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Functional Response of *Oxyopes javanus* (Araneidae: Oxyopidae) to *Sogatella furcifera* (Hemiptera: Delphacidae) in Laboratory and Mesocosm

Abida Butt* and Muhammad Xaaceph
Department of Zoology, University of the Punjab, Lahore, Pakistan

Abstract.- Most spiders species are generalist predator and used as a biological control agent of insect pests in agroecosystems including rice. Predatory potential of the spider depends upon their interaction pattern with the prey. In present study, functional response of adult hunting spider, *Oxyopes javanus* (Araneae: Oxyopidae) against different densities of adult white back planthoppers (*Sogatella furcifera*) was assessed in laboratory and mesocosm. The proportion of prey killed at different densities of prey represents type II functional response both in laboratory and mesocosm. Handling time was low and the attack rate and efficiency of attack was high in laboratory as compared to mesocosm. In both experimental arenas, increase of prey density resulted decrease in total search time and search efficiency while handling time increased. The attack rate did not change with the prey density in both experiments. The observed feeding strategy of *O. javanus* suggested that its relationship with the prey is affected by the density of the prey and complexity of the habitat.

Key words: White back planthopper, functional response, predation, spider

INTRODUCTION

Rice is second most widely consumed cereal crop in Pakistan and play a significant role in the uplifting of the economy of growers and country. Pakistan produces 3.44 tons of paddy per hectare and export about 3.75 million tons of rice annually, including basmati rice. The production of rice in Pakistan is less than many other countries (like China, India, Japan, Bangladesh) due to many factors such as climatic conditions, shortage of water, attack of many pathogens and pests. Hashmi (1994) reported 70 species of insect pest on the paddy of Pakistan. Among these pest, white backed planthopper, *Sogatella furcifera* (Horváth, 1899) is one of the major pests and causes 7-10% yield losses annually in both in coarse and basmati rice (Ashfaq *et al.*, 2005). Approximately 40 species of biological control agents have been recorded from rice fields of Pakistan including spiders (Salim, 2002; Tahir and Butt, 2008).

Previous studies showed that spiders are most abundant generalist predators in agroecosystem (Marc *et al.*, 1999; Nyffeler and Sunderlands, 2003; Pearce and Zalucki, 2006; Tahir and Butt, 2008). Most of them are polyphagous and feed on various insect pests of agricultural crops (Schmidt *et al.*, 2004; Takashi *et al.*, 2006). They significantly reduce prey densities in agricultural fields due to their top-down effects, microhabitat use, prey selection, polyphagy, wasteful killing, functional response, numerical response, and obligatory feeding strategies (Greenstone and Sunderland, 1999; Riechert, 1999; Symondson *et al.*, 2002; Schmidt *et al.*, 2004; Pearce and Zalucki, 2006).

Oxyopes javanus (Thorell, 1887) is one of the most dominant spiders in the rice fields of Punjab, Pakistan and constitute more than 13% of the total spider fauna. Its high density was recorded in September through October due to high pest's densities in these months (Tahir and Butt, 2008). They feed on prey which range from 1-2.9 mm in size. On the basis of prey size, it can be predicted that rice pests such as planthopper may be the part of spider's diet (Nyffeler *et al.*, 1992).

Biocontrol potential of a predator depends upon its functional and numerical responses against different densities of prey. Being univoltine, spiders are unable to increase their abundance rapidly in response to high prey density (Foelix, 1996). So their predatory efficiency can be estimated by functional response *i.e.*, variation in the attack rate of predator in response to variation of prey density

* Corresponding author: abdajawed@yahoo.com
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(Riechert and Lockley, 1984). Scientists designate four types of functional response *i.e.*, linear increase (type I), an increase decelerating at high density (type II), sigmoidal increase (type III), and a dome shape increase (type IV) (Holling, 1961; Pervez and Omkar, 2005; Sakaki and Sahragard, 2011). Studies reported functional responses of type II, III and IV in spiders. However, type II was much common than type III (Riechert and Lockley, 1984; Rypstra, 1995; Marc *et al.*, 1999; Liznarova and Pekar, 2013).

In this study, functional response of *Oxyopes javanus* (Araneae:Oxyopidae) was evaluated against different densities of adult planthopper (*Sogatella furcifera*) in laboratory as well as in the mesocosm.

MATERIALS AND METHODS

Maintenance of predator and prey

For experiments, adults of white backed planthoppers (*Sogatella furcifera*) were collected by sweep net from infested rice fields located at the University of the Punjab (Lahore, Pakistan). The captured specimens were brought to laboratory and released on the potted rice plants to develop the stock for the study. Adults of hunting spider, *O. javanus* (Family: Oxypidae) were collected by hand picking and sweep net from rice fields and kept singly in transparent glass container (5cm in height x1.5 cm in diameter). At the base of each container, 1 cm thick layer of wet sand was placed to maintain the humidity. The mouth of container was covered with muslin cloth and spiders were fed daily *ad libitum* with different types of prey available in rice fields. The stock of spider and brown planthoppers was maintained in laboratory at 35±5 °C and 50±20 % RH.

Laboratory experiments

To evaluate the predatory potential of *O. javanus*, six densities (*i.e.*, 5, 10, 15, 20, 30 and 40) of adult *S. furcifera* were used as prey. These densities were offered separately to an individual predator starved for 72 h in a transparent plastic container (15 cm height x 5 cm diameter) with one or two leaves of rice planted cut from the base and embedded in wet sponge surrounded by soil. Walls of the plastic container were rough so spider can walk on the walls. Prey was offered with 10% sucrose solution in small packets of parafilm attached near the mouth of the container. Experiment was performed at 35±5°C and 50±20% RH, and photoperiod of 14:10 h. The number of prey killed by predator was recorded after 48 h. Dead prey was not replaced during the experiment. To estimate natural mortality in predator and prey, their densities used in experiment were also maintained separately in the laboratory as control. Each experimental treatment repeated thirty times in three groups.

Mesocosm experiments

For experiments, mesocosm was created using a potted rice plant encaged in a clear plastic cylinder. The top of the cylinder was covered with white cotton cloth for ventilation. Cylinder was 16 cm high and 6 cm in diameter and fixed in the soil of the pot. In each pot, one seedling of rice (15 days old) was transferred and allowed to grow for 35 days. For the experiment, only one tiller of rice plant with 6 leaves (approximately 15–20 cm long) was left and all other tillers cut down. Microcosm was placed in open field at a temperature of 35±7°C and 50±20% RH, and photoperiod of 14:10 h. To evaluate the functional response of *O. javanus* against adult planthoppers, the design of laboratory study was followed. We added planthopper in a mesocosm according to experimental plan and allowed them to settle on the leaves. After two hours, single predator was added to microcosm. To estimate natural mortality in the prey specimens, different densities of prey were also maintained in mesocosm without predator. Each experimental treatment was replicated thirty times in three groups. The mortality of prey was recorded after 2 days to avoid disturbance in the arena. Dead prey was not replaced during the experiment.

Data analyses

To determine the type of functional response, data was fitted to polynomial function that describes relationship between proportion of prey killed (N_a) in relation to prey density offered (N_o) (Holling, 1959a,b). For this purpose, cuboid model in logistic regression analysis was used (Juliano, 2001):

$$Na / N_0 = \exp (P_0 + P_1N_0 + P_2N^2_0 + P_3N^3_0) / [1+ \exp (P_0 + P_1N_0 + P_2N^2_0 + P_3N^3_0)]$$

P_0, P_1, P_2, P_3 were intercept, linear, quadratic and cubic coefficients, respectively. Negative value of P_1describe type II functional response, while positive value a type III functional response. The values of handling time (T_h) and attack rate (a) were calculated using Holling disc equation modified by reciprocal linear transformation (Livdah and Stiven, 1983). The linear regression was y= ax+ b. The modified equation was

$$1 /N_a = 1/a \,.\, 1/T\ N_o + T_h / T$$

In this equation, $1/N_a$ represents y, 1/a represents a, $1/T\ N_o$ represents x and T_h/T represents b. N_a represent number of consumed prey, N_o initial prey density, T total observation time (48 h) and T_h handling time. From estimated handling time, we calculated total handling time ($Th_{total} = T_h \times N_a$), search time ($Ts = T - Th_{total}$), attack rate ($a = N_a / (N_o \times Ts)$) and search efficiency ($E = N_a / N_o$) for each prey density (Hassell, 2000; Rocha and Redaelli, 2004).

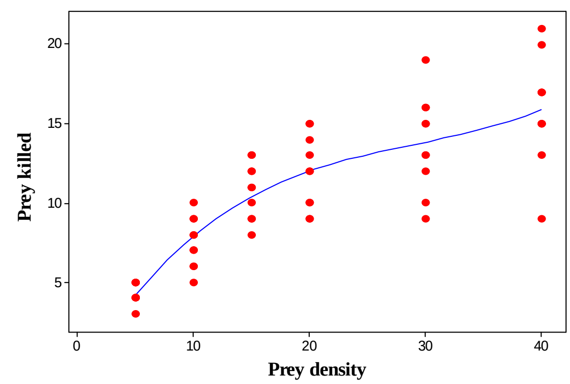
General linear model was applied to assess the variations in killing rate of predator in different experimental plans and prey densities. ANOVA was used to assess the difference in the searching time, handling time, attack rate and efficiency of predator at different prey densities. Two sample t test was applied to compare the consumption rate in laboratory and mesocosm at a particular prey density. All these analysis were performed using statistical software MINITAB.

RESULTS

Logistic regression analysis revealed that *O. javanus* exhibited Type II functional response against *S. furcifera* both in laboratory and mesocosm. The linear parameter P1 is negative and proportion of prey killed by *O .javanus* decreased as prey density increased in arena (Table I, Fig. 1). Average mortality in *S. furcifera* ranged from 40% to 86% in laboratory and 25% to 64% in mesocosm at maximum and minimum prey density, respectively. Due to 98% survival rate in control groups, mortality estimates were not adjusted. The mortality in prey was higher in laboratory as compared to mesocosm ($F_{1,\ 348}$ = 73.49; P= 0.00), even at each prey density also ($F_{5,\ 348}$ = 46.21; P= 0.00: t= 2.82, 3.64.5.17, 3.12, 3.17, 4.06 at density of 5, 10, 15, 20, 30 and 40 respectively; P<.0.005).

Table I.- **Regression Parameters of functional response of *O. javanus* against different prey densities.**

	Laboratory	Mesocosm
Intercept	0.9146	0.8313
Linear	- 0.0105	-0.0469
Quadratic	-0.00043	0.00163
Cubic	0.00009	0.00002
R^2	0.360	0.267
F	36.74	14.93
d.f.	3,56	3,56
P	<0.010	<0.010



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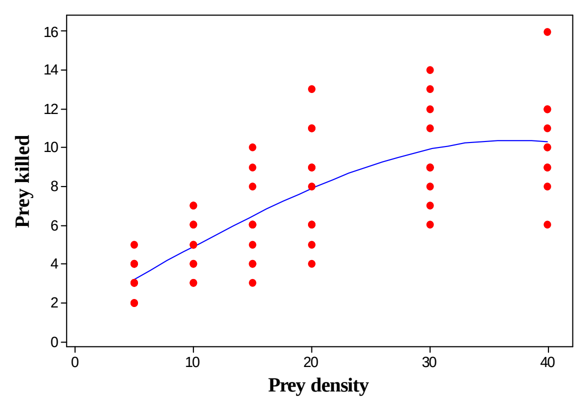

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Fig. 1. Functional response of *O. javanus* against different densities of *S. furcifera* in (a) laboratory and (b) mesocosm.

Parameters of functional response *i.e.*, handling time (T_h), attack rate (a) and maximum predation rate per predator (calculated by linear regression using Holling disk equation) for *O. javanus* are represented in Table II. Handling time was shorter (1.72 h) in laboratory than mesocosm (3.26 h). While attack and predation rate by *O. javanus* was higher in laboratory than mesocosm. Density of the prey was directly proportional to the handling time in both types of arena. However the searching time and search efficiency decrease with the increase of prey density. No difference was recorded in attack rate of predator at different densities of the preys (Table III).

Table II.- Estimations of functional response parameters by Hollings disc equation.

	Laboratory	Mesocosm
Handling time (T_h)	1.72	3.26
Attack rate (a)	0.52	0.4
Maximum predation rate (T/T_h)	27.91	14.72

Table III.- Functional response parameters of *O. javanus* at different densities of *S. furcifera* in (a) laboratory and (b) mesocosm.

No. of prey offered	Total handling time (Th)	Total search time (Ts)	Attack rate (a)	Search efficiency (E)
Laboratory				
5	7.4 (0.34)a	40.6 (0.34)a	0.021 (1.4×10^{-3})a	0.86 (0.042)a
10	12.9 (0.86)b	35.1 (0.86)b	0.042 (1.9×10^{-3})a	0.75 (0.050)ab
15	18.5 (0.95)c	29.5 (0.95)c	0.024 (2.0×10^{-3})a	0.72 (0.037)ab
20	20.4 (1.27)c	27.6 (1.27)c	0.021 (2.4×10^{-3})a	0.59 (0.037)bc
30	23.7 (1.64)cd	24.2 (1.64)cd	0.018 (2.9×10^{-3})a	0.46 (0.032)cd
40	27.3 (1.86)d	20.6 (1.86)d	0.019 (3.5×10^{-3})a	0.39 (0.027)d
Mesocosm				
5	10.43 (1.06)a	37.5 (1.06)a	0.017 (2.3×10^{-3})a	0.64 (0.065)a
10	16.3 (1.54)a	31.7 (1.54)a	0.015 (2.4×10^{-3})a	0.50 (0.065)ab
15	19.8 (2.35)ab	28.1 (2.35)ab	0.014 (3.9×10^{-3})a	0.40 (0.065)bc
20	26.7 (3.03)bc	21.3 (3.03)bc	0.019 (10.0×10^{-3})a	0.41 (0.065)bc
30	31.9 (2.70)c	16.1 (2.70)c	0.020 (18.5×10^{-3})a	0.32 (0.065)bc
40	33.5 (2.79)c	14.4 (2.79)c	0.017 (11.8×10^{-3})a	0.25 (0.065)c

DISCUSSION

In this study, *O. javanus* showed type II functional response both in laboratory and mesocosm when exposed to six different densities of prey, *Sogatella furcifera*. Many studies have reported type II or III of functional response in different species of spiders such as *Grammonota trivitatta* (Denno *et al.*, 2004), *Cheiracanthium mildei* Koch (Clubionidae), *Philidromus rufus* Dondale (Marc *et al*., 1999), and genus *Portia* of jumping spiders (Salticidae) (Jackson and Pollard, 1996). Type of the functional response showed by the predators play important role in the stability of prey population (Begon *et al*., 1996).

Functional response of a predator is affected by many factors such as temperature (Gitonga *et al*., 2002; Zamani *et al*., 2006), predator, prey size and density (Kooijman, 1993; Aljetlawi *et al*., 2004), presence of alternative pray (Abrams, 1990), environmental factors, complexity of the habitat and internal state of the predator (Hassel *et al*., 1976). In this study laboratory arena was very simple as compared to mesocosm. Factors such as leaf size, foliage overlap and habitat spatial structure was decreasing the predatory efficiency of the spider in the mesocosm (Kaiser, 1983; Karevia and Perry, 1989; Messina and Hanks, 1998).

The application of optimum foraging theory (Cook and Cockrell, 1978; Stephens and Krebs, 1986) on predator prey relationship predicted changes in searching time, handling time and predation rates, with the change of prey density. At higher prey density, predators spend less time on searching of prey and more time on attacking and consuming of the prey (Claver *et al.*, 2003). Denno *et al.* (2004) reported that sheet web spider *Grammonota trivitatta* capture more prey at high plant hopper density but the proportion of prey didn't increase with the prey offered. This type of response is often called the "invertebrate curve" and indeed seems to be common in spiders (Hardman and Turnbull, 1974; Riechert and Harp, 1987).

In the study, size of the arena determined the killing rate of the hoppers. The size of laboratory arena was 275 cm^2 and of mesocosm 3768 cm^2. Small arena of laboratory allowed predators to find their prey faster and re-attack those that escaped (Wiedenmann and O' Neil, 1991). In contrast, the predators have more difficulty searching for prey in large mesocosm, which increase the time spent for searching and thus decreases the encounter and the attack rate. However, a longer handling time may allow a better intake of nutrients from the prey and increase the longevity of predators (Montserrat *et al.*, 2000). Laboratory arena was also less complex so prey did not have more hiding places as compared to mesocosm. Presence of plant makes the environment more complex. Due to complexity, the prey has hiding places and has more chances to escape the predator.

Handling time is good source of information about predation rate and effectiveness of predator because its shows cumulative effect of time taken during capturing, killing, subduing, and digesting the prey (Atlihan and Bora, 2010). Hassell *et al.* (1976) reported that at high densities, as the prey availability increases or searching area decreases, predators increased their attack rate and decrease the handling time. Predators have a different strategy at low prey densities. Predators usually reduce the searching activity at low prey density in order to reduce the use of energy and nutrients (Opit, 1997). In present study, attack rate remain constant in both laboratory and mesocosm arena even with the increase of prey density.

At short handling time, curve reduces to the asymptote very rapidly (Nordlund and Morrism, 1990). It also affects the search time and search efficiency of the predator. In our experiment also, spider spend less time in handling the prey in laboratory than in mesocosm. Holling (1959) reported that attack rate did not depend upon density of the prey. However, attack rate, efficiency parameters were more in laboratory than mesocosm.

The results of this study are helpful to estimate potential of *O. javanus* in suppression of *S. furcifera* in the rice field. However, elaborated field studies are necessary to incorporate *O. javanus* in the integrated pest management programs against *S. furcifera*.

REFERENCES

ABRAMS, P.A., 1990. The effect of adaptive behavior on the type -2 functional response. *Ecology*, 71: 877-885.

ALJETLAWI, A.A., SPARREVIK, E. AND LEONARDSSON, K., 2004. Prey-predator size dependent functional response: derivation and rescaling to the real world. *J. Anim. Ecol*., **73**: 239–252.

ASHFAQ, M., MANSOOR-UL-HASSAN AND SAGHEER, M., 2005. Integrated pest management of rice insect pests with special reference to biological control. *Proc. Int. Sem. Rice Crop*, Oct.2-3, 2005. pp: 239-249.

ATLIHAN, R. AND BORA, K, M., 2010. Functional response of the coccinellid predator, *Adalia fasciatopunctata revelierei* to walnut aphid (Callaphis juglandis). *Phytopara,* **38**: 23–29.

BEGON, M., HARPER, J. L. AND TOWNSEND, C. R., 1996. *Ecology. Individuals, population and communities*. Blackwell Science Ltd. Milan: 3rd ed.

CLAVER, M.A., RAVICHANDRA, B., KHAN, M.M. AND AMBROSE, D.P., 2003. Impact of cypermethrin on functional response, predatory and mating behavior of non-target potential biological control agent *Acanthaspis pedestris* (Stal) (Het., Reduviidae). *J. appl. Ent.*, **127**: 18-22.

COOK, R.M. AND COCKRELL, B.J., 1978. Predator ingestion rate and its bearing on feeding time and theory of optimal diets. *J. appl. Ent.*, **47**: 529-547.

DENNO, R.F., MARGARET, S., MITTER, G., LANGELLOTTO, A., CLAUDIGO, M. AND BORAH, D.I., 2004. Interaction Between a hunting spider and web builder and consequences of intraguild predation and cannibalism for prey suppression. *Ecol. Ent.*, **29**: 560-567.

FOELIX, R. F., 1996. *Biology of spiders*. 2nd ed. Harvard University Press, Cambridge, pp. 330.

GITONGA, L. M., OVERHOLT, W. A., LOHR, B., MAGAMBO, J. K. AND MUEKE, J. M., 2002, Functional response of *Orius albidipennis* (Hemiptera: Anthocoridae) to *Megalurothrips sjostedti* (Thysanoptera: Thripidae). *Biol. Contr.*, **24**:1

GREENSTONE, M.H. AND SUNDERLAND, K.D., 1999. Why a symposium on spiders in agroecosystems now? *J. Arachnol.*, **27**: 267-269.

HARDMAN, J.M. AND TURNBULL, A.L., 1974. The interaction of spatial heterogeneity, predator competition and the functional response to prey density in a laboratory system of wolf spiders (Araneae: Lycosidae) and fruit flies (Diptera: Drosophilidae). *J. Anim. Ecol.*, **43**: 155-171.

HASHMI, A.A., 1994. Insect pest of paddy rice. In: *Insect pest management of cereal and cash crops*. Pakistan Agricultural Research Council, Islamabad, pp: 1-59.

HASSEL, M.P., 2000. *Advancing theory the spatial and* *temporal dynamics of host–parasitoid interactions*. Oxford University Press, UK

HASSELL, M. P., 1978, *The dynamics of arthropod predator-prey systems*. Princeton University Press, Princeton, pp. 237.

HASSELL, M.P., LAWTON, J.H. AND BENDDINGTON, J.R., 1976. Components of arthropod predation. prey-death-rate. *J. Anim. Ecol.,* **45**: 135-164.

HOLLING, C. S., 1959a. The components of predation as revealed by a study of small-mammal predation of the European pine sawfly. *Canad. Entomol.,* 91: 293-320.

HOLLING, C. S., 1959b. Some characteristics of simple types of predation and parasitism. *Canad. Entomol.,* 91: 385-398.

HOLLING, C.S., 1961. Principles of insect predation. *Annu. Rev. Ent.,* **6**: 163-182.

JACKSON, R.R. AND POLLARD, S.D., 1996. Predatory behavior of jumping spiders. *Ann. Rev. Ent*., **41**: 287-308 .

JULIANO, S.A., 2001. Nonlinear curve fitting: predation and functional response curves. In: *Design and analysis of ecological experiments* (eds. S.M. Scheiner and J. Gurevitch). Oxford University Press, New York, pp. 432.

KAISER, H., 1983. Small scale spatial heterogeneity influences predation success in an unexpected way: model experiments on the functional response of predatory mites (Acarina). *Oecologia,* **56**: 249-256.

KAREIVA, P. AND PERRY, R., 1989. Leaf overlap and the ability of ladybird beetles to search among plants. *Ecol. Ent.,* **14**: 127-129.

KOOIJMAN, S.A.L.M., 1993. *Dynamic energy budgets in biology systems _ theory and applications in ecotoxicology*. Cambridge University Press, Cambridge.

LIVDAH, T.P. AND STIVEN, A.E., 1983. Statistical difficulties in the analysis of predator functional response data. *Canad. Entomol.,* **115**: 1365–1370.

LÍZNAROVÁ, E. AND PEKÁR, S., 2013. Dangerous prey is associated with a type 4 functional response in spiders.*Anim. Behav.,* **85**: 1183-1190.

MARC, P. CANNARD AND YSNEL, J., 1999. Spiders (Araneae) useful for pest limitation and bioindication. *Agric. Ecosyst. Environ.*, **74**: 229. 273.

MESSINA, F. J. AND HANKS, J. B., 1998. Host plant alters the shape of the functional response of an aphid predator (Coleoptera: Coccinellidae). *Environ. Ent.,* **27**: 1196–1202.

MONTSERRAT, M., ALBAJES, R. AND CASTANE, C., 2000. Functional Response of four heteroperan predators preying on greenhouse whitefly (Homoptera: Aleyrodidae) and western flower thrips (Thysanoptera: Thripidae). *Environ. Ent.,* **29**: 1075-1082.

NORDLUND, D.A. AND MORRISON, R.K., 1990. Handling time, prey preference, and functional response for *Chrysoperla rufilabris* in the laboratory. *Ent. exp. Appl.,* **57**: 237-242.

NYFFELER, M. AND SUNDERLAND, D.K., 2003. Composition, abundance and pest control potential of spider communities in agroecosystem. A comparison of European and U.S. studies. *Agric. Ecosyst. Environ.,* **95**: 579-612.

NYFFELER, M., DEAN, D.A. AND STERLING, W.L., 1992. Diets, feeding specialization, and predatory role of two lynx spiders, *Oxyopidae salticus* and *Peucetia viridans* (Araneae: Oxyopidae), in a Texas cotton agroecosystem. *Environ. Ent.,* **21**: 1457-1465.

OPIT, G.P., 1997. The functional response and prey preference of *Feltiela acarisuga* (Vallot) (Diptera: Cecidomyiidae) for two of its prey: Male and female two spotted mites, *Tetranychus urticae* Koch (Acari: Tetranichiidae). *Canad. Entomol.*, **129**: 221-227.

PEARCE, S. AND ZALUCKI, M.P., 2006. Do predators aggregate in response to pest density in agroecosystems? Assessing within-field spatial patterns. *J. appl. Ecol.,* **43**: 128–140.

PERVEZ, A. AND OMKAR, P., 2005. Functional responses of coccinellid predators: an illustration of a logistic approach. *J. Insect* Sci., **5**: 1–6.

REICHERT, S .E. AND LOCKLEY, T., 1984. Spiders as biological control agents. *Annu. Rev. Ent.,* **29**: 299-320.

RIECHERT, S. AND HARP, J., 1987. Nutritional ecology of spiders. In: *Nutritional ecology of insects, mites, spiders, and related invertebrates* (eds. F. Slansky and J.G. Rodriguez). John Wiley & Sons, New York. pp. 645.672.

RIECHERT, S.E., 1999. The hows and whys of successful pest suppression by spiders: insights from case studies. *J. Arachnol*., **27**: 387.396.

ROCHA, L.D.A. AND REDAELLI, L.R., 2004. Functional response of *Cosmoclopius nigroannulatus* (Hem.: Reduviidae) to different densities of *Spartocera dentiventris* (Hem.: Coreidae) nymphs. *Braz. J. Biol*., **64**: 309-316.

RYPSTRA, A.L., 1995. Spider predators reduce herbivory; both by direct consumption and by altering the foraging behavior of insect pests. *Ent. exp. Appl.,* **76**: 383.

SAKAKI, S. AND SAHRAGARD, A., 2011. A new method to study the functional response of *Scymnus syriacus* (Coleoptera: Coccinellidae) to different densities of *Aphis gossypii*. *J. Asia-Pacic. Ent.,* **14**: 459-462.

SALIM, M., 2002. *Tillage by nutrient interaction in rice-wheat system,* Final Technical DFID Project Report NARC, Islamabad, pp.13-25.

SCHMIDT, H.M., THIES, C. AND TSCHAMTKE, T., 2004. Lannscape context of arthropod biological control. In: *Ecological engineering for pest management; advances in habitat manipulation for arthropods* (eds. G.M. Gurr, S.D. Wratten and M.A. Altier). CSIRO press, Collingwood, pp. 55-63

STEPHENS, D. W. AND KREBS, J. R., 1986. *Foraging theory*. Princeton University Press.

SYMONDSON, W.O.C., SUNDERLAND, K.D. AND GREENSTONE, M.H., 2002. Can generalist predators be effective biocontrol agents? *Annu. Rev. Ent.*, **47**: 561-594.

TAHIR, H.M. AND BUTT, A., 2008. Activities of spiders in rice fields of central Punjab, Pakistan. *Acta zool. Sin.*, **54**: 701-711.

TAKASHI, M., CHIKARA, I., MOTONORI, T., MIHOKO, M., AYAME, T., KAZUMASA, H. AND YASUHISA, K., 2006. Effect of tillage practices on spider assemblage in rice paddy fields. *Appl. J. Ent*., **41**: 371-381.

WIEDENMANN, R.N. AND O'NEIL, R.J., 1991. Laboratory Measurement of the Functional Response of *Podisus maculiventris* (Say) (Heteroptera: Pentatomidae). *Canad. Entomol.*, **104**: 61-69.

ZAMANI, A.A., TALEBI, A.A., FATHIPOUR, Y. AND BANIAMERI, V., 2006, Temperature-dependent functional response of two aphid parasitoids, *Aphidius colemani* and *Aphidius matricariae* (Hymenoptera: Aphidiidae), on the cotton aphid. *J. Pestic. Sci.*, **79**: 183-188.

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