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ORIGINAL ARTICLE

Breeding and Multiplication Patterns of the Variegated Ladybeetle [*Hippodamia variegata* (Goeze)], Under Field Conditions in Khartoum, Sudan

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Abstract

Various ladybeetles, including *Hippodamia variegata* (Coleoptera: Coccinellidae), are potential biological control agents worldwide. Recent studies in Sudan proved that *H. variegata* is widely distributed. This research aimed to trail the habitat, breeding times and seasonal multiplication of this predator during the periods 2001-2005 and 2010-2015 in Khartoum State. The breeding times were tackled in two consecutive years via regular surveys of adults and immature stages on two major crops viz., Sorghum (*Sorghum bicolor*) and alfalfa (*Medicago sativa*). Such stages were separately recorded and compared. The results showed wide habitat diversity especially in winter. A total of 31 major hosts (cultivated and wild) harboring the predator was recorded, on which a sum of > 20 prey species were attacked. Higher multiplication of *H. variegata* was found on the field crops than on the vegetables investigated. The highest breeding and abundance of *H. variegata* on *S. bicolor* was between January–April, whereas on *M. sativa* it occurred primarily between February–June and to some extent secondly in September. In the other months reduced population of all stages were detected on both crops, with the least number almost found in December and August. However, the number of immature stages was comparable with or exceeded the number of adults in mid winter (January-February) and end of autumn (September–October) on sorghum and alfalfa, respectively. The conditions in both autumn and winter seasons seemed to enhance the multiplication of this predator, though mechanical suppression occurs during heavy rains. It is concluded that *H. variegata* breeds successfully on different crops throughout the year without any noticeable resting period in the studied area, a fact that certainly adds to its potential value in pest management.

Keywords: Coccinellid, aphidophagous, Adonis' ladybird, habitat diversity, seasonality.

Introduction

Various ladybeetles, including certain *Hippodamia* spp. (Coleoptera: Coccinellidae), are potential predators which contribute significantly in natural balance of copious agricultural pests particularly aphids (Fan and Zhao, 1988; Kalushkov *et al*., 1991; Franzman, 2002; Jovicic *et al*., 2013, and Khanjani, 2013). Accordingly, several species are considered as important agents in biological control and IPM programs worldwide (Obrycki, 1998; Ellis *et al*., 1999;

Brown *et al*., 2008, and Iqbal *et al*., 2008). Among such species the variegated ladybeetle, also called the variegated ladybird or Adonis' ladybird [*Hippodamia* (=*Adonia*) *variegata* (Goeze)] is well known as an efficient aphidophagous predator used for biological control of different aphid species in a number of counties. An eminent example is that occurred in vast areas in mid-western and western USA where many releases of this predator were made during the period from 1957 to 1993 (Ellis *et al*., 1999).

The variegated ladybeetle is a Palearctic coccinellid that has been distributed (accidentally or intentionally) and established in different regions globally (Gordon, 1987; Gordon and Vandenberg, 1991; Wheeler and Stoops, 1996, and Franzman, 2002). It is worth mentioning that no records of *H. variegata* are found in earlier studies in Sudan until 1970, and therefore it is thought to be an accidently introduced species. However, recent studies in Sudan proved that *H. variegata* is one of the common and widespread coccinellids in different parts of the country (Abdalla and Beije, 1997; Satti *et al*., 1998, and Satti and Bilal, 2012). It seems to occur on some different host plants among vegetable and field crops, but its real habitat diversity needs to be checked in depth. Its major preys on these host plants were observed to consist mainly of aphids and other agricultural pests (Kuol, 2003; Satti, 2007; Bilal and Satti, 2012, and Satti, 2015), which also need further clarification.

In spite of the fact that sporadic studies are conducted on the biology and seasonal abundance of *H. variegata* on some crops in Khartoum area and few other locations in the country (Badawy, 1968; Satti *et al*., 1998; Kuol, 2003, and Bilal and Satti, 2012), but it is not known whether this predator breeds during certain seasons or throughout the year. The previous works dealt merely with total population count of the predator on its host plants without consideration of pre-adult's trend at monthly and annual bases.

Therefore, the present investigation was set to explore host and prey diversity of *H. variegata* and to follow its breeding times and multiplication on certain major crops in Khartoum area, as a step forward to cover various ecological aspects of this important predator.

Materials and Methods

1. Predator's survey on different crops

Field surveys were carried out in Khartoum State, concentrating at Shambat area, during two periods, 2001 – 2005 and 2010 – 2015, in order to monitor the occurrence of *Hippodamia variegata* on different host plants. The survey activities targeted the following points:

a) To prepare a list of host plants: Since *H. variegata* is thought to be an introduced species, this research was aimed to put a step forward to complete its current picture in the country, especially with respect to its ecological habitats. This can be useful in directing ecological studies in future research, and also in exploring the size of habitat diversity which is largely responsible for spreading and establishment of this bioagent as suggested by Ellis *et al*. (1999). Thus, different plant species (wild and cultivated) encountered in the surveyed area were inspected at sporadic times of the year in search of the predator. No counts were performed in this case, but host plants showed positive result were just recorded, besides some observations on prey hosts. The cumulative records obtained throughout the survey periods (2001 – 2005 and 2010 – 2015) were arranged in a list to show the existing hosts harboring the predator in the studied area. In addition, short accounts of main prey species attacked on such hosts were also added.

b) To track seasonal trends on selected crops: From the above surveyed plant species, six main crops generally grown at Shambat area were allocated for this activity. They included field and vegetable crops, namely; forage sorghum "Abu-sabein" (*Sorghum bicolor* L. Moench), maize (*Zea mays* L.), alfalfa (*Medicago sativa* L.), okra

(*Abelmoschus esculentus* (L.) Moench), snake cucumber (*Cucumis sativus* L. var. *flexuosus* Alef.) and eggplant (*Solanum melongena* L.). These were subjected to regular survey and counts (at fortnight intervals) of the predator, covering all seasons (winter, summer and autumn) and repeated in the two consecutive years. The count was done per 25 random plants in all crops, except in alfalfa where it was performed per $1m^2$. The total numbers (irrespective of the stages, except in cases of sorghum and alfalfa as explained below) of the predator were counted as affected randomly in one place, and replicated in three locations of untreated fields for each crop. Such samplings were based on Randomized Complete Block (RCB) design. Hence, seasonal population abundance of *H. variegata* was scrutinized and compared among the six crops, from which the peak times of reproduction and the most attractive plant species for the predator were identified. Also, this activity plus the previous one could allow understanding to what extent *H. variegata* is distributed among different host plants, which in turn reflected the diversity in prey species being attacked by this predator. Rain fall data were obtained from Shambat metrological station.

2. Regular inspection of immature stages

This study was aimed to track the breeding pattern of the variegated ladybeetle through periodical (fortnightly) counts of the immature stages during all seasons in two consecutive years (2001 - 2002), so the results may answer the hypothesis that *H. variegata* is an all seasons' predator at least in this part (Khartoum) of the country. The study was performed on two major plant species (i.e., *Sorghum bicolor* and *Medicago sativa*) chosen from the six crops indicated for the previous research activity. These two crops are grown all the year round in Khartoum State, as compared to others, that is why they were selected to secure continuous counts. Accordingly, the survey and counts performed above, which targeted the total numbers of predator, concurrently included regular counts of immature stages (egg batches, larvae, pre-pupae and pupae) and adults on the two designated crops, where each of the encountered stages was recorded separately. Equally, surveys were repeated at fortnight intervals and continued for two consecutive years. Data obtained were analyzed statistically, and compared between stages and crops.

Results and Discussion

Although *Hippodamia variegata* is an old world (Palearctic) coccinellid distributed and established in different parts of the world (Gordon, 1987; Gordon and Vandenberg, 1991; Wheeler and Stoops, 1996, and Franzman, 2002), but no records of this predator are found in earlier studies that dealt with natural enemies in Sudan until 1970 (Bashir, 1968; Schmutterer, 1969, and Kranz *et al*., 1978). Therefore, it is thought to be an introduced species, and most probably entered the country from elsewhere during the period between 1970 and 1990. This notion is consistent with the first record of this species which occurred as a result of surveys conducted during early 1990s in central region of the country (Abdalla and Beije, 1997; Beije and Ahmed, 1997, and Beije and Gamer-elanbia, 1997). Subsequent reports on the biology and ecology of the species were scattered and incomplete. The present study was therefore set to provide some basic information on bio-ecological aspects of *H. variegata* pertinent to its employment in biological control. Results of the different parameters studied were presented and discussed as follows:

1. Survey results of host plants and prey species

Table 1 listed the main host plants detected to harbor *H. variegata* in Khartoum area. The table also showed the main prey species attacked by the predator on the different crops, denoted with numbers, whereas their names including brief nomenclatural information were listed in table 2. Accordingly, the first table showed a total of 31 hosts found to be visited by the predator, among which 21 plant species were cultivated crops and 10 were wild plants.

Table 1. The main host plants harboring *Hippodamia variegata* in Khartoum State, during the periods (2001-2005; 2010- 2015).

No.	Plant species (Family)	Common/"local" name	Main pests serve as preys*
Cultivated crops:			
1	*Medicago sativa* (Fabaceae)	Alfalfa	2, 7, 13, 17
2	*Sorghum bicolor* (Poaceae)	Sorghum	4, 5, 6, 15, 16, 18
3	*Triticum aestivum* (Poaceae)	Wheat	4, 5, 6, 18
4	*Zea mays* (Poaceae)	Maize	4, 5, 6, 15, 13, 16, 18
5	*Helianthus annuus* (Asteraceae)	Sunflower	8, 12, 17
6	*Gossypium* spp. (Malvaceae)	Cotton	1, 8, 9, 10, 12, 14, 17
7	*Abelmoschus esculentus* (Malvaceae)	Okra	1, 8, 9, 10, 12, 14, 17
8	*Solanum lycopersicum* (Solanaceae)	Tomato	1, 8, 10,12, 17
9	*Solanum melongena* (Solanaceae)	Eggplant	1, 8, 9, 10, 17, 19
10	*Solanum tuberosum* (Solanaceae)	Potato	1, 8, 10, 17
11	*Vicia faba* (Fabaceae)	Faba bean	2, 8, 10, 11, 12, 17
12	*Lablab purpureus* (Fabaceae)	Lablab bean	2, 8, 10, 11, 12, 17
13	*Phaseolus vulgaris* (Fabaceae)	Common & snap beans	2, 8, 10, 11, 12, 17
14	*Vigna unguiculata* (Fabaceae)	Cowpea	2, 8, 10, 11, 12, 17
15	*Cajanus cajan* (Fabaceae)	Pigeon pea	2, 10, 12, 19, 20
16	*Cucumis sativus* var. *flexusus* (Cucurbitaceae)	Snake cucumber	1, 8, 17
17	*Cucumis melo* (Cucurbitaceae)	Muskmelon	1, 8, 17
18	*Cucurbita pepo* (Cucurbitaceae)	Squash	1, 8, 17
19	*Cucurbita maxima* (Cucurbitaceae)	Pumpkin	1, 8, 17
20	*Citrullus lanatus* (Cucurbitaceae)	Watermelon	1, 8, 17
21	*Ipomoea batatas* (Convolvulaceae)	Sweet potato	8
22	*Allium cepa* (Amaryllidaceae)	Onion	10
23	*Capsicum annuum* (Solanaceae)	Sweet pepper	1, 8, 10
24	*Capsicum frutescence* (Solanaceae)	Hot pepper	1, 8, 10
25	*Trigonella foenum graecum* (Fabaceae)	Fenugreek	10
21	*Coriandrum sativum* (Apiaceae)	Coriander	10
Shrubs and herbaceous weeds:			
22	*Calotropis procera* (Asclepiadaceae)	Sodom apple	3
23	*Leptadeniaheterophylla* (Asclepiadaceae)	Leptadenia/ "Lewais"	3
24	*Nerium oleander* (Apocynaceae)	Oleander	3
25	*Solanum dubium* (Solanaceae)	"Gubain"	1, 8, 9, 10, 17, 19
26	*Abutilon* spp. (Malvaceae)	"Hambouk" (Arabic)	1, 8, 9, 10, 14
27	*Xanthium brasilicum* (Compositae)	Cocklebur	20
28	*Lantana camara* (Verbenaceae)	Lantana	8
29	*Citrullus colocynthis* (Cucurbitaceae)	Bitter cucumber	1, 8, 17
30	*Datura inoxia*(Solanaceae)	Prickly burr	1, 8, 10, 17
31	*Datura stramonium* (Solanaceae)	*Jimson weed*	1, 8, 10, 17

* = See table 2 for names of prey species according to numbering.

Most of these crops, especially legumes and some vegetables are winter crops, while few are summer or all seasons' ones. Although, this was considered as one of rare studies which gave more attention to habitat diversity of the variegated ladybird in the country, but certain common species of the listed hosts were frequently mentioned in previous works (Satti *et al*., 1998; Kuol, 2003; Bilal and Satti, 2012, and Satti and Bilal, 2012). The results indicated that *H. variegata* has a wide habitat range particularly in winter time, a factor that contributed substantially to its multiplication and increased population. This is contrarily to the dearth of summer period which forced the predator to seek restricted niches to sustain its life through limited reproduction. According to Ellis *et al*. (1999), the landscape diversity including aphid rich crops found in the northeast U.S is thought to be responsible for successful establishment and spreading of *H. variegata* in that region, whereas in contrast, the failure of this bioagent to survive in major wheat-growing areas of the north-central and

Table 2. The main insect prey species targeted by *Hippodamia variegata* on different surveyed plants in Khartoum State, during the periods (2001-2005; 2010- 2015).

No.	Scientific name of prey species	Order: Family	Common name
1	*Aphis gossypii* (Glov.)	Homoptera: Aphididae	Cotton aphid
2	*Aphis craccivora* Koch	Homoptera: Aphididae	Cowpea aphid
3	*Aphis nerii* Boyer	Homoptera: Aphididae	Oleander aphid
4	*Melanaphis sacchari* (Zehntner)	Homoptera: Aphididae	Sorghum aphid
5	*Rhopalosiphum maidis* (Fitch)	Homoptera: Aphididae	Corn leaf aphid
6	*Schizaphis graminum* (Rondani)	Homoptera: Aphididae	Greenbug/ Wheat aphid
7	*Therioaphis trifolii maculata* (Monell)	Homoptera: Aphididae	Spotted alfalfa aphid
8	*Bemisia tabaci* (Genn.)	Homoptera: Aleyrodidae	Cotton whitefly
9	*Jacobiasca lybica* (de Berg.)	Homoptera: Cicadellidae	Cotton jassid
10	*Thrips tabaci* (L.)	Thysanoptera: Thripidae	Onion thrips
11	*Caliothrips* spp.	Thysanoptera: Thripidae	Grey & dark cotton leaf thrips
12	*Helicoverpa armigera* (Hub.)	Lepidoptera: Noctuidae	African bollworm
13	*Spodopteraexigua* (Hub.)	Lepidoptera: Noctuidae	Leaf worm
14	*Earias* spp.	Lepidoptera: Noctuidae	Egyptian & spotted bollworms
15	S*esamia cretica* Lederer	Lepidoptera: Noctuidae	Pink stem borer
16	*Chilo partellus* (Swinhoe)	Lepidoptera: Crambidae	Spotted stem borer
17	*Liriomyza* spp.	Diptera: Agromyzidae	Serpentine leaf miners
18	*Campylomma* sp.	Hemiptera: Miridae	Plant bug
19	*Urentius* spp.	Hemiptera: Tingidae	Eggplant tingid bug
20	*Phenacoccus solenopsis* Tinsley	Hemiptera: Pseudococcidae	Cotton mealy bug

western parts was attributed to the large wheat fields connected with overall reduced habitat diversity in the latter case. Therefore, the current preliminary results should be supported with additional prerequisite studies leading to solid conclusion on conservation programs for this interesting coccinellid species.

Concerning the prey diversity, table 2 showed > 20 species in 5 orders and 10 families of important insect pests for the recorded hosts. In addition, there were also other unidentified minor insects serving as prey sources on various hosts. The most important preys which seemed to direct the movement of the variegated ladybird among the different host plants appeared to be the homopteran insects particularly some genera and species within Aphididae (six of them are key preys; *Aphis gossypii*, *Aphis craccivora*, *Aphis nerii*, *Melanaphis sacchari*, *Rhopalosiphum maidis* and *Schizaphis graminum*), and members of Thysanoptera (thrips) and to some extent the immature stages of Lepidoptera, whereas the hemipteran pests like lace bugs and mealy bugs in addition to species of cicadellid (jassids) and agromyzid (leaf miners) pests were the least attacked. This assumption agrees with Kuol (2003) who reported that *H. variegata* is more prevalent on plants harboring different species of aphids, and also proved that the predator shows relative feeding preference to certain aphid species compared to other tested ones. Iperti (1966) stated that *Aphis nerii* is poisonous to most coccinellids except *Hippodamia variegata*. Equally, the above stated observation confirmed some laboratory results obtained on comparative feeding test among three predators including *H. variegata*, which revealed the least consumption of lace bugs by the latter species as compared with the other predators (Satti, 2003).

2. Seasonal occurrence of the predator on selected crops

The results of seasonal trends of *H. variegata* among the six surveyed field and vegetable crops are presented in table 3. Comparisons of overall means on all crops between seasons, and the annual population means between the six crops, are depicted in figures 1A and 1B, respectively. The data of seasonal means (Table 3) indicated that in almost all crops the predator buildup was highest in winter season followed by

Table 3. Seasonal mean numbers of *Hippodamia variegata* surveyed on six crops during various seasons in the period (2001-2005) at Shambat area, Khartoum North.

Season	Seasonal population mean* on different crops					
	Sorghum	Maize	Alfalfa	Okra	Snake Cucumber	Eggplant
Winter	9.60	11.66	5.70	2.45	1.05	1.10
Summer	2.32	07.48	6.01	0.05	0.10	0.03
Autumn	0.17	00.73	5.94	0.43	0.13	0.00

* Mean numbers per 25 plants in all crops, except alfalfa per $1m^2$.

summer and then autumn. An exception for that occurred on alfalfa where the winter season in contrast witnessed the lowest abundance, while summer and autumn revealed the highest. Comparison of the overall seasonal means on all crops revealed significantly higher population in winter than in autumn, but summer attained an intermediate level without significant differences from both seasons (Fig. 1A). On the other hand, the comparison between the different six plant species reflected that the three field crops (maize, alfalfa and sorghum) sustained significantly higher populations (4.03-6.62) of the predator, as the most attractive habitats, than those (0.38-0.98) of the tested vegetable crops (Fig. 1B). The data analysis as appeared in figure 1A had assured high variation in population abundance of the predator among the six crops in the different seasons; though such variation was relatively lower in winter as a result of favorable environment. Similarly, the relatively high variations connected with annual means of all crops (except alfalfa) confirmed the high fluctuation in the predator buildup which occurred from one time to another on these crops, whereas in contrast, that very low standard error depicted on alfalfa is a good indicator of population stability on this host as compared with the others (Fig. 1B). Therefore, alfalfa can be studied as a promising habitat candidate for conserving *H. variegata* in Khartoum State.

It was observed that on almost all crops the egg masses of this coccinellid predator were generally laid on the undersides of the lower leaves in plant canopy, the larvae and adults were found wandering about at different plant heights, while on the other hand the pupae were always fixed to the upper surfaces of leaves on the upper third of plant heights particularly during cool seasons, in a way looked as if they were exposed to the sun light. Such phenomena wait scientific clarification.

Based on the current results, the apparent highest buildup of the predator population on most crops during winter as compared to other seasons was attributed largely to variation in climatic factors, particularly temperature and relative humidity. The mild winter season (av. 25ºC & 35% R.H) in Khartoum seemed to be more suitable for reproduction of *H. variegata* than other seasons. It is well documented that climatic conditions are among potent factors affecting biology, reproduction and development of insects. For example, Mandour *et al*. (2011) stated that temperature had significant effect on the development and food consumption of *H. variegata*, as the best life tables' data and the greatest fecundity (1075 eggs) are attained at 25°C when *Aphis craccivora* is used for feeding, hence this temperature degree is recommended for the predator's rearing. Also, Skouras and Stathas (2015) found that 25°C is the optimum temperature for the development and growth of *H. variegata* as a biological control agent since the highest total prey consumption and lowest larval mortality were recorded under this temperature.

The reasons why alfalfa sustained higher population in summer than in winter could be firstly attributed to the fact that the end of winter period generally witnesses a transitional dearth time where the majority

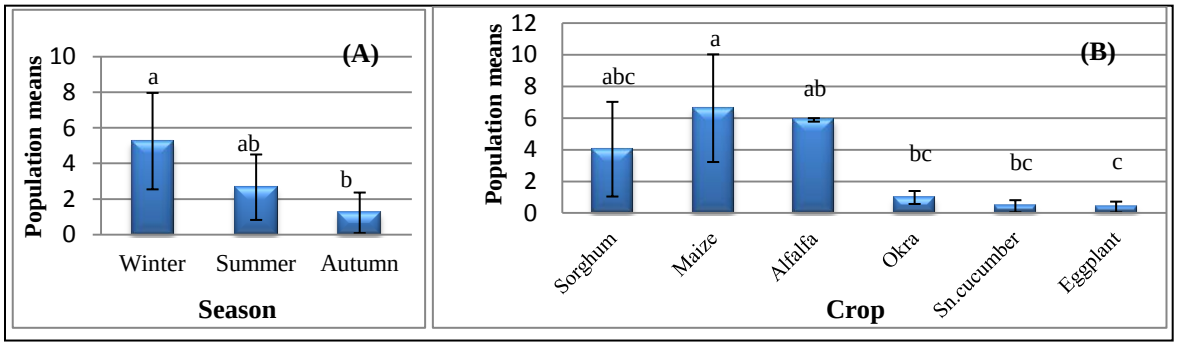

Figure 1. Trends of *Hippodamia variegata* on six crops surveyed at Khartoum State (2001-2005); **A)** overall seasonal means on the six crops between the three seasons, **B)** annual means between the six crops.

of seasonal and annual crops are harvested or become moribund and dry out, as observed from current surveys and reported in preceded studies (Satti, 2009). Thus, the predator finds suitable refuge in alfalfa as one of the rare crops thriving in the field a year round. A second point is that this crop was found to harbor various soft insects including species of aphids and thrips which serve to secure feeding and multiplication of the predator and other natural enemies during such critical period. Alfalfa is a unique crop in sustaining some lepidopterous insects and more than one species of aphids namely, *Aphis craccivora* and *Therioaphis trifolii* (Bashir, 1968, and El Abjar, 1985); most of them seemed to extend their occurrence in summer season. The findings are congruent in various aspects with some previous studies (Bashir, 1968; Satti and Bilal, 2012, and Jovicic *et al*., 2013). For instances, Bashir (1968) reported that *Aphis craccivora* and *Spodoptera exigua* are found to show their maximum activity on alfalfa in Khartoum province during January-May and May-June, respectively. In Serbia, Jovicic *et al*. (2013) even recorded a third aphid species [*Acyrthosiphon pisum* (Harris)] besides the aforesaid ones in alfalfa field, which is considered as the most important crop sustaining a wide biodiversity of predators consisting of seven major aphidophagous coccinellids including *H. variegata*. Nevertheless, the obtained results should be supported via deep research on each crop to specify the numbers of key preys and their predator's population densities for correlation testing using an appropriate formula.

However, regarding the relative preference shown by the predator towards the three field crops including alfalfa could be partially revert to the same previous reasons, but in other way it might be connected with prey preference as divergent hosts are expected to be different in their insect fauna. In this context, preference of *H. variegata* towards different genera and species of aphids are recognized by some investigators (e.g., Kuol, 2003). Kuol (2003) indicated that *H. variegata* relatively preferred feeding on *Melanaphis sacchari* and *Schizaphis graminum* (both are cereal pests) than on *Aphis craccivora*, *Aphis gossypii* and *Aphis nerii*. Even more, the type of host plant fed upon by a species of aphid is found to affect the development of *H. variegata*, as different life tables results were obtained when this predator fed on *Aphis gossypii* reared separately on three different crops (Yousif, 2005), a factor that ultimately affects its abundance on that host. Also, since micro-climate is different among the various vegetative strata from one crop to another, hence, besides suitability of prey species habitat ecological quality is considered as an additional factor governing the preference of coccinellids to certain vegetations (Thompson, 1951). In this respect, Satti (2007) reported that in hot seasons both *H. variegata* and *Cheilomenes propinqua vicina*

generally find suitable habitat within the leaf whorls of cereal plants (maize and sorghum) where insect preys like *Rhopalosiphum maidis* and others are also confined. Therefore, such cereals as well as alfalfa can be emphasized as intercropping or guard crops in upcoming research for enhancing preservation and population buildup of coccinellid predators, namely *H. variegata*, in agricultural fields.

3. Annual trends of breeding and multiplication

Results obtained through two consecutive years of thorough investigations concerning breeding times and multiplication trends of *H. variegata* on two crops (forage sorghum and alfalfa) are presented. Table 4 explains the monthly mean counts of adults and immature stages (pre-adults) on forage sorghum. The pre-adults may include, egg batches, larvae, pre-pupae or pupae. It is obvious that the highest breeding on this crop occurred during midwinter-early summer phase (January-April), followed by a sharp reduction thereafter. This finding indicates that in the other months of the year the adults gradually decreased and the pre-adults were scarcely detected, except in October. August-September and November-December witnessed the lowest reproduction periods in autumn and winter, respectively. The autumn reduction coincided with peak rain falls (av. 90mm) in both years. However, comparison of adult (2.69±2.17/ 25 plants) with pre-adult (1.34±1.11) stages showed no significant difference among their overall average counts; it revealed a ratio of 2:1 adults to pre-adults.

Regarding alfalfa, table 5 shows the results of the two same years as mentioned for sorghum crop. Here both the adult and pre-adult stages nearly showed gradual increases in numbers starting from the onset of winter (December) and up to the end of summer (June). All stages manifested sharp reduction during the first half of autumn (July-August), but high breeding recovery soon occurred in September. Again, the heavy rain falls occurred in July-August of the first year (and August of the second year) seemed to suppress the predator population at this time on alfalfa as well as on sorghum crop. As opposite to sorghum, the detection of pre-adult stages during all months of the year proved continuous breeding of the predator on alfalfa. However, two breeding peaks were evident, one in summer (July) and the other in autumn (September), whereas the

Table 4. Monthly and annual mean numbers of adults and immature stages of *Hippodamia variegata* per 25 plants of *Sorghum bicolor*, during two consecutive years (2001-2002), in Khartoum State.

	Monthly means of different stages in two years				**Average of two years**	
	2001		**2002**			
Month	**Adults**	**Im. St.**	**Adults**	**Im. St.**	**Adults**	**Im.St.**
January	9.80	10.80	1.93	1.67	5.87	6.24
February	7.25	12.50	7.59	2.92	7.42	7.71
March	11.00	0.58	7.50	3.25	9.25	1.92
April	3.50	0.08	7.58	0.00	5.54	0.04
May	0.67	0.00	2.13	0.13	1.40	0.07
June	2.33	0.00	1.00	0.00	1.67	0.00
July	0.73	0.00	0.40	0.00	0.57	0.00
August	0.25	0.00	0.08	0.00	0.17	0.00
September	0.25	0.00	0.17	0.00	0.21	0.00
October	0.00	0.00	0.27	0.27	0.14	0.14
November	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00	0.00	0.00
Total					32.24	16.12
Overall mean±S.E.					**2.69±2.17^{ns}**	**1.34±1.11^{ns}**

Im.St. = Immature stages; ns = non significant.

Table 5. Monthly and annual mean population density of adults and immature stages of *Hippodamia variegata* per $1m^2$ of *Medicago sativa* crop, during two consecutive years (2001-2002), in Khartoum.

Month	Monthly means of different stages in two years				Average of two years	
	2001		2002			
	Adults	Im. St.	Adults	Im. St.	Adults	Im.St.
January	2.33	1.87	2.40	1.20	2.37	1.54
February	3.67	2.67	4.17	3.00	3.92	2.84
March	6.42	1.67	4.17	1.92	5.30	1.80
April	5.42	3.83	3.50	0.83	4.46	2.33
May	5.27	5.33	4.00	1.67	4.64	3.50
June	6.42	7.09	8.17	0.50	7.30	3.80
July	2.93	0.00	2.67	0.40	2.80	0.20
August	1.58	0.50	1.17	0.08	1.38	0.29
September	4.08	16.58	2.17	1.25	3.13	8.92
October	3.00	3.20	2.00	1.80	2.50	2.50
November	3.92	1.42	1.08	0.50	2.50	0.96
December	1.33	2.00	0.33	0.25	0.83	1.13
Total					41.13	29.81
Overall (mean ± S.E.)					**3.43 ± 1.27^{ns}**	**2.48 ± 1.64^{ns}**

Im. St. = Immature stages; ns = non significant.

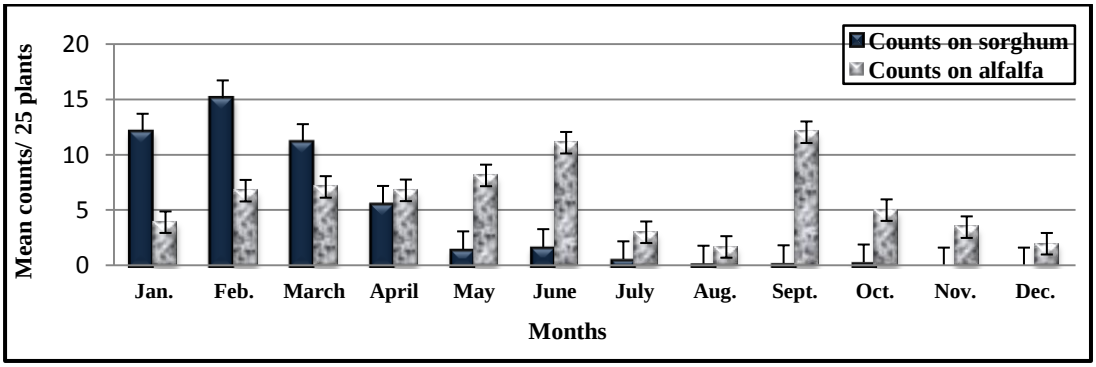

Figure 2. Comparison of monthly mean counts of *Hippodamia variegata* (adults + immature stages) between two crops (sorghum & alfalfa) surveyed at Khartoum State (2001-2002).

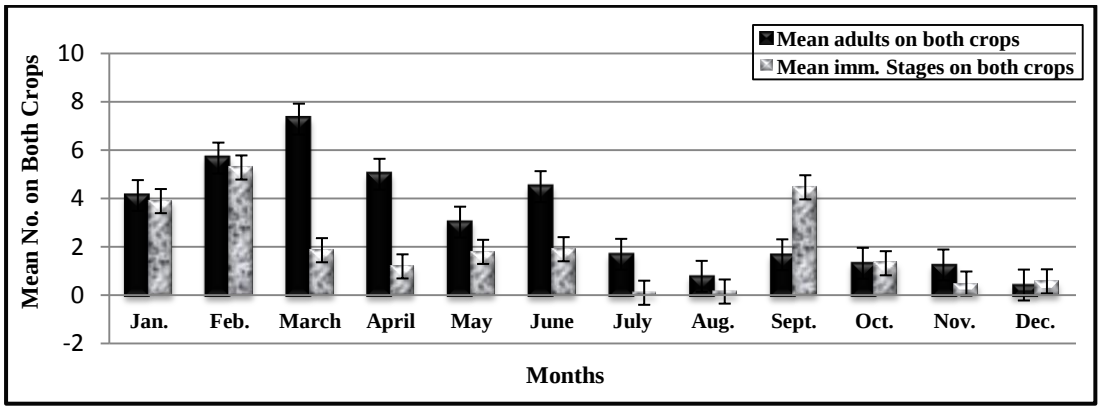

Figure 3. Comparison between the monthly mean adults and immature stages of *Hippodamia variegata* on the two crops (sorghum & alfalfa) surveyed at Khartoum State (2001-2002).

lowest breeding times appeared virtually in July/August and in December of the two seasons, respectively. Comparing the overall average of adults with that of pre-adults also reflected no significant differences between such groups on alfalfa, though, adults (3.43±1.27) were relatively higher than pre-adults (2.48±1.64) (Table 5). Here the ratio of adults to pre-adults was relatively lower (1.4:1) than that recorded for sorghum, which verified the fact that the highest breeding is on alfalfa. Figure 2 clearly shows the difference in the coccinellid trends between the two crops.

In general, the variegated ladybeetle (*H. variegata*) proved to breed successfully on both sorghum and alfalfa especially during winter time (peaked in February), but with relatively higher reproduction rate on sorghum than on the latter crop. Contrarily, the predator was largely depended on alfalfa for summer and autumn breeding (Tables 4 and 5, and Fig. 2). However, the depicted average counts recorded from the two crops for each stage group (adults and pre-adults) have confirmed adult peak at the end of winter (March), while that of pre-adults showed two peaks in mid-winter (February) and late-autumn (September) (Fig. 3). According to Rebolledo *et al*. (2009) the annual population maxima for coccinellids in alfalfa in the Metropolitana Region took place a little bit late at the end of March; this is reasonable due to different situations between the two countries. To conclude, it is well established that *H. variegata* can breeds all the year round without resting period in the studied area, a fact that certainly adds to its potential value in pest management; but the adverse conditions limiting its buildup in certain times should have to be settled.

Moreover, computation of the data showed that *H. variegata* population was the highest (>70%) as the dominant species among the total predatory complex detected on alfalfa during the two years of surveys. The aforementioned results indicated that *H. variegata* managed to replace other previously recognized coccinellid predators on alfalfa and sorghum crops; a fact, consistent with notion that *H. variegata* is an alien species. Monitoring of predatory fauna on alfalfa in Khartoum during 1960s showed that *Coccinella undecimpunctata* L. and *Cheilomenes propinqua vicina* (Mulsant) were the dominant coccinellids, and no *Hippodamia* species was reported (Bashir, 1968). However, during the last three decades *H. variegata* surpassed other coccinellids in some fields (Satti, 2007, Satti and Bilal, 2012). The fast distribution of *H. variegata* on a variety of crops, preying on different pest species, as a new exotic predator in Australia was acknowledged (Franzmann, 2002).

Conclusion

The variegated ladybeetle (*Hippodamia variegata*) is becoming established and adaptive to different habitats and geographical locations during the last decades in Sudan. It seemed to replace other species in agricultural fields to show itself as the dominant predator of numerous pests particularly aphids of variable genera and species on wide range of host plants. Studies on various aspects of this predator are going on so as to maximize its role in pest management. The current findings assured that *H. variegata* can breed successfully all the year round in Khartoum State and no diapausing stage seemed to be found. Although, peak populations' buildup was detected at different seasons, but annual trends on most crops appeared to be instable depending on multiple factors, mainly connected with variability in climatic conditions (seasonality) and cropping systems besides availability and fluctuation of preferable prey species. Nevertheless, the relative population stability on alfalfa, in particular, proved that this crop is promising in conservation programs of *H. variegata*. Therefore, further research to delineate factors affecting breeding and multiplication and consequently population balance of this predator is imperative.

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