

Spider fauna of soybean crops in south-east Queensland and their potential as predators of *Helicoverpa* spp. (Lepidoptera: Noctuidae)

Sarina Pearce,^{1*} Wendy M Hebron,² Robert J Raven,² Myron P Zalucki¹ and Errol Hassan³

¹School of Life Sciences, The University of Queensland, Qld 4072, Australia.

²Queensland Museum, PO Box 3300, South Brisbane, Qld 4101, Australia.

³School of Agriculture and Horticulture, The University of Queensland, Gatton campus, Gatton, Qld 4343, Australia.

Abstract

Spiders are among the most abundant predators recorded in grain crops in Australia. They are voracious predators, and combined with their high abundance, may play an important role in the reduction of pest populations. The significance of spider assemblages as biological control agents of key pests such as *Helicoverpa* spp. in Australian agroecosystems is largely unknown. A thorough inventory was made of the spider fauna inhabiting unsprayed soybean fields at Gatton, south-east Queensland. One-hundred-and-two morphospecies from 28 families were collected using vacuum sampling and pitfall traps across two summer seasons (2000–01, 2001–02). No-choice feeding tests in the laboratory, using eggs and larvae of *Helicoverpa armigera* (Hübner) as prey, were used to ascertain the predatory potential of each spider group. The field-collected spider assemblage ate on average 2.4 (± 0.7 standard error) to 5.0 (± 0.8) eggs per 24 h per spider (10–25% of those available), depending on level of starvation. Clubionidae were the only spiders to readily consume eggs in the laboratory (mean of 18.4 ± 1.5 eggs per starved spider and 8.2 ± 3.9 per non-starved spider after 24 h). Starved spiders consumed 9.4 (± 0.1) first-instar larvae per 24 h per spider (90% of those available). This information was combined with field observations and literature from Australian and overseas studies to assess the potential of spider groups as predators of *Helicoverpa* spp. Lycosidae, Clubionidae, Oxyopidae, Salticidae and Thomisidae have the capacity to contribute to control of *Helicoverpa* spp.

Key words Araneae, predators, diversity, no-choice feeding tests, pitfall traps.

INTRODUCTION

Helicoverpa armigera (Hübner) and *H. punctigera* (Wallengren) are major lepidopterous pests of field crops in Australia (Zalucki *et al.* 1986; Fitt 1989). The management costs of *Helicoverpa* spp. have been estimated at almost \$3 million per year in Queensland grain legumes, and the damage costs are far greater (Adamson *et al.* 1997). The use of conventional insecticides to control *Helicoverpa* spp. in broad-acre crops in the future is uncertain, given the increasing levels of insecticide resistance reported in *H. armigera* (Forrester 1994). Research into biological control options that can be incorporated in integrated pest management programs are a priority, and the impact of naturally occurring arthropod predators on *Helicoverpa* spp. populations in Australian crops is under investigation (Mansfield & Lawrence 2002; Wade *et al.* 2002).

Spiders are among the most abundant predators recorded in grain crops in Australia (Johnson *et al.* 2000; Whitehouse & Lawrence 2001). All adult spiders are predaceous, and may play an important role in the reduction of pest populations

(Greenstone 1999; Riechert 1999). However, individual spider species lack many of the characteristics suggested as necessary for a successful biological-control agent (Murdoch *et al.* 1985). They feed on a variety of prey and do not exhibit density-dependent tracking of prey populations (Table 1). Nonetheless, spider assemblages as a whole impose high levels of mortality on pest populations in various crops (Riechert & Bishop 1990; Nyffeler *et al.* 1994; Carter & Rypstra 1995; Riechert 1999). The significance of spider assemblages for biological control of pests in Australian agroecosystems is largely unknown, and spiders have been the subject of very few investigations (Bishop 1978, 1980; Bishop & Blood 1981). In the majority of studies that examine predators, spider species are either grouped together or given cursory treatment (Bishop & Milne 1986; Stanley 1997). As a result, our knowledge of the biology and ecology of spiders in Australian crops is limited.

The paucity of understanding of spider ecology is compounded by difficulties with taxonomy. In 1986, it was estimated that approximately one-fifth of the Australian spider fauna had been described (Raven 1986). Today, it still remains difficult to obtain genus and species level identification for spiders in a number of families (e.g., Gnaphosidae). Australian studies that list spider species (often in combination with other beneficials) have mostly been conducted in cotton (Bishop &

*Author to whom correspondence should be addressed (Email: s.pearce@uq.edu.au).

Blood 1977; Bishop 1978, 1980; Room 1979; Stanley 1997). Less effort has been directed at other crops, with individual studies in lucerne (Bishop & Holtkamp 1982), grain legumes (Shepard *et al.* 1983) and soybean (Evans 1985). Few of these studies make comment on the feeding strategies of the spider species recorded (Room 1979 is an exception). In order to effectively study the spider assemblage in grain crops, we must first determine the species composition.

The spider fauna in soybean fields was intensively sampled using a variety of collection methods over 2 years and specimens were identified to species. The international literature was searched to better define the feeding activities of the spider species identified. This information, combined with laboratory-based no-choice feeding tests and field observations, was used to assess the potential of particular spider groups as predators of *Helicoverpa* spp. in grain crops.

MATERIALS AND METHODS

Spider collection, identification and abundance ranking

Spider collections were conducted in soybean fields at the University of Queensland, Gatton campus (27°34'S, 152°20'E). Soybean was planted in rows adjacent to lucerne fields in December 2000 (two fields; 5 ha and 10 ha) and 2001 (two fields; 5.5 ha and 8.8 ha) and harvested approximately 5 months later. Throughout the season, the crops were inter-row cultivated to reduce weeds, and irrigated when necessary, but no insecticides were applied.

Vacuum sampling, pitfall traps and water traps were used regularly throughout the season. The vacuum sampler was a converted Echo PB2105 leaf blower (Tokyo, Japan) with black pipe (diameter 12 cm) inserted over the exhaust fan into which a collection bag was attached by an elastic band. A 10 m row of soybean was sampled by slowly moving the vacuum nozzle through the foliage and up and down the plant stem along each side of the row. Every 2–3 d throughout the season we sampled five sites per soybean field. Collection bags were removed from the nozzle while the vacuum was still running and sealed. The bags were kept chilled until they were returned to the

laboratory and placed in a freezer overnight to kill the arthropods. Pitfall traps were made out of a 7 cm diameter plastic sleeve that was buried flush with the ground surface. A plastic disposable drinking cup (200 mL) was inserted into it and three-quarters filled with a solution of 50% ethanol and a small amount of detergent. A lid made from a plastic plate was placed 3 cm above the trap for protection. Throughout the season, traps were emptied every 7 d and sieved (0.5 mm mesh) before the arthropods were sorted under a dissecting microscope. The water traps were designed to catch ballooning spiders and consisted of an open rectangular plastic container (21 cm wide, 29 cm long, 9 cm deep) attached to a metal star picket. The container was positioned at 120 cm above the ground and filled with water and a small amount of detergent. Tangle-Trap paste (Tanglefoot Company, Grand Rapids, USA) was coated around the pole to prevent ground-dwelling spiders and insects from being captured. Traps were visually inspected weekly and any spiders found were removed, placed in 80% ethanol and examined under a dissecting microscope.

Occasionally throughout the season, beat sheets and searching of whole plants were used. A 1 m beat-sheet sample was taken at 10 sites per soybean field 3–4 times during the season. The beat sheet was laid on the ground with the tail of the sheet covering the adjacent row and the target row knocked over the sheet four times using a stick. All spiders collected were identified to family level and stored in 80% ethanol. When a new spider morphospecies was collected, it was given a number and included in the voucher collection housed at the Queensland Museum, Brisbane.

An overall relative rank measure of abundance for each morphospecies in soybean was estimated based on all the sampling data. An abundance rank was used in preference to presenting raw collection data because the numbers collected were confounded by the variety of sampling techniques used. For the purposes of this paper, a simple estimation of abundance was most appropriate. An abundance measure of 1 was given to species commonly collected throughout both seasons. Those species that were usually uncommon but occasionally reached high numbers were given a score of 2. Those species that were uncommon throughout both seasons or represented by only a single individual (singletons) were given an abundance measure of 3.

Table 1 Characteristics of spiders that influence their potential as biological control agents of field-crop pests (adapted from Wise 1993; Greenstone 1999; Riechert 1999)

Positive attributes	Negative attributes
High dispersal ability. Ballooning allows spiders to re-colonise fields early in the season.	
Generalist predators. Prey includes a wide range of pest species.	Generalist predators. Prey includes other spiders and beneficial insects as well as pest species.
Predaceous throughout all life stages.	
Long-lived and resistant to starvation and desiccation.	Long generation times relative to the pests, slow temporal numerical response.
The spider assemblage can exhibit density-dependent tracking of prey.	Individual spider species seldom exhibit density-dependent tracking of prey.
High abundance. Often numerically the most dominate component of the predator complex.	Exhibit some territorial behaviour (both within species, and within-guild) that may limit maximum population size.

Table 2 Mean number of eggs and first-instar larvae of *Helicoverpa armigera* eaten by spiders belonging to different families at 24 h after introduction of eggs or larvae. Each spider was offered 20 eggs or 10 larvae in a no-choice test in a limited search arena

Family	Eggs				First-instar larvae	
	No. spiders	Starved No. eggs eaten/spider	No. spiders	Non-starved No. eggs eaten/spider	No. spiders	No. larva eaten/spider
Oxyopidae	41	0.73 (0.26)	32	0.19 (0.08)	28	9.10 (0.26)
Pisauridae	20	9.70 (1.44)	16	6.88 (1.96)	14	9.64 (0.20)
Thomisidae	17	0.29 (0.19)	10	0	15	9.46 (0.14)
Clubionidae	13	18.40 (1.53)	6	8.17 (3.92)	8	9.63 (0.26)
Salticidae	2	0	6	0	3	9.67 (0.33)
Lycosidae	3	4.00 (2.31)	–	–	–	–
All spiders	96	5.00 (0.76)	70	2.36 (0.67)	68	9.37 (0.12)

–, Not tested. Numbers in brackets indicate standard error.

No-choice feeding tests in the laboratory

Hunting spiders were collected from lucerne and wheat fields during September and October 2000 using a sweep net. The web-building spiders (Araneidae, Tetragnathidae and Theridiidae) were not included in the feeding tests because it was unlikely that *H. armigera* eggs and larvae would be captured in their webs in the field. Hunting spiders from five to six families, all ages and both sexes were used for the feeding experiments. The collection of spiders used reflected the spider families and age structure present in the crop at a single point in time. This resulted in unequal numbers of spiders in each family for each feeding test (Table 2). All the spider families, and many of the spider species, collected within these fields were also present in soybean fields (Evans 1985; Johnson *et al.* 2000). Spiders were stored individually in 28 mL plastic portion cups (Solo cups, Highland Park, Illinois, USA) and kept cool whilst being transported back to the laboratory. Each spider was transferred to a Petri dish that contained a wet dental wick and stored in a constant temperature cabinet (14 : 10 light:dark; 24 : 20°C; 65% relative humidity). As the weather began to get warmer, the temperature within the cabinet was increased by 2°C to reflect natural conditions. No spider was used in more than one feeding experiment.

Spiders were starved for a maximum of 14 d prior to the introduction of eggs or larvae of *H. armigera*. Single starved spiders in the first group ($n = 96$) were provided with 20 eggs in a Petri dish at 0800 h and the cumulative number of eggs consumed by each spider after 2, 4, 6, 8 and 24 h was recorded. The same protocol was used for a second group of spiders ($n = 70$) that had been incubated for 1 d after field collection (non-starved spiders).

A feeding experiment with larvae as prey was conducted using another group of starved spiders ($n = 68$). We placed 10 *H. armigera* first-instar larvae into a Petri dish with a spider and sealed with plastic wrap and sticky tape. The dishes were examined 2, 4, 6 and 24 h after introduction of the larvae and number of larvae consumed recorded. Control dishes ($n = 9$) containing 10 larvae, but no spider, were used to assess the number of larvae that died or escaped from the Petri dish at 2, 4, 6 and 24 h after introduction. The loss rate (at each time point) in the controls was used to correct the results recorded in the feeding experiment.

RESULTS

Spider collection, identification and abundance ranking

We collected 102 morphospecies from 27 families (Tables 3,4) in soybean fields. Of these, 28 could be identified to species, 50 could be identified to genus, and 24 could be identified only to family. The unidentified morphospecies belonged to families that are under revision or have no current taxonomic keys to Australian genera or species (e.g., Gnaphosidae, Theridiidae, Linyphiidae). The identification of some morphospecies was hampered by the lack of adult stages from both sexes in the voucher collection.

The spider families caught in the pitfall traps were different to those caught by vacuum sampling the soybean foliage. Few morphospecies were caught by both sampling techniques and visual searching of the crop was the only effective way to capture some orb-weaving spiders. The majority of the morphospecies ($n = 49$) were generally rare in the soybean field. Twenty morphospecies were commonly found and the remainder ($n = 33$) occasionally reached high numbers (Table 3).

No-choice feeding tests in the laboratory

Oxyopidae and Pisauridae were the most abundant families collected by sweep netting for the egg-feeding experiments, allowing the composition of hunting spiders in the starved and non-starved spider groups to be similar (Table 2). A similar family composition was sampled for the starved spiders used in the larvae-feeding experiment, with Oxyopidae and Thomisidae being the most abundant (Table 2). The Pisauridae consisted mostly of immature spiders, whereas immatures and adults of both sexes of Oxyopidae, Thomisidae and Clubionidae were collected.

The spiders generally did not readily consume eggs in the laboratory. After 8 h, 15% (± 3.1) of the available eggs had been consumed by the starved spiders and 25% (± 3.8) had been consumed after 24 h. Non-starved spiders consumed 6% (± 2.4) of the available eggs after 8 h and 12% (± 3.3) after 24 h. Spiders in the family Clubionidae consumed the greatest number of eggs: 18.4 (± 1.5) eggs per starved spider and 8.2 (± 3.9) eggs per non-starved spider after 24 h (Table 2). Salticidae,

Table 3 Spiders collected in soybean crops at Gatton, Queensland

Morphospecies number	Family	Genus, species	Collection method	Abundance measure
Ara 1	Araneidae	<i>Cyclosa trilobata</i> (Urquhart)	V	1
Ara 3		<i>Eriophora</i> sp1	V	1
Ara 90		<i>Eriophora</i> sp2	V,S	3
Ara 91		<i>Eriophora</i> sp3	V,S	3
Ara 4		<i>Eriophora</i> sp4 (undescribed)	V	2
Ara 5		<i>Neoscona theisi</i> (Walckenaer)	V	3
Ara 64		<i>Araneus</i> sp1	WT	2
Ara 67		<i>Larinia phthisica</i> (L. Koch)	V,S	2
Ara 75		<i>Austracantha minax</i> (Thorell)	V,S	1
Ara 76		<i>Dolophones tuberculata</i> (Keyserling)	WT	1
Ara 77		<i>Celaenia excavata</i> (L. Koch)	V	1
Ara 78		<i>Celaenia distincta</i> (Cambridge)	V	1
Ara 79		<i>Carepalxis</i> sp.	WT	1
Ara 83		<i>Gea theridioides</i> (L. Koch)	V	1
Ara 88		<i>Argiope</i> sp.	V	1
Ara 89		<i>Argiope trifasciata</i> (Forskoel)	V,S	2
Ara 2		Araneidae sp1	V	1
Ara 16	Clubionidae	<i>Cheiracanthium</i> sp.	V,S,PT	2
Ara17		<i>Clubiona</i> sp.	V,PT	2
Ara 93		Clubionidae sp1 (undescribed)	WT	2 in WT
Ara 56	Corinnidae	<i>Poecilipia</i> sp.	PT	2
Ara 57		<i>Supunna versicolor</i> Simon	PT	1
Ara 68		<i>Nucastia</i> sp.	PT	1
Ara 61	Ctenidae	<i>Leptoctenus</i> sp.	PT	2
Ara 62	Dictynidae	Dictynidae sp1 (near <i>Callevopthalmus</i> sp.)	PT	3
Ara 96	Gallieniellidae	Gallieniellidae sp1	PT	1
Ara 22	Gnaphosidae	Gnaphosidae sp1	PT	1
Ara 23		Gnaphosidae sp2	PT	2
Ara 24		Gnaphosidae sp3	PT	2
Ara 19		Gnaphosidae sp4	V	1
Ara 54		Gnaphosidae sp5	V	1
Ara 18		Gnaphosidae sp6	S	1
Ara 51		<i>Hemicloea</i> sp.	V	1
Ara 52	Hahniidae	<i>Scotopilus</i> sp.	PT	2
Ara 106		Hahniidae sp1	PT	2
Ara 103	Lamponidae	<i>Centrothele</i> sp.	V	1
Ara 63		<i>Lampona</i> sp.	V	2
Ara 12	Linyphiidae	<i>Laperousea</i> sp.	V	2
Ara 47		<i>Erigone</i> sp1	PT,WT	3
Ara 71		<i>Erigone</i> sp2	PT,WT,V	3
Ara 66		<i>Lepthyphantes</i> sp1	PT	2
Ara 81		<i>Lepthyphantes</i> sp2	V	1
Ara 70		<i>Lepthyphantes</i> sp3	PT	1
Ara 59		Linyphiidae sp1	V	1
Ara 60		Linyphiidae sp2 (<i>Erigone</i> sp.?)	PT,WT	2
Ara 82		Linyphiidae sp3	PT	2
Ara 69		Linyphiidae sp4	V	1
Ara 20	Liocranidae	<i>Sphingius</i> sp1	V	1
Ara 38	Lycosidae	<i>Venatrix (goyderi?)</i>	PT	3
Ara 39		<i>Venatrix</i> sp1. (near <i>brisbanae</i>)	PT	3
Ara 44		<i>Venatrix</i> sp2	PT	1
Ara 73		<i>Venatrix</i> sp3	PT	1
Ara 105		<i>Venatrix</i> sp4 (near <i>frontis</i>)	PT	1
Ara 40		<i>Artoria quadrata</i> Framenau	PT	3
Ara 42		<i>Artoria parvula</i> Thorell	PT	3
Ara 45		<i>Venonia micarioides</i> (L. Koch)	PT	3
Ara 46		<i>Artoria</i> sp1	PT	3
Ara 72		<i>Lycosa godeffroyi</i> L. Koch	PT	2
Ara 37		Lycosidae sp1	PT	2
Ara 74		Lycosidae sp2 (undescribed)	S	2
Ara 41		Lycosidae sp3	PT	2
Ara 43		Lycosidae sp4	PT	2
Ara 94	Micropholcommatidae	<i>Textricella</i> sp.	PT	2
Ara 58	Mimetidae	<i>Australomimetes</i> sp.	PT	1

Table 3 Continued

Morphospecies number	Family	Genus, species	Collection method	Abundance measure
Ara 21	Miturgidae	<i>Miturga gilva</i> L. Koch	PT	3
Ara 14	Oxyopidae	<i>Oxyopes elegans</i> L. Koch	V	3
Ara 104		<i>Oxyopes gratus</i> L. Koch	V	3
Ara 15		<i>Oxyopes</i> sp1	V	1
Ara 84	Philodromidae	<i>Tibellus tenellus</i> (L. Koch)	V	1
Ara 65	Pholcidae	<i>Pholcus phalangioides</i> (Fuesslin)	V	1
Ara 53	Pisauridae	<i>Dolomedes</i> sp1	V	3
Ara 80		<i>Dolomedes</i> sp2	PT	1
Ara 55	Prodidomidae	<i>Molycrta</i> spp.	PT	3
Ara 92	Salticidae	<i>Gangus concinnus</i> (Keyserling)	S	1
Ara 26		<i>Lycidas</i> sp.	V,PT	2
Ara 28		<i>Bianor maculatus</i> (Keyserling)	V,PT	2
Ara 29		<i>Maratus</i> sp.	PT	1
Ara 30		<i>Grayenulla</i> sp.	PT	1
Ara 25		<i>Myrmarachne</i> sp.	V	1
Ara 87	Sparassidae	<i>Neosparassus</i> sp.	V	1
Ara 100	Tetragnathidae	<i>Nephila plumipes</i> (Latreille)	S	1
Ara 13		Tetragnathidae sp1	V	1
Ara 6	Theridiidae	<i>Latrodectus hasseltii</i> Thorell	V,S	1
Ara 7		<i>Achaeearanea veruculata</i> (Urquhart)	V	3
Ara 11		<i>Steatoda</i> sp2	PT	2
Ara 10		<i>Argyrodes antipodianus</i> (Cambridge)	V,S	2
Ara 48		Theridiidae sp1	PT	1
Ara 98		Theridiidae sp2	V	1
Ara 101		Theridiidae sp3	S	1
Ara 8		<i>Steatoda</i> sp1	PT	1
Ara 9		<i>Euryopsis</i> sp.	PT	2
Ara 31	Thomisidae	<i>Runcinia elongata</i> (L. Koch)	V	3
Ara 33		<i>Tharpyna albosignata</i> L. Koch	PT	2
Ara 35		<i>Tharpyna</i> sp.	PT,V	2
Ara 36		<i>Tmarus</i> sp.	V	1
Ara 32		<i>Diaea</i> sp1	V	3
Ara 27		<i>Diaea</i> sp2	PT	1
Ara 97		<i>Diaea</i> sp3 (<i>rubicunda</i> ?)	V	1
Ara 85	Uloboridae	<i>Zosis geniculata</i> (Olivier)	V	2
Ara 49	Zodariidae	<i>Habronestes</i> sp.	PT	3
Ara 102		<i>Euasteron</i> sp.	PT	1
Ara 50		Zodariidae sp1	PT	1

PT, pitfall traps; V, vacuum samples; WT, water traps; S searching plants; 1, species rarely found in soybean; 2, species are usually rare but occasionally reaching high numbers; 3, species always common in soybean fields.

Thomisidae and Oxyopidae consumed few or no eggs after 24 h. Most of the eggs consumed were eaten between 8 and 24 h after the start of the experiment. The experiment commenced in the morning and the first 8 h were during the day, suggesting that some spiders did not consume eggs until it became dark.

All spiders readily consumed larvae in the laboratory. The starved spiders consumed 67% (± 3.1) of the larvae after 2 h and 94% (± 1.2) after 24 h. There were no non-starved spiders for comparison in this experiment. Spiders belonging to all families consumed over nine larvae in 24 h (Table 2).

DISCUSSION

Unsprayed soybean crops harbour an abundant and relatively diverse assemblage of spider species, some of which may contribute to pest control. Many species, not previously

recorded in soybean were collected throughout this study. Past studies have focused on collecting the spiders found within the crop canopy, and have underestimated the diversity of spiders utilising the crop. The total number of morphospecies that we collected is higher than in previous studies. Evans (1985) collected 33 spider species from 12 families in soybean, and Bishop (1978, 1980) collected 25 species from ten families in cotton. A review of Australian literature on beneficials in cotton farming systems lists 41 species from 13 families (Johnson *et al.* 2000). Notably the dominant Linyphiidae has not been recorded in previous studies. The Amaurobiidae was the only family recorded in the review (Johnson *et al.* 2000) that was not recorded in this study.

Pitfall traps and vacuum sampling in combination with searching of webs captured all of the families expected, based on studies in other crops. No absolute sampling was performed to determine how many species were not collected using these sampling techniques. Green (1999) showed that four of 21

Table 4 Families of spiders collected in soybean fields and the numbers of morphospecies (mps) collected

Family	No. mps	% of total
Araneidae†	17	16.5
Lycosidae†	14	13.6
Linyphiidae	10	9.7
Theridiidae†	9	8.7
Gnaphosidae†	7	6.8
Thomisidae†	7	6.8
Salticidae†	6	5.8
Oxyopidae†	3	2.9
Clubionidae†	3	2.9
Zodariidae	3	2.9
Hahniidae	3	2.9
Corinnidae	3	2.9
Tetragnathidae†	2	1.9
Pisauridae†	2	1.9
Lamponidae	2	1.9
Sparassidae†	1	1.0
Philodromidae	1	1.0
Uloboridae†	1	1.0
Micropholcommatidae	1	1.0
Gallieniellidae	1	1.0
Liocranidae	1	1.0
Miturguridae	1	1.0
Mimetidae	1	1.0
Ctenidae	1	1.0
Dictynidae	1	1.0
Pholcidae	1	1.0
Prodidomidae	1	1.0

†family was recorded in the review of literature on beneficials in cotton farming systems (Johnson *et al.* 2000).

spider families in orchards were only collected nocturnally. In our study, the pitfall traps, which were open during the day and night, would have captured ground-dwelling nocturnal spiders but no attempt was made to capture foliage-dwelling nocturnal spiders.

Laboratory feeding tests suggest that the spider assemblage as a whole may potentially be able to consume 2–5 *H. armigera* eggs per day per spider (10–25% of those available) depending on level of starvation. Insect predators are known to feed on varying numbers of *Helicoverpa* spp. eggs under similar conditions. For example, *Solenopsis invicta* Buren (red imported fire ant) ate 1.5 eggs (± 0.2) in 24 h (Agnew & Sterling 1982), and *Dicranolaius bellulus* (Guérin Méneville) (red and blue beetle) fed on an average of 34.4 (± 3.6) eggs and *Nabis kinbergii* Reuter (damselfly bug) fed on 51.3 (± 4.6) in 24 h after being offered 100 (Johnson 1999). If the spiders tested are in a state of food limitation they may potentially be able to consume nine *H. armigera* first-instar larvae per day per spider (90% of those available). In the field, many factors, such as area and complexity of search arena, prey movement and escape behaviours, predator–species interactions and weather, will impact on predation rates of spiders (Johnson 1999). Until such factors have been investigated further, these results will have limited application to field situations. Our results may be better used to highlight spider families that should be targeted for further study.

Spider families that show significant predatory potential against *Helicoverpa* spp. or other soybean pests are discussed below. The majority of the literature found on the diet preferences of individual spider species and spider groups in agroecosystems came from overseas studies. This literature is included in the discussion, but caution must be taken against translating this work directly to Australian agroecosystems.

Lycosids are ground-dwelling hunting spiders that often build burrows in the soil between the crop rows (Humphreys 1975; Pyke & Brown 1996). We collected 14 morphospecies of Lycosidae, many belonging to the genera *Venatrix* and *Artoria*, from soybean fields. We identified one species as *Venonia micarioides*, and one as *Lycosa godeffroyi*. In previous studies in Australian agroecosystems only a single genus, *Lycosa* has been recognised (Bishop & Blood 1977; Room 1979; Bishop 1980; Evans 1985). The taxonomy of the Lycosidae in Australia is only now under active scrutiny (for example, Framenau & Vink 2001) and, hence, the higher generic diversity was not recognised in previous studies. All authors note this group as being known predators of *Helicoverpa* spp. larvae. In our laboratory-feeding tests they consumed an average of four *H. armigera* eggs over 24 h, but very few individuals were tested ($n = 3$). We did not test lycosids in the larvae-feeding experiments, but Bishop (1978) observed Lycosidae feeding on *Anomis flava* (Fabricius) (cotton looper larvae) and *Earias huegeli* Rogenhofer (rough bollworm larvae) in cotton. Agnew & Smith (1989) estimated that almost 8% of the diet of lycosids in Texan peanut fields consisted of Lepidoptera.

Lycosids are generally overlooked because they are not sampled on plants during the day and are difficult (for non-taxonomists) to identify to genus. Pitfall traps are the most effective method for capturing these spiders (Table 3). They do climb into the soybean foliage, but are rarely captured using a vacuum sampler or sweep net. Ballooning may be the primary source of very young colonisers, but the adults are capable of travelling great distances by walking (Pearce & Zalucki 2002a). They are most abundant at the start of the season, before crop-canopy closure (Agnew & Smith 1989; Pearce & Zalucki 2002b). Further investigation into the feeding activity of lycosids is warranted, particularly because they are abundant early in the season when other predators are rare.

Clubionids that we collected from soybean were classified into three morphospecies. The *Cheiracanthium* sp. (yellow night-stalking spider) and *Clubiona* sp. have been recognised in past studies (Bishop 1978; Room 1979; Austin 1984, 1986; Evans 1985). The third morphospecies (Ara 93) could not be identified and may be an undescribed species. This species was collected mainly from water traps in the second field season. Adults of both sexes are small and could balloon.

Cheiracanthium sp. have been observed at night feeding on *H. armigera* eggs on cards in soybean, and will readily eat eggs and larvae in the laboratory (Scholz *et al.* 2000; Pearce & Zalucki 2002a). Bishop (1978) recorded *Helicoverpa* spp. in the diet of *Cheiracanthium* sp. in cotton fields, as well as *A. flava* and *Nezara viridula* (Linnaeus) (green vegetable bug). Our feeding test shows that clubionids can potentially eat 18

eggs per day if starved and eight eggs per day if not starved. This is a higher estimate than that of Room (1979), who estimated five eggs per day if starved and one egg per day if not starved under comparable conditions. Despite this discrepancy, it is clear that this family has significant potential as predators of *Helicoverpa* spp. eggs in soybean.

The Araneidae have been subject to major phylogenetic research and revision in the last 10 years (Scharff 1997; Griswold *et al.* 1998), making it difficult to compare past literature. We collected 17 morphospecies from soybean crops. Generally, two genera (*Araneus* and *Argiope*) have been recognised in previous work (Pyke & Brown 1996). Most araneids are capable of constructing large orb webs (Griswold *et al.* 1998). The prey species captured by this group of spiders is dependent on web location and structure. Many of the larger species collected in soybean fields (*Neoscona theisi* and *Argiope trifasciata*) were capable of constructing webs between rows of 75 cm spacing. It is generally thought that these webs are capable of capturing adult moths, including *Helicoverpa* spp. Araneids were not included in our no-choice feeding tests and there are very few Australian studies that record prey captured in araneid webs in cropping areas (Bishop 1978 is one exception). Overseas studies have recorded other spiders, small flies, cicadellids, ants, beetles, as well as adult Lepidoptera, in orb webs (Nyffeler *et al.* 1989). Aphids (35–90%) were the most abundant prey for five orb weaving spiders in Texas cotton (Nyffeler *et al.* 1989). Homoptera (36%), Diptera (21%) and Coleoptera (24%) were the most abundant prey caught in *Argiope* sp. and *Neoscona* sp. webs (Nyffeler 1999).

Linyphiids are easily overlooked due to their small size and inconspicuous sheet-webs. They constitute a significant proportion of the ballooning spider fauna and the ground-dwelling spider fauna and both adults and immatures have been recorded ballooning (Pearce & Zalucki 2002a). These spiders build horizontal sheet-webs on the ground, around the bases of the plants and between clumps of dirt. We collected 10 morphospecies from the genera *Erigone*, *Lepthyphantes* and *Laperousea*, but this may be an underestimate of their true diversity.

Little information exists about the diet range of this family of spiders. Due to their size, their diet would consist mainly of smaller arthropods that are present in the lower vegetation and ground surface. In European and American studies, diets of linyphiids consisted of 48% Collembola, 33% Homoptera and no Lepidoptera (Nyffeler 1999), and in British studies, 60% of prey captured in linyphiid webs were Collembola (Harwood *et al.* 2001). Collembola, followed by aphids and thrips, were the most abundant prey caught in linyphiid webs (Sunderland *et al.* 1986a,b) and linyphiids have been recorded feeding on eggs of *Heliothis virescens* (Fabricius) in cotton (Nyffeler *et al.* 1990). Whilst it appears that this group, despite their abundance, may have little impact on *Helicoverpa* spp. in soybean, their potential as aphid predators should be investigated.

We classified the theridiids that we found in soybeans into nine morphospecies and identified *Latrodectus hasseltii*,

Acheareana veruculata, *Steatoda* sp., *Euryopis* sp. and *Argyrodes antipodiana*. Theridiids build untidy tangle-webs within the soybean foliage and around the base of the plants. Most of the species collected are small in size, and like the linyphiids, would capture only smaller sized prey. Bishop (1978) recorded *A. flava*, *E. huegeli* and aphids as their prey in cotton. In the laboratory, *A. veruculata* has been recorded eating *Helicoverpa* spp. larvae (Room 1979). In overseas studies, Homoptera (26%), Hymenoptera (32%) and Diptera (15%) were the most abundant prey caught in webs (Nyffeler 1999).

Salticidae, or jumping spiders, are sighted diurnal hunters within the soybean canopy. They are difficult to capture in the foliage and may be underrepresented in most collections. In the feeding tests, salticids (as well as thomisids and oxyopids) consumed few or no eggs after 24 h. Some hunting spiders lie in ambush rather than actively hunting down prey; attacking only when the prey moves very close (Foelix 1996). Mechanical vibrations, or immediate contact with prey may induce catching behaviour. Such cues would not be present when the prey item is a stationary egg. Salticids (and some lycosids) have well-developed eyes and use visual cues to orientate themselves towards prey, even motionless prey. They may still require prey movement to illicit an attack (Foelix 1996). Salticids, thomisids and oxyopids have been recorded feeding on eggs of *Helicoverpa* spp. in cotton fields (Nyffeler *et al.* 1990), suggesting that these spider families should not be discounted as predators of *Helicoverpa* spp. eggs until field studies have been conducted. Overseas studies show that the diet of salticids consists mainly of Miridae (26%), other Araneae (21%), Diptera (15%) and Lepidoptera (6%) (Nyffeler *et al.* 1994).

Oxyopids and thomisids, known as lynx spiders and crab spiders, respectively, were commonly collected in the soybean foliage. Like the salticids, they are hunting spiders. The three morphospecies of Oxyopidae collected all belonged to *Oxyopes*. This genus has been recognised in cotton (Bishop 1978) and other Australian crops, lucerne (Bishop & Holtkamp 1982) and soybean (Evans 1985), for many years. Oxyopids generally do not eat eggs of *Helicoverpa* spp. in the laboratory, but did eat on average nine larvae per spider per day. Room (1979) showed that *Oxyopes* sp. ate no eggs in no-choice feeding tests, and consumed less than two larvae per spider per day. Bishop (1978) recorded *Oxyopes* sp. feeding on *Helicoverpa* spp. larvae in cotton fields. Studies from Texas have shown that predaceous arthropods made up 42% of the diet of *Oxyopes salticus* in cotton (Nyffeler & Benz 1987; Nyffeler *et al.* 1992).

We collected seven morphospecies of Thomisidae in soybean. They were identified as *Runcinia elongata*, *Tharpyna albosignata*, *Tmarus* sp. and *Diaea* sp. Like the oxyopids, this family of spiders has been identified in agroecosystems for a number of years (Bishop 1978; Evans 1985). They do not eat eggs of *Helicoverpa* sp. in the laboratory, but will readily consume larvae. Bishop (1978) recorded them eating aphids and small lepidopteran larvae in cotton. What proportion of their diet consists of beneficial arthropods is unknown.

It is clear that some spider groups found within soybean are capable of feeding on eggs and larvae of *Helicoverpa*

spp. in the laboratory and may do so in the field. The impact of spiders on populations of *Helicoverpa* spp. in the field must be quantified before they can be fully incorporated into Integrated Pest Management programs. The mortality that they impose on predaceous arthropods is still unknown and may negate some of their potential as biological control agents.

ACKNOWLEDGEMENTS

The Grains Research and Development Corporation and The School of Life Sciences at the University of Queensland funded this work. The taxonomy was conducted at the Queensland Museum. Many thanks to Colin Birch and others at Gatton farms, The University of Queensland, who maintained the field sites. Sue Maclean (Department of Primary Industries, Toowoomba) supplied the *H. armigera* eggs and larvae. Mike Furlong and Mark Wade (University of Queensland) provided helpful comments on the manuscript.

REFERENCES

- Adamson D, Thomas G & Davis E. 1997. *An Economic Estimate of Helicoverpa's Effect on Australian Agricultural Production*. Report 1, *Helicoverpa* series. Cooperative Research Centre for Tropical Pest Management, Brisbane, Australia.
- Agnew CW & Smith JWJ. 1989. Ecology of spiders (Araneae) in a peanut agroecosystem. *Environmental Entomology* **18**, 30–42.
- Agnew CW & Sterling WL. 1982. Predation rates of the red imported fire ant on eggs of the tobacco budworm. *Protection Ecology* **4**, 151–158.
- Austin AD. 1984. Life history of *Clubiona robusta* L. Koch and related species (Araneae, Clubionidae) in South Australia. *Journal of Arachnology* **12**, 87–104.
- Austin AD. 1986. Guarding behaviour, egg mass shape and the egg sac in *Clubiona robusta* L. Koch (Araneae: Clubionidae). In: *Australian Arachnology* (eds AD Austin & NW Heather), pp. 87–95. Australian Entomological Society, Adelaide, Australia.
- Bishop AL. 1978. The Role of Spiders as Predators in a Cotton Ecosystem. MSc Thesis, University of Queensland, Brisbane, Australia.
- Bishop AL. 1980. The composition and abundance of the spider fauna of south-east Queensland cotton. *Australian Journal of Zoology* **28**, 699–708.
- Bishop AL & Blood PR. 1977. A record of beneficial arthropods and insect diseases in southeast Queensland cotton. *Pest Articles and News Summaries* **23**, 384–386.
- Bishop AL & Blood PR. 1981. Interactions between natural populations of spiders and pests in cotton and their importance to cotton production in southeastern Queensland. *General and Applied Entomology* **13**, 98–104.
- Bishop AL & Holtkamp RH. 1982. The arthropod fauna of lucerne in the Hunter Valley, New South Wales. *General and Applied Entomology* **14**, 21–32.
- Bishop AL & Milne WM. 1986. The impact of predators on lucerne aphids and the seasonal production of lucerne in the Hunter Valley, New South Wales (Australia). *Journal of the Australian Entomological Society* **25**, 333–337.
- Carter PE & Rypstra AL. 1995. Top-down effects in soybean agroecosystems: Spider density affects herbivore damage. *Oikos* **72**, 433–439.
- Evans ML. 1985. Arthropod species in soybeans in southeast Queensland (Australia). *Journal of the Australian Entomological Society* **24**, 169–177.
- Fitt GP. 1989. The ecology of *Heliothis* species in relation to agroecosystems. *Annual Review of Entomology* **34**, 17–52.
- Foelix RF. 1996. *Biology of Spiders*. Oxford University Press, New York, USA.
- Forrester NW. 1994. Use of *Bacillus thuringiensis* in integrated control, especially on cotton pests. *Agriculture, Ecosystems and Environment* **49**, 77–83.
- Framenau W & Vink CJ. 2001. Revision of the wolf spider genus *Ventratrix* Roewer (Araneae: Lycosidae). *Invertebrate Taxonomy* **15**, 927–970.
- Green J. 1999. Sampling method and time determines composition of spider collections. *Journal of Arachnology* **27**, 176–182.
- Greenstone MH. 1999. Spider predation: How and why we study it. *Journal of Arachnology* **27**, 333–342.
- Griswold CE, Coddington G, Hormiga G & Scharff N. 1998. Phylogeny of the orb-web building spiders (Araneae, Orbiculariae: Deinopidea, Araneoidea). *Zoological Journal of the Linnean Society* **123**, 1–99.
- Harwood JD, Sunderland KD & Symondson WO. 2001. Living where the food is: Web location by linyphiid spiders in relation to prey availability in winter wheat. *Journal of Applied Ecology* **38**, 88–99.
- Humphreys WF. 1975. The influence of burrowing and thermoregulatory behaviour on the water relations of *Geolycosa godeffroyi* (Araneae: Lycosidae), an Australian wolf spider. *Oecologia* **21**, 291–311.
- Johnson ML. 1999. Comparing Predatory Insects of *Helicoverpa* spp. in Australian Cotton: Approaches to Measuring Prey Consumption. PhD Thesis, University of New England, Armidale, Australia.
- Johnson ML, Pearce S, Wade M, et al. 2000. *Review of Beneficials in Cotton Farming Systems*. Cotton Research and Development Corporation, Narrabri, Australia.
- Mansfield S & Lawrence L. 2002. The complexities of predicting predation on *Helicoverpa*. *Australian Cotton Grower* **23**, 18–21.
- Murdoch WW, Chesson J & Chesson PL. 1985. Biological control in theory and practice. *American Naturalist* **125**, 344–366.
- Nyffeler M. 1999. Prey selection of spiders in the field. *Journal of Arachnology* **27**, 317–324.
- Nyffeler M & Benz G. 1987. Spider in natural pest control: a review. *Journal of Applied Entomology* **103**, 321–339.
- Nyffeler M, Breene RG, Dean DA & Sterling WL. 1990. Spiders as predators of arthropod eggs. *Journal of Applied Entomology* **109**, 490–501.
- Nyffeler M, Dean DA & Sterling WL. 1989. Prey selection and predatory importance of orb-weaving spiders (Araneae: Araneidae, Uloboridae) in Texas (USA) cotton. *Environmental Entomology* **18**, 373–380.
- Nyffeler M, Dean DA & Sterling WL. 1992. Diets, feeding specialization, and predatory role of two lynx spiders, *Oxyopes salticus* and *Peucetia viridans* (Araneae: Oxyopidae), in a Texas cotton agroecosystem. *Environmental Entomology* **21**, 1457–1465.
- Nyffeler M, Sterling WL & Dean DA. 1994. Insectivorous activities of spiders in United States field crops. *Journal of Applied Entomology* **118**, 113–128.
- Pearce S & Zalucki MP. 2002a. Spider ballooning in crops: A web of intrigue. *Australian Grain* **12** (4), vi–vii.
- Pearce S & Zalucki MP. 2002b. A wolf with a beneficial bite. *Australian Grain* **12** (5), vi–vii.
- Pyke BA & Brown EH. 1996. *The Cotton Pest and Beneficial Guide*. CRDC, CTPM and CRC for Sustainable Cotton Production, Woolloongabba, Australia.
- Raven R. 1986. The current status of Australian spider systematics. In: *Australian Arachnology* (eds AD Austin & NW Heather), pp. 37–47. Australian Entomological Society, Adelaide, Australia.
- Riechert SE. 1999. The hows and whys of successful pest suppression by spiders: Insights from case studies. *Journal of Arachnology* **27**, 387–396.
- Riechert SE & Bishop L. 1990. Prey control by an assemblage of generalist predators: Spiders in garden test systems. *Ecology* **71**, 1441–1450.
- Room PM. 1979. Parasites and predators of *Heliothis* spp. (Lepidoptera: Noctuidae) in cotton in the Namoi valley, New South Wales. *Journal of the Australian Entomological Society* **18**, 223–228.

- Scharff N. 1997. A phylogenetic analysis of the orb-weaving spider family Araneidae (Arachnida, Araneae). *Zoological Journal of the Linnean Society* **120**, 355–434.
- Scholz BC, Cleary AJ, Lloyd RJ & Murray DA. 2000. Predation of heliothis eggs in dryland cotton on the Darling Downs. *Proceedings of the Tenth Australian Cotton Conference*, 16–18 August, Brisbane, pp. 113–119. Australian Cotton Growers Research Association, Weewaa, Australia.
- Shepard M, Lawn RJ & Schneider MA. 1983. *Insects on Grain Legumes in Northern Australia: a Survey of Potential Pests and Their Enemies*. University of Queensland Press, St. Lucia, Australia.
- Stanley J. 1997. The Seasonal Abundance and Impact of Predatory Arthropods on *Helicoverpa* spp. in Australian Cotton Fields. PhD Thesis, University of New England, Armidale, Australia.
- Sunderland KD, Fraser AM & Dixon AF. 1986a. Distribution of linyphiid spiders in relation to capture of prey in cereal fields. *Pedobiologia* **29**, 367–375.
- Sunderland KD, Fraser AM & Dixon AF. 1986b. Field and laboratory studies on money spiders (Linyphiidae) as predators of cereal aphids. *Journal of Applied Ecology* **23**, 433–448.
- Wade M, Zalucki M & Franzmann B. 2002. What are damsel bugs doing in cotton? Implications for IPM. *Australian Cotton Grower* **23** (7), 48–50.
- Whitehouse ME & Lawrence L. 2001. Are spiders the perfect predator? *Australian Cotton Grower* **22**, 30–33.
- Wise DH. 1993. *Spiders in Ecological Webs*. Cambridge University Press, Cambridge, UK.
- Zalucki MP, Daghli G, Firempong S & Twine P. 1986. The biology and ecology of *Heliothis armigera* (Hübner) and *H. punctigera* Wallengren (Lepidoptera: Noctuidae) in Australia: What do we know? *Australian Journal of Zoology* **34**, 779–814.

Accepted for publication 31 May 2003.