Sociobiology 69(2): e7746 (June, 2022) DOI: 10.13102/sociobiology.v69i2.7746

Sociobiology
An international journal on social insects

RESEARCH ARTICLE - ANTS

Ants (Hymenoptera: Formicidae) increase predation of *Belenois solilucis* (Lepidoptera: Pieridae) eggs in organic agriculture production systems: a multiple-site field study at Rashad, Sudan

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Article History

Edited by
Evandro Nascimento Silva, UEFS, Brazil
Received 22 January 2022
Initial acceptance 23 May 2022
Final acceptance 09 June 2022
Publication date 24 June 2022

Keywords
Biodiversity, Biological control, Disturbance, Land use, Population.

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Abstract

Organic farming is becoming more popular as there is a greater demand for pesticide-free food. Pest control in organic agricultural production requires a set of skills, including the identification of effective predators and land-use practices. Predation by selected Coleopteran, Dipteran, and Hemipteran insects and Araneae is well established, whereas the predatory role of ants (Hymenoptera: Formicidae) has received little attention in the Rashad district, Sudan. This study was carried out to assess the predation rates of *Belenois solilucis* eggs and the impact of the land use type around the properties on these rates. An experiment involving predation tests on *Belenois solilucis* eggs and fauna sampling were conducted in 18 areas of organic agriculture in the Rashad district. The study showed that ants can reduce the eggs population by 26.8% per day. At the same time, other predator taxa, primarily Coleoptera, from Coccinellidae and Staphylinidae families, removed only 13% of the eggs. Ant species with the most significant recruiting power were *Axinidris acholli*, *Tapinoma carininotum*, and *Technomyrmex moerens*. Ant genera such as *Linepithema*, *Dorymyrmex*, and *Camponotus* ants were also frequently observed. The proportion of the planted area within a 500-meter radius, in addition to the interaction of other landscape categories, had a minor influence on predation, but only when the predators were not ants. The landscape does not affect predation by predators in general, including ants, or on ant predation in particular.

Introduction

One of the eight Millennium Development Goals of the United Nations is to ensure sustainable development (UNPD, 2012). This implies changing the way food is produced today because what is currently happening is, for the most part, a process of intensifying land usage to increase productivity, which consequently amplifies the negative effects on biodiversity (Maitima et al., 2009; Taube et al., 2014). On the other hand, increasing land-use intensification is not the only way to increase productivity.

According to Yanoviak et al. (2009), land use intensifies complex natural systems toward managed and simpler ecosystems, dependent on artificial sums, mechanization, and frequent human intervention. In addition to the loss of species due to intensification, there is a reduction in ecological services

ISSN: 0361-6525

such as pollination (Nicholls & Altieri, 2007), biological control (Mori et al., 2013), and this increases the dependence of these systems on human intervention. However, other alternatives, such as organic production (Settle & Garba, 2011), reduce this impact; although some uncertainties remain about its true environmental benefits (Davis et al., 2015). In this type of agricultural production, we highlight the production of organic vegetables, which has a lower "ecological footprint" than grain and meat production (Jin et al., 2020) and has the added benefit of being associated with healthier foods owing to the absence of pesticides (Popp et al., 2013).

The transition from conventional to organic agriculture requires management adjustments that pose specific risks. Organic production depends on the restoration and conservation of many ecological services, making sustainable agricultural production viable (Röös et al., 2018). Therefore, one of the critical needs of farmers is connected to phytosanitary issues with insect pests, which cannot be controled with pesticides in organic systems. As a result, biological control is used (Bielza et al., 2020). For example, the use of insects that are parasitoids of agricultural pests is currently a commercially available tool in which the parasitoid efficiently limits the population size of its hosts (Georgis et al., 2006).

The most widely used and investigated strategy in recent decades to boost biological control while not favoring insects pests has been the increase in plant diversity at scales ranging from the crop plot to the diversity of the agricultural landscape (Tuomisto et al., 2012; Tuck et al., 2014). An increase in plant diversity at the first trophic level, in general, tends to have a positive influence on natural enemies but a detrimental one on herbivores (de Siqueira Neves et al., 2011). On the other hand, increased plant diversity leads to increased habitat complexity, which reduces the chance of insect pests being excluded from this environment while decreasing the probability of the population explosion of these insects (Karp et al., 2018). These have been studied regarding agricultural landscapes to explain why some areas host more predators and have greater levels of predation on insect pests (Morandin et al., 2014). According to these researches, agricultural landscapes with an increase in the complexity or proportion of native areas have more species (reviewed by Moser et al., 2002) and higher rates of predation and productivity. However, this impact is also related to the taxon, and some studies did not detect landscape effects (Bianchi et al., 2006; Rusch et al., 2016).

The most studied beneficial organisms within organic areas are coccinellids, often known as ladybugs (Coleoptera: Coccinellidae) (Jones & Gillett, 2005), and micro-hymenopterans. However, in addition to predatory behavior and eusocial organization, referred to as a superorganism (Gowdy & Krall, 2014), ants possess all the characteristics required to be termed as biological control agents. According to Elizalde et al. (2020), ants of the genus *Oecophylla* reduce pests' abundance and damage while increasing financial gains in a variety of crops. Their effectiveness was deemed even better than that of chemical pesticides, with additional advantages of being low cost.

Based on this information, we sought to assess the contribution of ants to the natural biological control of herbivorous insects in agro-systems and determine which factors influence predation rates in organic areas. Specifically, we attempted to know: (1) if ants are a group that effectively reduces the herbivore population by predating on eggs of *Belenois solilucis* Butler, 1874; and (2) if these predation rates are explained by the abundance of predators (including taxa other than ants), the occurrence of ants, and land use around and within properties.

Material and methods

Study areas

This study was conducted in the Rashad district from February to June 2020 and February to May 2021, covering an area of 7,872 km² (located in the center of the Kordofan between latitudes 10°, 13° N and longitudes 29°, 33° E), in 18 areas of organic agriculture production (Eisawi et al., 2021) (Fig 1). The distance between the locations was 1.5 km, with each region having a distinct land use. The crops cultivated in each site vary, but mainly include eggplants, okra, carrots, yams, corn, zucchini, tomatoes, and peppers. The cultivation methods are also diverse. Some locations have a single type of cultivation, while others have many cultivation lines of different vegetable species. Finally, in the same line of cultivation, certain properties combine more than one type of vegetable. In addition, types of agronomic management vary from one property to the next – such as fertilization or the use of natural products to combat pests – making it hard to assess how this affects biological control due to the lack of repetition and gradient of change across properties.

Sample design

The stakes are strong wooden or metal post with a point at one end, driven into the ground to support a tree, form part of a fence, act as a boundary mark, etc. In each location, sixty stakes were installed, including 40 predation stakes, and 20 sampling stakes, totaling 1,080 in 18 location. The stakes were distributed following the cultivation lines, at a distance of 7 m from each other, in the following order: sampling stakes, predation stakes with cards containing 1 to 10 eggs, predation stakes with cards containing 11 to 90 eggs, and so on repeatedly. Therefore, 20 sampling and 40 predation stakes were installed in each location, showed in a 413-meter-long straight line. However, because most plots are less than 40 meters long, a second line was installed seven meters away parallel to this one. Finally, care was taken to alternate predation stakes with low and high egg densities to avoid eggs concentration in a certain region of the locality and skewing the results.

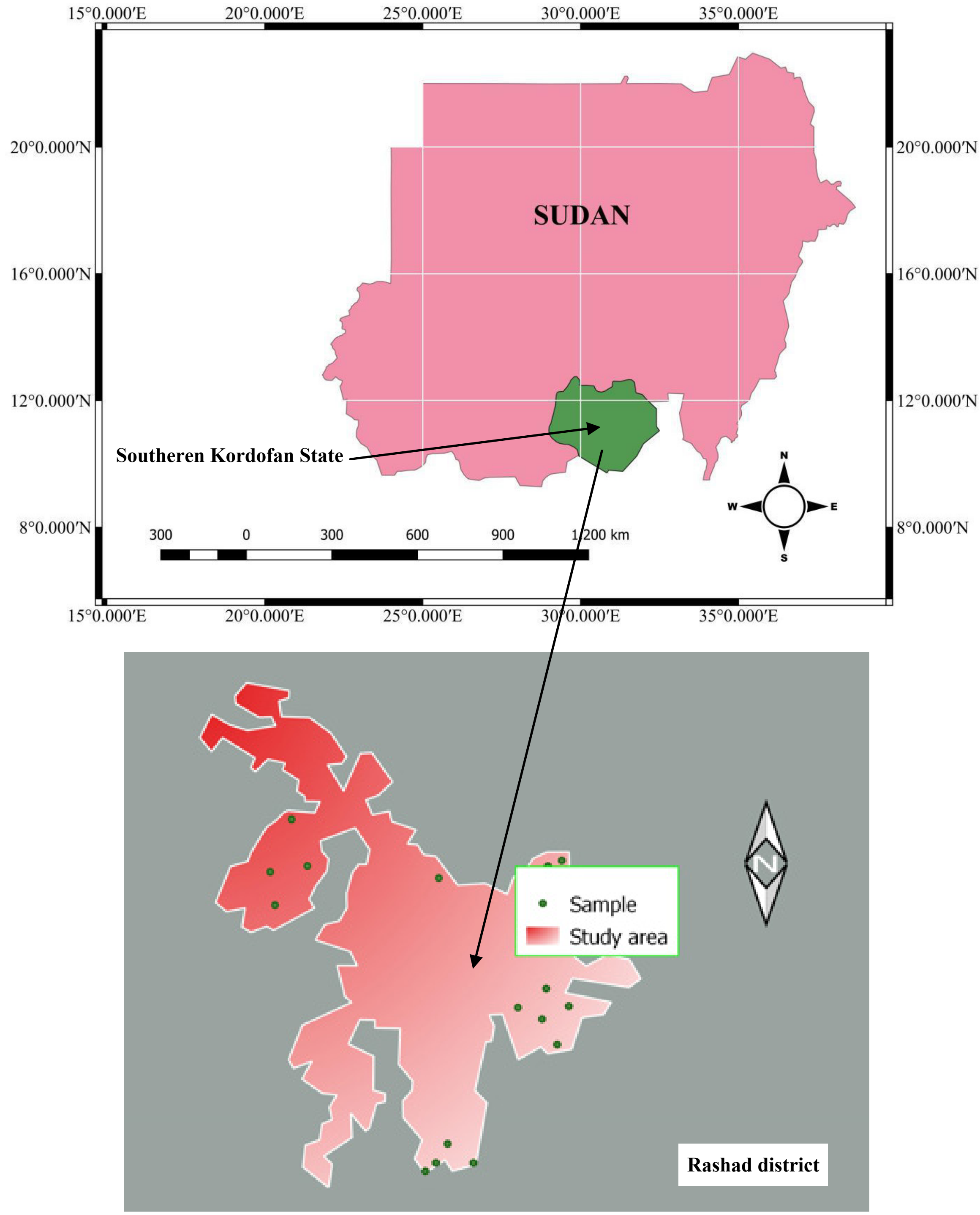

Fig 1. Map of the study area showing distribution of sampling sites.

To measure predation rates, a 24-hour experiment was developed, for which a device (called predation stakes) that simulates a plant (Fig 2A) was crafted, in which eggs of *Belenois solilucis* (Lepidoptera: Pieridae), a plague insect of various crops (especially soybean), raised in the laboratory, were made available for use in research. The predation stakes had a height of 25 to 30 cm, and six "branches" on its top, which hold, at the tips, rectangles of green cardboard with approximately 5 x 3 cm, simulating leaves. Each of these devices contained: a) a branch with a leaf containing eggs that could be accessed by all possible predators – this leaf was called treatment; and b) a second branch covered with lithium grease (also known as white grease), an odorless, insoluble substance that prevents the transit of unwinged animals, primarily ants, and, at the tip of this branch, a leaf, called control. Eggs were also made available in this second leaf, with the care of laying several eggs equal to or nearly the treatment pack in each predation stakes. Due to the variation in eggs density from the rearing of *Belenois solilucis*, the age of the colony and the number of eggs available in each pack ranged from 1-90 to prevent this from influencing the results. stakes with low density (≤20 eggs) were interspersed with high-density stakes (20 eggs).

In addition, to simulate the natural laying conditions of most insect pests, all eggs were made available on the bottom surface of the leaf (face down). Finally, before going into the field, the number of eggs in each card was counted and written on the card itself (Fig 2B). As a result, the number of predated eggs may be determined immediately after the cardboard is exposed in the field. In addition to these devices to measure predation, sampling stakes were established to sample the fauna that accesses the predation stakes (Fig 2C). Also, with a height of 25 – 30 cm and universal collector of 100 ml was installed, which was filled up to half its volume by water with detergent in the field. A small amount of honey was poured around the edge of the collector as an attractive. In addition to this collector, there was a branch isolated by lithium grease, with a 5 x 5 cm piece of green cardboard, at its tip containing at least 20 eggs of *Belenois solilucis* and a 5 x 3 cm piece of yellow adhesive trap (Fig 2D). As a result, the fauna that rises in the cuttings could be seen, distinguishing the one that possibly accesses the eggs of the treatment (captured in the universal collector) or control (caught in the yellow adhesive trap).

Fig 2. Images of the methodology used in the 18 locations of organic vegetable production in the Rashad, Sudan, from February to June 2020 and February to May 2021. (A) Photograph of one of the 720-predation stakes in the field, where two cards with eggs of *Belenois solilucis* were available. (B) Photo of the egg cartons after 24 hours in the field, with the number of initial eggs written in pencil, and the predation of all eggs on the left cartouche occurred. (C) Photograph of one of the 320 sampling stakes, containing a universal collector and a yellow adhesive trap card. (D) Photo of one of the sampling cards that remained in the field, with a strip containing eggs as an attractant on top and covered by transparent plastic for storage. Arrows indicate the locations in (A) and (C) that have white grease preventing ants' passage.

Data analysis

All analyses were performed in the R program (Pinheiro et al., 2020). Initially, a paired t-test was used to determine if the ants effectively contributed to the increase in predation rates in the treatment cards vs control, with the stake serving as the pairing factor. We have chosen models to verify if the landscape influences egg predation rates. In this analysis, three response variables were evaluated: (1) the number of eggs predated in the treatment (predation by ants and other predators), (2) the number of eggs predated in control (predation by alated arthropods, excluding ants) and (3) the number of eggs predated in the treatment minus the control (predation attributed to ants). The explanatory variables were areas of the landscape categories (tree cover, planting, without planting and construction) and all possible interactions between two of these variables. For each of these response variables, four models were constructed to evaluate landscape effect. Landscape was delimited as a buffer and we developed a model for each buffer (1,000 m, 500 m, 250 m and 125 m). We applied the "backward" process using the lm function of R (Pinheiro et al., 2020), to perform the model selection procedure. The modeling began with a model containing all the variables and then we sequentially removed the variables with the highest p obtained in the model until only significant variables remained. In addition, we used function R to compare each new model with a variable removed from the previous one to verify that it undergoes significant changes. Finally, to determine the best model, the Akaike criterion was applied, with the AIC function of R (Sakamoto et al., 1986).

To determine the number of preyed eggs related to the number of predators, three simple regressions were performed: (a) the number of eggs pre-given in the treatment according to the total number of predators; (b) the number of eggs pre-given in control as a function of predators excluding ants; and (c) the number of eggs pre-given in the treatment minus control according to the number of occurrences of ants.

Specimens were identified using a single key to identify subfamilies, a series of keys to identify genera and a series of keys to identify species (Bingham, 1903; Holldobler & Wilson, 1990; Mathew & Tiwari, 2000), and comparison with voucher specimens housed in the Museum of Natural Science, Department of Biological Sciences, Louisiana State University, comparison with type images available at AntWeb (www.antweb.org), AntWiki (www.antwiki.org).

Results

A total of 3,631 individual arthropods were collected, (Fig 3) among them 406 were predators (Fig 4). The most common predators were Coleopterans (178 individuals), particularly from the families Staphylinidae (105) and

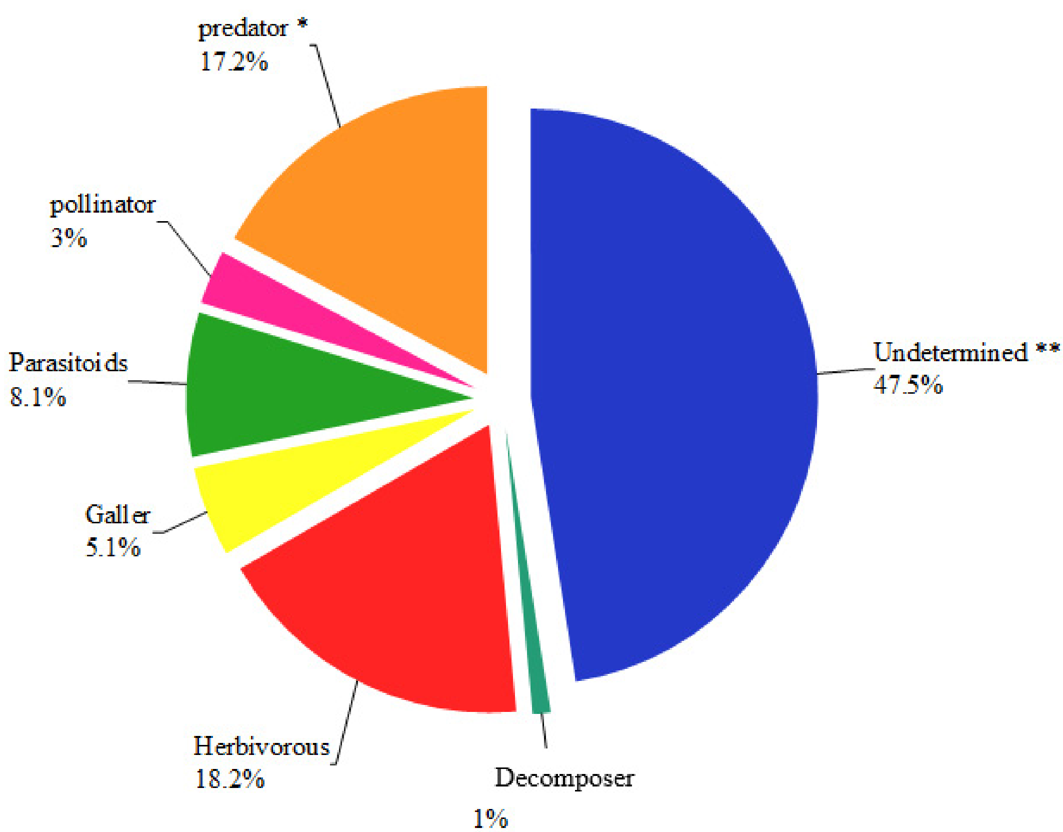

Fig 3. Proportion of the 3,875 individuals captured according to the functional group to which they belong. The collections were carried out in 18 localities of organic vegetable production in the Rashad, Sudan, from February to June 2020 and February to May 2021, using 360 universal collectors and 360 yellow adhesive trap cards.

*For the predator group, ants were counted in number of occurrence (244) instead of number of individuals (1,831).,

**For the indeterminate group, of the 1,814 records, 1,558 were of the order Diptera, that is, 86%.

Coccinellidae (71). The order Diptera was the second most prevalent among predators, mainly from the family Dolichopodidae (128). Still, these are predominantly predators of animals in flight and small animals (Harterreiten Souza, oral communication), not being observed in the field directly preying eggs of *Belenois solilucis*, so they were not included in the analyses of predators. The other predators found were Hemiptera-Heteroptera (35), Araneae (27), Hymenoptera – Vespoidea (25), Neuroptera (6), Psocoptera (2), Pseudoscorpionida (1), Coleoptera-Melyridae (1) and Coleoptera-Carabidae (1). The use of white grease to inhibit the passage of ants proved to be effective, although not infallible (Fig 4). Overall, 1,831 ant individuals were captured in 244 occurrences (Table 1) belonging to 35 different species which have potential to act as predators. The most frequent ant species were *Axinidris acholli*, *Tapinoma carininotum* and *Technomyrmex moerens*, all from the subfamily Dolichoderinae. However, the species with the most individuals was *Pheidole megacephala*,

Table 1. List of ant species potentially predatory on *Belenois solilucis* eggs captured in the 360 sampling cuttings. The collections were carried out in 18 locations of production of organic vegetables in the Rashad, Sudan, from February to June 2020 and February to May 2021.

Species	Number of locations with occurrence	Number of captured individuals	Occurrence	Cumulative Percentage of Occurrence
Axinidris acholli Weber, 1941	11	371	44	18%
Tapinoma carininotum Weber, 1941	10	245	33	32%
Technomyrmex moerens Santschi, 1913	7	154	22	41%
Camponotus bayeri Forel, 1913	9	26	22	50%
Camponotus brutus Forel, 1886	8	57	20	58%
Pheidole megacephala Forel, 1913	7	493	14	64%
Tetraponera bifoveolata	5	82	14	69%
Pheidole punctulata Santschi, 1937	7	104	12	74%
Pheidole rugaticeps Emery, 1881	5	102	8	77%
Solenopsis orbula Forel, 1905	4	44	8	81%
Camponotus acvapimensis Donisthorpe, 1945	6	13	6	83%
Bothroponera pachyderma Santschi, 1920	4	47	5	85%
Pheidole aeberlii Emery, 1901	3	14	4	87%
Camponotus aegyptiacus Santschi, 1926	3	7	4	89%
Pheidole rugaticeps arabs Emery, 1881	1	9	2	89%
Monomorium abeillei Collingwood, 1996	1	8	2	90%
Pheidole termitophila Forel, 1911	2	7	2	91%
Pheidole sinaitica Forel, 1907	2	7	2	92%
Bothroponera crassa Emery, 1877	2	6	2	93%
Atopomyrmex mocquerysi Santschi, 1924	2	6	2	93%
Brachyponera sennaarensis Santschi, 1921	2	2	2	94%
Leptogenys crustosa Weber, 1942	1	6	1	95%
Camponotus etiolipes Bolton, 1995	1	4	1	95%
Crematogaster latuka Weber, 1943	1	3	1	95%
Pheidole speculifera Santschi, 1930	1	3	1	96%
Camponotus cinctellus Santschi, 1939	1	2	1	96%
Camponotus kersteni Gerstäcker, 1871	1	1	1	97%
Camponotus maculatus Weber, 1943	1	1	1	97%
Camponotus tricolor Bolton, 1995	1	1	1	98%
Cardiocondyla fajumensis Weber, 1952	1	1	1	98%
Pheidole crassinoda ruspolii Emery, 1897	1	1	1	98%
Pheidole decarinata Santschi, 1929	1	1	1	99%
Pheidole jordanica Stitz, 1917	1	1	1	99%
Leptogenys maxillosa Emery, 1895	1	1	1	99%
Solenopsis punctaticeps Weber, 1943	1	1	1	100%

a myrmecine ant. In general, the ten most frequent ant species accounted for more than 80% of the occurrence of ants.

The number of eggs pretested between control and treatment (Fig 5) indicates that ants were its main predators (t-test, $t = 12.445$, $df = 717$, $p < 0, 0001$). On average, approximately 39.8% of offered eggs were consumed per day, with ants accounting for 26.8% and other predators accounting for 13%. However, there are substantial variations in the properties, both in total predation (ranging from 9.4% to 63.2% eggs), as in predation only by ants (from 5.3% to 52.4%) and other predators (4.2% to 21%). The analysis of linear models shows that the total number of predating eggs and eggs pressed by ants in each organic locality is not influenced by the landscape (Table 2). The planted area within 500 meters, on the other hand, positively influences the predator eggs in control and interactions with the rest of the landscape. The regressions between the number of pre-given eggs and the number of predators were significant (Fig 6). The number of eggs perused in the treatment is positive and significantly related to the total number of predators (Number of pre-given

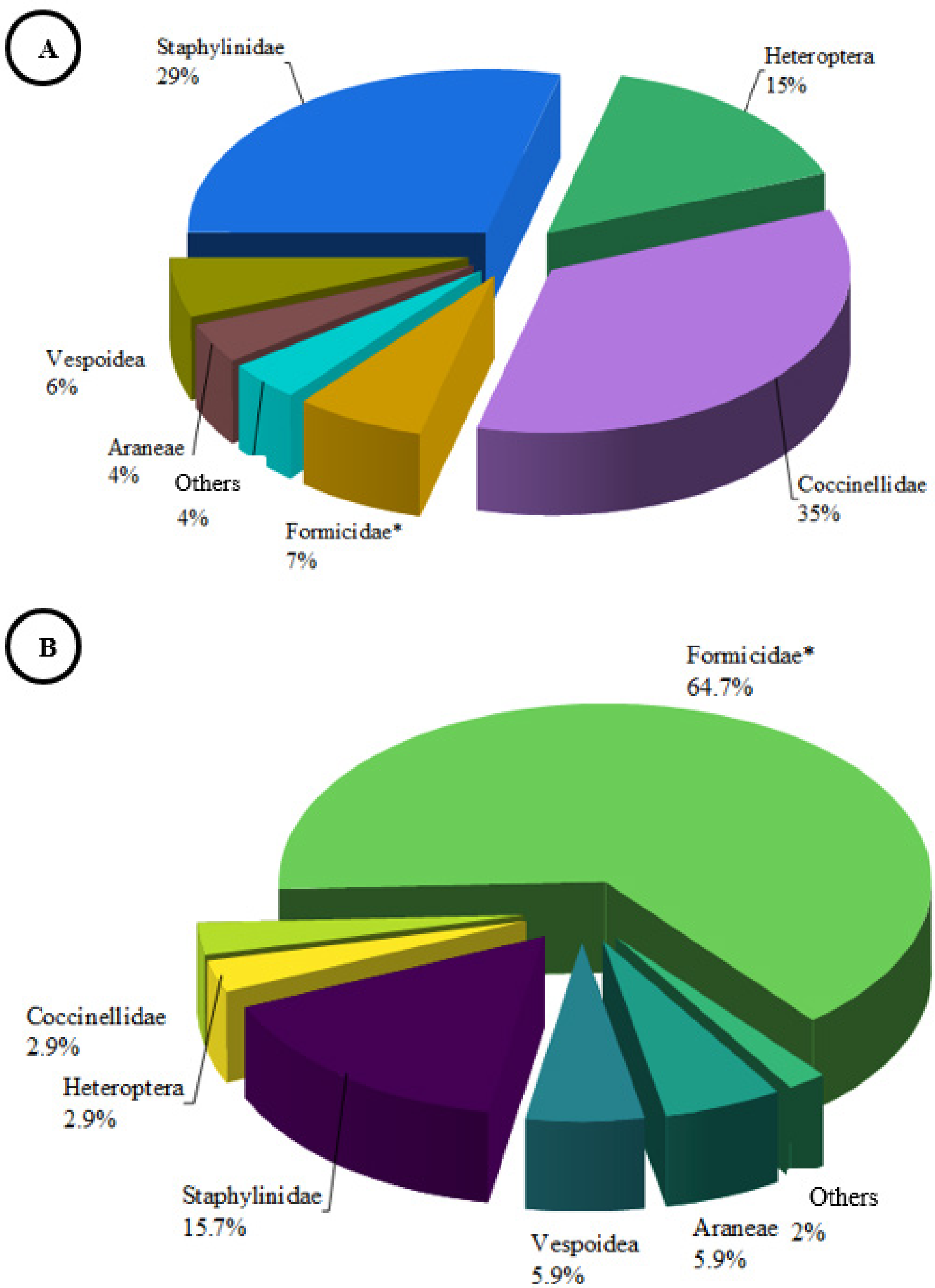

Fig 4. Proportion of predators taxon captured in the yellow adhesive trap (**170 records**) and in the universal collector (**352 records**). The collections were carried out in 18 localities of organic vegetable production in the Rashad, Sudan, from February to June 2020 and February to May 2021, using 360 universal collectors and 360 yellow adhesive trap cards (A. Predators shown in the yellow sticky trap, B. Predators shown in universal collector). In this figure, the family Dolichopodidae, with **128 individuals,** has been suppressed.

*For the Formicidae family, ants were counted in number of occurrence **(244)** instead of number of individuals (1,831).

eggs = 129.4 + 4.878 x Number of predators, $R^2 = 0.41$, $p = 0.004$). As well as the control (Number of predating eggs = 49.8 + 2.6 x Number of non-ant predators, $R^2 = 0.27$, $p = 0.025$) and the treatment minus the control (Number of pre-given e ggs = 110.5 + 5.185 x Number of occurrence of ants, $R^2 = 0.30$, $p = 0.017$). Finally, ants showed a correlation between their occurrence and species richness ($t = 7{,}5254$, $R = 0{,}88$, $p < 0{,}001$).

Discussion

In this study, it was possible to isolate the effects of winged predators from those of non-winged predators by using white grease, as also performed by Östman et al. (2003) (Fig 4). Although this isolation is not complete, we can consider it effective since 12 ants were also found in yellow sticky traps. Ants were not the only predators isolated during the experiment; besides these, in principle, spiders, nymphs, and predator larvae may have been isolated, contributing to predation rates in the treatment. However, the occurrence of these predators was similar to the control and negligible when compared to ants. Therefore, the data strongly suggest that ants are the main predators of *Belenois solilucis* on vegetables and shrubs in organic agriculture (Fig 5). Other studies in different countries found similar results such as in southern Mexico, where Habel et al. (2010) measured an ant predation rate of 30.5% on the coffee borer (*Hypothenemus hampei*) in five days, and Kaushal and Vats (1983) found a predation rate of 65.5% to 71.8% on *Belenois* eggs, during 22 hours on golf courses. Rahman et al. (2021) reviewwith studies from Oceania and Southeast Asia, shows that, out of 17 different publications, ants of the genus *Oecophylla* did not reduce the pest population size in only one of the studies.

Among the ant species sampled, it is evident that few are responsible for most of the predation (Table 1). Surprisingly, the three most frequent species captured in the cuttings belong to the genera *Linepthema* and *Dorymyrmex* (subfamily Dolichoderinae), recognized as a group that presents thermal tolerance to high temperatures and preference for open places (Grimaldi & Agosti, 2002). Generally, studies have identified the genus *Pheidole* and *Solenopsis* as the primary predators in Neotropical agricultural areas (Groc et al., 2017). The ability of species from the genera *Dorymyrmex* and *Linepithema*, as well as secondarily the genus *Camponotus*, to climb plants places them as the primary predators of *Belenois solilucis* eggs on vegetables. However, the ants of the Myrmecinae subfamily, which account for 24% of the occurrences and are represented mainly by the genus *Pheidole*, had the highest means of individuals recruited per occurrence (mean of 13.4 individuals) compared to the subfamily Dolichoderinae (7.5) and Formicinae (2,6). Complementing the role played by ants,

Table 2. Linear model that explains the influence of landscape on predation rates on *Belenois solilucis* eggs. The experiment was carried out in 18 localities of production of organic vegetables in the Rashad, Sudan, Sudan, from February to June 2020 and February to May 2021.

Factor and spatial scale	Model	Estimates	R^2 Adjusted	AIC	*P* Value
a) Predator eggs (total)					
Buffer 1000m	(none)	-	-	-	<0,05
Buffer 500m	(none)	-	-	-	<0,05
Buffer 250m	(none)	-	-	-	<0,05
Buffer 125m	(none)	-	-	-	<0,05
b) new predator by ants					
Buffer 1000m	(none)	-	-	-	<0,05
Buffer 500m	(none)	-	-	-	<0,05
Buffer 250m	(none)	-	-	-	<0,05
Buffer 125m	(none)	-	-	-	<0,05
c) Predator Eggs in Control					
Buffer 1000m	(none)	-	-	-	<0,05
	Planting	2.306e-03			**0,0103**
	Construction x Tree Cover	2.533e-09			**0,0361**
Buffer 500m	Planting x Construction Tree cover x No planting	-3.550e-08	0.3003	189,7	**0,0142**
		-1.577e-09			**0,0065**
	Planting x No Planting	-2.402e-09			**0,0337**
Buffer 250m	(none)	-	-	-	<0,05
Buffer 125m	(none)	-	-	-	<0,05

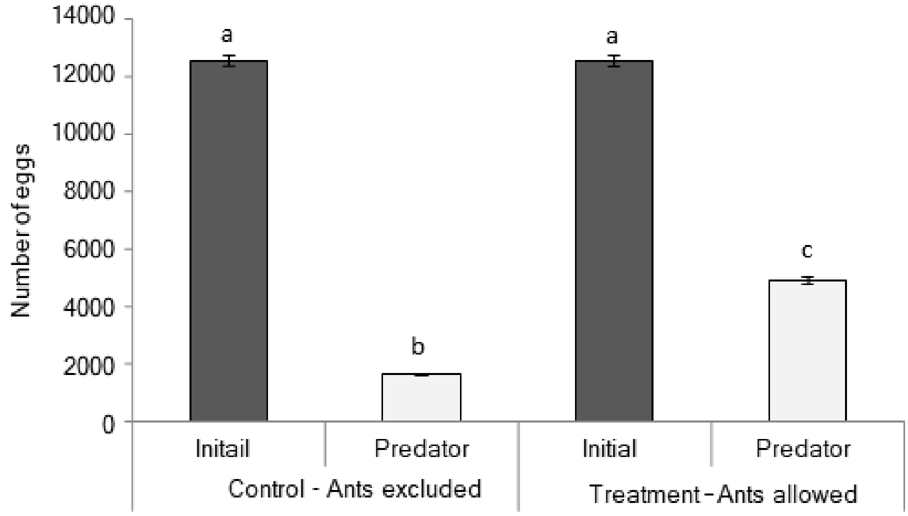

Fig 5. Number of *Belenois solilucis* eggs available (dark grey) and preyed (light grey) on the control cards (without access to ants) and treatment (with access to ants). The experiment was carried out in 18 locations within the Rashad, Sudan, from February to June 2020 and February to May 2021. Bars represent standard deviation and different letters indicate significant differences ($p < 0.05$).

a meta-analysis with studies in agrosystems found that generalist predators control the abundance of herbivores in 79% of analyzed publications. In 65% of the studies, they reduce plant damage or increase production yield (Panwar et al., 2016). The existence of commercial organic crops is only possible due to predators that control the occurrence of pests (Ratnadass et al., 2012). In addition, other predators belonging to the orders Coleoptera, Dermaptera, Neuroptera and Diptera also contribute substantially to this ecological service (Sáenz-Romo et al., 2019).

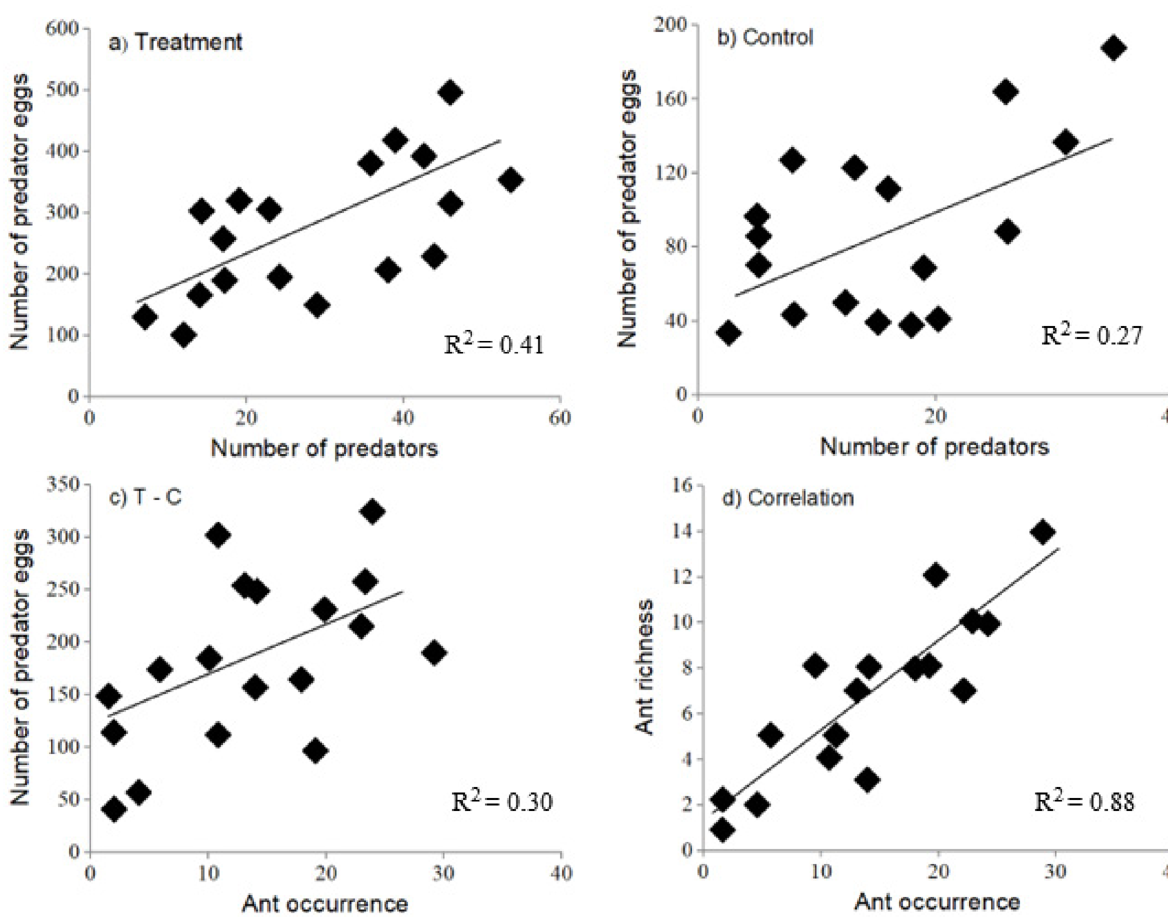

Fig 6. Linear relationships between abundance, predation or richness, such that: (a) eggs predated on the cards treatment in relation to all predators; (b) eggs predated on control cards in relation to predators except ants; (c) eggs predated in the treatment minus the control (predation attributed to ants) in relation to the occurrence of ants; and (d) correlation between ant richness and its occurrence. For all regressions and correlation, the results were significant (p<0.05). These data are based on the experiment carried out in 18 locations within the Rashad, Sudan, from February to June 2020 and February to May 2021.

When analyzing pest control in agricultural systems, it is essential to emphasize that the pest's identity affects its ability to be controlled by a particular predator taxon. For example, ants are excellent egg predators, as seen here. Still, winged pests such as adults of the whitefly (Kenis et al., 2009), in theory, would hardly be preyed upon by ants due to their small size and ability to fly, this being the preferred target of some predators of the orders Hemiptera, Neuroptera and Coleoptera (Rosenheim et al., 1995). Another example is the presence of aphids, a phytophagous that can coexist with ants while being protected by them (Bishop et al., 2014). Ladybugs (Coccinellidae) would therefore serve as complementary predators for aphids and redundant for eggs (Munyai & Foord, 2015). To better demonstrate how much predation can be beneficial to producers, we can simulate leaf herbivory calculations. According to Hlongwane (2019), throughout the larval stage of *Belenois solilucis*, it consumes an average of 89 cm² of the soybean leaf area (varying between types of cultivar). Assuming that all predated eggs in this experiment generated larvae that devoured 89 cm²/individual leaf area, each location would suffer damage of 2.4m²/day of leaf area loss on average. Non-winged predators and the remainder avoided one-third of this leaf loss by ant predation.

Many studies have shown that the landscape is critical; it provides biodiversity and can increase the presence of predators of multiple taxa and consequently increase the ecological, biological control service (Eisawi et al., 2022). However, in this study, it is observed that the landscape does not influence the total number of preyed eggs and those preyed only by ants (Table 2). As seen in other studies, the influence and importance of each landscape factor vary according to the taxon studied (Bishop et al., 2015). According to Netshilaphala et al. (2005), it is possible to maintain the biological control of pests in organic systems, regardless of the landscape, through pest management. However, this management is dependent on the species of pest, predators, and their interaction.

The ant community in forest settings is made up of a distinct set of species than those found in agrosystems. However, another study showed that the presence of scattered trees in agricultural systems increases the local richness of ant species (Sithole et al., 2010), which correlates with ants' occurrence (Fig 6) and may result in an increase in predation rates, although this remains unproven scientifically. For predators, excluding ants, tree cover influences predation rates by interacting with other landscape categories (Table 2). According to Maurice Kouakou et al. (2018), forest formation increases the diversity of both herbivores and predators in the surrounding crops, serving as a source of natural enemies. The presence of forest formations in the landscape is associated to an increase in alternative resources and the availability of a refuge site during periods of low resource availability for both predators and pests (Ratnadass et al., 2012).

The presence of planting in the landscape, on the other hand, significantly increases predation rates by winged predators (Groc et al., 2017), most likely because it is linked to the hypothesis of resource concentration (Hlongwane et al., 2019) and because it maintains an already regional set of species adapted to agrosystems. Nonetheless, it is essential to note that very high proportions of conventional planting in the landscape – above 31.2% of the landscape, as analyzed here – have had a detrimental impact on biodiversity and its services (Mauda et al., 2018). Furthermore, as shown in Table 2, there are several interactions between landscape categories, indicating that the rest of the landscape also influences egg predation by winged predators, despite the fact that these interactions are complex patterns and with a model that relatively poorly fitted to the data (fitted R^2=0.30). However, in order to explain predation rates, significant relationships were found with the abundance of all predators, in addition to winged predators and ants (Fig 6). This is most likely related to the resource-consumer hypothesis (Yanoviak et al., 2008), which states that the more resources are available, the more consumers there are. In this situation, a larger concentration of resources on a property implies a greater number of predators and, consequently, higher predation rates. This suggests success in properties with high predation rates to increase the number of predators, but it was not possible to determine what causes this greater abundance. In the literature, the availability of floral resources is an alternative food for predators such as ladybugs (Fotso Kuate et al., 2015). In addition, farms can be managed to create an adequate "ecological infrastructure" to enhance biological control (Mauda et al., 2018).

Conclusion

Despite farmers' ignorance, ants are an important group of predatory insects capable of reducing the eggs population of a *Belenois solilucis* pest on organic farm plants by an average of 26.8% per day. It is also noteworthy that other predators sampled mainly consist of two families of the order Coleoptera (Coccinellidae and Staphylinidae), which, together with other predator taxa, removed 13% of the available eggs.

The landscape has a limited effect solely on predation carried out by winged predators, being positively influenced by planting areas and interactions with the remainder of the landscape within a 500-meters radius. Finally, a positive relationship was found between the abundance of predators and their respective predation rates. This indicates that the successful conservation of biological control within organic areas is associated with the ability of these systems to manage to maintain a large number of predators.

Compliance with Ethical Standards

Conflict of Interest

The authors declare that they have no conflict of interest.

Acknowledgements

I would like to express my deep gratitude to Professor He Hong, my research supervisors, for their patient guidance, enthusiastic encouragement and useful critiques of this research work.

We also thank the Northwest A & F University and University of East Kordofan for financing field data collection and providing financial and other material support during the study.

Authors' Contributions

Conceptualisation, study design, field data collection, data analysis and interpretation: KAE Eisawi. Writing-initial draft: IP Subedi. Supervision, study design: H He. Writing-revisions: CD Yode. All authors read and approved the final manuscript.

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