolia</i>	Morning glories	Convolvulaceae	6
<i>Acanthospermum hispidum</i>	Bristly starbur	Asteraceae	5
<i>Commelina benghalensis</i>	-----	Commelinaceae	5
<i>Sida rhombifolia</i>	Rhombus-leaved sida	Malvaceae	5
<i>Conyza bonaeriensis</i>	Flax-leaf fleabane	Asteraceae	4
<i>Sonchus oleraceus</i>	Annual sowthistle	Asteraceae	4
<i>Brassica rapa</i>	Field mustard	Brassicaceae	3
<i>Amaranthus deflexus</i>	-----	Amaranthaceae	2
<i>Artemisia</i> sp.	Mugwort	Asteraceae	1
<i>Phyllanthus</i> sp.	Leaf Flower	Phyllanthaceae	1

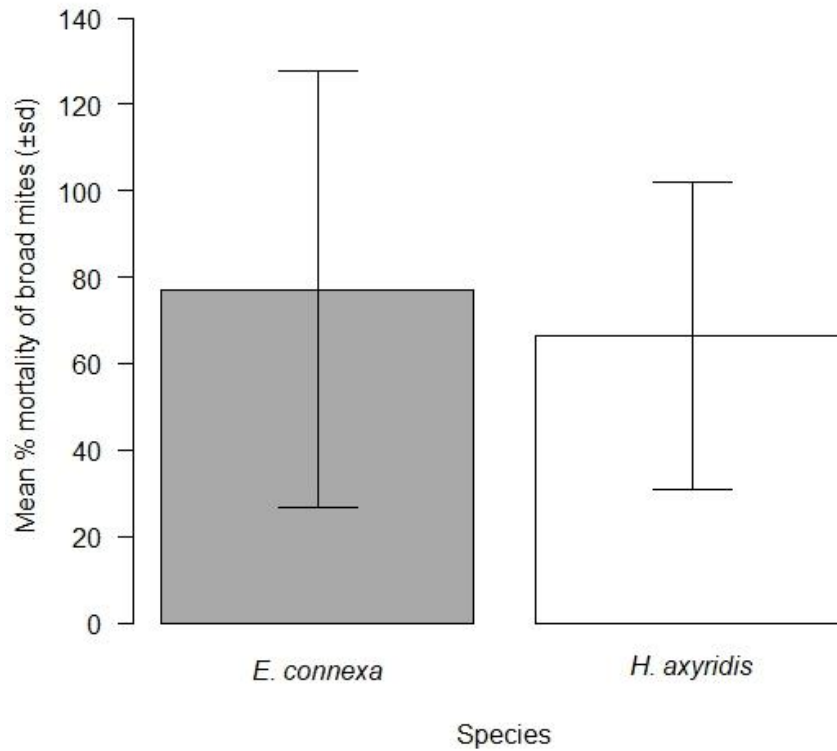


Figure 2. Mean percentage mortality (\pm SD) of broad mites caused by predation of first instar larvae of coccinellids *Eriopis connexa* and *Harmonia axyridis* after 24 hours in a chili pepper seedling conditioned in glass vials containing cotton with water and infested with 100 broad mite adults in laboratory. Replicates were done for *E. connexa* n=64, *H. axyridis* n=56 and control treatment=64. No differences were observed between species (p= 0.1756).

Table 2. *Eriopsis connexa* first instar larval survival comparison feeding on different foods. Log-rank test – Probability values (valor p), was used to compare the survival curves among the different treatments. ns: not statistically significant.

Comparison between treatments	Chi-squared	p-value
Broad mite vs control	22.5	< 0.0001
Broad mite vs aphids	62.7	< 0.0001
Broad mite vs <i>A. conyzoides</i> flowers	17.4	< 0.0001
Broad mite vs Broad mite+ <i>A. conyzoides</i> flowers	1.4	0.236 n.s
Broad mite + <i>A. conyzoides</i> flowers vs <i>A. conyzoides</i> flowers	28.2	< 0.0001
Broad mite + <i>A. conyzoides</i> flowers vs aphids	63	< 0.0001
Broad mite + <i>A. conyzoides</i> flowers vs Control	31.9	< 0.0001
<i>A. conyzoides</i> flowers vs Control	0	0.91 n.s
Aphids vs Control	65.3	< 0.0001
Aphids vs <i>A. conyzoides</i> flowers	70.2	0

Values in bold indicate significance $\alpha/c = 0.005$ of probability in the comparisons of treatments, where α/c is Bonferroni correction, α being the level of significance adopted (5%) and c the total number of comparisons.

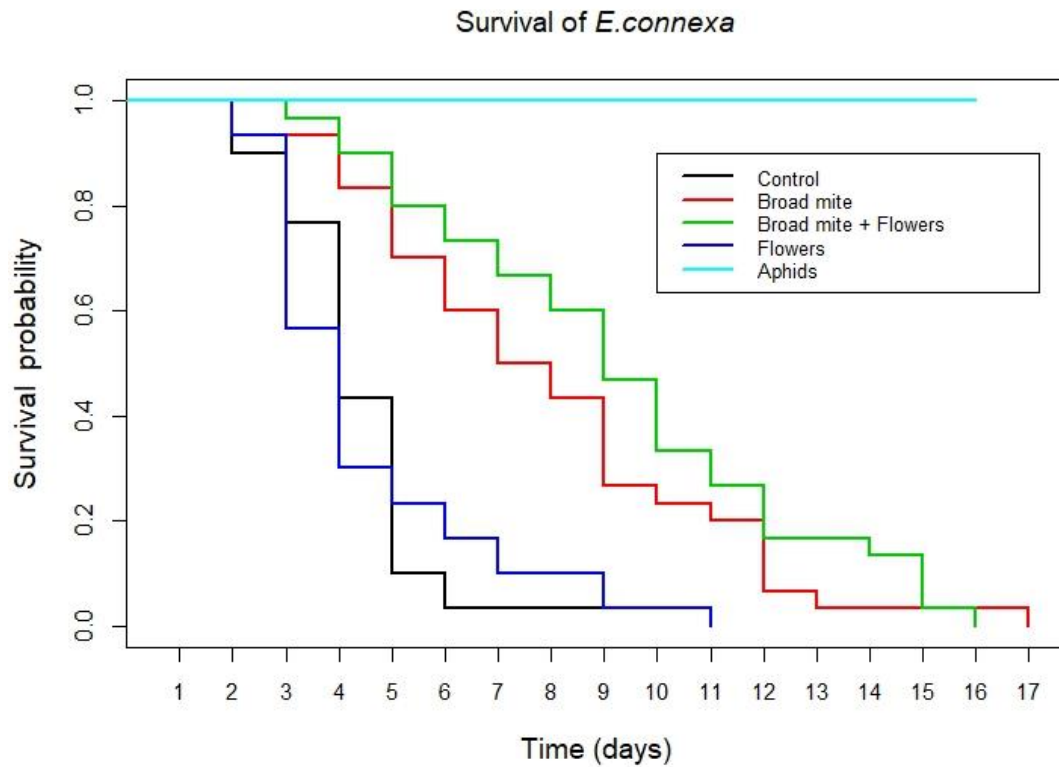


Figure 3. Kaplan–Meier estimates of survivorship of first instar larvae of *Eriopsis connexa* in the following diets: clean chili pepper seedlings (control), seedlings of chili pepper infested with broad mites, *A. conizoides* flowers + chili pepper seedlings infested with broad mites, *A. conizoides* flowers and seedlings of chili pepper with aphids. Time was calculated until the death of the larvae or stage of pupa.

Table 3. – *Harmonia axirydis* first instar larval survival comparison feeding on different foods. Log-rank test – Probability values (valor p), was used to compare the survival curves among the different treatments. ns: not statistically significant.

Comparison between treatments	Chi-squared	p-value
Broad mite vs control	2	0.161 n.s
Broad mite vs aphids	67.8	< 0.0001
Broad mite vs <i>A. conyzoides</i> flowers	3.1	0.0761 n.s
Broad mite vs Broad mite+ <i>A. conyzoides</i> flowers	9.6	0.002
Broad mite + <i>A. conyzoides</i> flowers vs <i>A. conyzoides</i> flowers	13.9	0.000189
Broad mite + <i>A. conyzoides</i> flowers vs aphids	67.9	< 0.0001
Broad mite + <i>A. conyzoides</i> flowers vs Control	15.5	< 0.0001
<i>A. conyzoides</i> flowers vs Control	0.1	0.725 n.s
Aphids vs Control	68.6	< 0.0001
Aphids vs <i>A. conyzoides</i> flowers	68.7	< 0.0001

Values in bold indicate significance $\alpha/c = 0.005$ of probability in the comparisons of treatments, where α/c is Bonferroni correction, α being the level of significance adopted (5%) and c the total number of comparisons.

Survival of *H. axyridis*

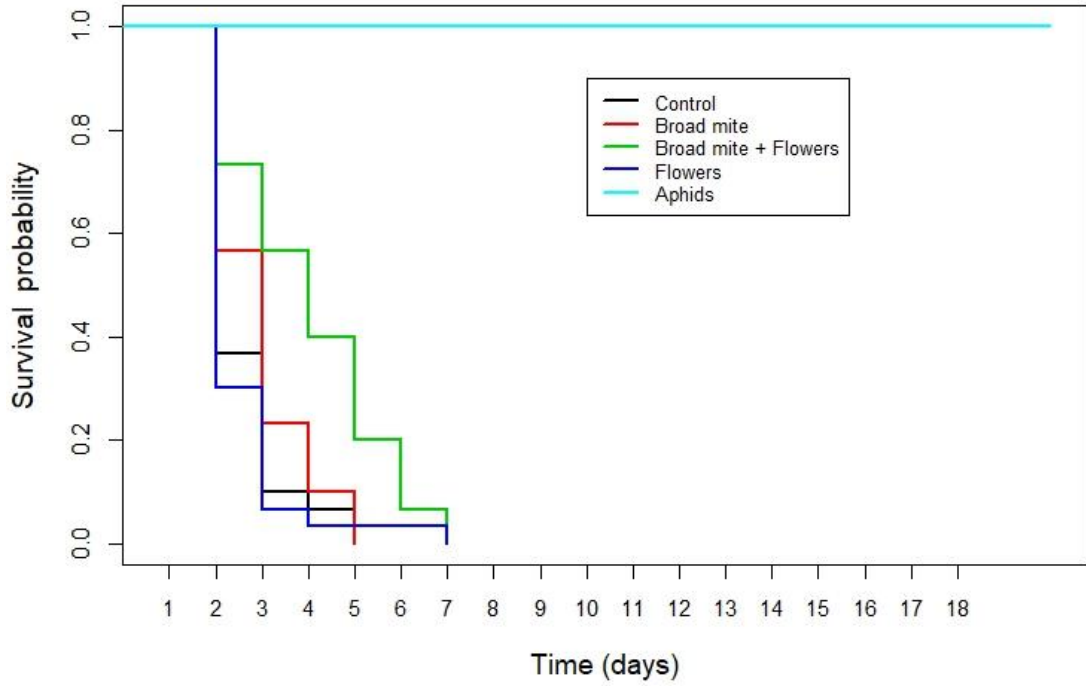


Figure 4. Kaplan–Meier estimates of survivorship of first instar larvae of *Harmonia axyridis* in following diets: clean chili pepper seedlings (control), seedlings of chili pepper infested with broad mites, *A. conizoides* flowers + chili pepper seedlings infested with broad mites, *Ageratum conizoides* flowers and seedlings of chili pepper with aphids. The time was calculated until the death of the larvae or stage of pupa.

Conclusões gerais

Práticas de manejo como a conservação de plantas espontâneas associadas a cultura de pimenta-malagueta e a não aplicação de agrotóxicos favorece a abundância de grupos funcionais tais como predadores, parasitoides e polinizadores, importantes promotores de serviço ecossistêmicos. Herbívoros que não causam danos econômicos na pimenta-malagueta também foram favorecidos.

Larvas de *Eriopis connexa* e *Harmonia axyridis* predam o ácaro-branco (*Polyphagotarsonemus latus*), praga-chave da cultura da pimenta, utilizando-o como presa alternativa. Flores de mentrasto (*Ageratum conyzoides*) comumente encontradas nos plantios de pimenta podem ser utilizadas por ambas espécies de predadores como alimento alternativo, contribuindo para o controle desta praga.

Implementação de estratégias de manejo através da conservação de plantas espontâneas associadas ou adjacentes a cultura de pimenta-malagueta e a eliminação de agrotóxicos contribuem para um aumento da biodiversidade de grupos funcionais. Especificamente, estas práticas aumentam a abundância e diversidade de predadores coccinélídeos, importantes agentes de controle biológico de pragas da pimenta, por fornecerem presas e recursos alternativos.