Chapter 2
Lady Beetles; Lots of Efforts but few Successes

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2.1 Introduction, Why Lady Beetles Are so Important?

Undoubtedly, the family Coccinellidae has been considered as important and well-known predators of sap feeder pests. This easily identified group contains 6000 described species world widely (Biranvand et al. 2016; Giorgi and Vandenberg 2009). Adults are generally convex and oval, brightly colored; their body size ranges from 0.8 to 10 mm (Triplehorn and Johnson 2005). Their tarsal formula is 3-3-3 or 4-4-4 that separate them from similar Chrysomelids (Triplehorn and Johnson 2005; Hodek et al. 2012). The life span includes seven stages, egg, four larval instars, pupa and Adult. Larvae are elongate, vigorous and their body covered by hairy tubercles or different patterns characterize them. Most ladybirds overwinter as adults in different sites. The food habits of lady beetles are various from carnivory (mostly) to herbivory (subfamily Epilachninae), and even fungivory has been identified among lady beetles (Coccinellinae: Tribe Psylloborini). Prey types are different, but most Coccinellids prefer coccids or aphids. This family has been divided into seven subfamilies; among them subfamily Coccinellinae is a very important in aphid biocontrol. One of the main species of this group is *Hippodamia vareigata* (Kontodimas and Stathas, 2005). This is a Palearctic species that has been reported from different parts of the world (Franzmann 2002), including many parts of Iran (Yaghmaee and Kharazi Pakdel 1995; Lotfalizadeh 2001; Haghshenas et al. 2004; Jafari et al. 2008b; Ansari pour and Shakarami, 2012). The striking point is that this species is the dominant species of lady beetles in most parts and crops. It attacks many aphid species and also feeds on non-aphid pest species (Asghari et al. 2012). Many studies have been conducted on different biological aspects of *H. variegata* in

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J. Karimi, H. Madadi (eds.), *Biological Control of Insect and Mite Pests in Iran*,
Progress in Biological Control 18, https://doi.org/10.1007/978-3-030-63990-7_2

Iran. One goal of this this review is to consider those studies, their strengths and weakness.

Lady beetles can be found within many agroecosystems, orchards, greenhouses, pastures, parks, countryside and even urban environments. Because of brightly colored bodies and easy identification, most people are familiar with them and know some things about them. Most researchers consider them as a voracious predatory group that could be useful in some cases in suppressing pest populations substantially. Literately, there are some characters attributed to an efficient natural enemy. Some of the most important desirable properties enumerated for a biocontrol agent are high fecundity rate, weather concordance with prey habitat, direct numerical response to prey increase, high searching rate, ability to disperse within host habitat, patch time allocation behavior, high consumption rate, mass rearing simplicity and synchrony with host physiology, especially for parasitoids.

Lady beetles have many biological properties making them effective candidates for biological control projects. Some species (e.g., *Stethorus* species are monophagous or oligophagous and prey on a few mite species) while most others are generalist aphidophagous or coccidophagous species. It should be noted that prey types of lady beetles are not limited to mites, aphids and coccids. Spotted lady beetle, *Colemegilla maculata* (Degeer) is an effective natural enemy of eggs and larvae of Colorado potato beetle –*Leptinotarsa decemlineata* Say- in North America and Canada (Arpaia et al. 1997). Furthermore, it has been documented that other Coccinellid species frequently feed on psyllids, whiteflies, thrips, eggs and early larvae of Lepidoptera, and even alfalfa weevil, *Hypera postica* (Gyllenhal) small larvae opportunistically (Edward 2009). Many Coccinellids are voracious predators both as adults and prematures e.g., one *Hippodamia variegata* fourth instar larvae can kill up to 112.2 ± 2.05 and 114 ± 2.15 fourth instar cotton aphid and pea aphid nymphs during 24 h under laboratory conditions (Madadi et al. 2011). Consequently, the fourth instar larvae or females have been suggested as releasing stages. The life history studies of lady beetle show that most of them are active during the growing season and multivoltine. Furthermore, they could be reared under laboratory conditions on relatively simple diets. Most Coccinellids do not have special requirements for mass production. Recently, there are some attempts to rear them on artificial diets (Mirkhalilzadeh et al. 2013). Many Coccinellid species could use pollen or other non-prey foods besides natural prey allowing them to survive in the absence of their prey.

2.2 The Most Important Lady Beetles Species Reported from Iran

There are many studies conducted on faunistic of lady beetle species and determining the dominant species in different parts of Iran, but some of them are old conference papers or simple checklists which were not available digitally. Here we tried to address a list of described ladybird species plus their distribution and sometimes their prey as follows.

2.2.1 Adalia bipunctata *(Linnaeus 1758)*

This species is a common species and has been reported from different parts of Iran, including Tehran and Mazandaran provinces (Vojdani 1965), Kerman (Koohpayezadeh and Mossadegh 1991), Khorasan (Yaghmaee and Kharrazi Pakdel 1995), Golestan (Montazeri and Mossadegh 1995), Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995; Noorbakhsh 2000), Guilan (Haji-Zadeh et al. 1998), Hamedan (Ahmadi 2000), Moghan plain (Ardebill province) (Lotfalizadeh 2002; Razmjou and Hajizadeh 2000), West Azerbaijan (Akbarzadeh Shoukat and Rezvani 2000), West Khorasan (Kalantari and Sadeghi 2000), Qazvin (Mohammadbeigi 2000), Fars (Fallahzadeh et al. 2000), Isfahan (Haghshenas et al. 2004), Sistan and Baluchestan (Modarres Najaf Abadi et al. 2008a), Lorestan (Jafari and Kamali 2007; Ansari pour and Shakarami 2011; Biranvand et al. 2014), Varamin and vicinity (Samin and Shojai 2013), Kermanshah (Gholami Moghaddam et al. 2014).

2.2.2 Adalia decempunctata *(Linnaeus 1758)*

Golestan (Montazeri and Mossadegh 1995), Lorestan (Jafari and Kamali 2007; Ansari pour and Shakarami 2011; Biranvand et al. 2014), Arak, Markazi province (Ahmadi et al. 2012).

2.2.3 Adalia fasciatopunctata revelierei *Muls*

Zanjan (Mohiseni et al. 1998).

2.2.4 Adalia tetraspilota *(Hope 1831)*

Lorestan province (Biranvand et al. 2014).

2.2.5 Anisosticta bitriangularis *Say*

Khorasan (Yaghmaee and Kharazi-Pakdel 1995).

2.2.6 Anisosticta novemdecimpunctata *(Linnaeus 1758)*

Karaj region (Tehran province) from alfalfa fields (Vojdani 1965).

2.2.7 Bromus gebleri *Weise*

Fars province (Fallahzadeh et al. 2006).

2.2.8 Bromus octosignatus *(Gebler 1830)*

This coccidophgous lady beetle has been reported from North as well as Isfahan and Tehran provinces firstly (Vojdani 1965), then it has been reported from Kerman (Koohpayezadeh and Mossadegh 1991) Khorasan (Yaghmaee and Kharazi-Pakdel 1995), and Guilan (Haji-Zadeh et al. 1998).

2.2.9 Bromus undulatus

Arak, Markazi province (Ahmadi et al. 2012).

2.2.10 Calvia quatrodecimguttata *(Linnaeus 1758)*

Kerman (Koohpayezadeh and Mossadegh 1991).

2.2.11 Cheilomenes sexmaculatus *(Fabricius 1781)*

Kerman (Koohpayezadeh and Mossadegh 1991).

2.2.12 Chilocorus bipustulatus *(Linnaeus 1758)*

Northern part of Iran (Vojdani 1965), Kerman (Koohpayezadeh and Mossadegh 1991; Yazdani and Ebrahimi 1993), Chaharmahal va Bakhtiari Province (Bagheri and Mossadegh 1995), Golestan (Montazeri and Mossadegh 1995), Khorasan

(Yaghmaee and Kharazi Pakdel 1995), Kohkiloyeh va Boyer Ahmad (Saeedi 1998), Hamedan (Sadeghi and Khanjani 1998), Zanjan (Mohiseni et al. 1998), Mazandaran (Maafi et al. 1998), Guilan (Haji-Zadeh et al. 1998), West Khorasan (Kalantari and Sadeghi 2000), Fars (Alemansoor and 1993; Fallahzadeh et al. 2000, 2004, 2006), Fars province, Jahrom (Fallahzadeh and Hesami 2004) Alborz (Ansari pour 2012), Arak, Markazi province (Ahmadi et al. 2012), Tehran (Ghanbari et al. 2012), Varamin (South of Tehran province) (Samin and Shojai 2013), Lorestan (Biranvand et al. 2014).

2.2.13 Clitostethus arcuatus *Rossi*

Kerman (Koohpayezadeh and Mossadegh 1991), Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995), Golestan (Montazeri and Mossadegh 1995), Fars (Alemansoor and Ahmadi 1993; Fallahzadeh et al. 2004).

2.2.14 Coccinella elegantula *(Weise 1980)*

Khorasan (Yaghmaee and Kharazi Pakdel 1995), Isfahan (Bagheri and Emami 1998), Lorestan province, Khorramabad (Ansari pour and Shakarami 2011).

2.2.15 Coccinella magnopunctata Rybakow

Khorasan Razavi (Farahi and Sadeghi Namaghi 2011).

2.2.16 Coccinella novemnotata *Herbst*

Khuzestan (Ebrahimzadeh and Mossadegh 2004).

2.2.17 Coccinella quatrodecimpustulata *(Linnaeus 1758)*

Najafabad, Kashan (Isfahan province) (Vojdani 1965), Hamedan (Sadeghi and Khanjani 1998), Isfahan (Seifollahi et al. 2000).

2.2.18 Coccinella redemita *(Weise 1895)*

Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995).

2.2.19 Coccinella septempunctata *(Linnaeus 1758)*

This is a native and most famous species reported nearly from all faunistic studies of ladybirds in different ecosystems and crops. Vojdani (1965) firstly reported this species from Karaj vicinity. Then, it has been reported from almost all parts of Iran. Additionally, it has been reported from Kerman (Koohpayezadeh and Mossadegh 1991), Khorasan (Yaghmaee and Kharazi Pakdel 1995), Golestan(Montazeri and Mossadegh 1995), Chaharmahal va Bakhtiari (Bagheri and Mossedegh 1995; Noorbakhsh 2000), Kohkiloyeh va Boyer Ahmad (Saeedi 1998) Hamedan (Ahmadi 2000; Sadeghi and Khanjani 1998), Zanjan (Mohiseni et al. 1998), Guilan (Haji-Zadeh et al. 1998), Moghan (Ardebill province) (Razmjou and Hajizadeh 2000); Lotfalizadeh 2002), West Azerbaijan (Akbarzadeh Shoukat and Rezvani 2000), Khuzestan (Ebrahimzadeh and Mossadegh 2004; Kalantari and Sadeghi 2000), Qazvin (Mohammadbeigi 2000), Fars (Alemansoor and Ahmadi 1993; Fallahzadeh et al. 2000), East Azerbaijan (Sadaghian et al. 2000), Isfahan (Haghshenas et al. 2004), Sistan and Baluchestan (Modarres Najaf Abadi et al. 2008a, b) on cabbage aphid and green wheat aphids respectively. This species is also dominant in Lorestan (Ansari pour and Shakarami 2011, 2012; Biranvand et al. 2014), Arak, Markazi province (Ahmadi et al. 2012), Alborz (Ansari pour 2012), Varamin and vicinity (Samin and Shojai 2013), Tehran (Ghanbari et al. 2012) and Kermanshah (Gholami Moghaddam et al. 2014).

2.2.20 Coccinella undecimpunctata *(Linnaeus 1758)*

Tehran, Isfahan, Golestan, Mazandaran, West Azerbaijan provinces (Montazeri and Mossadegh 1995; Vojdani 1965), Kerman (Koohpayezadeh and Mossadegh 1991), Fars (Alemansoor and Ahmadi 1993), Khorasan (Yaghmaee and Kharazi Pakdel 1995), Hamedan (Sadeghi and Khanjani 1998), Guilan (Haji-Zadeh et al. 1998), Moghan plain (Ardebill province) (Razmjou and Hajizadeh 2000), West Khorasan (Kalantari and Sadeghi 2000), Khuzestan (Ebrahimzadeh and Mossadegh 2004), Sistan and Baluchestan province (Modarres Najaf Abadi et al. 2008a, b) on cabbage aphid and green wheat aphids, Alborz (Ansari pour 2012), Varamin and vicinity (Samin and Shojai 2013).

2.2.21 Cryptolaemus montrouzieri *(Mulsant 1853)*

One of the most well-known and usable lady beetle species, widely mass reared and used against mealy bugs, especially in the tropical and subtropical part of Iran (North part, Guilan, Mazandaran and Golestan provinces (Montazeri and Mossadegh 1995), Lorestan province (Ansari pour and Shakarami 2011), Markazi province (Ahmadi et al. 2012). This exotic species has been introduced to Iran about 50 years before and has been used successfully.

2.2.22 Diloponis furschi *Ahmadi and Yazdani*

Fars province (Ahmadi et al. 1993a).

2.2.23 Diomus rubidus *(Motschulsky 1837)*

Koohpayezadeh and Mossadegh (1991) from Kerman province.

2.2.24 Exochomus flavipes *(Thunberg 1781)*

Tehran and Isfahan provinces (Vojdani 1965), Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995), Khorasan (Yaghmaee and Kharazi Pakdel 1995; Farahi and Sadeghi Namghi 2009), Lorestan (Jafari and Kamali 2007; Ansari pour and Shakarami 2012).

2.2.25 Exochomus illaesicollis *Roubal*

Kerman (Yazdani and Ebrahimi 1993).

2.2.26 Exochomus melanocephalus *(Zoubkoff 1833)*

This species has been reported from Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995), Khorasan (Yaghmaee and Kharazi-Pakdel 1995) and alfalfa fields of Lorestan province (Ansari pour and Shakarami 2012; Biranvand et al. 2014).

2.2.27 Exochomus nigripennis *Erichsion*

Kerman (Koohpayezadeh and Mossadegh 1991; Yazdani and Ebrahimi 1993), Golestan (Montazeri and Mossadegh 1995), Guilan (Haji-Zadeh et al. 1998), West Khorasan (Kalantari and Sadeghi 2000), Fars province on cotton whitefly (Alemansoor and Ahmadi 1993), on *Maconellicoccus hirsutus* (Fallahzadeh and Hesami 2004) and mealybugs (Fallahzadeh et al. 2006). Additionally, it was reported by Sadat Alizadeh et al. (2013) from Ahvaz, Khuzestan province and by Samin and Shojai (2013) from Varamin (Tehran province).

2.2.28 Exochomus nigromaculatus *(Goeze, 1777)*

Kerman (Yazdani and Ebrahimi 1993), Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995), Golestan (Montazeri and Mossadegh 1995), Hamedan (Sadeghi and Khanjani 1998), Zanjan (Mohiseni et al. 1998), Isfahan (Bagheri and Emami 1998; Haghshenas et al. 2004), Guilan (Haji-Zadeh et al. 1998), Fars (Alemansoor and Ahmadi 1993; Fallahzadeh et al. 2006; Fallahzadeh and Hesami 2004), Alborz (Ansari pour 2012), Arak, Markazi province (Ahmadi et al. 2012), Tehran (Ghanbari et al. 2012), Lorestan (Biranvand et al. 2014).

2.2.29 Exochomus pubescens *(Kuster 1848)*

Kerman (Yazdani and Ebrahimi 1993), Fars (Alemansoor and Ahmadi 1993), Golestan province (Montazeri and Mossadegh 1995), Isfahan (Haghshenas et al. 2004), Khuzestan (Ebrahimzadeh and Mossadegh 2004), Sistan and Baluchestan (Modarres Najaf Abadi 2008b) on green wheat aphids, Lorestan province (Jafari and Kamali 2007; Ansari pour and Shakarami 2012; Biranvand et al. 2014), Varamin and vicinity (Samin and Shojai 2013).

2.2.30 Exochomus quadripustulatus *(Linnaeus 1758)*

Northern part of Iran (Vojdani 1965), Kerman (Koohpayezadeh and Mossadegh 1991; Yazdani and Ebrahimi 1993), Khorasan (Yaghmaee and Kharazi Pakdel 1995) and Chaharmahal va Bakhtiari by (Bagheri and Mossadegh 1995), Kohkiloyeh va Boyer Ahmad (Saeedi 1998), Zanjan (Mohiseni et al. 1998), Isfahan (Bagheri and Emami 1998), Qazvin (Mohammadbeigi 2000), Fars (Fallahzadeh et al. 2000, 2006; Fallahzadeh and Hesami 2004), Lorestan (Ansari pour and Shakarami 2011; Biranvand et al. 2014), Alborz (Ansari pour 2012). Fallahzadeh et al. (2011)

reported this species from vine mealybug, *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae).

2.2.31 Exochomus undulatus *(Weise 1878)*

Kerman (Yazdani and Ebrahimi 1993), Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995), Golestan (Montazeri and Mossadegh 1995), Kohkiloyeh va Boyer Ahmad (Saeedi 1998), Isfahan (Bagheri and Emami 1998), Fars (Fallahzadeh et al. 2000), Khorasan (Farahi and Sadeghi Namghi 2009), Lorestan (Ansari pour and Shakarami 2011; Biranvand et al. 2014), Tehran (Ghanbari et al. 2012), Kermanshah (Gholami Moghaddam et al. 2014).

2.2.32 Hippodamia *(*Adonia*)* variegata *(Goeze 1777)*

This Palearctic famous species is quietly common in different parts of Iran and mostly has been reported from Alfalfa fields. Tehran province (Vojdani 1965), Kerman (Koohpayezadeh and Mossadegh 1991), Khorasan (Yaghmaee and Kharazi Pakdel 1995), Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995), Golestan (Montazeri and Mossadegh 1995), Kohkiloyeh va Boyer Ahmad (Saeedi 1998), Hamedan (Sadeghi and Khanjani 1998), Guilan (Haji-Zadeh et al. 1998), Moghan plain (Ardebill province) (Lotfalizadeh 2002; Razmjou and Hajizadeh 2000), West Khorasan (Kalantari and Sadeghi 2000), Qazvin (Mohammadbeigi 2000), Fars (Alemansoor and Ahmadi 1993; Fallahzadeh et al. 2000), Isfahan (Haghshenas et al. 2004; Seifollahi et al. 2000), Khuzestan (Ebrahimzadeh and Mossadegh 2004), Sistan and Baluchestan (Modarres Najaf Abadi et al. 2008a, b), Lorestan (Ansari pour and Shakarami 2011, 2012; Biranvand et al. 2014) Alborz (Ansari pour 2012), Arak, Markazi province (Ahmadi et al. 2012), Tehran (Ghanbari et al. 2012), Varamin and vicinity (Samin and Shojai 2013), Kermanshah (Gholami Moghaddam et al. 2014).

2.2.33 Hippodamia tredecimpunctata *(Linnaeus 1758)*

Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995), Kohkiloyeh va Boyer Ahmad (Saeedi 1998).

2.2.34 Hyperaspis duvergeri *(Fursch 1985)*

Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995).

2.2.35 Hyperaspis concolor *(Suffrian 1843)*

Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995).

2.2.36 Hyperaspis marmottani *Fairmaire*

Khorasan (Yaghmaee and Kharazi Pakdel 1995).

2.2.37 Hyperaspis polita *Weise*

This species reported from unknown mealybug species (Asadeh and Mossadegh 1991; Novin et al. 2000) from Khuzestan province. Moreover, it has been recorded from Kerman province (Koohpayezadeh and Mossadegh 1991) and Golestan (Montazeri and Mossadegh 1995). Furthermore, it was reported on vine mealybug, *Planococcus ficus* (Fallahzadeh et al. 2011), pink Hibiscus mealybug, *Maconellicoccus hirsutus* (Greenblatt) (Hemiptera: Pseudococcidae) (Fallahzadeh and Hesami 2004), different mealybug species (Fallahzadeh et al. 2006) from Fars province and on *M. hirsutus* from Khuzestan province (Sadat Alizadeh et al. 2013).

2.2.38 Hyperaspis quadrimaculata *(Redtenbacher 1844)*

Lorestan (Jafari and Kamali 2007; Ansari pour and Shakarami 2011, 2012).

2.2.39 Hyperaspis reppensis *(Herbst 1783)*

Alborz (Ansari pour 2012), Yazd (Zare Khormizi et al. 2014).

2.2.40 Hyperaspis syriaco *(Weise 1885)*

Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995).

2.2.41 Hyperaspis vinciqerrae *Capra*

This species was firstly reported by Sadat Alizadeh et al. (2013) as a new report on *M. hirsutus* from Ahvaz, Khuzestan Province (Southwest of Iran).

2.2.42 Nephus arcuatus *Kapur*

Ahvaz, Khuzestan province on pink Hibiscus mealybug *M. hirsutus* (Greenblatt) (Hemiptera: Pseudococcidae) (Sadat Alizadeh et al. 2013).

2.2.43 Nephus bipunctatus *(Kugelann 1794)*

Kerman (Koohpayezadeh and Mossadegh 1991), Zanjan (Mohiseni et al. 1998), Guilan (Haji-Zadeh et al. 1998) and Chahar Mahal va Bakhtiari (Esfandiari et al. 2002). On top of this, this species reported on cotton whitefly and Vine mealybug, *P. ficus* from Fars province (Alemansoor and Ahmadi 1993; Fallahzadeh et al. 2011, respectively).

2.2.44 Nephus biguttatus

Golestan (Montazeri and Mossadegh 1995).

2.2.45 Nephus bisignatus etesiacus *Fursch*

Khorasan (Yaghmaee and Kharazi Pakdel 1995).

2.2.46 Nephus fenestratus *Sahlberg*

Khuzestan (Novin et al. 2000), Jahrom, Fars Jahrom (Fallahzadeh et al. 2006; Fallahzadeh and Hesami 2004).

2.2.47 Nephus includes *Kirsch*

It has been reported as a predator of mealybugs from Khuzestan province (Asadeh and Mossadegh 1991; Novin et al. 2000), Jahrom, Fars province (Fallahzadeh et al. 2004).

2.2.48 Nephus nigricans *(Weise 1879)*

Lorestan (Biranvand et al. 2014).

2.2.49 Nephus quadrimaculatus *(Herbst 1783)*

This species formerly known as *Scymnus quadrimaculatus* has been reported on several mealybugs and Coccids from North provinces of Iran (Vojdani 1965) and Kermanshah (Gholami Moghaddam et al. 2014).

2.2.50 Nephus ulbrichi *(Fursch 1977)*

This species firstly reported by Jalilvand et al. (2012) on *Planococcus vovae* (Hemiptera: Pseudococcidae).

2.2.51 Oenopia conglobata *(Linnaeus 1758)*

Kerman (Koohpayezadeh and Mossadegh 1991), Khorasan (Yaghmaee and Kharazi Pakdel 1995), Golestan (Montazeri and Mossadegh 1995), Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995), Kohkiloyeh va Boyer Ahmad (Saeedi 1998), Hamedan (Sadeghi and Khanjani 1998), Guilan (Haji-Zadeh et al. 1998), West Khorasan (Kalantari and Sadeghi 2000), Qazvin (Mohammadbeigi 2000), Moghan region (Ardebill province) (Lotfalizadeh 2002), Fars province (Alemansoor and Ahmadi 1993; Fallahzadeh et al. 2000, 2006; Fallahzadeh and Hesami 2004), Lorestan (Jafari and Kamali 2007; Ansari pour and Shakarami 2011, 2012; Biranvand et al. 2014), Alborz (Ansari pour 2012), Tehran (Ghanbari et al. 2012), Varamin and vicinity (Samin and Shojai 2013).

2.2.52 **Oenopia oncina** ***(Olivier 1808)***

This species reported from Tehran, Khuzestan, Hormozgan provinces (Vojdani 1965), Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995), Golestan (Montazeri and Mossadegh 1995), West Khorasan (Kalantari and Sadeghi 2000), Isfahan (Seifollahi et al. 2000), Fars province, Jahrom (Alemansoor and Ahmadi 1993; Fallahzadeh et al. 2006; Fallahzadeh and Hesami 2004), Lorestan Province (Ansaripour and Shakarami 2011, b, 2012; Biranvand et al. 2014), Arak, Markazi province (Ahmadi et al. 2012), Kermanshah (Gholami Moghaddam et al. 2014).

2.2.53 **Pharoscymnus brunneosignatus** ***(Marder 1949)***

It has been reported from Khorasan Razavi (Ebrahimi et al. 2012).

2.2.54 **Pharoscymnus ovoideus** ***Anthor,*** **P. arabicus** ***Anthor and*** **P. setulesus** ***Chevrolat***

These three species have been reported by Ahmadi and Yazdani (1991) from Fars province feeding on scale insects (Diaspididae) especially *Parlatoria blanchardi*. The first one has been reported by Haji-Zadeh et al. (1998) from Guilan.

2.2.55 **Pharoscymnus pharoides** ***Marseul***

It was reported by Ahmadi et al. (1993b) from Fars province on Diaspidid scale insects firstly. Then Bagheri and Mossedegh (1995) reported it from Chaharmahal va Bakhtiari.

2.2.56 **Pharoscymnus** ***cf.*** **smirnovi** ***(Dobzhansky l927)***

Yazd (Zare Khormizi et al. 2014).

2.2.57 Propylea quatuordecimpuctata *(Linnaeus 1758)*

Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995), Khorasan (Yaghmaee and Kharazi Pakdel 1995), Golestan (Montazeri and Mossadegh 1995), Kohkiloyeh va Boyer Ahmad (Saeedi 1998), Hamedan (Sadeghi and Khanjani 1998), Mazandaran (Maafi et al. 1998), Guilan (Haji-Zadeh et al. 1998), Moghan plain (Ardebill province) (Lotfalizadeh 2002; Razmjou and Hajizadeh 2000), East Azerbaijan (Sadaghian et al. 2000), Isfahan (Haghshenas et al. (2004), Lorestan (Jafari and Kamali 2007; Ansari pour and Shakarami 2011, 2012; Biranvand et al. 2014), Alborz (Ansari pour 2012).

2.2.58 Psyllobora vigintiduopunctata *(Linnaeus 1758)*

Karaj, Alborz Province (Vojdani 1965), Kerman (Koohpayezadeh and Mossadegh 1991), Golestan (Montazeri and Mossadegh 1995), Golestan (Montazeri and Mossadegh 1995), Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995; Esfandiari et al. 2002), Khorasan (Yaghmaee and Kharazi Pakdel 1995), Kohkiloyeh va Boyer Ahmad (Saeedi 1998), Hamedan (Sadeghi and Khanjani 1998), Zanjan (Mohiseni et al. 1998), Guilan (Haji-Zadeh et al. 1998), West Khorasan (Kalantari and Sadeghi 2000), Fars (Fallahzadeh et al. 2000), East Azerbaijan (Sadaghian et al. 2000), Lorestan (Jafari and Kamali 2007; Ansari pour and Shakarami 2011, 2012; Biranvand et al. 2014).

2.2.59 Rodolia cardinalis *(Mulsant 1850)*

It is one of the most successful ladybeetle species that have been arrived in Iran in 1912. Now this species is well established in many citrus orchards (Vojdani 1965). Golestan (Montazeri and Mossadegh 1995) and Guilan (Haji-Zadeh et al. 1998) are recorded as the main sites of distribution of this predator.

2.2.60 Rodolia fusti *Weise*

Khorasan (Yaghmaee and Kharazi Pakdel 1995).

2.2.61 Scymniscus biflammatus *(Motschulsky 1837)*

Lorestan (Biranvand et al. 2014).

2.2.62 Scymnus argutus *Mulsant*

Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995).

2.2.63 Scymnus araraticus *(Iablokoff-Khnzorian 1969)*

Fars province (Yazdani and Ahmadi 1991), Guilan (Haji-Zadeh et al. 1998), Loretan (Biranvand et al. 2014).

2.2.64 Scymnus araxicola *(Fleischer 1900)*

Kermanshah (Gholami Moghaddam et al. 2014).

2.2.65 Scymnus apetzi *(Mulsant 1846)*

Fars province (Alemansoor and Ahmadi 1993; Yazdani and Ahmadi 1991), Golestan province (Montazeri and Mossadegh 1995), Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995), Mazandaran (Maafi et al. 1998), Isfahan (Bagheri and Emami 1998; Haghshenas et al. 2004), Guilan (Haji-Zadeh et al. 1998), Lorestan province (Jafari and Kamali 2007; Ansari pour and Shakarami 2011, 2012; Biranvand et al. 2014), Alborz (Ansari pour 2012).

2.2.66 Scymnus auritus *(Thunberg 1795)*

Fars province (Yazdani and Ahmadi 1991), Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995), Guilan (Haji-Zadeh et al. 1998).

2.2.67 Scymnus flavicollis *(Redtenbacher 1844)*

Fars province (Alemansoor and Ahmadi 1993; Yazdani and Ahmadi 1991), Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995), Isfahan (Bagheri and Emami 1998; Haghshenas et al. 2004), Guilan (Haji-Zadeh et al. 1998), Khuzestan (Ebrahimzadeh and Mossadegh 2004), Lorestn province (Ansari pour and

Shakarami 2011, 2012), Arak, Markazi province (Ahmadi et al. 2012), Varamin and vicinity (Samin and Shojai 2013).

2.2.68 Scymnus frontalis *(Fabricius 1787)*

Khorasan (Yaghmaee and Kharazi Pakdel 1995).

2.2.69 Scymnus impexus *(Mulsant, 1850)*

West Khorasan (Kalantari and Sadeghi 2000).

2.2.70 Scymnus levaillanti *(Mulsant 1850)*

This species has been reported from Kerman (Koohpayezadeh and Mossadegh 1991), Fars (Alemansoor and Ahmadi 1993; Yazdani and Ahmadi 1991), Khuzestan (Ebrahimzadeh and Mossadegh 2004).

2.2.71 Scymnus mongolicus *Weiser*

Isfahan (Bagheri and Emami 1998), Khuzestan (Ebrahimzadeh and Mossadegh 2004).

2.2.72 Scymnus nubilus *(Mulsant 1846)*

Lorestan province (Biranvand et al. 2014).

2.2.73 Scymnus pallipediformis *(Gunther 1958)*

Arak, Markazi province (Ahmadi et al. 2012).

2.2.74 Scymnus pallipes *(Mulsant 1850)*

This species was reported from Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995), Golestan (Montazeri and Mossadegh 1995), Khorasan (Yaghmaee and Kharazi Pakdel 1995), Isfahan (Bagheri and Emami 1998), and from Alfalfa fields of Lorestan province (Ansari pour and Shakarami 2012).

2.2.75 Scymnus quadriguttatus *(Fürsch and Kreissl 1967)*

Fars (Yazdani and Ahmadi 1991), Khorasan (Yaghmaee and Kharazi Pakdel 1995), Golestan (Montazeri and Mossadegh 1995), Guilan (Haji-Zadeh et al. 1998), Sistan and Baluchestan province (Modarres Najaf Abadi et al. 2008a).

2.2.76 Scymnus rubromaculatus *Goeze*

Fars (Alemansoor and Ahmadi 1993; Yazdani and Ahmadi 1991), Guilan (Haji-Zadeh et al. 1998), Isfahan (Seifollahi et al. 2000), Moghan region (Ardebill province) (Lotfalizadeh 2002), Fars province (Fallahzadeh et al. 2004), Kermanshah (Gholami Moghaddam et al. 2014), Lorestan (Biranvand et al. 2014).

2.2.77 Scymnus schmidt *Fürsch*

Khorasan Razavi (Ebrahimi et al. 2012).

2.2.78 Scymnus subvillosus *Goeze*

Kerman (Koohpayezadeh and Mossadegh 1991), Mazandaran (Agha-Janzadeh et al. 1995; Maafi et al. 1998).

2.2.79 Scymnus suffrianioides *(Sahlberg 1913)*

Lorestan (Biranvand et al. 2014).

2.2.80 Scymnus suffrianioides apetzoides *(Capra and Fursch 1967)*

Yazd (Zare Khormizi et al. 2014).

2.2.81 Scymnus syriacus *(Marseul 1868)*

Fars (Alemansoor and Ahmadi 1993; Yazdani and Ahmadi 1991), Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995), Golestan (Montazeri and Mossadegh 1995), Khorasan (Yaghmaee and Kharazi Pakdel 1995), Zanjan (Mohiseni et al. 1998), Isfahan (Bagheri and Emami 1998), Guilan (Haji-Zadeh et al. 1998), Moghan plain (Ardebill province) (Lotfalizadeh 2002; Razmjou and Hajizadeh 2000), Fars province (Fallahzadeh et al. 2004), Ahvaz, Khuzestan province (Ebrahimzadeh and Mossadegh 2004; Sadat Alizadeh et al. 2013), Arak, Markazi province (Ahmadi et al. 2012), Varamin and vicinity (Samin and Shojai 2013), Lorestan (Biranvand et al. 2014).

2.2.82 Scymnus testaceus *(Motschulsky 1837)*

Lorestan province (Biranvand et al. 2014).

2.2.83 Serangium montazerii *Fursch*

Golestan (Montazeri and Mossadegh 1995), Zanjan (Mohiseni et al. 1998), Guilan (Haji-Zadeh et al. 1998).

2.2.84 Sidis *(Nephus)* biflamulatus

Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995).

2.2.85 Stethorus gilvifrons *(Mulsant 1850)*

Kerman (Koohpayezadeh and Mossadegh 1991), Golestan (Montazeri and Mossadegh 1995), Khorasan (Yaghmaee and Kharazi Pakdel 1995), Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995), Isfahan (Bagheri and Emami 1998), Guilan (Haji-Zadeh et al. 1998), Moghan plain, Ardebill province (Razmjou and Hajizadeh 2000), Lorestan province (Jafari and Kamali 2007; Ansari pour and Shakarami 2011; Biranvand et al. 2014), Alborz (Ansari pour 2012), Varamin and vicinity (Samin and Shojai 2013).

2.2.86 Stethorus punctillum *(Weise 1891)*

Firstly, it was reported from Tehran province (Vojdani 1965) on pear trees infested to spider mites. Chaharmahal va Bakhtiari (Bagheri and Mossadegh 1995), Guilan (Haji-Zadeh et al. 1998), Lorestan (Biranvand et al. 2014).

2.2.87 Stethorus siphonulus *(Kapur 1948)*

It has been reported first time from Lorestan province (Ansari pour and Shakarami 2011).

2.2.88 Sympherobious elegans *Stephens*

Mazandaran (Maafi et al. 1998).

2.2.89 Synharmonia conglobata *L.*

Zanjan (Mohiseni et al. 1998).

2.2.90 Thea vigintiduopunctata *L.*

Hamedan (Ahmadi 2000).

2.2.91 Tytthaspis gebleri *(Mulsant 1850)*

Lorestan province (Biranvand et al. 2014).

2.2.92 Vibidia duodecimguttata (poda, 1761)

East Azerbaijan (Mohammadi et al. 2013).

Perhaps, the outstanding publication of Iran's lady beetles written in Persian with French abstract is one of the earliest publications about the ladybird fauna of Iran (Vojdani 1965). Afterward, Many faunal studies have been conducted which there is not enough space to point to all of them. Parvizi et al. (1987) published a revision on the ladybird fauna of the West Azerbaijan province. They reported 19 species from 14 genera, which all but one (*Bulea lichatchovi* Humn.) collected species were predators of aphids, coccids, whiteflies (*Bemisia*) and herbivorous mites.

Koohpayezadeh and Mossadegh (1991), during a two-year study on lady beetle fauna of Kerman Province (South of Iran), reported 24 species. Ahmadi and Yazdani (1991) reported three new ladybird species for Iran's fauna on Diaspidid scale insects. Yazdani and Ahmadi (1991) reported eight species of genus *Scymnus* from Fars province which two species, *S. quadriguttatus* and *S. auritus* were new records for Iran's fauna of lady beetles. Yaghmaee and Kharazi Pakdel (1995) and Bagheri and Mossadegh (1995) reported 24 and 28 species in a faunistic survey on Coccinellidae from Mashhad (Khorasan) and Chaharmahal va Bakhtiari regions, respectively. From those, four species, including *Scymnus palipediformis* Gunther, *Scymnus polyps*, *Exochomus melanocephalus* Zoubk and *Rodolia fausti* Weise and five species including *Hyperaspis duvergeri* (Fursch), *H. concolor* (Suffrian), *H. syriaco* (Weiser) and *Coccinula redemita* (Weiser) were reported for the first time from Iran. In a study carried on from 1993 to 1994 in Gorgan plain (North of Iran), 27 species reported which *Serangium montazerii* Fursch was a new world record (Montazeri and Mossadegh 1995).

Some faunistic studies have been conducted on the species fauna of lady beetles in a specific crop, e.g., Sadeghi and Khanjani (1998) and Saeedi (1998), who reported 10 ladybird species of alfalfa from Hamedan and Kohkiloyeh va Boyer Ahmad (Southwest of Iran) provinces of Iran respectively. They stated the variegated lady beetle, *Hippodamia variegata* could be an important species suppressing the aphid population, especially at the second and third harvesting of alfalfa (Sadeghi and Khanjani 1998). Maafi et al. (1998) recorded five Coccinellids as natural enemies of *P. citri* from Mazandaran province. Mohiseni et al. (1998), in a four-year study, stressed on the role of some species against olive psyllid (*Euphyllura olivina* Costa) (Zanjan Province). Three species of lady beetles have been reported from Hamedan province as natural enemies of Russian wheat Aphid (Ahmadi 2000). Razmjou and Hajizadeh (2000) reported eight species in Moghan Plain (Northwest of Iran, Ardebill province) from cotton fields, of which *C. septempunctata* and *H. variegata* played an essential role in reducing cotton aphid populations. Besides aphidophagous, Coccidophagous lady beetles have been studied in different parts of Iran. Kalantari and Sadeghi (2000) listed 13 lady beetle species in dry almond orchards, while the *Adonia* (*Hippodamia*) *variegata* was the dominant species in spring and *A. bipunctata* was the most abundant in summer and autumn. Additionally, Mehrnejad (2000a) recorded the four important lady beetle species, *Oenopia* *conglobata, Exochomus nigripennis*, *Coccinella spetempunctata* and *C. undecimpunctata* as predators feeding on pistachio psylla, *Aganoscena pistaciae* in Kerman province. Among them, the *O. conglobata* was an active psyllids predator and all others preyed upon aphids and scales. Lady beetle species of other preys except aphids and coccids also have been considered e.g., Fallahzadeh et al. (2000) reported nine lady beetles preyed on olive psylla from Fars province.

In terms of habitat, most studies about lady beetle fauna have been carried on in fruit orchards and crop fields. As a rare case, Seifollahi et al. (2000) reported four lady beetle species as predators of Gaz psyllid, *Cyamophila dicora* Lognivora, from which *H. variegata* was the most dominant.

In a study on natural enemies of Ash whitefly, *Siphoninus phillyreae* conducted in Shiraz, *Nephus* (*Sidis*) *hiekei* collected and reported as a new species (Fallahzadeh et al. 2003). This species is thermophilous and has been reported previously from different countries of the Middle East (Fallahzadeh et al. 2003).

Mossadegh and Aleosfoor (2004) recorded 16 lady beetle species feeding on oleander aphid in Shiraz and Khuzestan provinces (two Southern provinces of Iran). Surprisingly, they reported aphidophagy of *Chilocorus bipustulatus*, *Rodolia cardinalis* and *Stethorus* sp. despite their different feeding regime. Hesami and Fallahzadeh (2004) reported eight species as natural enemies of citrus mealybug from Fars province and noted to the potential of *Hyperaspis polita* Weise and *Exochomus nigripennis* Erichson. Haghshenas et al. (2004) stated that the *H. variegata* contributed 65.8% lady beetle complex of Isfahan province wheat fields, which was a dominant species in that region.

Lady beetle faunistic of Lorestan province (West of Iran) was surveyed during 2003–2006 (Jafari and Kamali 2007). They reported 28 species from 14 different genera collectively, which *Aphidecta obliterata* (Linnaeus) 1758 and *Scymnus mediterraneus* Iablokoff-Khnzorian, 1977 were new reported for the first time from Iran. (Jafari and Kamali 2007). Those species were collected on oak, spear thistle, *Cirsium vulagare* and Almond. Similar to many related studies, they reported *C. septempunctata* is the dominant among the collected species.

Modarres Najaf Abadi et al. (2008a, b) in two different studies, reported five and four lady beetle species on cabbage aphid (*Brevicoryne brassicae*) and green wheat aphid in the Sistan province while the seven spotted ladybird, *C. septempunctata* with 58.3% and 70.1% contribution was the dominant species among them.

Jafari et al. (2012) reviewed the lady beetle fauna of the Zarand Region (Kerman province, South of Iran). They recorded 13 species from nine genera from this region. They have been collected on different crops, vegetables, rosaceous fruit trees, pomegranate and pistachio. Among the collected species, *H. variegata* was a dominant species with a 52% contribution in collecting species composition.

Jafari and Kamali (2007) reported 19 ladybugs from Lorestan province, which *Hyperaspis quadrimaculata* (Redtenbacher 1843) was a new species for Iran. This species has been collected from the alfalfa field fed on cowpea aphid as prey (Ansari pour et al. 2011).

Urban lady beetles have been studied scarcely. As a rare case, 16 lady beetle species reported from Chitgar Park (Northwest of Tehran) which *O. conglobata* was the dominant species with 34.1% of species composition. All species predating on aphids, Coccids and the dominant species also feed on elm leaf beetle eggs and larvae (*Xanthogaleruca luteola* (Müller 1766)) (Coleoptera: Chrysomelidae) (Abdi et al. 2013). Mohammadi et al. (2013) reported the *Vibidia duodecimguttata* as a new record for Iranian fauna. They collected this species from East Azerbaijan province (46° 34′ 27″ N, 38° 47′ 0″ E) and 47° 21′ 58″ N, 38° 51′ 2″ E). This is a fungivorous species that feeds on powdery mildew fungi.

The *Pharoscymnus brunneosignatus* Marder and *Scymnus schmidt* Fürsch were reported for the Iran's fauna for the first time (Ebrahimi et al. 2014) in a collection program took from 2011 through 2012 on Mashhad (Northeast of Iran). This species is a coccidophagous one and was reported from France, Brazil, China, India, Pakistan, Yemen, Nepal before. In another study, *Nephus ulbrichi* Fursch was recorded on *Planococcus vovae* (Hemiptera: Pseudococcidae) on cypress trees for the first time in Iran (Jalilvand et al. 2012).

Sadat Alizadeh et al. (2013) reported the most important natural enemies of pink hibiscus mealybug (PHM), *M.hirsutus* and recorded five species which among them, the *Hyperaspis vinciquerrae* Capra was a new record for Iran. They reported that among described lady beetle species as expected, *N. arcuatus* had a high density during a relatively long period and thus, it could be the main predator of PHM in Ahvaz. Referring to the thermophilous nature of this species, this result was entirely predictable.

Most studies about the Iranian ladybird fauna are limited to recording new species or dealing with the lady beetle fauna of a specific region or province. Although recently, subfamily of Iranian Scymnine was reviewed as a checklist (Jafari et al. 2013).

In a checklist of scymninae of Iran, Jalilvand et al. (2014) surveyed natural enemies of mealybugs in Kermanshah province. Besides, Biranvand et al. (2016) published a checklist of subfamily Microweiseinae of Iran. They recorded 11 species or this subfamily and presented host plant and prey data for those species.

2.3 Life History and Demography

Reviewing the papers and other records published in Iran, shows that perhaps the most studied aspect of lady beetles is their life history and biology which have been studied extensively. Most of the studies have been done under laboratory conditions on one or several prey types. In most of these studies, main life table parameters like intrinsic rate of increase (r), net reproductive rate (R_0), mean generation time (T), finite rate of increase (λ) and gross reproductive rate (GRR) have been estimated. However, earlier studies only included simple descriptive data about reproduction or mean duration of different life stages. Recently, some researchers used life table data to show the effect of different factors on the survival and fecundity of lady beetles more efficiently. Development of age-stage, two-sex life table theory which includes the role of both males and females in population increase and consumption, helped create a progress in life table studies and many Iranian researchers rearrange their studies based on this new analysing method. However, still, there are some publications that use the traditional female-based method. In this period, many similar studies evaluated different suitability of aphids or even other prey (Pistachio psylla) (Mehrnejad et al. 2011) to the development and survival of *H. variegata*. One of the serious deficiencies of life history studies of lady beetles is that nearly all of them have been conducted under very artificial conditions, at constant temperature and humidity. Obviously, these results could not be extrapolated to real conditions and need to be validated. Most of these invesstigations have been done at 25 ± 1 °C, but a few researchers tested different temperatures too.

Like functional response studies, an important part of life history researches has been devoted to variegated lady beetle species as an ubiquitous dominant species in Iran. For conciseness, demographic values of different species of genus *Hippodamia* were summarized in Table 2.1 separately. Mollashahi et al. (2002) reported the life table parameters of *H. variegata* by feeding on melon aphids. Mollashahi et al. (2004a) revealed that the product index of *H. variegata* and *C. septempunctata* could be influenced by temperature and prey species; as such, this index of both species was highest at 30 °C when that were fed on *Aphis craccivora*. Studying the temperature - dependent development of *H. variegata* revealed that the minimum temperature threshold needed for growth of first instar larvae and pupae was 2.47 and 14.63, respectively. Furthermore, this species needs 346.4 degree- days (DD) to complete its development (Jafari and Vafaei Shoushatri 2010).

Stored moth egg as factitious prey has been suggested for the rearing of different lady beetle species. It has been stated that the Mediterranean flour moth was the best diet for rearing and mass production of *Pharoscymnus ovoideus* (Hajizadeh 1993). Furthermore, Tavoosi Ajvad et al. (2011) showed that *H. variagata* could complete its life cycle on Mediterranean flour moth (MFM) eggs and adult longevity on cotton aphids, pea aphids and *Ephestia kuehniella* were 53.83, 52.43 and 67.75 days. Thus the use of MFM eggs reduced the use of natural prey and labor needed.

Recently, tritrophic relationships became as a significant field of interest for Coccinellids studies and many researchers studied the basic biology of ladybirds under this context. In a tritrophic study, it was proved that host plant resistance could be effective on consumption rate of *C. septempunctata* and resulted in higher feeding rate of adults than feeding on aphids on susceptible crops (Barkhordar et al. 2012). Ghafouri Moghaddam et al. (2013) showed the premature period and survival of *H. variegata* significantly influenced by host plants. Thus, the *Sitobion avenae* Fabricius reared on wheat was more profitable for this lady beetle species. Similarly, it has been shown that Mustard plants affected on laboratory biology of this lady beetle via feeding on cabbage aphid (Nikan Jablou et al. 2013). Accordingly, the suitability of cereal aphids reared on different host plants for mass rearing of *H. variegata* has been evaluated by a few studies. Asgharian et al. (2014) showed the higher suitability of barley for this species among the four host plant tested of Russian wheat aphid. Another related research considered the effect of two resistant and susceptible wheat cultivars to *Diuraphis noxia* (Kurdjumov) on basic biology and life history of *H. variegata* (Zanganeh et al. 2015). They found a

Table 2.1 The life history traits of *Hippodamia variegata* under different treatments

Prey species	Developmental time (days)	Female longevity (days)	Fecundity (eggs/female)	APOP	TPOP	r (day^{-1})	R_0 (eggs)	λ (day^{-1})	T (days)	References
Aphis gossypii	–	–	–	–	–	0.23	–	–	–	Jalali et al. (2002)
Aphis gossypii	–	53.4 ± 4.44	1916 ± 127	5.6 ± 0.27	–	0.254	387.9	–	23.46	Mollashahi et al. (2004b)
Aphis fabae	–	–	943.9 ± 53.53	6.2 ± 0.13	–	0.287	509	–	21.7	Jafari et al. (2008a)
Schizaphis graminum	–	–	–	–	–	0.195	310.5		29.42	Mollashahi and Saboori (2010)
Agonoscena pistaciae	12.51 ± 0.4	–	–	–	–	0.21	–	–	–	Mehrnejad et al. (2011)
Aphis gossypii	11.69 ± 0.7	–	–	–	–	0.23	–	–	–	Mehrnejad et al. (2011)
Aphis fabae	16.3 ± 0.07	44.9 ± 3.1	1139.2 ± 67.8	3.4 ± 0.16	19.6 ± 0.15	0.203 ± 0.005	389.0 ± 54.0	1.225 ± 0.007	29.4 ± 0.4	Farhadi et al. (2011)
Agonoscena pistaciae	–	–	–	6.1	–	0.149	70.64	1.16	28.88	Asghari et al. (2011)
Aphis gossypii	–	–	–	–	–	0.033 ± 0.012	3.011 ± 1.158	1.033 ± 0.013	33.464 ± 0.894	Mohajeri Parizi et al. (2012)
Acyrthosiphon pisum	–	–	–	–	–	0.143 ± 0.007	118.511 ± 19.734	1.154 ± 0.009	33.422 ± 1.076	Mohajeri Parizi et al. (2012)
A. fabae	–	64.75 ± 0.87	799.65 ± 29.51	3.15 ± 0.11	–	0.181 ± 0.004	236.54 ± 15.59	1.198 ± 0.004	30.23 ± 0.39	Golizadeh and Jafari-Behi (2012)
Aphis gossypii	–	72.50 ± 1.61	587.75 ± 38.10	3.00 ± 0.10	–	0.183 ± 0.002	290.97 ± 12.79	1.201 ± 0.002	31.02 ± 0.26	Golizadeh and Jafari-Behi (2012)
Macrosiphum rosae	–	73.10 ± 1.20	446.95 ± 11.49	3.05 ± 0.14	–	0.156 ± 0.003	183.23 ± 7.52	1.169 ± 0.004	33.37 ± 0.61	Golizadeh and Jafari-Behi (2012)
Aphis fabae	–	60.86 ± 3.0	709.3 ± 59.69	3.53 ± 0.15	18.03 ± 0.18	0.18 ± 0.007	232.49 ± 39.44	1.20 ± 0.008	29.03 ± 0.49	Rahmani and Bandani (2013a)
Aphis gossypii	13.65 ± 0.09	94.31 ± 2.04	1332.2 ± 57.6	5.67 ± 1.19	19.89 ± 1.19	0.187 ± 0.009	621.09 ± 116.56	1.2056 ± 0.011	34.39 ± 1.26	Davoodi Dehkordi et al. (2013b)
Aphis gossypii	–	–	–	–	–	0.178 ± 0.005	262.66 ± 39.67	1.195 ± 0.006	31.33 ± 0.44	Bigdelou (2012)

Agonoscena pistaciae (Hexaflumuron treatment)	–	–	–	–	–	0.086 ± 0.006	23.17 ± 0.346	1.09 ± 0.007	39.25 ± 2.46	Alimohammadi Davarani et al. (2013)
Agonoscena pistaciae (Spirodiclofen treatment)	–	–	–	–	–	0.108 ± 0.004	53.23 ± 0.51	1.11 ± 0.005	37.57 ± 1.525	Alimohammadi Davarani et al. (2013)
Aphis fabae (thiamethoxam-LC_{10})		58.15 ± 6.32	656.5 ± 80.38	2.92 ± 0.076	18.846 ± 0.337	0.15 ± 0.012	114.60 ± 31.57	1.16 ± 0.014	30.56 ± 1.51	Rahmani and Bandani (2013b)
Aphis fabae (thiamethoxam-LC_{30})	–	56.58 ± 7.135	524.8 ± 93.81	3.400 ± 0.221	19.10 ± 0.458	0.13 ± 0.013	68.51 ± 21.58	1.14 ± 0.015	31.24 ± 1.58	Rahmani and Bandani (2013b)
Diuraphis noxia (on Omid wheat c.v.)	–	–	1716	–	–	0.24 ± 0.01	399.35 ± 53.01	1.27 ± 0.01	24.67 ± 0.28	Zanganeh et al. (2015)
Diuraphis noxia (on Sardari wheat c.v.)	–	–	1480	–	–	0.20 ± 0.01	221.56 ± 34.68	1.23 ± 0.01	26.50 ± 0.41	Zanganeh et al. (2015)
Sitobion avenae (on Wheat)	14.89 ± 0.13	48.40 ± 1.60	470.34 ± 19.08	4.32 ± 0.28	19.36 ± 0.35	0.181 ± 0.006	235.05 ± 36.15	1.199 ± 007	29.95 ± 0.41	Ghafouri Moghaddam et al. (2016)
Sitobion avenae (Barley)	16.31 ± 0.15	44.40 ± 1.27	432.79 ± 14.38	4.27 ± 0.24	20.73 ± 0.33	0.162 ± 0.006	183.97 ± 33.37	1.176 ± 0.007	32.03 ± 0.44	Ghafouri Moghaddam et al. (2016)
Sitobion avenae (Corn)	15.89 ± 0.14	53.28 ± 1.31	587.31 ± 15.71	3.88 ± 0.21	19.76 ± 0.23	0.179 ± 0.006	291.14 ± 46.66	1.197 ± 0.008	31.48 ± 0.40	Ghafouri Moghaddam et al. (2016)
Sitobion avenae (Sorghum)	16.02 ± 0.09	39.10 ± 1.54	362.47 ± 16.42	4.63 ± 0.29	20.68 ± 0.33	0.163 ± 0.006	134.30 ± 23.66	1.177 ± 0.008	29.87 ± 0.33	Ghafouri Moghaddam et al. (2016)

significant positive relationship between wheat resistance to Russian wheat aphid and effect on developmental time, fecundity, survival and predation rate of *H. variegata*. Suppose this synergistic effect is shown to be occurred and confirmed by more real field experiments, in that case, there is a big step towards combining biological control and host plant resistance against Russian wheat aphid. Correspondingly, the effect of four host plants of English grain aphid, *S. avenae* on life table parameters of *H .variegata* has been assessed (Ghafouri Moghaddam et al. 2016). They suggested that the wheat (c.v. Tajan) was the most suitable among four host plants tested while the barley (c.v. dasht) was the least suitable for *H. variegata* as a host plant of *S. avenae*. This difference could be chemical-based; indeed semiochemicals of different host plants or even different cultivars might affect growth, development and reproduction of lady beetles indirectly.

One of the major applications of life table is the mass rearing of predator and parasitoids. Mass rearing of lady beetles, especially *H. variegata* have been noted in many Iranian kinds of literature. Most of those studies have been carried out by using natural aphid species as prey. Talebi et al. (2014) tested the basic biology of *H. variegata* on three cereal species and in terms of female body weights, the *S. avenae* was the most profitable species to feed. As a rare study, it has been shown that the use of canola pollen with black bean aphid significantly reduced the larval period and improved the rearing of *H. variegata* (Mirkhalilzadeh Ershadi et al. 2013). Besides, they tested the effect of different artificial diets on survival and fecundity of *H. variegata* and concluded that it completed life cycle on some artificial diet albeit with a lower rate (Mirkhalilzadeh Ershadi et al. 2013). However, they did not assess the effect of feeding from artificial diets on fecundity of *H. variegata*. It seems that there is still a big gap between suitability of natural prey species and artificial diets in terms of *Hippodmia* fecundity. As a novel case study, Davoodi Dehkordi et al. (2013) proved that with increasing prey densities, the fecundity and intrinsic rate of increase of *H. variegata* raised while the developmental time and preoviposition period decreased. This study stressed the role of prey biomass quantity that a lady beetle receives to reach the development and reproduction potentials. Optimization of lady beetle sex ratio in mass rearing project is an ignored aspect which was addressed (Aldaghi et al. 2013). They showed that despite common belief, the fecundity of *H. variegata* is not reduced with decreasing male to female ratio; therefore they recommended sex ratio could be manipulated in laboratory rearings of variegated lady beetle in such a way that saves labor and maximizes reproduction output.

Demographic toxicology studies have been started recently in Iran. Some researchers studied the effects of different pesticides and acute or sublethal effects of many compounds with different modes of action assessed on life history and reproduction of different lady beetles especially *Hippodamia variegata* (Table 2.1). Possible use of *H. variegata* with pesticide application surveyed by evaluating the sublethal effect of pesticides on life history and demography of lady beetles. (Alimohammadi Davarani et al. 2013; Rahmani and Bandani 2013b). For instance, the safety of Spirodiclofen to larval stages of *H. variegata* was revealed; however, it was not safe for eggs (Alimohammadi Davarani et al. 2014). This information certainly would improve the concomitant use of insecticides and lady beetles under an IPM framework.

Another important lady beetle species that has been noted largely by Iranian researchers is *C. septempunctata*. The demography and life table parameters of this species similar to *H. variegata* have been reported under different conditions and presented briefly in Table 2.1. As a case study, some life history parameters of this species have been addressed on several combinations of mustard aphid, *Lipaphis erysimi* (Kaltenbach 1843) (Hemiptera: Aphididae) and two-spotted spider mite (Kianpour et al. 2011). Their study showed that diet including two-spotted spider mite only could not be used as an effective alternative diet for seven spotted lady beetle adults; however life table analysis would give a better insight.

Many Iranian pertinent studies considered the effect of different temperatures, and some others took into account the effects of quantity and quality of prey on ladybird biology. Hajizadeh et al. (1995) concluded that the 25–30 °C was the optimum range for activity and reproduction of an acarophagous lady beetle, *Stethorus givifrons* on two-spotted spider mite, but at 40 °C, the reproduction of *S. gilvifrons* was stopped. Moreover, the effect of seven constant temperatures on development and life table parameters of *S. gilvifrons* has been reported (Taghizadeh et al. 2008a, b). In this regard, they estimated 222.72 degree-days and 12. 47 °C as thermal constant and low temperature threshold for *S. gilvifrons* entire developmental time on *T. urtice*. This is not surprising because it is a thermophile species and has been collected from Iran's hot and arid regions. Jalali et al. (2002) reported theoretical lower threshold and thermal constant for *H. variegata*, *C. undecimpunctata*, *O. conglobata contaminata* and *E. nigripennis*. They also reported the intrinsic rate of increase of those four lady beetle species reared on psyllid or aphid prey in another study. The degree-days and lower temperature threshold for the complete life cycle of *O. conglobata* was estimated as 270.32 DD and 10 °C (Mojib Hagh Ghadam et al. 2004). These values have been reported as 285.71 DD and 9.34 °C respectively by feeding on pomegranate green aphid (Rounagh et al. 2014). Nazari et al. (2004) reported the lowest developmental threshold of *Exochomus nigromaculatus* as 10.87 for fourth instar larvae. The optimum temperature for *O. conglobata contaminata* rearing was estimated between 25–30 °C (Mokhtari and Samih 2014) and 27.5 to 32.5 °C (Rounagh et al. 2014) by feeding on *M. persicae* and *A. punicae*, respectively. Their study showed the degree-day and thermal thresholds could be impressed by prey species (Mokhtari and Samih 2014; Rounagh et al. 2014). The effects of five constant temperatures intervaled by 5 °C on demography and population growth of *Nephus arcuatus* has been presented at 25 °C (Table 2.1). Of five temperature tested, the highest life table parameters (except mean generation time) was highest at 30 °C. Thus, it has been suggested that this species shows the best efficacy at 30 °C and active in hot regions when all other lady beetles may not efficient (Zarghami et al. 2014b). In another study with cotton mealybugs, the 35 °C has been reported as an optimum temperature for growth and reproduction of *N. arcatus* (Table 2.1). The survey of the life table of *C. montrouzieri* at three temperatures showed the maximum and minimum intrinsic rate of increase (*r*) and mean generation time (T) at 27 °C and confirmed the earlier results. Therefore, 27 °C as an optimum temperature for mass production of this species was recommended (Mortazavi Malekshah et al. 2015).

Apart from *H. variegata* and *C. septempunctata*, life table and population parameters of other ladybird species have been studied. Two-spotted lady beetle, *Adalia bipunctata* is one of efficient species against different aphids, especially in orchards. The reproduction parameters of this predator was evaluated against *A. punicae* (Dehghan Dehnavi et al. 2008). Based on developmental time, immature survival and life table parameters of *A. bipunctata revelierei* Mulsant *E. kuehniella* eggs was the inferior diet compared to green peach aphid and pistachio psylla (Table 2.2) (Mehrnejad et al. 2015). Meanwhile, it has been suggested that *A. pistaciae* was an essential prey for *A. bipunctata* and this lady beetle could be used as a biocontrol candidate against pistachio psylla. Emami et al. (1998) showed that the total and daily fecundity of *Scymnus syriacus* increased linearly with temperature. Another Coccinellid which is well studied relatively is *O. conglobata*. Mojib Hagh Ghadam et al. (2002a) in surveying the effect of three different aphid species on laboratory biology of *O. conglobata* suggested the positive impact of suitable prey on predator and prey populations. Additionally, they reported the least preimaginal development rate, highest total fecundities and ovipositional duration of *O. conglobata* feeding upon poplar shoot aphid (*Chaitophorus populeti* (Panz)) at 30 °C among three distinct temperatures (20, 25 and 30 °C) tested (Mojib Hagh Ghadam et al. 2002b). The degree-day of this species was recorded as 217.3 DD. They also studied the biology of this species on *Timocallis saltans* (Nev) (Mojib Hagh Ghadam et al. 2002c). Poplar aphid, *Chaitophorus leucomelas* (Koch) was another aphid that serves as prey to study the laboratory biology of *O. conglobata*. The highest mortality was occurred at the egg stage and afterward, the mortality has been reduced. They also showed that fourth instar larvae was the most voracious stage in terms of daily feeding rate (Sadeghi et al. 2004). Most studies of ecology and predation rate of *O. conglobata* have been done in Rafsanjan region (Kerman province), the main center of pistachio and pomegranate production of Iran, where this species is one of the most dominant predators of pomegranate aphid (*Aphis punicae* Pass) and pistachio psylla. As one of the earliest study, they estimated descriptive biological parameters, prey preference and consumption rates of *O. conglobata* on pistachio psylla, confirmed the superiority of pistachio psylla than cotton aphid for development and reproduction of this species, however, it should be considered the cotton aphid as an alternative prey when pistachio psylla is unavailable (Mehrnejad and Jalali 2004). This study suggested that besides aphids, *O. conglobata* could be considered as a main predator of other target pests like psyllids. In this regard, the life table output of this predator showed the possible efficiency of *O. conglobata contaminata* to bring pomegranate green aphid under control (Table 2.2) (Rounagh and Samih 2014). The biology and consumption rate of *O. conglobata* on *Rhopalosiphum padi*, *Macrosiphum rosae* and *C. populi* showed that feeding of *R. padi* increased fecundity of *O. conglobata* significantly (Ajam Hassani 2015). The effect of three diets including pistachio psylla, cotton aphid and Meditteranean flour moth eggs on life table parameters and fitness of *O. conglobata* and *Cheilomenes sexmaculata* (Fabricius, 1781) showed the best

Table 2.2 The life history traits of lady beetle species reared on various preys or treated with different pesticides

Predator (prey species)	Developmental time (days)	Female longevity (days)	Fecundity (eggs/female)	APOP	TPOP	r (day$^{-1)}$	R_0 (Eggs)	λ (day$^{-1)}$	T (days)	References
Oenopia conglobata contaminata (Cotton Aphid)	–	–	–	–	–	0.18	–	–	–	Jalali et al. (2002)
Coccinella undecimpunctata (Cotton Aphid)	–	–	–	–	–	0.23	–	–	–	Jalali et al. (2002)
Elytroleptus nigripennis (Cotton Aphid)	–	–	–	–	–	0.13	–	–	–	Jalali et al. (2002)
Coccinella septempunctata (*Aphis gossypii*)	–	–	1267 ± 149	–	–	0.159	373.9		37.25	Mollashahi et al. (2004b)
Oenopia conglobata (*Aganoscena pistaciae*)	–	–	–	–	–	0.16	–	1.8	–	Hassani et al. (2004)
Oenopia conglobata contaminata (*Agonoscena pistaciae*)	–	–	310 ± 16.6	5.7 ± 0.2	–	0.19	–	–	–	Mehrnejad and Jalali (2004)
Oenopia conglobata contaminata (*Aphis gossypii*)	–	–	–	5.8 ± 0.12	–	0.18	–	–	–	Mehrnejad and Jalali (2004)
Exochomus quadripustulatus (*Planococcus vovae*)	–	181.17 ± 4.16	468.35 ± 1.63	–	–	0.092 ± 0.00007	291.31 ± 1.01	1.09 ± 0.0001	61.906 ± 0.045	Ameri et al. (2006)
Stethorus gilvifrons (*Olionychus afrasiaticus*)	–	44.22 ± 0.361	–	–	–	0.189 ± 0.002	70.01 ± 4.72	1.2 ± 0.003	22.38	Matin et al. (2008)
Stethorus gilvifrons (*Eutetranychus orientalis*)	–	45.05 ± 3.36	318.00 ± 32.57	2.88 ± 0.21	–	0.221 ± 0.011	154.08 ± 30.56	1.247 ± 0.014	22.83 ± 0.84	Imani et al. (2009)

(continued)

Table 2.2 (continued)

Predator (prey species)	Developmental time (days)	Female longevity (days)	Fecundity (eggs/female)	APOP	TPOP	r (day$^{-1)}$	R_0 (Eggs)	λ (day$^{-1)}$	T (days)	References
Stethorus gilvifrons (*Tetranychus turkestani*)	–	58.00 ± 0.53	175.14 ± 3.19	2.85 ± 0.09	–	0.171 ± 0.007	97.6 ± 15.86	1.186 ± 0.008	26.76 ± 0.62	Imani et al. (2009)
Coccinella septempunctata (*Aphis gossypii*)		–	1267 ± 14.0	–	–	0.159	373.91	1.4	37.25	Mollashahi et al. (2009)
Clistothetus arcuatus (*Trialeurodes vaporariorum*)	27.68 ± 0.31	–	–	6.86 ± 0.35		0.063 ± 0.002	224.6	1.065 ± 0.002	43.4 ± 1.1	Yazdani et al. (2010)
Cryptolaemus montrouzieri (*Planococcus maritimus*)	30.76 ± 0.123	41.24 ± 1.93	449.482 ± 0.99	–	–	0.13	336.67 ± 0.74	1.14	44.97	Keshtkar et al. (2010)
Cryptolaemus montrouzieri - Abamectin treated	–	17.1 ± 1.32	41.2 ± 5.1	–	–	0.286 ± 0.0015	–	–	–	Ahmadi et al. (2010)
Cryptolaemus montrouzieri – Imidacloprid treated	–	32.5 ± 5.73	86.4 ± 10.69	–	–	0.296 ± 0.0009	–	–	–	Ahmadi et al. (2010)
Coccinella undecimpunctata (*Agonoscena pistaciae*)	12.38 ± 0.19	–	–	–	–	0.22	–	–	–	Mehrnejad et al. (2011)
Coccinella undecimpunctata (*Aphis gossypii*)	11.39 ± 0.17	–	–	–	–	0.23	–	–	–	Mehrnejad et al. (2011)
Exochomus nigripennis (*Agonoscena pistaciae*)	–	–	–	–	–	0.12	–	–	–	Mehrnejad et al. (2011)

Exochomus nigripennis (*Aphis gossypii*)	–	–	–	–	–	0.13	–	–	–	Mehrnejad et al. (2011)
Oenopia conglobata contaminata (hexaflumuron treated)	–	–	–	–	–	0.10 ± 0.005	15.67 ± 2.68	1.10 ± 0.005	28.49 ± 1.51	Baniasadi et al. (2012)
Oenopia conglobata contaminata (thiamethoxam treated)	–	–	–	–	–	0.08 ± 0.003	8.68 ± 0.99	1.09 ± 0.003	26.03 ± 0.77	Baniasadi et al. (2012)
Coccinella elegantula (*Agonoscena pistaciae*)	–	–	–	–	–	0.093	61.54	1.09	43.9	Parish et al. (2012b)
Coccinella elegantula (*Aphis craccivora*)	–	–	–	–	–	0.07	39.36	1.11	44.73	Parish et al. (2012b)
Oenopia conglobata (*Myzus persicae*)	–	61 ± 3.3	1104 ± 34.8	3.2 ± 0.12	–	–	–	–	–	Ajam Hassani (2013)
Nephus arcuatus (*Nipaecoccus viridis*)	–	116.52 ± 6.56	660.47 ± 37.97	3.8 ± 0.8	21.2 ± 0.2	0.165 ± 0.0069	198.14 ± 32.3	1.179 ± 0.0083	32.12 ± 0.7	Zarghami et al. (2013)
Serangium montazerii (*Diaphorina citri* on Page tangerine)	20.84 ± 0.302	87 ± 0.79	457.14 ± 11.10	–	–	0.126 ± 0.006	160 ± 35.12	1.14 ± 0.08	40.57 ± 0.46	Fotukkiaii et al. (2013)
Serangium montazerii (*Diaphorina citri* on Thompson navel orange)	19.27 ± 0.251	85.57 ± 0.55	528.57 ± 12.37	–	–	0.134 ± 0.063	185 ± 40.59	1.15 ± 0.08	39.03 ± 0.5	Fotukkiaii et al. (2013)
Cryptolaemus montrouzieri (*Pulvinaria auranti* on mandarin)	27.48 ± 0.09	80.19 ± 0.39	801.0 ± 7.12	4.11 ± 0.06	31.78 ± 0.11	0.122 ± 0.003	309.02 ± 46.68	1.129 ± 0.004	47.1 ± 0.3	Bozorg-Amirkalaee et al. (2014)
Cryptolaemus montrouzieri	28.28 ± 0.12	80.55 ± 0.61	752.65 ± 5.11	4.25 ± 0.1	32.7 ± 0.21	0.11 ± 0.004	214.21 ± 40.79	1.116 ± 0.002	48.76 ± 0.66	Bozorg-Amirkalaee et al. (2014)

(continued)

Table 2.2 (continued)

Predator (prey species)	Developmental time (days)	Female longevity (days)	Fecundity (eggs/female)	APOP	TPOP	r (day$^{-1)}$	R_0 (Eggs)	λ (day$^{-1)}$	T (days)	References
(*Pulvinaria auranti* on Sour orange)										
Nephus arcuatus (*Nipaecoccus viridis*)	29.5 ± 0.2	93.8 ± 10.7	415.2 ± 57.8	5.8 ± 0.3	35.5 ± 0.3	0.088 ± 0.005	95.4 ± 21.6	1.0918 ± 0.005	51.5 ± 1.1	Zarghami et al. (2014b)
Coccinella septempunctata (*Macrosiphum rosae*)	–	–	–	–	–	0.17	187.55	1.18	30.78	Aminafshar et al. (2014)
Oenopia conglobata (*Aphis punicae*)	–	–	592.11 ± 72.7	–	–	0.18 ± 0.009	251.65 ± 55.86	1.98 ± 0.011	30.5 ± 0.75	Rounagh and Samih (2014)
Cryptolaemus montrouzieri (*Planococcus citri*)	36.43	183.53 ± 5.78	278.62 ± 0.21	7.66 ± 0.10	–	0.081 ± 0.001	103.86 ± 5.73	1.085 ± 0.001	57.11 ± 0.75	Abdollahi Ahi et al. (2015)
Cryptolaemus montrouzieri (*Pseudococcus viburni*)	–	78.50 ± 2.1	385.33 ± 0.84	6.3 ± 0.16	–	0.094 ± 0.001	169.27 ± 5.98	1.099 ± 0.001	54.57 ± 0.14	Abdollahi Ahi et al. (2015)
Cryptolaemus montrouzieri (*Planococcus citri*-20 °C)	–	–	–	–	–	0.045 ± 0.0005	77.52 ± 5.73	1.04 ± 0.0006	96.94 ± 1.91	Mortazavi Malekshah et al. (2015)
Cryptolaemus montrouzieri (*Planococcus citri*-25 °C)	–	–	–	–	–	0.084 ± 0.0009	208.48 ± 9.12	1.14 ± 0.055	61.99 ± 0.74	Mortazavi Malekshah et al. (2015)
Cryptolaemus montrouzieri (*Planococcus citri*-27 °C)	–	–	–	–	–	0.085 ± 0.0009	147.87 ± 6.97	1.08 ± 0.00125	57.37 ± 0.94	Mortazavi Malekshah et al. (2015)

Cheilomenes sexmaculata (*Ephestia* eggs)	9.76 ± 0.08	–	164.27 ± 35.67	4.09 ± 0.84	–	0.209 ± 0.001	55.332 ± 1.098	1.232 ± 0.002	–	Mirhosseini et al. (2015)
Oenopia conglobata (*Ephestia* eggs)	16.3 ± 0.10	–	192.8 ± 18.82	5.87 ± 0.38	–	0.159 ± 0.0003	77.317 ± 0.504	1.172 ± 0.0003	–	Mirhosseini et al. (2015)
Adalia bipunctata (*Agonoscena pistaciae*)	13.7 ± 0.08	–	–	6.13 ± 0.15	–	0.172	230.32	–	31.6	Mehrnejad et al. (2015)
Adalia bipunctata (*Myzus persicae*)	13.5 ± 0.15	–	–	6.67 ± 0.14	–	0.191	596.41	–	33.5	Mehrnejad et al. (2015)
Adalia bipunctata (*Ephestia kuehniella*)	16.1 ± 0.13	–	–	8.61 ± 0.16	–	0131	81.40	–	59.5	Mehrnejad et al. (2015)
Nephus arcuatus (*Phenacoccus* solenopsis)	–	61.46 ± 4.26	126.0 ± 14.42	–	–	0.150 ± 0.00	35.809 ± 4.10	1.162 ± 0.00	23.761 ± 0.51	Foruzan et al. (2016)
Oenopia conglobata contaminata (*Agonoscena pistacia*)	–	–	–	–	–	0.187 ± 0.0012	565.31 ± 18.21	1.206 ± 0.0015	23.67 ± 0.07	Mokhtari and Samih (2016)
Oenopia conglobata contaminata (*Myzus persicae*)	–	–	–	–	–	0.175 ± 0.002	576.63 ± 21.33	1.191 ± 0.002	36.13 ± 0.13	Mokhtari and Samih (2016)

diets among these three is pistachio psylla for both species. However, using moth eggs could be useful specifically for rearing premature life stages therefore, reducing costs and labor needed (Mirhosseini et al. 2015). Furthermore, the age-stage, two-sex life table of this species on green peach aphid and pistachio psylla showed no difference between these two prey species in terms of suitability for reproduction and growth of *O. conglobata contaminata* (Mokhtari and Samih 2016).

Regarding aphidophagous or cocidophagous lady beetles, the life table and descriptive biological parameters of Acarophagous lady beetle have been studied scarcely. Eslami Zadeh and Pourmirza (1998) reviewed the fecundity and predation rate of *Stethorus punctillum* on red spider mite. Preadult duration and daily fecundity of *S. gilvifrons* on the old world date mite, *Oligonychus afrasiaticus* (McGregor) was reported as 18 days and five eggs at 27 °C, respectively. The survey of basic biology and predation rate of *S. gilvifrons* on two-spotted spider mite showed this predator kills 212.34 mites during its premature development averagely. The suitability of two Tetranychid mite species, *Tetranychus turkestani* Ugarov and Nycolsky and *Eutetranychus orientalis* Klein for development and reproduction of *S. gilvifrons* revealed that both species could be used as essential and complete prey. Although, the citrus brown mite seems more suitable than *T. turkestani* slightly (Imani et al. 2009)

Similar to aphidophagous lady beetles, Coccidophagous species have been studied fairly detailed. Mehdian et al. (1998) considered the rearing of *Chilocorus bipustulatus* L. on Dictyospermum scale, black scale, the Mediterranean flour moth eggs and the Angoumois grain moth eggs (*Sitotroga cerealella* (Olivier 1789)). Among them, *C. bipustulatus* did not complete its life cycle on *S. cerealella*. Although, lack of significant differences between daily fecundity and preadult development period of lady beetles reared on natural and factitious prey proved that the *E. kuehniella* eggs could be used as alternative prey for mass rearing this species. However, Mehrnejad (2000b) showed significant differences in pupal mortality of *Exochomus nigripennis* reared on *S. cerealella* eggs and citrus mealybugs, *Pseudococcus citri*. The natural prey made them significantly larger and heavier than those reared on angoumois grain moth eggs. Similarly, Emmai et al. (2002) showed the inadequacy of *Ephestia* and *Sitotroga* eggs compare to green citrus aphid or Spirea aphid for reproduction and development of *S. syriacus*. Ghanadamooz et al. (2010) reported the suitability of mulberry scale, *Pseudaulacapis pentagona* Targioni cultivated on pumpkin and potato for rearing of *C. bipustulatus*. Lotalizadeh et al. (2000) studied *E. quadripustulatus* (L.) biology on cypress tree mealybug and reported total developmental time on *Planococcus vovae* (Nasanov) was 34.47 days.

Perhaps the mealybug destroyer, *Cryptolaemus montrouzieri* Mulsant, 1850 is the most known and efficient Coccidophagous lady beetle in Iran. Therefore, the laboratory biology, life table parameters and consumption rate of *C. montrouzieri* Mulsant, 1850 have been studied extensively on different prey species or at various circumstances (Table 2.2). It has been revealed that this species is one of the main predators of coccids and feeds on *Pulvinaria* ovisacs, especially on citrus trees. In a choice test, the fourth instar larvae prefer cottony camellia scale, *P. floccifera*

Westwood ovisacs to *P. aurantii* Cockerell ones (Khazaeipool et al. 2008). The potential effects of Imidacloprid and Abamectin on life table and demography of *C. mountrouzieri* showed that these two pesticides had some adverse effects on fecundity and life table parameters of this lady beetle and could not be used together (Ahmadi et al. 2010). Crypt ladybird is an Australian species well accommodated with Mediterranean climate of Northern parts of Iran. Therefore, the thermal requirements and zero developmental temperature of *C. montrouzieri* was estimated as 441.09 DD and 10.46 °C for immature stages (Mortazavi Malekshah et al. 2010). It also seems that this species tolerates critical high temperatures in such a way that adult emergence and egg mortality (%) were estimated as 82 ± 2.58 and 10 ± 2.0 at 37.5 ° C. (Saberi et al. 2013). Tritrophic surveys included crypt ladybeetle, orange pulvinaria scale and citrus trees showed that the Grapefruit (c.v. Red blush) was the best host tree for this scale in terms of population parameters (Bozorg-Amirkalaee et al. 2015). Life table study also suggested that the obscure mealybug *Pseudococcus viburni* Signoret is a more suitable diet than the citrus mealybug (*Planococcus citri* Risso) as the *C. montouzieri* had higher rate of increase and net reproduction when fed by obscure mealybugs (Abdollahi Ahi et al. 2015).

2.4 Miscellaneous Studies

Besides aphids, cooccids, and mites, as mentioned earlier, psyllids constitute a major food item in the lady beetle food list. The thermal requirements and life table of *Coccinula elegantula* by feeding on *A. pistaciae* was evaluated (Parish et al. 2012a, b). According to results, the theoretical lower threshold and thermal constant (°D) required for complete premature development was estimated 14.9 °C and 256.4 DD (Parish et al. 2012a). The basic biology of *C. bipustulatus* on pistaschio psylla has been surveyed repeatedly. (Atrchian et al. 2014). In a tritrophic study, it has been shown that host plant species did not have any influence on life history and demography of *Serangium montazerii* feeding on citrus whitfly unexpectedly (Fotukkiaii et al. 2013). Although Bozorg-Amirkalaee et al. (2014) revealed the superiority of clementine mandarin to Sour orange as a host plant of orange *pulvinaria* scale, *Pulvinaria auranti* to survival and fecundity of *C. montrouzieri* (Table 2.2).

Collectively, numerous studies about life table have been done in Iran. In most cases, the effect of one or more factors on the population parameters of a few lady beetle species under completely artificial conditions have been investigated. Interestingly, from an extensive review of life table studies it has been cleared that from 16 studies of *H.variegata* in seven and five cases, cotton aphid and black bean aphid have been used respectively (Table 2.1). This may impose repetition of results without any further innovations. The other problem relates to data analysis. Many of the earlier studies used traditional female-based life table, while in recent years, the age-stage, two-sex life table have been used more frequently. This method estimates population parameters more accurately however, the differences between these two methods seem negligible, still, because of the unrealistic assumptions of traditional life table analysing method, the estimated outputs are unreliable. Another deficiency of conducted studies is the small cohort size, which is so small that it might produce an incorrect estimation of population parameters.

2.5 Predator-Prey Dynamics

2.5.1 Functional Response of Most Important Coccinellid Species to Different Prey Types

The functional response (F.R.) assessment is one of the most commonly used criteria evaluating predator efficiency. This is a quantitative description of a predator's ability to consume prey. Although Solomon (1949) introduced it initially, Holling (1959) developed the concept in details and described quantitative methods for measuring the functional response. It describes the relation of predation with increasing prey densities. Basically, there are three types of functional response to initial prey densities, the linear (type I), the curvilinear (type II) and the sigmoidal (type III). The output parameters of functional response experiments are search rate and handling time. Instantaneous search rate (or attack constant) is a function of encounter rate between predator and prey. It could be defined as the extent of area covered in a time unit by a predator (Holling 1961; Rogers 1972). Handling time is the amount of time spent on non-searching activities (subduing, killing, eating a prey and resting) (Juliano 2001). The type of functional response and values of related parameters of different species of lady beetles, especially variegated lady beetle, *Hippodamia variegata* towards different prey species has been addressed in Iranian studies extensively (Table 2.3).

One of the earliest functional response studies of variegated lady beetle done in Iran dates back to Jafari and Goldasteh (2009) who reported the functional response of *H. variegata* females and males to different densities of black bean aphid. Farhadi et al. (2010) considered the functional response of all life stages of *H. variegata* on the same aphid species *Aphis fabae*. Both researchers reported a type II functional response for *H. vareigata*. In spite of the shared prey type and similar equation used for analysis, their results were very different (Table 2.3). They reported type II response for all life stages, however, searching efficiency of females was more than 100 times higher than that reported by Jafari and Goldasteh (2009) although, the handling time showed lesser difference (two times). Based on their results, males and secondly, the fourth instar larvae have the highest searching efficiency among life stages and the females and fourth instar larvae showed the shortest handling time. Therefore, it seems that females are the most voracious stage. This has been confirmed by Madadi et al. (2011), who reported the fourth instar larvae has the lowest handling time compared to other stages tested in their study on the effects of prey types and experimental set-ups on the functional response type of *H. variegata*.

Table 2.3 Functional response type and parameters of *Hippodamia variegata* to different aphid species

Aphid species	Predator life stage	Type	Search rate (h^{-1})	Handling time (h)	Arena	Reference and model used
Aphis fabae	Female	II	0.00078 ± 0.0000111	0.1774 ± 0.0004	Plexiglas cage (6*11*23 cm)	Jafari and Goldasteh (2009) (Disc equation)
Aphis fabae	Female	II	0.00093 ± 0.000201	0.1999 ± 0.0094	Plexiglas cage (6*11*23 cm)	Jafari and Goldasteh (2009) (Random predator equation)
Aphis fabae	1st instar larvae	II	0.0634 ± 0.0164	6.9332 ± 0.6657	Petri dish	Farhadi et al. (2010)
Aphis fabae	2nd instar larvae	II	0.0596 ± 0.0103	3.3433 ± 0.24	Petri dish	Farhadi et al. (2010)
Aphis fabae	3rd instar larvae	II	0.1031 ± 0.0293	1.9099 ± 0.1272	Petri dish	Farhadi et al. (2010)
Aphis fabae	4th instar larvae	II	0.1138 ± 0.0223	0.4547 ± 0.028	Petri dish	Farhadi et al. (2010)
Aphis fabae	Females	II	0.0926 ± 0.0212	0.4098 ± 0.048	Petri dish	Farhadi et al. (2010)
Aphis fabae	Males	II	0.1589 ± 0.0435	1.1945 ± 0.0691	Petri dish	Farhadi et al. (2010)
Aphis nerii	4th instar larvae	II	0.862	0.289	Petri dish	Esmaeily et al. (2011)
Aphis gossypii	3rd instar larvae	II	0.033 ± 0.006	0.074 ± 0.041	Three- dimensional-set-up	Madadi et al. (2011) (Disc equation)
Aphis gossypii	4th instar larvae	II	0.039 ± 0.002	0.023 ± 0.01	Three- dimensional-set-up	Madadi et al. (2011) (Disc equation)
Aphis gossypii	Females	II	0.043 ± 0.002	0.102 ± 0.013	Three- dimensional-set-up	Madadi et al. (2011) (Disc equation)
Aphis gossypii	3rd instar larvae	II	0.099 ± 0.014	0.057 ± 0.023	Cucumber Leaf disc	Madadi et al. (2011) (Random predator equation)
Aphis gossypii	4th instar larvae	II	0.122 ± 0.014	0.06 ± 0.016	Cucumber Leaf disc	Madadi et al. (2011) (Random predator equation)
Aphis gossypii	Females	II	0.094 ± 0.002	0.112 ± 0.018	Cucumber Leaf disc	Madadi et al. (2011) (Random predator equation)
Acyrthosiphon pisum	3rd. instar larvae	II	0.066 ± 0.009	0.074 ± 0.031	Petri dish	Madadi et al. (2011)
Acyrthosiphon pisum	4th instar larvae	II	0.06 ± 0.005	0.002 ± 0.024	Petri dish	Madadi et al. (2011)

(continued)

Table 2.3 (continued)

Aphid species	Predator life stage	Type	Search rate (h^{-1})	Handling time (h)	Arena	Reference and model used
Acyrthosiphon pisum	Females	II	0.099 ± 0.006	0.086 ± 0.01	Petri dish	Madadi et al. (2011)
Aphis gossypii	4th instar larvae	III	0.0106 ± 0.00383	0.5040 ± 0.0189	Cucumber leaf discs	Bigdelou (2012)
Aphis gossypii	Females	II	0.1208 ± 0.0162	0.1843 ± 0.017	Cucumber leaf discs	Bigdelou (2012)
Aphis gossypii	Males	II	0.1340 ± 0.0218	0.6234 ± 0.0422	Cucumber leaf discs	Bigdelou (2012)
Aphis gossypii	Female (One predator individual)	II	0. 122 ± 0.021	0.105 ± 0.048	Black eyed bean leaf	Davvodi Dehkordi et al. (2012)
Aphis gossypii	Female (Two predator individuals)	II	0.003 ± 0.000424	0.106 ± 0.00441	Black eyed bean leaf	Davvodi Dehkordi et al. (2012)
Aphis gossypii	Female	II	0.083 ± 0.011	0.197 ± 0.040	Open Patch design. (18 × 23 × 5 cm)	Davvodi Dehkordi and Sahragard (2013a)
Aphis gossypii	4th instar larvae	II	0.1780 ± 0.0592	0.392 ± 0.0337	Cucumber Leaf disc-20 °C	Ebrahimi Arfaa (2014)
Aphis gossypii	Females	III	0.00809 ± 0.00233	0.4647 ± 0.0225	Cucumber Leaf disc-20 °C	Ebrahimi Arfaa (2014)
Aphis gossypii	Males	II	0.1264 ± 0.0494	0.5067 ± 0.0864	Cucumber Leaf disc-20 °C	Ebrahimi Arfaa (2014)
Aphis gossypii	4th instar larvae	II	0.5134 ± 0.2191	0.3070 ± 0.0154	Cucumber Leaf disc-25 °C	Ebrahimi Arfaa (2014)
Aphis gossypii	Females	II	0.0856 ± 0.0147	0.0975 ± 0.0212	Cucumber Leaf disc-25 °C	Ebrahimi Arfaa (2014)
Aphis gossypii	Males	II	0.1347 ± 0.0528	1.1192 ± 0.1063	Cucumber Leaf disc-25 °C	Ebrahimi Arfaa (2014)
Aphis gossypii	4th instar larvae	II	0.0463 ± 0.00508	0.0683 ± 0.0183	Cucumber Leaf disc-30 °C	Ebrahimi Arfaa (2014)
Aphis gossypii	Females	II	0.0484 ± 0.0057	0.0861 ± 0.0199	Cucumber Leaf disc-30 °C	Ebrahimi Arfaa (2014)

Aphis gossypii	Males	II	0.0554 ± 0.00445	0.2034 ± 0.0247	Cucumber Leaf disc-30 °C	Ebrahimi Arfaa (2014)
Myzus persicae	Females	II	0.1335 ± 0.0171	0.1935 ± 0.0228	Leaf disc	Hassankhani and Allahyari (2013)
Myzus persicae	Males	II	0.1667 ± 0.0207	0.3339 ± 0.0237	Leaf disc	Hassankhani and Allahyari (2013)
Diuraphis noxia	3rd instar larvae	II	0.0285 ± 0.00309	0.00791 ± 0.0309	Potted wheat plant (Sardari c.v.)	Behnazar and Madadi (2015)
Diuraphis noxia	4th instar larvae	II	0.0561 ± 0.00204	$1 \times 10^{-8} \pm 0$	Potted wheat plant (Sardari c.v.)	Behnazar and Madadi (2015)
Diuraphis noxia	Females	II	0.059 ± 0.0051	0.0168 ± 0.0119	Potted wheat plant (Sardari c.v.)	Behnazar and Madadi (2015)
Diuraphis noxia	Males	II	0.0412 ± 0.00419	0.0173 ± 0.0176	Potted wheat plant (Sardari c.v.)	Behnazar and Madadi (2015)
Diuraphis noxia	3rd instar larvae	II	0.0475 ± 0.00486	0.0782 ± 0.0185	Potted wheat plant (Back cross c.v.)	Behnazar and Madadi (2015)
Diuraphis noxia	4th instar larvae	II	0.0753 ± 0.00749	0.0529 ± 0.0132	Potted wheat plant (Back cross c.v.)	Behnazar and Madadi (2015)
Diuraphis noxia	Females	II	0.0516 ± 0.00416	0.0077 ± 0.0123	Potted wheat plant (Back cross c.v.)	Behnazar and Madadi (2015)
Diuraphis noxia	Males	II	0.045 ± 0.00358	0.00604 ± 0.0132	Potted wheat plant (Back cross c.v.)	Behnazar and Madadi (2015)

They showed that prey type did not have any impact on searching rate and handling time of fourth instar larvae but did on third instar larvae and females. They postulated the fourth instar larvae is the most voracious stage of this predator and in addition to females it could be considered as releasing stages in an inundative biocontrol project against cotton aphid. This speculation was confirmed again by using Russian wheat aphid (RWA) as prey for *H. variegata* (Behnazar and Madadi 2015). Their results supported that fourth instar larvae and female adults had the highest searching efficiency on Sardari c.v. of wheat, but instead, male adults was the most voracious stage on Back cross c.v. of wheat (Table 2.3).

Virtually all of these F.R. studies on Coccinellids used the two-step analysis method developed by Juliano (2001). This method determines the type of response precisely and produces acceptable estimates of attack constant and handling time. Collectively, studies conducted on functional response of *H. variegata* in Iran showed different values for attack constant and handling time that makes comparison difficult. The first point is that most of these studies (except three cases) have been done on small artificial arenas like leaf disc or even more simple medium like Petri dish that increases predator-prey encounter rate and therefore type II functional response has been reported. However, large-scale experiments did not change the response type (Madadi et al. 2011; Davoodi Dehkordi and Sahragard 2013a). Indeed, small scale experiment only gives an insight into the predator's maximum predation potential and does not produce actual value of predation rate. Additionally, extrapolating the results of these studies to real conditions is difficult. This point is one issue that should be considered in future experiments and as possible as Petri dish experiments should be discarded. Most of these studies exhibited no difference in F.R. response type. Furthermore, searching efficiency and handling time did not deviate from corresponding values of other studies substantially. Although, as a novelty, Davoodi Dehkordi and Sahragad (2013a) used an open patch design to study the functional response of *H. variegata* to the cotton aphid. The design included the black eyed bean leaf's petiole wrapped with a wet cotton wool and was placed in an open larger plastic box (18 × 23 × 5 cm) which unlike Petri dish arena allow the lady beetles to freely move across the experimental unit. Another point is that many F.R. studies have been done with only one prey stage (mostly fourth instar nymphs), while it is obvious that predators usually encounter with a mixture of prey stages simultaneously while searching in nature. This deficiency might be attributed to difficulties in data analysis that the number of killed prey from different stages could not be incorporated in the analysis. The development of multistage functional response models could be useful for analyzing this kind of data. Similar to life table studies, among aphids, only five species have been used in F.R. evaluations and cotton aphid was used more than other preys (Table 2.3), meanwhile few fruit tree aphid species have been used as prey. This might be due to difficulties in rearing fruit tree aphid pests under laboratory conditions, but certainly, this is an apparent defect of F.R. studies of *H. variegata* conducted to date in Iran.

All life stages of *H. variegata* have predatory habits and kill their prey, but in many of F.R. studies, only a single life stage of *H. variegata* has been used individually. Although, this is a good approach to quantifying the predation potential of a single stage of a species, all life stages should be employed to reach a right conclusion. It has rarely been seen in nature that only one predatory stage kills the prey.

The other artifact of this kind of experiment is that it does not permit detection of mutual interference on number of prey killed. Actually, only in one case, two predator individuals have been used in F.R. experimental unit. The results showed it decreased searching efficiency but not handling time relative to the classic F.R. experiments used only one predator individual. Moreover, in most cases, a complex of aphidophagous predators present in a prey patch and compete with each other for shared prey. Under experimental condition, the effects of intra- and interspecific competition could not be clarified. Solving this problem could be done with prey labeling, i.e., if possible, prey labeled with traceable colors, proteins, or radioactive compounds in a way that number of killed prey by each stage could be estimated. This design also improves the reality of experiments because the effect of mutual interference among different predatory stages could be evaluated. Finally, the spatial distribution of predator and prey is a crusial factor affecting the predation rate that could not be simulated in Petri dish based experiments. Table 2.3 shows there are some variations in searching efficiency and handling time with regard to prey species and experimental arena. As would be expected, the immature stages of *H. variegata* influenced more intensively by small experimental arena than adults. This might be because adult body size is too large to be influenced by leaf area extent or host plant physical traits. Only in one case (Jafari and Goldasteh 2009) the searching rate was very small compared to other studies. This difference might be attributed to size of experimental unit. In their studies the volume of three-dimensional experimental arena searched by females was 1518 cm^3 while in most two dimensional experiments (leaf discs) the searching area volume was not more than about 80 cm^3 approximately.

Another F.R. parameter (the handling time) shows high variations among different studies. It ranges from low and biologically unrealistic values as 1×10^{-8} h to high value as 1.9 h. This variation seems inconceivable; because it means that one third instar larva spents about 114 min in non-searching activities (pursuing, feeding, digesting, grooming and resting) for a single prey. Conversely, in another study, fourth instar larvae spent nearly zero time for handling the prey that clearly it is unrealistic and resulting from artificial data gathering and analyzing. The handling time of *H. variegata* female showed less variations and it was more congruent.

The one point that tended to be overlooked in some F.R. experiments is that some lack any control to correct treatment mortality. Of course, control mortality is negligible but considering control mortality would be increased results accuracy.

Other issue that should not be ignored in comparing the results of functional response studies is that those studies conducted at different parts of Iran and lady beetles used have been collected from different elevations and climates. It has been shown that variegated lady beetle or spotted amber ladybird shows variations in their wing size regarding their origins (Abdollahi Mesbah et al. 2015); therefore it is possible that local populations composed of different morphs with diverse biological properties that may also vary in terms of searching efficiency or handling time. However, this hypothesis needs to be validated.

The effect of different factors on searching efficiency and handling time of *H. variegata* has been evaluated. Prey types, developmental stages of predator (Bigdelou 2012; Farhadi et al. 2010; Madadi et al. 2011), experimental scale, host cultivar properties (Behnazar and Madadi 2015), temperature (Asghari et al. 2012; Ebrahimi Arfaa 2014), predator sex (Farhadi et al. 2010; Hassankhani and Allahyari 2013) and even some pesticides (Alimohammadi Davarani et al. 2012) are among the factors that have been surveyed but still it seems that the influence of many other traits (e.g. moisture, host plant qualities, feeding history and plant structure) on functional response of *H. variegata* should be addressed.

H. variegata, as a dominant lady beetle species of most parts of Iran, attracted most of attention to itself and it is more studied than any native lady beetle species. In addition to this species, the sporadic researches have been done on functional response of other species more or less. Similar to most *H. variegata* studies, it has been reported that *A. bipunctata* (Linnaeus 1758) exhibited type II response, while the fourth instar larvae had higher searching efficiency and lower handling time than females to pomegranate aphids, *A. punicae* (Dehghan Dehnavi et al. 2007).

There are a few studies dealing with the functional response of lady beetles to herbivorous mites. Most of these studies have been focused on functional response studies with *S. gilvifrons* (Mulsant), a major predator of different aphid species especially in South of Iran, mainly found in sugarcane and castor bean fields (Hajizadeh 1995; Modarres Awal 2001; Afshari et al. 2007; Mehrkhou et al. 2008) (Table 2.4). All such studies except Sohrabi and Shishehbor (2007), exhibited a type II response for *S. gilvifrons*. This could be doubtful, mainly because they did not specify the analysis method used for determining the type of response. The noticeable point in *S. gilvifrons* studies is low attack constant and long handling time to strawberry spider mite (Sohrabi and Shishehbor 2007). Imani et al. (2009) reported the type II functional response of *S. gilvifrons* Mulsant females to different life stages of citrus brown mite, *Eutetranychus orientalis* Klein on leaf discs. Accordingly, they reported that among stages, ladybeetle females had the lowest handling time for citrus brown mite larvae. In another study, functional response of all predatory stages of *S. gilvifrons* to *E. orientalis* (Klein) eggs assessed. Similarly, using the same prey, the fourth instar larvae of *S. gilvifrons* showed the maximum predation rate relative to females and third instar larvae. This was not unpredictable, but the striking point in their results was that the instantaneous searching rate of *S. gilvifrons* female was lower than all other tested stages, even the first instar larvae (Imani and Shishehbor 2011). Of course, they did not compare the results statistically, but 95% confidence intervals of searching efficiency were overlapped, which might imply nonsignificant difference in results. In terms of handling time, the fourth instar larvae and females have the most voracious life stages of *S. gilviforns* similar to aphidophagous lady beetles. Approximately all of these studies have been conducted under artificial laboratory conditions. This might be inevitable because the size of predator and prey mites is tiny and recording the number of killed prey is not possible easily without examining under stereomicroscope. It should be noted that apart from *S. gilvifrons*

Table 2.4 Functional response type and parameters of acarophagous lady beetle, *Stethorus gilvifrons* to different mite species

Predator species	Prey species	Type	Search rate (h^{-1}) or b (type III)	Handling time (h)	Arena	Study
Stethorus gilvifrons (Female)	*Tetranychus turkestani*	III	0.0012	0.415	Cowpea leaf disc	Sohrabi and Shishehbor (2007)
Stethorus gilvifrons (Female)	*Oligonychus afrasiaticus*	II	0.085	0.138	Petri Dish	Matin et al. (2010)
Stethorus gilvifrons (1st instar larvae)	*Eutetranychus orientalis*	II	0.065 ± 0.10	0.207 ± 0.036	Castor bean leaf arena (16 cm^2)	Imani and Shishehbor (2011)
Stethorus gilvifrons (2nd instar larvae)	*Eutetranychus orientalis*	II	0.089 ± 0.014	0.166 ± 0.029	Castor bean leaf arena (16 cm^2)	Imani and Shishehbor (2011)
Stethorus gilvifrons (3rd instar larvae)	*Eutetranychus orientalis*	II	0.143 ± 0.033	0.150 ± 0.029	Castor bean leaf arena (16 cm^2)	Imani and Shishehbor (2011)
Stethorus gilvifrons (4th instar larvae)	*Eutetranychus orientalis*	II	0.125 ± 0.028	0.134 ± 0.034	Castor bean leaf arena (16 cm^2)	Imani and Shishehbor (2011)
Stethorus gilvifrons (female)	*Eutetranychus orientalis*	II	0.046 ± 0.004	0.082 ± 0.02	Castor bean leaf arena (16 cm^2)	Imani and Shishehbor (2011)
Stethorus gilvifrons	*Eotetranychus hirsti* (Eggs)	II	0.13	0.196	Petri Dish	Sharifnia (2012)
Stethorus gilvifrons	*Eotetranychus hirsti* (Female)	II	0.14	0.193	Petri Dish	Sharifnia (2012)
Stethorus gilvifrons	*Tetranychus urticae*	II	0.038	0.139	Not mentioned- 15 °C	Mehrkhou et al. (2008)
Stethorus gilvifrons	*Tetranychus urticae*	II	0.053	0.053	Not mentioned- 35 °C	Mehrkhou et al. (2008)

other acarophagous lady beetle species have not been studied so far and this should be considered in future researches in Iran.

In addition to those researches presented here, some studies have been done on the functional response of *S. gilvifrons* to different prey types or under different conditions but most of them mainly were unpublished MSc. thesis, so that access to their results or experimental details is difficult or impossible.

Except those studies mentioned above, there are some sporadic investigations about the functional response of other native or exotic lady beetles such as *Exochomus nigromaculatus* (Goeze), *Adalia bipunctata* (Linnaeus 1758), *Nephus arccuatus* Kapur, *Serangium montazerii* Fürsch, *Cryptolaemus montrouzieri* Mulsant and *Scymnus syriacus* Marseul with different prey species (Table 2.5). In most of these studies, the different life stages of ladybird showed type II that is common among related documents (Table 2.5). Different aphid species have been used as prey in most of F.R. studies. Below, we will review some of the most relevant ones.

Exochomus nigromaculatus Goeze is one of the important but less known lady beetles species showing type II functional response to two aphid species, oleander aphid, *A. nerii* Boyer de Fonscolombe and cowpea aphid, *A. craccivora* Koch, 1854 (Nazari et al. 2005). They reported the higher suitability of oleander aphid relative to cowpea aphid for *E. nigromaculatus* feeding according to searching efficiency.

Dehghan Dehnavi et al. (2007) again showed the superiority of fourth instar larvae of *A. bipunctata* in predation of their prey relative to females. However, their study duration was only six hours which makes the comparison of outcomes be more complex, because typical F.R. experiments last about 24 hours.

Another native lady beetle species, *Scymnus syriacus* Marseul adults, exhibited an inverse density- dependent response to black bean aphid density. As expected, the females have higher instantaneous searching efficiency and lower handling time than males (Sabaghi et al. 2011a). Although, this species showed type III functional response to increasing prey densities of *A. craccivora*. They showed the inverse relationship of arena size and increasing prey densities with the searching efficacy of *S. syriacus*. The handling time ranged from 0.494 to 0.687, depending on arena size (Sabaghi et al. 2011b).

Fotukkiaii and Sahragard (2012, 2013) reported type II response of whitefly lady beetle, *S. montazerii* females to different densities of citrus whitefly eggs, while the kind of patch design (closed or open) did not have any influence on functional response type. They also showed the patch time residence of *S. montazerii* was inversely dependent on prey density (Fotukkiaii and Sahragard 2013). They stressed higher efficiencies of fourth instar larvae than females of *S. montazerii* against citrus whitefly that have been confirmed with another lady beetle species. Although, they implied their control potential against *D. citri*.

The functional response of *Cryptolaemus montrouzieri* Mulsant (fourth Instar larvae and females) to different stages of citrus mealybug *Planococcus citri* (Risso) (second, third and females) was also investigated (Abdollahi Ahi et al. 2012). They showed that fourth instar larvae of *C. montrouzieri* showed a type III response to the second instar nymph of citrus mealybug suggesting that the earlier release of

Table 2.5 Functional response type and parameters of different lady beetles to various kinds of prey

Predator species	Prey species	Type	Search rate (h^{-1}) or b (Type III)	Handling time (h)	Arena	Study (Model)
Oenopia conglobata	*Aganoscena pistaciae*	II	0.0469	0.0152	Petri dish (Pistachio leaf disc)	Hassani et al. (2004)
Exochomus nigromaculatus (4th instar larvae)	*Aphis nerii*	II	1.24	0.006	Petri dish (Host plant leaf)	Nazari et al. (2005) Disc equation
Exochomus nigromaculatus (Female)	*Aphis nerii*	II	1.12	0.007	Petri dish (Host plant leaf)	Nazari et al. (2005) (Disc equation)
Exochomus nigromaculatus (4th instar larvae)	*Aphis craccivora*	II	1.17	0.009	(Host plant leaf) Petri dish	Nazari et al. (2005) (Disc equation)
Exochomus nigromaculatus (Female)	*Aphis craccivora*	II	1.01	0.008	(Host plant leaf) Petri dish	Nazari et al. (2005) (Disc equation)
Adalia bipunctata (4th instar larvae)	*Aphis punicae*	II	0.22 ± 0.037	0.073 ± 0.021	Pomegranate leaf disc	Dehghan Dehnavi et al. (2007)
Adalia bipunctata (Female)	*Aphis punicae*	II	0.144 ± 0.031	0.084 ± 0.037	Pomegranate leaf disc	Dehghan Dehnavi et al. (2007)
Scymnus syriacus (Female)	*Aphis fabae*	II	0.123 ± 0.007	0.4349 ± 0.012	Plastic container (15x13 cm).	Sabaghi et al. (2011a)
Scymnus syriacus (Male)	*Aphis fabae*	II	0.115 ± 0.008	0.5145 ± 0.0169	Plastic container (15x13 cm).	Sabaghi et al. (2011a)
Scymnus syriacus (Female)	*Aphis craccivora*	III	Different values	–	Broad bean leaf at five different arenas (195, 247, 304, 385 and 650 cm^2)	Sabaghi et al. (2011b)

(continued)

Table 2.5 (continued)

Predator species	Prey species	Type	Search rate (h^{-1}) or b (Type III)	Handling time (h)	Arena	Study (Model)
Oenopia conglobata contaminata	*Brevicoryne brassicae*	II	0.041 ± 0.012	1.3867 ± 0.164	Petri Dish (Cabbage leaf)	Rounagh and Samih (2012)
Cryptolaemus montrouzieri (female)	*Planococcus citri* (3rd instar nymphs)	II	0.053 ± 0.008	0.4934 ± 0.054	Petri Dish (Coleus leaves)	Ghorbanian, et al. (2010)
Cryptolaemus montrouzieri (male)	*Planococcus citri* (3rd instar nymphs)	II	0.0403 ± 0.0056	0.4625 ± 0.0568	Petri Dish (Coleus leaves)	Ghorbanian et al. (2010)
Cryptolaemus montrouzieri (4th instar larvae)	*Planococcus citri* (2nd instar nymphs)	III	0.0126 ± 0.004	0.701 ± 0.033	Petri dish	Abdollahi Ahi et al. (2012)
Cryptolaemus montrouzieri (4th instar larvae)	*Planococcus citri* (3rd. instar nymphs)	III	0.0165 ± 0.0067	1.012 ± 0.0504	Petri dish	Abdollahi Ahi et al. (2012)
Cryptolaemus montrouzieri (4th instar larvae)	*Planococcus citri* (female)	II	0.002 ± 0.0032	2.05 ± 0.059	Petri dish	Abdollahi Ahi et al. (2) (Disc equation)
Cryptolaemus montrouzieri (female)	*Planococcus citri* (2nd instar nymphs)	II	0.048 ± 0.003	0.177 ± 0.033	Petri dish	Abdollahi Ahi et al. (2) (Disc equation)
Cryptolaemus montrouzieri (female)	*Planococcus citri* (3rd instar nymphs)	III	0.013 ± 0.0064	0.843 ± 0.058	Petri dish	Abdollahi Ahi et al. (2)
Cryptolaemus montrouzieri (female)	*Planococcus citri* (female)	II	0.098 ± 0.0186	2.794 ± 0.123	Petri dish	Abdollahi Ahi et al. (2) (Disc equation)
Rodolia cardinalis (females and 4th instar larvae)	*Icerya purchase* (Maskell)	II	Not available	Not available	Petri dish (Bitter orange and Spurge laurels)	Bazyar et al. (2012) (Disc equation)

Serangium montazerii (4th instar larvae)	*Dialeurodes citri*	II	0.2540 ± 0.0587	0.3715 ± 0.0174	Petri dish (on Citrus leaf)	Fotukkiaii and Sahragard (2013)
Serangium montazerii (Female)	*Dialeurodes citri*	II	0.1614 ± 0.0456	0.4641 ± 0.0377	Petri dish (on Citrus leaf)	Fotukkiaii and Sahragard (2013)
Serangium montazerii	*Dialeurodes citri*	II	0.0421 ± 0.00945	0.0896 ± 0.0362	Open patch design (transparent plastic container 12 × 9 × 5 cm)	Fotukkiaii and Sahragard (2013)
Oenopia conglobata contaminata (Female)	*Myzus persicae*	II	0.063 ± 0.0089	0.1425 ± 0.029	Petri Dish (on Cabbage leaf disc)	Samih and Mokhtari (2014)
Nephus arcuatus	*Nipaecoccus viridis* (Eggs)	III	0.00811 ± 0.00267	0.2819 ± 0.0107	Plastic container (9 × 7 × 3)	Zarghami et al. (2014a)
Oenopia conglobata contaminata (3rd instar larvae)	*Aphis punicae*	II (at 25 °C)	0.092 ± 0.0194	0.5008 ± 0.0428	Petri dish	Rounagh and Samih (2015)
Oenopia conglobata contaminata (4th instar larvae)	*Aphis punicae*	III (at 25 °C)	0.0124 ± 0.0596	0.3389 ± 0.0410	Petri dish	Rounagh and Samih (2015)
Oenopia conglobata contaminata (Female)	*Aphis punicae*	II (at 25 °C)	0.1276 ± 0.0379	0.3965 ± 0.0452	Petri dish	Rounagh and Samih (2015)
Cryptolaemus montrouzieri (3rd instar larvae, female and male)	*Planococcus citri*	II (except for 3rd instar larvae at 40 °C)	Different values	Different values	Petri dish	Mohasesian et al. (2015)

fourth instar larvae could be more profitable. The authors used Holling's disc equation and Roger's random predator equation for estimating searching efficiency and handling time for type II and III functional responses of *C. montrouzieri*, respectively. The selection of each these two models for the data analysis does not depend on the type of F.R. exhibited by the predator but the random predator equation should have been used whenever there is prey depletion (Juliano 2001).

In a detailed study, the functional response of *C. montrouzieri* (third instar larva, female and male) to citrus mealybug (second and third instar nymphs) at seven different temperatures ranged from 15 to 40 °C with 5 degrees intervals was investigated (Mohasesian et al. 2015). They also showed type II response for all predator stages except the third instar larvae at 40 °C exhibited type III. Moreover, there is an increase in searching efficiency (from 0.004 ± 0.015 to 0.008 ± 0.031 h^{-1} for females) and decrease in handling time (from 0.279 ± 2.314 to 0.216 ± 1.821 h for females) of *C. montrouzieri* associated with increasing temperature. This issue implies the greater potential of this predator at higher temperatures, especially against mealybugs (Mohasesian et al. 2015).

Samih and Mokhtari (2014) worked on functional and numerical responses and the predation rate of *O. conglobata contaminata* recommended use of this lady beetle against green peach aphid in orchards.

As a case study, native lady beetle *Nephus arcuatus* Kapur functional response to mealybug *Nipaecoccus viridis* (Newstead) matched Holling's type III response (Zarghami et al. 2014a, 2015). This result suggests this thermophilic species, mainly found in South and Southwestern of Iran could regulate the citrus mealybug populations. High consumption rate, long oviposition period, density-dependent functional response, direct numerical response, high reproductive potential and ability to survive under hot temperatures all contribute to its potential to reduce the mealybug population.

It must be remembered that there were some other functional response studies with different lady beetle species that did not contain specific values for searching efficiency or handling time, so we could not consider them here (Bazyar et al. 2012).

Most of the functional response studies with different lady beetle species have been carried on to crop pests. As an exception, Rounagh and Samih (2015) reported the type of functional response of third and fourth instars larvae and females of *O. conglobata contaminata* (Menetries) to pomegranate green aphids, *A. punicae* at two different temperatures. They recorded type II response for all tested stages except fourth instar larvae, which showed type III at 25 °C (Rounagh and Samih 2015). They showed the effect of increasing temperatures on searching efficiency and handling time. As in many other studies, attack constant and handling time demonstrate that release of fourth instar larvae of *O. conglobata contaminata* at 27.5 °C would be the most useful approach against pomegranate aphid. However, referring to rearing storing and releasing difficulties of a large number of fourth instar larvae, the females seem to be the most appropriate releasing stage.

A common deficiency of some of the above F.R. studies is the low numbers of used replicates. In some experiments, just five or six replicates have been used while obtaining precise estimates of search rate and handling time needs at least

15 replications or even more, especially at low initial densities of prey offered. The low number of replicates can increase variations and in turn, standard error of mean among different treatments lead to incorrect estimations of searching efficiency or handling time. Additionally, again, the control treatment has not been used to correct observed mortality. Moreover, in some outdated investigations, only the Holling's disc model was used before testing the Roger's random predator equation, which is more realistic and considers prey depletion during the experimental period.

2.5.2 Numerical Response

The numerical response is another crucial aspect of predation. By definition, the numerical response is an increase in the number of predator densities in response to increasing prey density (Holling 1959). It has three primary forms, direct, no response and inverse (Solomon 1949).

Compare to functional response, there are very few numerical response studies and these kinds of surveys have been done scarcely in Iran. Partially, this due to complicated set-ups of numerical response experiments, which is more time consuming than a short-term experiment. Another point is that there is not a standard set-up or even standard data analysis method for these kinds of investigations. A brief review revealed puzzling variations in data-analysis and set-ups. Most carried out together with functional response studies concomitantly. Many researchers used the same set-up of functional response with slight modifications (i.e., they used a longer experimental duration for numerical response experiments instead of 24 h commonly used for functional response (Zarghami et al. 2015). Actually, the functional and numerical respons experimental set-ups are similar to each other apparently, but the different point is that in numerical response experiments, the number of eggs laid by predator in response to increasing prey densities is recorded. In contrast, the functional response considers the number of killed prey in response to initial different prey densities. Even though, there were more sophisticated studies with up to two weeks or longer as experimental duration (Mokhtari and Madadi 2013; Zarghami et al. 2015). Generally, at nearly all numerical response experiments, it has been exhibited that oviposition increases with increasing prey density (Sabaghi et al. 2011a ; Mokhtari and Madadi 2013). It has been suggested that the number of eggs laid by *H . variegata* to *A. fabae* increases curvilinearly up to an asymptote and then levelled up at density of 96 black bean aphids (Mokhtari and Madadi 2013). Moreover, there was an inverse density-dependent relationship between increasing prey density and premature developmental time. The numerical response of *Nephus arccuatus* to *Nipaecoccus viridis* (Newstead) eggs was also curvilinear reached a plateau at 115 spherical mealybugs (Zarghami et al. 2015). This value was 80 for the reproductive numerical response of *S. syriacus* to black bean aphid (Sabaghi et al. 2011a). Sohrabi and Shishehbor (2007) showed a linear numerical response between *Tetranychus turkestani* density and *S. gilvifrons* oviposition and the lower egg production threshold was eight *T. turkestani* females.

2.6 Population Fluctuations of *Hippodamia variegata* and Other Lady Beetle Species

Insect populations like other organisms in response to different factors increase, decline and oscillate profoundly. Clearly, different factors such as climatic factors, competition, host quality and quantity, diseases, natural enemies and others might be influential and arise or dampen insect populations. Population dynamics attempt to find the causes of those fluctuations, their periods and strength. Although it seems that many questions have not been answered yet. Undoubtedly, knowledge of the population dynamics of aphids and their natural enemies leads us to a better understanding of their associations and integrated pest management (Rakhshani et al. 2009).

There are few studies that dealt with the population structure and fluctuation of lady beetle in Iran. Usually, the population oscillations of aphids and lady beetle have been presented across one or two consequent years. Sometimes, the relation of different abiotic or biotic factors with prey and lady beetle populations has been correlated. It has been expressed that *H. variegata* was an abundant species in central plain of Iran and its population had two peaks yearly (May–July and early of autumn) while the seven spotted lady beetle had just one dominant peak during autumn (Rakhshani et al. 2009). The interesting point was that the lady beetle population was positively correlated with aphid populations. This synchrony increases the effectiveness of the lady beetle to suppress the aphid population. Similarly, the main population peaks of these two lady beetles reached on May–July and September in Alfalfa fields of Hamedan province (Soleimani and Madadi 2015; Tavoosi Ajvad et al. 2012). The *H. variegata* population varies significantly with increasing temperatures, but unlike *C. septempunctata*, it was not correlated with pea aphid population significantly. Farsi et al. (2010) reported the peak of *C. septempunctata* in the middle of March following canola aphids rising in Ahvaz (Southern Iran). Furthermore, Afshari et al. (2000) reported the highest density of *S. gilvifrons* and *Oligonychus sacchari* McGregor, 1942 in late July and their populations were positively correlated. This species emerged on sugarcane in early summer and overwintered as an adult out of the sugarcane fields (Narrei et al. 2005).

2.7 Intraguild Predation Studies

Intraguild predation or predatory interference is a relatively new field in insect ecology. This term was coined by Polis et al. (1989) firstly and afterward became prevalent quickly. By definition, intraguild predation (IGP) is a combination of predation and competition, i.e. two or more competitors that compete for a shared prey involved in predation. In this interaction, one of the competitors is superior and named IG or top predator while, other is inferior, called IG prey. The shared herbivore prey often is extraguild prey (EXG). The outcome of IGP based on extraguild prey density, might be synergistic, additive, non-additive or even antagonistic Aphidophagous predators are a common guild which IGP occurs among them frequently. Most IGP studies have been conducted by different member of this guild. There are few published studies about intraguild predation in Iran, and many of them have been undertaken with predatory mites as intraguild predators and preys. In one of the earliest and most relevant records, the effect of IGP occurrence between *H. variegata* (H.v.) and *Episyrphus balteatus* De Geer (Diptera: Syrphidae) on cotton aphid population have been evaluated on a microcosm scale (Tavoosi Ajvad et al. 2014). According to their results, the IGP between third instar larvae of *E. balteatus* and *H. variegata* second instar larvae was asymmetrical, and the former acts as IG predator against the second instar larvae of *H. variegata*. They showed that the interaction of these two predators on the cotton aphid population was non-additive or even antagonistic i.e. using both predators did not suppress aphid population more efficiently than a single application of each predator stage.

Different attributes of predator and environment affect IGP outcome. It has been proposed that density of extraguild prey substantially influences of IGP occurrence (Hatami et al. 2013). However, the IGP interaction between *H. variegata* different life stages and *Aphidoletes aphidimyza* (Rondani 1847) two-days old larvae was antagonistic at highest density of extraguild prey (Hatami et al. 2013).

2.8 Applied Studies Employing Different Coccinellid Species in Greenhouse and Field Environment

Unfortunately, most Iranian researches on lady beetles have been restricted to laboratorical studies. Therefore, it is not easy to find practical studies with coccinellids in a small field or even greenhouse scale. They have been done under net covered cages which produce the illusive outcomes. It has been proposed that releasing 20 seven spotted lady beetle females per m^2 suppressed the cereal aphid population up to 45% (Haghshenas et al. 2006). The possibility of *Vedalia* beetle establishment in south citrus orchards despite hot summers considered (Eslami Zadeh and Barzkar 2006; Mossadegh et al. 2008b). Among the lady beetles, “Crypts” or “Mealybug destroyers” (*C. montrouzieri*) has been employed practically more than any other species to control mealybugs as far as more than 6,000,000 and 4,000,000 individuals were released in 2008 and 2009 (Malkeshi et al. 2010). In this regard, the possible application of this species against citrus spherical mealybug was prospective, although, hot summers suppressed activity on July (Mossadegh et al. 2008a). Of course, keep in mind that this species is sensitive to low temperatures and could not endure long-term storage (Shahriari et al. 2016).

Acknowledgement The special thanks dedicated to Prof. Dr. Steven Juliano for critically reading the part of this manuscript and sending his valuable comments.

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