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Impacts of Planting System, Plant Age, and Climatic Variables on Pests And Predators in Common Bean Fields

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Abstract

Understanding the environmental influences on insect pests and predator dynamics is essential for the development of integrated pest management strategies for common bean plants. This study aimed to determine the effects of the planting system, plant age, climatic variables, and predator populations on common bean pests under field conditions. Planting systems, plant age, climatic variables, and the abundance of insect pests and predators were evaluated under field conditions over two years in three planting seasons per year. A generalized linear mixed model (GLMM) was adjusted to quasi-Poisson and negative binomial distributions. Model selection was based on the Akaike information criterion. According to the selected model, chewing, sap-sucking, cell content-sucking, and boring insects were influenced by plant age, planting system, air temperature, rainfall, and relative humidity. Additionally, predators including spiders, beetles, ants, pirate bugs, and ladybugs were influenced by plant age, air temperature, rainfall, relative humidity, and abundance of insect pests on common bean plants. This information is essential for conservation biology programs and integrated pest management.

Keywords: planting system, plant age, planting season, temperature, day length, relative humidity, rainfall, arthropods

1. Introduction

Most phytosanitary problems in the common bean (*Phaseolus vulgari* L.) are caused by insect pests (De Barros et al., 2015; de Moura et al., 2018; Zambolim et al., 2008). In common bean production systems, a sap-sucking insect, the green leafhopper (*Empoasca kraemeri* [Hemiptera: Cicadellidae]), and silverleaf whitefly (*Bemisia tabaci* (Gennadius) [Hemiptera: Aleyrodidae]) are the main insect pests that attack plants (de Moura et al., 2018; Gallo et al., 2002; Quintela et al., 2019). *Empoasca kraemeri* causes damage by sucking plant sap and injecting toxins (de Moura et al., 2018; Gallo et al., 2002; Quintela et al., 2019). *Bemisia tabaci* is widely distributed and affects production by sucking plant sap and transmitting viral diseases (Gallo et al., 2002; Quintela et al., 2019).

Although there are few studies on *Aphis craccivora* (Koch) (Hemiptera: Aphididae) , it is known that this insect pest can cause crop losses when present at high densities, mainly by sucking plant sap (Fortes Portela et al., 2019; Gallo et al., 2002; Girão Filho et al., 2019). The thrips species *Caliothrips phaseoli* (Hood) (Thysanoptera: Thripidae) has become an important insect pest in common beans because it induces leaf senescence by sucking plant sap (Boiça Júnior et al., 2015; Gallo et al., 2002). The boring insects *Diabrotica speciosa* (Germar) (Coleoptera: Chrysomelidae) and *Cerotoma arcuate* (Olivier) (Coleoptera: Chrysomelidae), whose larvae produce galleries in roots and whose adults defoliate the plant canopy, are also important pests of common beans (Gallo et al., 2002; Quintela et al., 2019). The chewing insect *Lagria villosa* (Fabricius) (Coleoptera: Tenebrionidae) is a pest with the potential to cause losses as it defoliates plants (Gallo et al., 2002).

Understanding the influences of planting system, plant age, and climatic variables on agroecosystem insect population dynamics is essential for implementing integrated pest management and natural enemy conservation strategies (P. Barbosa, 1998; Fidelis et al., 2019; Semeão et al., 2012). Seasonal variations in climate influence insect pest dynamics and their relationship with natural predators in different crops (Fand et al., 2014; Fidelis et al., 2019; Kehoe et al., 2018; Semeão et al., 2012). Additionally, insect pest abundance is closely influenced by phenological stage, planting system, and natural predator populations (Alyokhin et al., 2020; P. Barbosa, 1998; Fidelis et al., 2019; Stinner & House, 1990).

Currently, little is known about the dynamics of common bean insect pests, predators, planting systems, plant age, and climatic variables that interfere with this population dynamics. However, there are few studies on the relationship between environmental variables and insect pests and their predators in common beans. Furthermore, most of these studies were conducted under laboratory conditions.

This study aimed to determine the effects of planting system, plant age, climatic variables, and predator populations on common bean insect pests under field conditions.

2. Materials and Methods

2.1 Experimental Conditions

This study was conducted at the experimental station of the Federal University of Viçosa, Coimbra, Minas Gerais, Brazil (20°51′24″ S and 42°48′10″ W). The climate is classified as Cwa (sub-tropical humid; Peel et al., 2007). The Ouro Vermelho cultivar was used (Alves et al., 2009), and all cultivation practices for common beans were followed (Vieira et al., 2013). No insecticides or fungicides were used during the study.

One field of common beans under conventional tillage was planted adjacent to another field under the non-tillage system. Planting was repeated in three planting seasons spread over two years. The area of each field was 1000 m^2. One week before each planting under the conventional tillage system, the field was plowed once and harrowed twice. In the non-tillage system, herbicides were applied for desiccation and straw formation 30 d before each plantation. The desiccated material was mixed with herbicides, glyphosate, and 2,4-D (1440 + 670 g ha^{-1}).

Before the experiment, the study area was fallow for five years. Planting took place during the winter–spring season (W–s), spring–summer season (S–s), or summer–autumn season (S–a). There was a river on the west side and a plantation of *Eucalyptus grandis* on the east side of the experimental site. In the first year, the Ouro Vermelho cultivar was planted on the north side of the site for seed multiplication, and in the second year, the area was left fallow. In addition, a farm of corn and tomato crops was located on the southern side of the experimental site. Climatic variables (day length, rainfall, relative humidity, and temperature) were monitored daily using a μMETOS® SMR 300 weather station installed on-site (Figure 1).

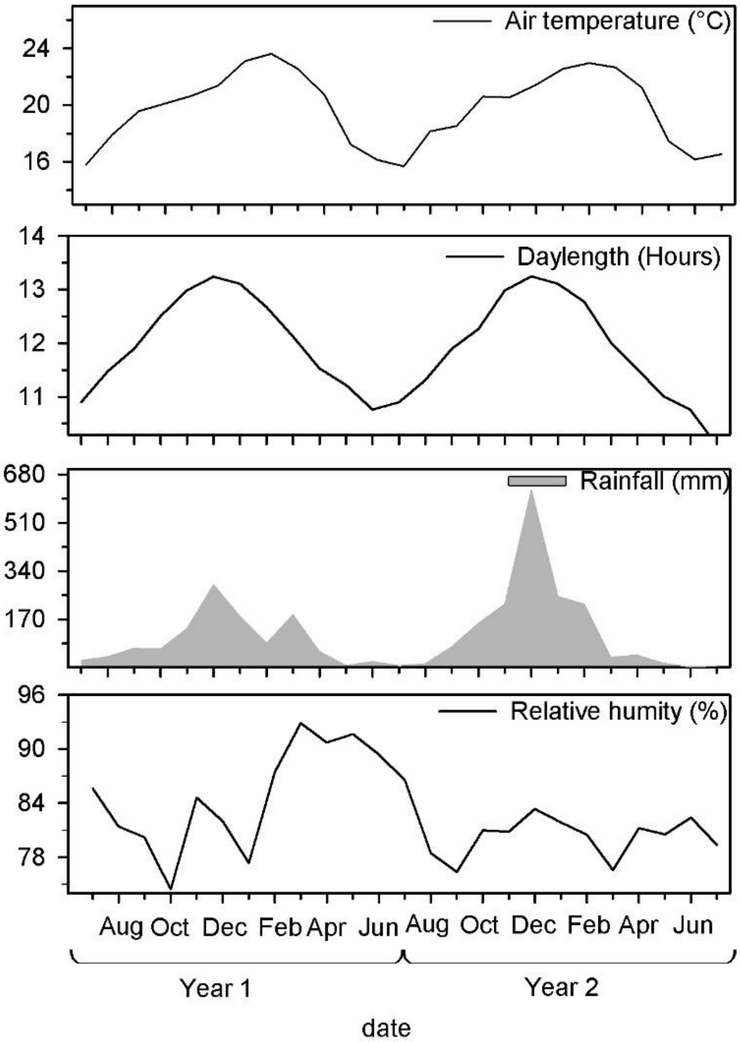

Figure 1. Seasonal variation of climatic variables over a two-year period, Coimbra, Minas Gerais, Brazil

2.3 Evaluation of Relative Abundances

The abundances of adult insect pests and predators in the crop canopies were evaluated weekly. Twenty-five random samples were collected from each field by beating plants over a plastic tray. This sampling technique is efficient, and recommended in sampling plans for insect pests of the common bean (de Moura et al., 2018). To determine the relative abundances, each crop was divided into three phenological stages: vegetative, flowering, and grain formation and filling. Plant age was used as an explanatory variable in the regression model (days after plant emergence). The insects were collected and identified according to the literature (Bastos et al., 2003; De Barros et al., 2015; Flávio L Fernandes et al., 2010; J. L. Pereira et al., 2010).

2.4 Statistical Analyses

All analyses were performed using R software (R Core Team, 2013). Initially, variables with a variance inflation factor below five were selected to avoid multicollinearity (Akinwande et al., 2015; Shresthan, 2020). The day length variable showed a variance inflation above five and, therefore, was removed from the regression models (Table 1).

Table 1. Variance inflation factor of climatic and insect pest variables, Coimbra, Minas Gerais, Brazil

Variables	x
Climatic variable	
At	4.105
N	7.700
Pa	1.235
Ps	NA
Rf	3.508
Rh	1.645
Insect variable	
Ac	1.066
Bm	1.082
Ca	1.355
Cp	1.655
Ds	1.587
Ek	1.654
Fk	2.068
Lv	1.175
Tt	1.251

Note: Ps, planting system; Pa, plant age; At, air temperature; Rf, rainfall; Rh, relative humidity; Ac, *Aphis craccivora*; Bt, *Bemisia Tabaci*; Cp, *Caliothrips phaseoli*; Ca, *Cerotoma arcuate*; Ds, *Diabrotica speciosa*; Ek, *Empoasca kraemeri*; Fk, *Frankliniella* spp.; Lv, *Lagria villosa*; Tt, *Thrips tabaci*

Overdispersion and zero-inflation were then evaluated using generalized linear mixed models (GLMM) with a Poisson distribution.

A GLMM was adjusted to quasi-Poisson and negative binomial distributions (Bates et al., 2015; Brooks et al., 2017; Venables & Ripley, 2002). The models were chosen based on the residuals observed after adjusting for the values (Hartig, 2018). The model selected based on the Akaike information criterion (AIC) was used to select the best overall model and the most critical variables. We calculated AIC, delta AIC (ΔAIC), and Akaike weight (wiAIC) values for the top four models according to Brooks et al. (2017).

Repeated measurements were performed for each field (i.e., random effect). The variables observed during the experiment included phytophagous insects (*A. craccivora, B. tabaci, C. phaseoli, C. arcuate, D. speciosa, E. kraemeri, Frankliniella* spp., *L. villosa*, and *T. tabaci*), predators (Araneae, *Anthicus* spp., *Crematogaster* spp., *Orius insidiosus*, *Scymnus* spp., and *Solenopsis* spp.), air temperature, rainfall, day length, relative humidity, planting system (conventional tillage and non-tillage), and plant age. Plant age was computed as the number of days since plant emergence.

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3. Results

3.1 Relative Abundances of Insect Pests and Predators

The abundances of cell content-sucking *Frankliniella* spp. and ants *Crematogaster* spp. in non-tillage systems were greater than those in conventional tillage systems (Figures 2, 3, and 4). Population peaks of sap-sucking *B. tabaci* (<1.50) and *E. kraemeri* (<27.00), and chewing *L. villosa* (<1.50) were observed in year one, whereas the cell content-sucking *T. tabaci* (<45.00) population peaked in year two during the W–S season (Figures 2 and 3).

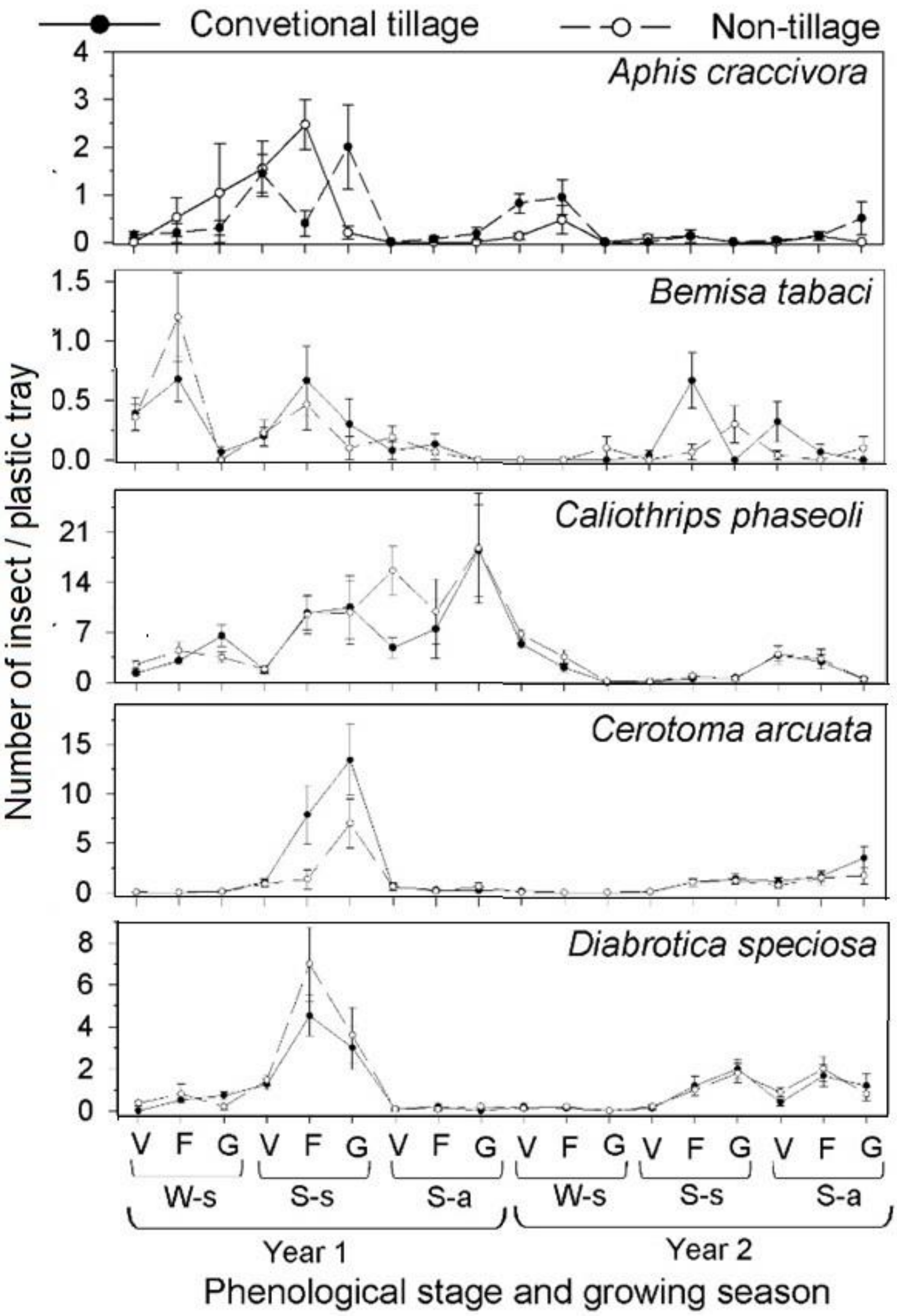

Figure 2. Insect pest abundances, Coimbra, Minas Gerais, Brazil. V, vegetative stage; F,

flower stage; G, grain stage; W-s winter–spring season; S-s, spring–summer season; S-a, summer–autumn season

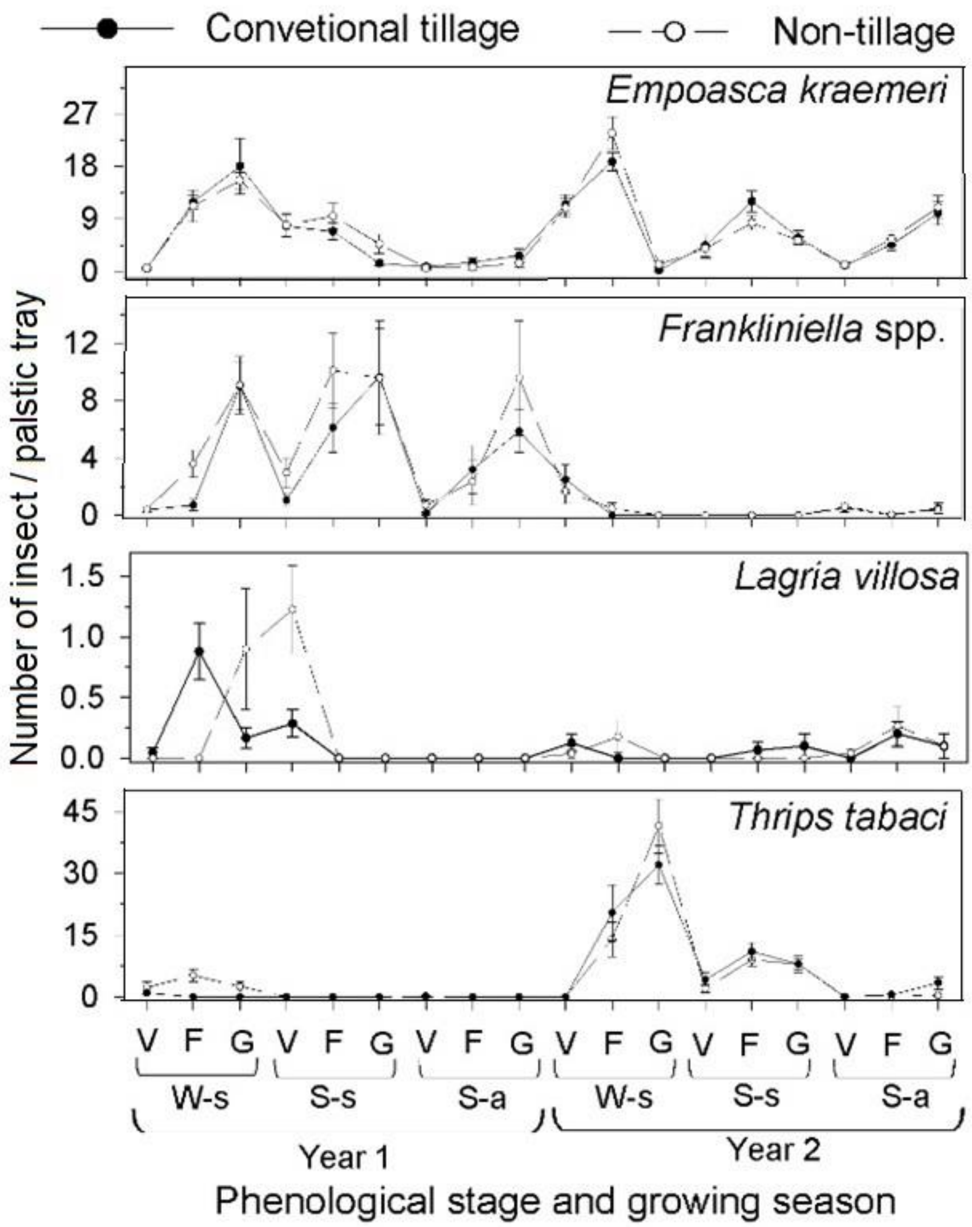

Figure 3. Insect pest abundances, Coimbra, Minas Gerais, Brazil. V, vegetative stage; F, flower stage; G, grain stage; W-s, winter–spring season; S-s, spring–summer season; S-a, summer–autumn season

Population peaks of sap-sucking *A. craccivora* (<3.00), and boring *C. arcuata* (<15.00) and *D. speciosa* (<8.00) were observed in year one during the S–S season (Figures 2 and 3). The populations of cell content-sucking *C. phaseoli* (<21.00) and *Frankliniella* spp. (<12.00) peaked in year one during the S–A season (Figures 2 and 3). Population peaks of *Crematogaster* spp. (<12.00) and *Solenopsis* spp. (Hymenoptera: Formicidae) (<8.00) were observed in year one during the W–S season.

The population of the predator *Orius insidiosus* (Say) (Heteroptera: Anthocoridae) (<1.80) peaked in year two during the W–S season, and the spider (Araneae) population peaked in the S–A season (<3.00). Population peaks of predatory *Anthicus* spp. (Coleoptera: Anthicidae) were observed during the S–S season (<2.60) in year one. Predatory *Scymnus* spp. (Coleoptera: Coccinellidae) population peaks were observed in year two during the W–S and S–S seasons (Figure 4).

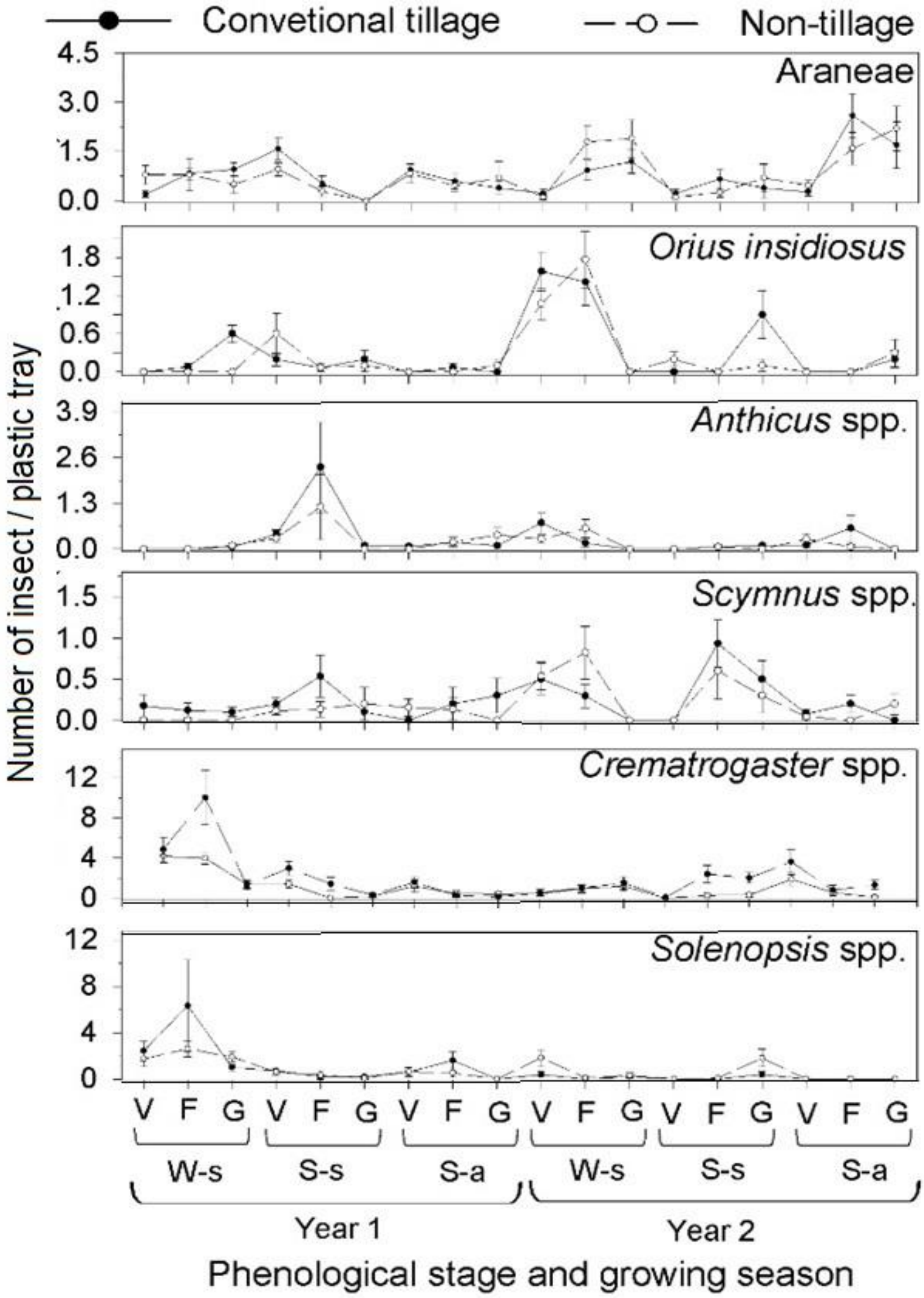

Figure 4. Abundances of ant and predatory taxa, Coimbra, Minas Gerais, Brazil. V, vegetative stage; F, flower stage; G, grain stage; W-s, winter–spring season; S-s, spring–summer season; S-a, summer–autumn season

3.1 Factors Affecting the Relative Abundances of Insect Pests

According to the selected model, sap-sucking *A. craccivora* abundance was negatively affected by rainfall. Air temperature positively influenced sap-sucking *B. tabaci* abundance, and air temperature and plant age positively influenced cell content-sucking *C. phaseoli* abundance (Tables 2 and 3).

Table 2. Results of the best fitting model for insect pest abundance as a function of planting system, plant age, air temperature, rainfall, and relative humidity in Coimbra, Minas Gerais, Brazil

Models selection	Distribution	ΔAIC	w_i(AIC)	AIC
Aphis craccivora				
Pa + Rf	Nbm2	0.000	0.539	671.196
At + Pa + Rf	Nbm2	1.878	0.211	673.016
At + Pa + Ps + Rf	Nbm2	3.550	0.091	674.796
Pa + Rf + Rh	Nbm2	3.675	0.086	674.921
Bemisia tabaci				
At	Nbm1	0.000	0.204	566.781
At + Ps	Nbm1	0.520	0.157	567.266
At + Ps	Nbm2	0.980	0.125	567.726
At + Rf	Nbm1	1.477	0.098	568.223
Caliothrips phaseoli				
At + Pa	Nbm2	0.000	0.297	2550.490
At +Pa + Rf	Nbm2	0.483	0.233	2550.930
At +Pa + Rh	Nbm2	0.940	0.186	2551.387
At + Pa + Ps	Nbm2	1.224	0.161	2551.671
Cerotoma arcuata				
At + Pa +Ps + Rh	Nbm2	0.000	0.507	1131.653
At + Pa + Rh	Nbm2	1.688	0.218	1133.390
At + Pa +Ps + Rf + Rh	Nbm2	2.035	0.183	1133.630
At + Pa + Rf + Rh	Nbm2	3.714	0.079	1135.367
Diabrotica speciosa				
Pa + Rf + Rh	Nbm2	0.000	0.395	1285.488
At + Pa + Rf + Rh	Nbm2	0.951	0.246	1286.389
Pa + Ps + Rf + Rh	Nbm2	1.392	0.197	1286.830
At + Pa +Ps + Rf + Rh	Nbm2	2.262	0.128	1287.643
Empoasca kraemeri				
At + Pa + Rh	Nbm1	0.000	0.397	2916.153
At + Pa + Rf + Rh	Nbm1	0.986	0.243	2917.089
At + Pa + Os + Rh	Nbm1	2.049	0.143	2918.151
At + Pa + Os + Rf + Rh	Nbm1	3.039	0.087	2919.084
Frankliniella spp.				
At + Pa + Ps + Rf + Rh	Nbm1	0.000	0.671	1383.951
At + Pa + Rf + Rh	Nbm1	2.158	0.228	1386.167
At + Pa + Ps + Rh	Nbm1	5.271	0.048	1389.279
Pa + Ps + Rf + Rh	Nbm1	6.389	0.028	1390.397
Lagria villosa				
At + Rf + Rh	Nbm2	0.000	0.357	427.457
At +Pa + Rf + Rh	Nbm2	1.074	0.209	428.482
At +Ps + Rf + Rh	Nbm2	1.107	0.205	428.515
At + Pa + Ps + Rf + Rh	Nbm2	2.304	0.113	429.654
Thrips tabaci				
At + Rf	Nbm1	0.000	0.417	1663.825

At + Rf + Rh	Nbm1	1.666	0.181	1665.449
At +Pa + Rf	Nbm1	1.811	0.169	1665.593
At + Ps + Rf	Nbm1	1.888	0.162	1665.671

Note: Ps, planting system; Pa, plant age; At, air temperature; Rf, rainfall; Rh, relative humidity; Nbm1, quasi-Poisson distribution; Nbm2, negative binomial distribution

Table 3. Generalized linear model results for factors that influenced the insect pest abundance, Coimbra, Minas Gerais, Brazil

Variable	Estimate	SE	z value	*p*
Aphis craccivora				
Intercept	-0.192	0.888	-0.217	0.829
Pa	0.018	0.009	1.946	0.052
Rf	-0.017	0.005	-3.692	0.000***
Bemisia tabaci				
Intercept	-8.488	2.158	-3.933	0.000***
At	0.311	0.099	3.138	0.002**
Caliothrips phaseoli				
Intercept	-6.462	1.559	-4.145	0.000***
At	0.331	0.067	4.938	0.000***
Pa	0.020	0.005	3.952	0.000***
Cerotoma arcuata				
Intercept	-21.386	5.439	-3.932	0.000***
At	0.242	0.079	3.074	0.002**
Pa	0.043	0.007	6.305	0.000***
Ps	-0.423	0.217	-1.944	0.052
Rh	0.168	0.055	3.041	0.002**
Diabrotica speciosa				
Intercept	6.203	2.762	2.246	0.025*
Pa	0.014	0.004	3.216	0.001***
Rf	-0.003	0.001	-2.981	0.003**
Rh	-0.086	0.032	-2.677	0.007**
Empoasca kraemeri				
Intercept	10.083	1.777	5.675	0.000***
At	-0.124	0.036	-3.451	0.001***
Pa	0.013	0.003	4.994	0.000***
Rh	-0.078	0.021	-3.746	0.000***
Frankliniella spp.				
Intercept	2.007	3.402	0.590	0.555
At	0.197	0.069	2.860	0.004**
Pa	0.028	0.006	4.949	0.000***
Ps	0.344	0.167	2.055	0.040*
Rf	-0.005	0.002	2.679	0.007**
Rh	-0.099	0.031	-3.225	0.001***
Lagria villosa				
Intercept	41.387	15.872	2.608	0.009**
At	-1.125	0.400	-2.813	0.005**
Rf	-0.014	0.005	-2.758	0.006**
Rh	-0.253	0.114	-2.214	0.027*
Thrips tabaci				
Intercept	9.999	2.351	4.253	0.000***
At	-0.454	0.108	-4.221	0.000***
Rf	-0.006	0.001	-5.126	0.000***

Note: Ps, planting system; Pa, plant age; At, air temperature; Rf, rainfall; Rh, relative humidity. Parameters are considered significant at: *** P<0.001; ** P<0.01; * P<0.05.

Air temperature, plant age, and relative humidity positively and significantly influenced the insect borer *C. arcuata*. *D. speciosa* population density was positively influenced by plant age and negatively affected by relative humidity and rainfall. The sap-sucking *E. kraemeri* attacks were significantly positively influenced by plant age and negatively influenced by air temperature and relative humidity (Table 3). Air temperature, plant age, and planting system positively influenced *Frankliniella* spp. abundance, whereas rainfall and relative humidity significantly negatively influenced these species. Air temperature, rainfall, and relative humidity significantly negatively affected *L. villosa* abundance. Air temperature and rainfall negatively influenced the cell content-sucking *T. tabaci* attacks (Tables 2 and 3).

3.2 Factors Affecting the Relative Abundances of Predators

Spider population abundance was positively and significantly affected by *C. phaseoli*, *D. speciosa*, and *L. villosa* population abundances. The factors that negatively affected spider population abundance were air temperature and rainfall. The predatory *Anthicus* spp. population abundance was significantly positively by *C. phaseoli*, *C. arcuate*, *D. speciosa*, *E. Kraemeri*, and *L. villosa* population abundances, and significantly negatively influenced by plant age and *T. tabaci* population abundance (Tables 4 and 5).

Table 4. The best fitting model of the predators abundance as a function of planting system, plant age, air temperature, rainfall, relative humidity, and abundance of insect pests Coimbra, Minas Gerais, Brazil

Models selection	Distribution	ΔAIC	w_i(AIC)	AIC
Araneae				
At + Ps + Rf + Cp + Ds + Lv + Tt	Nbm1	0.000	0.303	1336.596
At + Ps + Rf + Cp + Ds + Ek + Ls + Tt	Nbm1	0.710	0.213	1337.227
At + Ps + Rf + Ac + Cp + Ds + Lv + Tt	Nbm1	0.793	0.204	1337.310
At + Ps + Rf + Bt + Cp + Ds + Lv + Tt	Nbm1	0.969	0.187	1337.485
Anthicus spp.				
At + Pa + Ac + Ca + Cp + Ds + Ek + Lv + Tp	Nbm2	0.000	0.313	541.169
Pa + Ac + Ca + Cp + Ds + Ek + Lv + Tt	Nbm2	0.942	0.195	542.198
At + Ps + Ac + Ca + Cp + Ds + Ek + Pa + Lv + Tt	Nbm2	1.193	0.172	542.268
At + Pa + Rf + Ca + Ds + Ek + Lv + Tt	Nbm2	1.253	0.167	542.509
Crematogaster spp.				
At + Ps + Rh + Bt + Cp + Ca + Lv + Tt	Nbm1	0.000	0.277	1721.265
At + Ps + Rh + Ca + Bt + Ds + Lv + Tt + Cp	Nbm1	0.626	0.203	1721.805
At + Ps + Rf + Rh + Bt + Ca + Cp + Lv + Tt	Nbm1	0.768	0.189	1721.947
At + Ps + Bt + Lv + Tp + Cp + Rh	Nbm1	0.989	0.169	1722.168
Orius insidiosus				
At + Pa + Ps + Ac + Bt + Ca + Cp + Ds + Ek + Lv + Tt	Nbm1	0.000	0.170	570.417
At + Ps + Pa + Ac + Bt + Cp + Ds + Ek + Lv + Tt	Nbm1	0.217	0.153	570.736
At + Ps + Bt + Ca + Cp + Ds + Ek + Lv + Tt	Nbm1	0.582	0.127	571.195
At + Ps + Ac + Bt + Ca + Cp + Ds + Ek + Lv + Tt	Nbm1	0.630	0.124	571.149

Scymnus spp.				
Ps + Rf + Cp + Ds + Ek + Fk	Nbm1	0.000	0.276	554.374
Ps + Rf + Cp + Ds + Ek + Fk + Lv	Nbm1	0.362	0.230	554.663
Ps + Rf + Bt + Cp + Ds + Ek + Fk	Nbm1	1.045	0.163	555.346
At + Ps + Rf + Cp + Ds + Ek + Fk + Lv	Nbm1	1.102	0.159	555.324
Solenopsis spp.				
At + Rh + Bt + Fk + Lv	Nbm1	0.000	0.278	979.047
At + Rh + Bt + Ca + Fk + Lv	Nbm1	0.578	0.209	979.560
At + Rh + Bt + Fk + Lv + Tt	Nbm1	0.931	0.175	979.913
At + Rh + Bt + Ek + Fk + Lv	Nbm1	0.975	0.171	979.957

Note: Ps, planting system; Pa, plant age; At, air temperature; Rf, rainfall; Rh, relative humidity; Ac, *Aphis craccivora*; Bt, *Bemisia Tabaci*; Cp, *Caliothrips phaseoli*; Ca, *Cerotoma arcuata*; Ds, *Diabrotica speciosa*; Ek, *Empoasca kraemeri*; Fk, *Frankliniella* spp.; Lv, *Lagria villosa*; Tt, *Thrips tabaci*; Nbm1, quasi-Poisson distribution; Nbm2, negative binomial distribution

Table 5. Generalized linear model results for factors that influenced the predator abundance in Coimbra, Minas Gerais, Brazil

Variable	Estimate	SE	z value	*p*
Araneae				
Intercept	4.223	0.974	4.337	0.000***
At	-0.226	0.046	-4.859	0.000***
PS	-0.243	0.126	-1.925	0.054
Rf	-0.002	0.001	-2.036	0.042*
Cp	0.039	0.006	6.249	0.000***
Ds	0.098	0.023	4.207	0.000***
Lv	0.090	0.028	3.216	0.001***
Tt	0.007	0.004	1.859	0.063
Anthicus spp.				
Intercept	1.867	2.390	0.781	0.435
At	-0.191	0.109	-1.757	0.079
Pa	-0.023	0.009	-2.577	0.010**
Ac	-0.079	0.061	-1.302	0.193
Ca	0.074	0.030	2.434	0.015*
Cp	0.065	0.017	3.887	0.000***
Ds	0.174	0.081	2.142	0.032*
Ek	0.016	0.007	2.144	0.032*
Lv	0.212	0.105	2.022	0.043*
Tt	-0.043	0.013	-3.186	0.001***
Crematogaster spp.				
Intercept	-12.121	3.075	-3.942	0.000***
At	0.204	0.056	3.660	0.000***
Ps	0.323	0.126	2.558	0.011*
Rh	0.095	0.029	3.303	0.001***
Bt	0.281	0.078	3.590	0.000***
Ca	-0.029	0.018	-1.611	0.107
Cp	0.019	0.006	3.261	0.001***
Lv	0.082	0.027	3.019	0.003**
Tt	0.013	0.005	2.921	0.003**

Note: Ps, planting system; Pa, plant age; At, air temperature; Rf, rainfall; Rh, relative humidity; Ac, *Aphis craccivora*; Bt, *Bemisia Tabaci*; Cp, *Caliothrips phaseoli*; Ca, *Cerotoma arcuata*; Ds, *Diabrotica speciosa*; Ek, *Empoasca kraemeri*; Fk, *Frankliniella* spp.; Lv, *Lagria villosa*; Tt, *Thrips tabaci*. Parameters are considered significant at: *** $P<0.001$; ** $P<0.01$; * $P<0.05$.

The factors that significantly positively affected *Crematogaster* spp. population abundance were *B. tabaci*, *C. phaseoli*, *T. tabaci*, and *L. villosa* abundances, air temperature, planting system, and relative humidity (Tables 4 and 5). *Orius insidiosus* abundance was positively and significantly influenced by *C. phaseoli*, *T. tabaci*, *D. speciosa*, *E. kraemeri*, and *L. villosa* abundances and negatively influenced by air temperature and *B. tabaci* abundance (Tables 4 and 6).

Table 6. Generalized linear model results for factors that influenced the predator abundance in Coimbra, Minas Gerais, Brazil

Variable	Estimate	SE	z value	*p*
Orius insidiosus				
Intercept	9.486	3.968	2.391	0.017*
At	-0.621	0.211	-2.943	0.003**
Pa	0.012	0.008	1.564	0.118
Ps	-0.400	0.218	-1.836	0.066
Ac	0.000	0.000	1.725	0.085
Bt	-0.699	0.346	-2.020	0.043*
Ca	0.037	0.023	1.611	0.107
Cp	0.043	0.018	2.385	0.017*
Ds	0.128	0.049	2.587	0.010**
Ek	0.008	0.003	2.275	0.023*
Lv	0.164	0.038	4.271	0.000***
Tt	0.009	0.004	2.522	0.012*
Scymnus spp.				
Intercept	-1.611	0.521	-3.093	0.002**
Ps	-0.404	0.219	-1.842	0.065
Rf	-0.005	0.002	-2.802	0.005**
Cp	0.066	0.010	6.943	0.000***
Ds	0.172	0.039	4.400	0.000***
Ek	0.015	0.004	3.727	0.000***
Fk	-0.125	0.028	-4.430	0.000***
Solenopsis spp.				
Intercept	-15.067	4.665	-3.230	0.001***
At	0.215	0.107	2.013	0.044*
Rh	0.116	0.043	2.703	0.007**
Bt	0.365	0.106	3.452	0.001***
Fk	0.032	0.010	3.175	0.001***
Lv	0.111	0.034	3.252	0.001***

Note: Ps, planting system; Pa, plant age; At, air temperature; Rf, rainfall; Rh, relative humidity; Ac, *Aphis craccivora*; Bt, *Bemisia Tabaci*; Cp, *Caliothrips phaseoli*; Ca, *Cerotoma arcuata*; Ds, *Diabrotica speciosa*; Ek, *Empoasca kraemeri*; Fk, *Frankliniella* spp.; Lv, *Lagria villosa*; Tt, *Thrips tabaci*. Parameters are considered significant at: *** $P<0.001$; ** $P<0.01$; * $P<0.05$.

The *Scymnus* spp. population was positively and significantly affected by *C. phaseoli*, *D. speciosa*, and *E. kraemeri* population abundances and was negatively affected by *Frankliniella* spp. population abundance and rainfall (Tables 4 and 6).

Solenopsis spp. population abundance was positively and significantly affected by *B. tabaci*, *Frankliniella* spp., and *L. villosa* population abundances, air temperature, and relative humidity (Tables 4 and 6).

4. Discussion

Frankliniella spp. and *Crematogaster* spp. were affected by the common bean planting system and showed a higher occurrence in the no-tillage system. Soil cultivation causes agroecosystem disturbances, directly and indirectly affecting arthropods and their habitats, resources, and natural enemies (Alyokhin et al., 2020; Roger-Estrade et al., 2010; Zhang et al., 2017). However, plant defences against phytophagous insects are enhanced in non-tillage systems owing to the presence of natural enemies, and habitat modifications that prevent pest outbreaks (Alyokhin et al., 2020).

Generally, no-tillage practices have an adverse effect on insect pests, depending on the insect species and crops involved (Alyokhin et al., 2020). However, the mechanisms involved in the resistance and resilience of these arthropods to disturbed environments have not been fully elucidated (Brussaard et al., 2007). *Frankliniella* spp. and *Crematogaster* spp. are probably more adapted to the non-tillage system. However, most of the arthropods observed in this study did not respond to the planting system. This is probably because these insects are adapted to both planting systems.

Caliothrips phaseoli, *Frankliniella* spp., *C. arcuata*, *D. speciosa*, and *E. kraemeri* inflicted more intense attacks on common bean plants during later phenological growth stages. Food quality and the food preferences of insect pests can be critical factors, depending on the age of a plant (D'Auria et al., 2016; Fidelis et al., 2019; Moré et al., 2003). This is because the quality of food available to pests varies with plant age, and insect pests have different nutritional requirements and adaptations, such as foods rich in sugars or amino acids (Kiskini et al., 2016; Leite et al., 2006; Schoonhoven et al., 2005; Veromann et al., 2013). The insect populations showed a low relative abundance in the early phenological growth stages of the plants, probably because the populations were not yet established. Thus, economic damage caused by common bean insect pests is expected to occur in the later phenological growth stages of plants.

Anthicus spp. were more abundant during the early phenological growth stages of the plants. The density-dependent relationship between pests and predators plays an essential role in predator dynamics (Kersch-Becker et al., 2017). Thus, this relationship probably influences natural enemy abundance during the different phenological growth stages of common bean plants.

According to the regression models, air temperature influenced the insect pest attacks and predator abundance. For example, *B. tabaci*, *C. phaseoli*, *Frankliniella* spp., *C. arcuata*, *Crematogaster* spp., and *Solenopsis* spp. were more abundant at higher air temperatures. Conversely, *E. kraemeri*, *L. villosa*, *T. tabaci*, Araneae, and *O. insidiosus* populations were more abundant at lower air temperatures. There are few studies on the effect of air temperature on common bean arthropods, and most of these studies were conducted under laboratory conditions. Consequently, little is known about the effects of temperature on arthropod populations in common bean plants grown under field conditions.

Temperature plays an essential role in insect metabolism and population dynamics (Girão Filho et al., 2019; Nava & Parra, 2003; Wang et al., 2020). For example, temperature influences insect survival, fecundity, growth, and development rates (Eliopoulos et al., 2010; Laws & Belovsky, 2010; Li & Jackson, 1996; Silveira et al., 2005). This could explain the results of this study on common bean insect pests.

Several studies have reported the negative influence of rainfall on pest populations (Bacci et al., 2019; E. J. G. Pereira et al., 2007; Semeão et al., 2012). However, little is known about the effects of rainfall on arthropod populations in common bean fields. In the present study, rainfall negatively influenced the insect pests *A. craccivora*, *D. speciosa*, *Frankliniella* spp., *T. tabaci*, and *L. villosa*, and the predatory Araneae and *Scymnus* spp. populations.

According to some authors, rainfall affects insect populations because raindrops exert mechanical action on insects, causing increased entomopathogenic activity and asynchrony in the emergence of adults, limiting the dispersion of insects (Bacci et al., 2019; Bueno et al., 2011; Feng et al., 1991; Heller et al., 2008; Nunes et al., 2011; Semeão et al., 2012). Thus, in the rainy season, a decrease in arthropod activity on common beans is expected. In addition, phytosanitary problems associated with insect pests are expected to occur less frequently.

The abundances of *C. arcuata*, *D. speciosa*, *Crematogaster* spp., and *Solenopsis* spp. were higher under humid conditions. Conversely, *E. kraemeri*, *Frankliniella* spp., and *L. villosa* attacks were more intense under dry conditions. Insect populations can be affected by both low and high relative humidity. Low relative humidity increases desiccation and influenced the insect longevity and oviposition (Clark & Faeth, 1998; Jesus et al., 2010; Liu et al., 2011; Norhisham et al., 2013; Potts et al., 1984).

Conversely, high relative humidity positively influences entomopathogenic activity (Bueno et al., 2011; Han et al., 2014). Therefore, among common bean pests, some insects are adapted to dry conditions whereas others are adapted to humid conditions. Thus, farmers have to consider changes in the abundance of insect populations to develop strategies for insect pest control in common bean crops.

In the present study, the spider population was influenced by *C. phaseoli*, *D. speciosa*, and *L. villosa* populations. Spiders are important predators that consume the immature and adult stages of insect orders (Michalko & Pekár, 2015; Salomon, 2011). The *Anthicus* spp. population was influenced by the *C. phaseoli*, *T. tabaci*, *C. arcuata*, *D. speciosa*, *E. kraemeri*, and *L. villosa* populations. Predators of this family have a varied diet that includes the eggs, larvae, nymphs, and pupae of different insect orders, such as Coleoptera, Hemiptera, Lepidoptera, and Thysanoptera (Bastos et al., 2003; Flávio L Fernandes et al., 2010; Tillman et al., 2015).

The *Crematogaster* spp. population was influenced by the *B. tabaci*, *C. phaseoli*, *T. tabaci*, and *L. villosa* populations. *Bemisia tabaci*, *Frankliniella* spp., and *L. villosa* affected *Solenopsis* spp. Ants commonly have mutualistic interactions with Hemipteran species and predate upon species of different insect orders, such as Coleoptera, Hemiptera, and Thysanoptera (Canedo-Júnior et al., 2019; Castracani et al., 2017; Flávio Lemes Fernandes et al., 2015; Moya-Raygoza & Martinez, 2014; Rocha et al., 2015; Tillman et al., 2015).

Understanding the factors that influence common bean insect pest populations and their predators is essential for the implementation of integrated pest management systems (Bacci et al., 2019; Bueno et al., 2011; D'Auria et al., 2016; Semeão et al., 2012). Integrated pest management prevents pest insect outbreaks, environmental pollution, insecticide residues on food, the development of pesticide-resistant insect pests, and the negative impact of insecticides on beneficial insects (De Barros et al., 2015; Zambolim et al., 2008).

According to the results of this study, most insect pests do not respond to planting system and occur during the later phenological growth stages of common beans. In addition, insect pests were adapted to different climatic conditions. Thus, farmers must focus on the economic threshold level and monitor insect pest populations during the critical period of insect pest occurrence in common beans.

In contrast, predators were influenced by insect pests, and most of them were not influenced by planting system or the phenological growth stage of the common bean plants. In addition, the climatic variables evaluated in this study played an essential role in population dynamics.

This group of insects plays a vital role in pest control by maintaining insect pest populations at levels above the economic threshold (P. Barbosa, 1998; Quintela et al., 2019). Thus, farmers must implement methods that conserve the natural enemies of common bean pests by improving the survival rates, pest control efficacy, and reproductive success of predators. Selective insecticide use, intercropping, crop rotation, windbreaks, and maintenance of non-crop plants on the edges of common bean fields are examples of conservation biology strategies (P. Barbosa, 1998; Bickerton & Hamilton, 2012; De Barros et al., 2015; O'Rourke et al., 2008; Schmidt-Jeffris & Beers, 2018).

5. Conclusion

The abundance of chewing, sap-sucking, cell content-sucking, and boring insect pests of common beans is influenced by plant age, planting system, air temperature, rainfall, and relative humidity. In addition, predators of common bean insect pests, including spiders, beetles, ants, pirate bugs, and ladybugs, are influenced by plant age, air temperature, rainfall, relative humidity, and phytophagous insect populations.

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