



Impact of elevated CO₂ on feeding potential of wolf spider against brown planthopper (*Nilaparvata lugens*)

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ABSTRACT

An experiment was conducted at Department of Entomology, Indian Agricultural Research Institute, New Delhi during 2015–16 and 2016–17 to study the impact of elevated CO₂ on functional response of wolf spider, *Pardosa pseudoannulata* (Boesenberg and Strand, 1906) against brown planthopper, *Nilaparvata lugens* (Stal, 1854) (Hemiptera: Delphacidae). Spider feeding rate on BPH was higher in jar arena compared to microcosm arena both under ambient CO₂ and elevated CO₂ conditions. Regression of number of attacked prey (1/Ha) upon prey density per unit area (H) over time duration of experiment (T) in microcosm and in jar arena under ambient and elevated CO₂ revealed type II functional response. Attack rate, maximum attack rate and efficiency parameters were higher and handling time was lower in both jar arena and microcosm under elevated CO₂ condition compared to ambient CO₂ condition. Simultaneously, predators might have consumed more number of preys due to their poor nutrient quality under elevated CO₂ compared to ambient CO₂. It was revealed that with increase of predator density within the same prey density in same area under both ambient and elevated CO₂ conditions, the prey control might have optimized. This information generated would support the planthopper management by regulating predator number for increased predator efficiency.

Keywords: Biological control, Brown planthopper, Elevated CO₂, Rice, Spiders

For several years, rice (*Oryza sativa* L.) pest control was mainly dependent on chemical insecticides but the continuous, irregular and indiscriminate use of wide range of pesticides led to problems of resistance, secondary pest outbreaks, resurgence and environmental pollution. Among different IPM practices, biological control is considered very prominent. Spiders are the ubiquitous obligate carnivorous arthropods, which feed on different types of prey in cropping systems. Lycosids are the most abundant spiders in rice agro-ecosystems could effectively regulate leaf hoppers and plant hoppers (Ooi and Shepard 1994). The spiders are observed active throughout the cropping period of rice and their population is optimum from mid-October to mid-November (Venkateshalu 1996). The wolf spider, *Pardosa pseudoannulata* is a polyphagous predator in rice ecosystem in most parts of Asia. The type-II functional response is the most commonly fitted response to the behaviour of insect predators (Xaaceph and Butt 2014). Claver *et al.* (2003) stated that with increase of prey density, predator

needs minimal time for searching of prey and it spends more time for attacking and consuming, which increased its predation potential. Generally, spiders show spatial and temporal differences in activity in relation to prey capture in the habitat area.

The most possible way to study the impact of elevated CO₂ on natural enemies is through the traits, which are directly linked to their fitness such as parasitism, reproductive rates and survivorship. The plants under elevated CO₂ being deficient in nutrients and having low C:N ratio, make the herbivores to feed for a longer period of time to compensate for nutrient deficiency, thereby prolonging their exposure to natural enemies and leading to higher parasitism rates or predation rates (Stiling *et al.* 2002). As the plant quality changes under elevated CO₂, it might affect the herbivore populations feeding on them by behavioural changes such as mobility, survival capacity and mortality due to predators. Klaiber *et al.* (2013) observed that the defensive compounds such as glucosinolates released by *Brassica* are reduced under elevated CO₂ which impacted the beneficial insects as these compounds are used as location cues by many of them. Therefore, present study was carried out to assess the effect of elevated CO₂ on functional response of wolf spider on brown planthopper (BPH) population.

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MATERIALS AND METHODS

To study the feeding potential of wolf spider under elevated CO₂ conditions during 2015–16 and 2016–17, 3rd and 4th instar nymphs of brown planthopper were collected from open top chamber (OTC) maintained under elevated CO₂ (570±25 ppm) and ambient CO₂ (400±25 ppm) at Division of Plant Physiology, Indian Agricultural Research Institute, New Delhi.

Sexually matured wolf spiders were collected from unsprayed rice field and kept individually and starved (as the spiders are sexually cannibalistic) in glass jar arena (19 × 15 cm²) under laboratory condition and in glass chamber (37 × 37 cm²) at room temperature (25±2°C and 70±5%) for 3 days (Xaaceph *et al.* 2014). The experiment on functional response of spider was conducted in glass jar arena under laboratory condition at 25±2°C temperature and 70±5% RH and in microcosm that consisted of rice plant in glass chamber, conducted under glass house condition at 28±10°C temperature and 65±5% RH. Both the experiments were conducted under elevated CO₂ (570±25 ppm) *vis-a-vis* ambient CO₂ (400±25 ppm). Under both the conditions, spiders were provided with 3rd and 4th instar BPH nymphs in different prey densities 10, 20, 30, 40 and 50 BPH nymphs daily over a period of 3 days in both jar and microcosm. Three experiments were undertaken using 1, 2 and 3 spiders separately under both ambient CO₂ and elevated CO₂ condition and replicated thrice. The number of individuals consumed by each spider was also recorded daily for 3 days. Dead BPH that were not preyed by spiders and also deformed BPH were recorded.

The functional response of spider with respect to brown planthopper reared under ambient CO₂ and elevated CO₂ was analyzed separately for microcosm and jar. Handling time (T_h) and attack rate (a) were analyzed using Holling disc equation and modified reciprocal linear transformation (Livdahl and Stiven 1983) at different prey densities.

Predator activities comprised:

- Prey searching and
- Prey handling (chasing, killing, eating and digesting)

In this model, predator consumption rate is limited because despite availability of large prey population, it still needs more time for handling the prey although no time is

needed for searching the prey. So, the total time needed is equal to time needed for searching and handling:

$$T, T_{\text{search}} + T_{\text{handling}}$$

If a predator captured H_a prey during T time, time for handling should be proportional to the total number of prey captured:

$$T_{\text{handling}} = H_a + T_h$$

where 'T_h', time spent on handling of one prey.

Prey capturing is presumed to be a random process where a predator finds area 'a' per unit and captures all the prey available at that place. The parameter 'a' is often called as "area of discovery", and also as "search rate".

Predator after spending time 'T_{search}' for searching the prey, examines the area as:

$$a \times T_{\text{search}}$$

The number of captured prey thus equals - a × H × T_{search} where 'H', the prey density per unit area given as:

$$H = a \times H \times T_{\text{search}}$$

$$1/H_a = 1/a \times 1/H_t + T_h/T$$

where H_a, maximum no. of prey consumed (T_h/T); a, attack rate; H_t, handling time; T_h, maximum predation rate; T, time interval; T_h/T, maximum number of prey that can be attacked by the predator during the time interval considered.

Finally, number of attacked prey (1/H_a) was regressed upon prey density per unit area (H) over time duration of experiment (T), derived as 1/HT.

where 1/H_a, represents 'y'; (dependent variable), 1/a, represents 'a' (intercept) and 1/H_t, represents 'x' (independent variable) and T_h/T, represents 'b' [(regression coefficient) of the linear regression, y = ax + b].

RESULTS AND DISCUSSION

Under ambient CO₂ condition, in microcosm arena, mean number prey killed increased and predator consumption rate decreased with increase of prey density from 10–50 hoppers/spiders. Similarly in jar, mean number of prey killed increased and predator consumption rate decreased with increase of prey density. While, under elevated CO₂

Table 1 Functional response parameters of the wolf spider *Pardosa pseudoannulata* on BPH nymph in microcosm and jar under ambient and elevated CO₂ conditions

Experimental area	Experiment	Prey density offered (No. of nymphs)	Mean no. of prey killed (No. of nymphs)		Proportion killed (%)	
			Ambient	Elevated	Ambient	Elevated
Microcosm	I	10–50	4.7–10	5.7–11.3	46.7–20%	56.7–22.7%
	II	10–50	7–19.3	7.7–21	70–40%	76.7–40%
	III	10–50	8.3–22.7	8.7–23.7	83.3–45.3%	86.7–47.34%
Jar	I	10–50	8–21.3	8.3–22.3	80–42.7%	83.4–44.7%
	II	10–50	9.3–27.3	10–29.7	93.3–54.7%	100–59.3%
	III	10–50	10–31	10–30.3	100–62%	100–60.7%

Holling disc equation and modified reciprocal linear transformation were used for analysis of functional response parameters.

Table 2 Functional response parameters of wolf spiders in microcosm and jar under ambient and elevated CO₂ conditions from linearization of Holling type II model

Experimental area	Experiment	Attack rate		Maximum attack rate		Efficiency parameter		Handling time	
		Ambient	Elevated	Ambient	Elevated	Ambient	Elevated	Ambient	Elevated
Microcosm	I	0.22	0.30	0.59	0.59	0.04	0.04	5.11	5.11
	II	0.28	0.31	1.81	1.81	0.17	0.17	1.66	1.66
	III	0.34	0.35	1.98	1.98	0.23	0.23	1.51	1.51
Jar	I	0.33	0.34	1.89	0.62	0.21	0.06	1.58	4.82
	II	0.39	0.40	2.60	1.81	0.34	0.19	1.15	1.66
	III	0.41	0.43	4.17	2.08	0.53	0.25	0.72	1.44

Holling disc equation and modified reciprocal linear transformation were used for analysis of functional response parameters.

condition, in microcosm arena, mean number prey killed increased and predator consumption rate decreased with increase of prey density from 10–50 hoppers/spiders. Similarly, in jar arena mean number of prey killed increased and predator consumption rate decreased with increase of prey density (Table 1).

Further, killing rate by predator in microcosm and jar under elevated CO₂ was comparatively higher than under ambient CO₂ condition. Data revealed that in jar and microcosm arena prey killing rate, maximum attack rate and efficiency parameters were higher with increase of increased spider number compared to single spider at similar area (space), similar number of prey density and similar conditions under both ambient CO₂ and elevated CO₂ (Table 2). It was thus observed that with increase of predator counts in the limited area, the control of pest population may be achieved with greater efficiency thereby reducing the use of synthetic chemicals.

Regression between number of attacked prey $1/H_a$ and prey density per unit area (H) and time duration (T) of experiment, expressed as $1/HT$ in the microcosm and jar arenas at different spider densities revealed type II functional response of wolf spider against BPH nymphs under ambient CO₂ as well as elevated CO₂ (Fig 1). The attack rate, maximum attack rate and efficiency parameters of predator respectively, were higher but handling time was lower in jar compared to microcosm under ambient

CO₂. Similarly, under elevated CO₂, attack rate, maximum attack rate and efficiency parameters were higher but handling time was lower in jar compared to in microcosm. This could be attributed to limited arena of the jar, which reduced searching time of predator and ultimately increased killing rate. Besides attack rate, maximum attack rate and efficiency parameters of predator respectively were higher but handling time was lower in microcosm and jar under elevated CO₂ compared to microcosm and jar under ambient CO₂ because elevated CO₂ probably lowered the quality of rice plant and ultimately reduced the quality of prey. In order to compensate for poor nutrient quality of prey, predator might have consumed more number of prey under elevated CO₂ compared to ambient CO₂ (Table 2).

Our results showed that with increase of prey density, consumption rate of spider decreased in all the experiments, showing type-II functional response of the spider. This was consistent with the earlier reports of type-II insect-predator response of *Adalia fasciatopunctata revelierei* (Atlihan and Bora 2010) and *Neoscona theisi* (Xaaceph and Butt 2014). Claver *et al.* (2003) reported that with increase of prey density, predator needed less time for searching of prey and spent more time for attacking and consuming the prey that increased its predation potential. It has also been observed earlier that spider, *Grammonota trivitatta* captured more planthopper prey with increase of prey density but the consumption rate did not increase (Denno *et al.* 2004). This

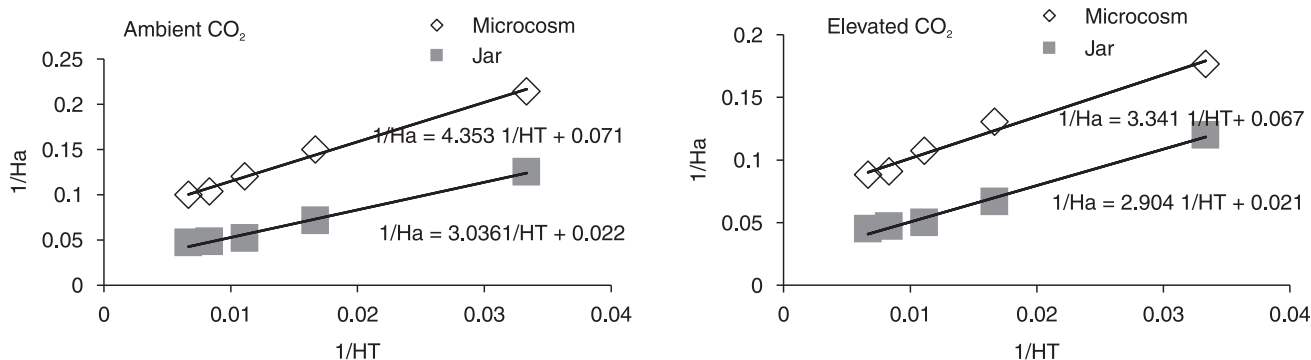


Fig 1 Relationship between $1/H_a$ and $1/HT$ of wolf spider in microcosm and lab under ambient and elevated CO₂. (A) Experiment under ambient condition, (B) Experiment under elevated condition.

type of response of predator was termed as “invertebrate response” and is common in spiders.

The results thus indicated that size of arena was an important factor that regulated the killing rate of predator at each density. In jar predator killing rate increased with increase of prey density, due to reduction of searching time under limited arena size of jar compared to microcosm under both ambient CO₂ and elevated CO₂ conditions. The results are in concurrence with reports of Xaaceph and Butt (2014), wherein white backed planthopper killing rate of *Neoscona theisi* was higher under laboratory study compared to microcosm due to the size of arena in microcosm being 14 times bigger than jar. Wiedenmann and O Neil (1991) studied the efficiency of predator *Epilachna varivestis* against *Podisus nigrispinus* in petri plates and concluded that predator attacked its prey faster by spending less time in searching under limited arena. Large arena thus allows spiders to search for BPH for a longer period of time thereby reducing their attack rate. Feeding potential of spider under microcosm was therefore less compared to jar. However, increase of handling time of predator under larger arena ensured better intake of nutrients from its prey for longer time and enhanced its longevity (Montserrat *et al.* 2000). Hassell *et al.* (1976) reported that predator attack rate increased and handling time decreased at high prey densities due to more availability of prey and the predator required less searching area. It has also been observed earlier by O Neil *et al.* (1996) that predators might develop diverse strategy to attack their prey in larger arena and at low densities, predators adapted to the complex environment by altering their behaviour and searching rate.

It had been observed earlier that, natural enemies feeding on insects under elevated CO₂ are affected indirectly through food chain i.e. trophic cascade (Bezemer and Jones 1998). Plants grown under elevated CO₂ are poor in nutrients due to low C:N ratio, which makes insect pests to feed on them for a longer period of time to compensate for nutrients. Similar results were also found in present study that mean number of brown plant hopper nymphs and their proportion killed were higher under elevated CO₂ further, prey killing rate of wolf spider both in microcosm and jar under elevated CO₂ was comparatively higher than under ambient CO₂. The results of present study are in concurrence with Yin *et al.* (2010) who reported that elevated CO₂ condition increased the food consumption and prolonged the development time of *Helicoverpa armigera*, due to the reduced nutritional quality of maize leaves, as a result of reduced nitrogen content and increased C:N ratio. Elevated CO₂ condition significantly reduced the food conversion rate and enhanced the food ingestion of *H. armigera*, which attributes to reduced nitrogen content of the cotton, Simian-3 (Chen *et al.* 2005b). However, Gao *et al.* (2010) reported that as the population abundance of *Aphis gossypii* markedly increased under elevated CO₂ conditions, the predatory ability of *Corcyra sinica* on *Aphis gossypii* will decrease, and damage caused by *A. gossypii* to cotton plants will increase when CO₂ concentrations are doubled.

In this study, it is reported that single generation but at different densities of wolf spider had provided a clearer picture of the dynamics of predation responses at elevated levels of CO₂. Predatory ability of matured wolf spiders fed on 3rd and 4th instar nymphs of brown planthopper raised under elevated CO₂ concentrations were considerably higher compared to those fed on 3rd and 4th instar nymphs of BPH raised under ambient conditions. Results of the present study are in concurrence with Stiling *et al.* (2002), who reported that insect herbivory fed under higher CO₂ condition prolong their exposure to natural enemies, which inturn leads to higher predation or parasitism. As the plant quality changes under elevated CO₂, it might influence herbivore population feeding on them by behavioural changes such as mobility, survival capacity and mortality due to predators. Our study showed that efficiency parameters, attack rate and maximum attack rate of predator was increased but handling time decreased upto certain limit in both jar and microcosm under elevated CO₂ compared to ambient CO₂. Any reduction in host plant quality is likely to reduce herbivore fitness, through changes in fecundity, survivorship or development rates. Elevated CO₂ considerably affected predator attack rates, however, this was influenced by prey CO₂ exposure. This phenomenon may be due to larger amounts of energy required by the spiders and higher respiration rates (Foss *et al.* 2013) to compensate for their increased activity under high CO₂ condition.

However, several reports have shown weak effect of elevated CO₂ on natural enemies. Aphid population might decrease, increase, or not be affected under elevated CO₂ (Chen *et al.* 2005a) but population of brown plant hopper population increased under elevated CO₂ (Veeranna *et al.* 2018). Earlier, it has been reported that parasitism of *Aphidius picipes* on wheat aphid increased under elevated CO₂ (Chen *et al.* 2007) that could be ascribed to decreased herbivore protein content due to decreased plant protein level under elevated CO₂ (Guerenstein and Hildebrand 2008). Chen *et al.* (2007) reported that the grubs of lady beetles (*Harmonia axyridis*) consumed more aphids, *Aphis gossypii* fed on cotton plants grown in elevated CO₂ in order to compensate for the reduced soluble protein in *A. gossypii* owing to the decrease in foliar N and the increase in the C:N ratio in the cotton plants.

Very few studies have considered the potential impact of elevated CO₂ condition on the interaction of prey predator response. Our study reported that change in CO₂ concentration may influence generalist predator, wolf spider prey choice under microcosm arena (wider area) or under jar arena (limited area).

Results showed how the increased predator number responded to a prey density on an isolated patch, represented by jar and microcosm with restricted mobility of both prey and predator, which would be useful in planning planthopper management by manipulating predator number for increased predator efficiency under changed climate.

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