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Native parasitoids of the fall webworm, *Hyphantria cunea* (Drury, 1773) (Lepidoptera, Erebidae), an invasive alien pest in northern Iran

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ABSTRACT. The fall webworm, *Hyphantria cunea* (Drury, 1773) (Lepidoptera, Erebidae), is one of the most important pests of forest trees in northern Iran. In order to identify the native parasitoids of this pest a survey was conducted in Guilan province, in 2019. The larvae and pupae of the fall webworm suspected being parasitized, were collected from different host trees and wood piles, and reared under laboratory conditions until the parasitoids emerged. This pest was found parasitized with five species of Hymenoptera, *Brachymeria lasus* (Walker, 1841) (Chalcididae), *Chouioia cunea* Yang, 1989 (Eulophidae), *Psychophagus omnivorus* (Walker, 1835) (Pteromalidae), *Pimpla rufipes* Brulle, 1846, *Virgichneumon dumeticola* (Gravenhorst, 1829) (Ichneumonidae), and four species of Diptera, *Compsilura concinnata* (Meigen, 1824), *Exorista larvarum* (Linnaeus, 1758), *Pales* sp. (Tachinidae), and *Megaselia scalaris* (Loew, 1866) (Phoridae). Among them six species (e.g., *P. rufipes*, *V. dumeticola*, *B. lasus*, *E. larvarum*, *C. concinnata* and *Pales* sp.) are newly reported as the parasitoids of *H. cunea* from Iran.

Key words: Invasive pest, conservation, parasitoid, Tachinidae, Chalcidoidea, Ichneumonoidea

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INTRODUCTION

The fall webworm, *Hyphantria cunea* (Drury, 1773) (Lepidoptera, Erebidae), is a species native to North America (Oliver, 1964; Edosa et al., 2019), has known as an invasive pest in Europe and Asia (Edosa et

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al., 2019). In Iran, this pest was first found in Guilan province in 2002 (Rezaei et al., 2003) and has since been invaded the other regions. This polyphagous defoliator causes severe damage to forest and urban ornamental trees and it is currently considered a major economic pest in Iran. Various control methods have been evaluated in the invaded areas to manage this pest. Controlling the population of these pest is primarily dependent on a continued aerial or foliar application of common insecticides (Choi & Park, 2012). However, polyphagy, high reproductive potential and ecological flexibility of this insect, makes it difficult to be managed by the pesticide chemicals that are being used till now (Saruhan et al., 2014; Wang et al., 2020). On the other hand, chemical control has been considered as a costly and short-term solution, so that the widespread and repeated use of these compounds for several decades has disrupted biological control by natural enemies and has led to outbreak of these pest populations and undesirable effects on nontarget organisms, and in urban ecosystems faces legal restrictions and causes environmental and human health concerns. The negative aspects of insecticide use highlights the need to develop new types of environmentally safe management methods and many researchers have been considering alternative ways to control this pest. Biological control can be an attractive alternative to chemical insecticides. Biological control agents are known to play a very important role in the population dynamics of insects. Identification of these agents and evaluation of their effectiveness are important toward major integrated pest management effort against pest insects. *Hyphantria cunea* has a large number of biocontrol agents such as parasitoids that they play an important role in keeping the population of this pest below the threshold level in natural forests (Edosa et al., 2019). Surprisingly, despite high populations and wide distribution of this pest in forests in the north of Iran, very little is known about parasitoids that might limit its population. The objective of the present study was to determine the major native parasitoids of *H. cunea* in northern Iran. That knowledge is important to understanding the contribution of these parasitoids to biological control of this moth and provides important baseline information for future studies.

MATERIAL AND METHODS

Observations on the native parasitoids of the fall webworm were made during September of 2019 in Guilan province, north of Iran. *Hyphantria cunea* larvae were collected on different forest trees and bush species by cutting the infested leaves and transfered to the laboratory. Then, they were in a clumped manner reared within transparent plastic cages with fine mesh gauze for ventilation and fresh leaves of the white mulberry trees (*Morus alba* L.) were provided as food until all parasitoids adults emerged. The cages were held in a growth chamber with constant conditions of 25 ± 1 °C, 60 ± 5% RH and a 16:8 h L:D photoperiod and were checked daily. During survey overwintering pupae of the pest were also collected from infested forest trees in studied areas (Fig. 1). The pupae were placed individually in screen topped petri dishes containing moistened filter paper until the adult parasitoids emerged. Parasitoid adults that emerged were transferred to 70% ethanol and kept separately. They were then card-mounted, labeled and subsequently identified using the keys of Tschorsnig and Herting (1994), O'Hara (2005), Brown and Oliver (2007), Gates et al. (2012), Choi et al. (2016), and Narendran and van Achterberg (2016).

Photographs were taken using an Olympus® SZX9 stereomicroscope equipped with a BMZ-04-DZ digital imaging camera (Behin Pajouhesh Co., Iran) and image stacks were combined with Combine ZP1.0 (Hadley, 2010). Voucher specimens were deposited in the Insect Collection of the Department of Entomology, Tarbiat Modares University, Tehran, Iran. The distributional data was obtained through a review of the available related literatures and the current study. The distribution maps were generated using SimpleMappr (Shorthouse, 2010). The field parasitism rate (%) was calculated as (number of parasitized *H. cunea* larvae and pupae/total number of collected larvae and pupae) × 100.

Figure 1. The sampling localities in Guilan province, northern Iran, where larvae and pupae of *Hyphantria cunea* (Drury, 1773) (Lepidoptera, Erebidae) were collected.

RESULTS

The larval and pupal parasitoids of *Hyphantria cunea* was studied in Guilan province, northern Iran. A total of five hymenopteran species of the families Chalcididae (one species), Eulophidae (one species), Pteromalidae (one species), Ichneumonidae (two genera, two species), and four dipteran species of the families Tachinidae (three genera, two species), and Phoridae (one species) were identified. Six host-parasitoid associations were recorded for the first time from Iran. The general distribution and host records of each species based on the previously recorded data throughout the world is also presented and discussed.

Order Hymenoptera Linnaeus, 1758

Superfamily Chalcidoidea Linnaeus, 1758

Family Chalcididae Latreille, 1817

Genus: *Brachymeria* Westwood, 1829

***Brachymeria lasus* (Walker, 1841)** (Fig. 2A)

For taxonomical and morphological characters of this species see Lotfalizadeh et al. (2012) and Narendran and van Achterberg (2016).

Material examined. Iran, Guilan province, Rezvanshahr, Paresar, Sandian, (37°57′22.70″ N, 49°12′82.95″ E), 02.ix.2019, 1♀; on pupae of *Hyphantria cunea*, leg. A. Karami.

Distribution in Iran. Kerman (Lotfalizadeh et al., 2012) and Guilan (current study) provinces.

General distribution. Australia (Queensland), Bangladesh, China (Beijing, Fujian, Guangxi, Guizhou, Hong Kong, Hubei, Hunan, Jiangsu, Shanxi, Sichuan, Zhejiang), Fiji, Guam, Hawaii, India (Andaman and Nicobar Islands, Arunachal Pradesh, Assam, Bihar, Delhi, Gujarat, Himachal Pradesh, Jammu and Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Meghalaya, Punjab, Tripura, Uttar Pradesh, West Bengal), Indochina, Indonesia (Java, West Papua), Iran, Japan,, Malaysia (

Sarawak), North Africa, Pakistan, Palau, Papua New Guinea, Philippines, South Korea, Taiwan, United States of America (Connecticut, Pennsylvania, Wisconsin), Vietnam (Devi & Singh, 2002; Konno et al., 2002; Gupta & Kalesh, 2012; Lotfalizadeh et al., 2012; Gupta et al., 2014; Narendran & van Achterberg, 2016; Noyes, 2019) (Fig. 4A).

Hosts. Lepidoptera: *Hyphantria cunea* (Drury, 1773), *Lymantria dispar* (Linnaeus, 1758) (Erebidae); *Homona magnanima* Diakonoff, 1948 (Tortricidae); *Opisina arenosella* Walker, 1864 (Oecophoridae) (Mao & Kunimi, 1994; Noyes, 2019).

Family Eulophidae Westwood 1829

Genus *Chouioia* Yang, 1989

Chouioia cunea Yang, 1989 (Fig. 2B)

For taxonomical and morphological characters of this species see Yang (1989) and Boriani (1991).

Material examined. Iran, Guilan province, Rezvanshahr, Paresar, Sandian, (37°57′22.70″ N, 49°12′82.95″ E), 02.ix.2019, 18♂, 712♀; gregarious parasitoid on pupae of *Hyphantria cunea*, leg. A. Karami.

Distribution in Iran. Guilan (Rezaei et al. 2003, current study)

General distribution. China (Beijing, Shaanxi, Shandong, Zhejiang), Georgia, Iran, Italy, Japan, South Korea and Turkey (Yang, 1989; Boriani, 1994; Yang et al., 2006; Zhu & Huang, 2001; Konno et al., 2002; Rezaei et al., 2003; Japoshvili et al., 2006; Sullivan et al., 2011; Noyes, 2019) (Fig. 4B).

Hosts. Lepidoptera: *Hyphantria cunea* (Drury, 1773), *Lymantria dispar* (Linnaeus, 1758), *Stilpnotia salicis* (Linnaeus, 1758), *S. candida* Staudinger, 1892, *Ivela ochropoda* (Eversmann, 1847) (Erebidae); *Heliothis armigera* (Hubner, 1808) (Noctuidae); *Dendrolimus spectabilis* Butler, 1877 (Lasiocampidae); *Clostera anachoreta* (Denis & Schiffermüller, 1775), *Micromelalopha troglodyta* Graeser, 1890 (Notodontidae); *Clania variegata* (Psychidae); *Ostrinia furnacalis* Guenée, 1854 (Crambidae); *Antheraea pernyi* (Guerin-Meneville, 1855) (Saturniidae) and Tachinidae (Diptera) attacking *Hyphantria cunea* (Yang, 1989; Boriani, 1991; Noyes, 2019).

Family Pteromalidae Latreille, 1809

Genus *Psychophagus* Mayr, 1904

Psychophagus omnivorus (Walker, 1835) (Fig. 2C)

For taxonomical and morphological characters of this species see Gates et al. (2012).

Material examined. Iran, Guilan province, Rezvanshahr, Paresar, Sandian, (37°57′22.70″ N, 49°12′82.95″ E), 02.ix.2019, 203♂, 262♀; on pupae of *Hyphantria cunea*, leg. A. Karami.

Distribution in Iran. Guilan (Rezaei et al., 2003; current study).

General distribution. Austria, Azerbaijan, Belgium, Canada (Ontario, Quebec), Croatia, Czech Republic, Czechoslovakia, France, Germany, Hungary, Iran, Macedonia, Moldova, the Netherlands, North Africa, Poland, Romania, Russia (Adygey AO, Karachai-Cherkess AR, Kostroma Oblast, Rostov Oblast), Serbia, Slovakia, Spain, Sweden, Transcaucasus, European part of Turkey, Ukraine, United Kingdom, USA (Colorado, Connecticut, Delaware, Maine, Massachusetts, New Hampshire, New Jersey, New York, Ohio, Wisconsin), former Yugoslavia (Sharov & Izhevskiy, 1987; Rezaei et al., 2003; Noyes, 2019; Rahamani et al., 2022) (Fig. 4C).

Hosts. Lepidoptera: *Hyphantria cunea* (Drury, 1773), *Arctia caja* (Linnaeus, 1758), *Panaxia dominula* Linnaeus, 1758 (Erebidae); *Cerura Vinula* (Linnaeus, 1758) (Notodontidae) (Askew, 1970; Noyes, 2019).

Superfamily Ichneumonoidea Latreille, 1802

Family Ichneumonidae Latreille, 1802

Genus *Pimpla* Fabricius, 1804

Pimpla rufipes Brulle, 1846 (Fig. 2D)

For taxonomical and morphological characters of this species see Choi et al. (2016) and Varga (2017).

Material examined. Iran, Guilan province, Rezvanshahr, Paresar, Sandian, (37°57′22.70″ N, 49°12′82.95″ E), 02.ix.2019, 1♂; on pupae of *Hyphantria cunea*, leg. A. Karami.

Distribution in Iran. East Azerbaijan (Kolarov & Ghahari, 2006; Masnadi-Yazdinejad & Jussila, 2008), Fars (Masnadi-Yazdinejad & Jussila, 2008), Golestan (Kolarov & Ghahari, 2006), Guilan (Mohammadi-Khoramabadi et al., 2013; current study), Kerman (Mohammadi-Khoramabadi et al., 2014), Mazandaran (Kolarov & Ghahari, 2006), Tehran (Masnadi-Yazdinejad & Jussila, 2008; Mohammadi-Khoramabadi et al., 2013; Ghahari & Gadallah, 2017) and West Azerbaijan (Masnadi-Yazdinejad & Jussila, 2008; Karimpour, 2018).

General distribution. Afghanistan, Algeria, Argentina, Armenia, Austria, Azerbaizan, Brazil, Bulgaria, China, Cyprus, Egypt, Georgia, Germany, India, Iran, Italy, Japan, Kazakhstan, Korea, Kyrgyzstan, Libya, Mongolia, Montenegro, Morocco, Poland, Romania, Russia, Sri Lanka, Tajikistan, Tunisia, Turkey, Turkmenistan, Vietnam, Ukraine, United States of America, Uruguay, Uzbekistan, former Yugoslavia (Atanassov, 1978; Coulson et al., 1986; Horstmann, 2001; Çoruh & Özbek, 2008; Masnadi-Yazdinejad & Jussila, 2008; Sullivan et al., 2010; Özbek & Coruh, 2012; Çoruh et al., 2014; Di Giovanni et al., 2015; Choi et al., 2016; Yu et al., 2016; Piekarska-Boniecka et al., 2018) (Fig. 4D).

Hosts. Lepidoptera: *Hyphantria cunea* (Drury,1773), *Lymantria dispar* (Linnaeus, 1758), *L. monacha* (Linnaeus, 1758), *Arctia caja* (Linnaeus, 1758), *Orgyia trigotephras* Boisduval, 1829, *Calliteara fascelina* (Linnaeus, 1758) (Erebidae); *Malacosoma castrensis* (Linnaeus, 1758), *M. franconica* (Denis & Schiffermüller, 1775), *M. neustria* (Linnaeus, 1758) **(**Lasiocampidae**)**; *Cydia pomonella* (Linnaeus, 1758), *Archips rosana* (Linnaeus, 1758) **(**Tortricidae**)**; *Pieris brassicae* (Linnaeus, 1758), *P. rapae* (Linnaeus, 1758), *P. napi* (Linnaeus, 1758), *Colias croceus* (Fourcroy, 1785), (Pieridae); *Papilio machaon* Linnaeus, 1758 (Papilionidae); *Lacanobia oleracea* (Linnaeus, 1758), *Acronicta rumicis* (Linnaeus, 1758) (Noctuidae); *Charaxes jasius* (Linnaeus, 1767), *Eurodryas aurinia* Rottemburg, 1775, *Vanessa atalanta* (Linnaeus, 1758) (Nymphalidae); *Lycaena dispar* (Haworth, 1802), *Polyommatus bellargus* (Rottemburg, 1775) (Lycaenidae); Coleoptera: *Lixus iridis* Olivier, 1807 (Curculionidae) (Atanassov, 1978; Okyar & Yurtcan, 2007; Çoruh & Özbek, 2008; Masnadi-Yazdinejad & Jussila, 2008; Shaw et al., 2009; Stefanescu et al., 2009; Sullivan et al., 2010; Mohammadi-Khoramabadi et al., 2013; Yu et al., 2016; Karimpour, 2018; Mifsud et al., 2019).

Genus *Virgichneumon* Heinrich, 1977

Virgichneumon dumeticola (Gravenhorst, 1829) (Fig. 2E)

For taxonomical and morphological characters of this species see Tereshkin (2006).

Material examined. Iran, Guilan province, Rezvanshahr, Paresar, Sandian, (37°57′22.70″ N, 49°12′82.95″ E), 02.ix.2019, 2♂, 3♀; on pupae of *Hyphantria cunea*, leg. A. Karami.

Distribution in Iran. Golestan (Riedel & Aghadokht, 2017), Guilan (Shirzadegan et al., 2021; current study), West Azarbaijan (Riedel & Aghadokht, 2017).

General distribution. Austria, Azerbaijan, Belarus, Belgium, China (Fujian), Denmark, France, Germany, Hungary, Iran, Italy, Moldova, Netherlands, Poland, Romania, Russia (Astrakhanskaya Oblast, Gorno-Altay, Krasnodar Kray, Yaroslavl Oblast), Spain, Sweden, Turkey, United Kingdom (Thirion, 2005; Tereshkin, 2006; Horstmann, 2008; Sullivan et al., 2010; Riedel & Magnusson, 2014; Yu et al., 2016) (Fig. 4E).

Hosts. Lepidoptera: *Hyphantria cunea* (Drury, 1773) (Erebidae) (Sharov & Izhevskiy, 1987; Tolkanitz, 1990; Sullivan et al., 2010)

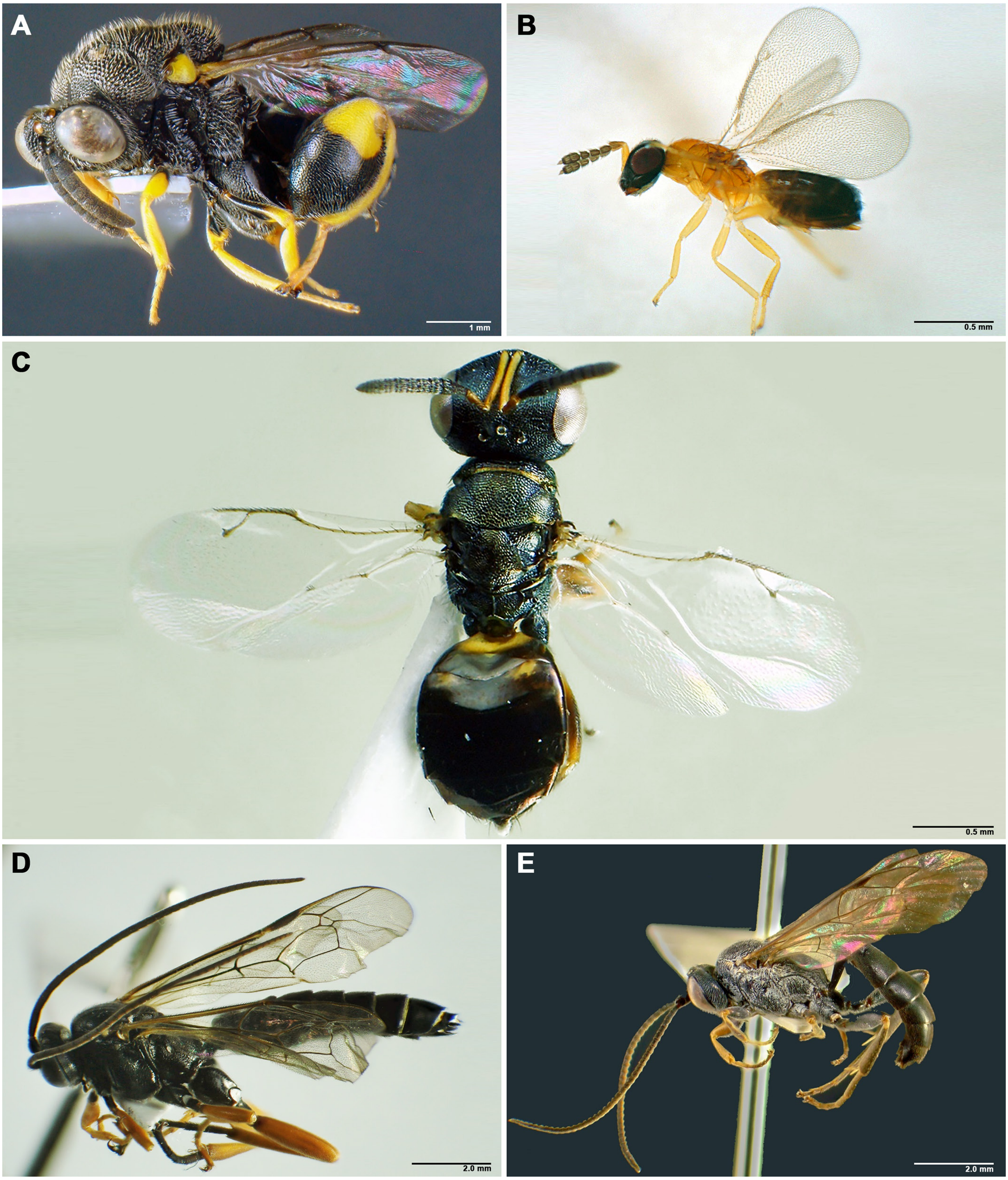

Figure 2. General habitus of the hymenopterus parasitoids of *Hyphantria cunea* (Drury, 1773) in North of Iran. **A.** *Brachymeria lasus* (Walker, 1841) (female) (Hymenoptera, Chalcididae); **B.** *Chouioia cunea* Yang, 1989 (female) (Hymenoptera, Eulophidae); **C.** *Psychophagus omnivorus* (Walker, 1835) (female) (Hymenoptera, Pteromalidae); **D.** *Pimpla rufipes* Brulle, 1846 (male); and **E.** *Virgichneumon dumeticola* (Gravenhorst, 1829) (male) (Hymenoptera, Ichneumonidae).

Order Diptera Linnaeus, 1758

Suborder Brachycera Zetterstedt, 1842

Family Tachinidae Robineau-Desvoidy, 1830

Genus *Compsilura* Bouché, 1834

***Compsilura concinnata* (Meigen, 1824)** (Fig. 3A)

For taxonomical and morphological characters of this species see Tschorsnig and Herting (1994) and Tachi et al. (2021).

Material examined. Iran, Guilan province, Rezvanshahr, Paresar, Sandian, (37°57′22.70″ N, 49°12′82.95″ E), 02.ix.2019, 190♂, 222♀; on larvae of *Hyphantria cunea*, leg. A. Karami.

Distribution in Iran. Guilan (Ghahari, 2017; current study), Mazandaran (Ghahari, 2017), Fars (Gheibi & Ostovan, 2010), Kohgiluyeh and Boyer-Ahmad (Saeidi, 2011) provinces.

General distribution. Albania, Algeria, Andorra, Armenia, Austria, Australia (New South Wales, Queensland), Azerbaijan, Belgium, Canada (introduced) (British Columbia, East, Ontario, Prairies), China, Czech Republic, Denmark, Egypt, England, France, Georgia, Germany, Greece, Hungary, Iran, India, Indonesia, Israel, Italy, Japan, Kyrgyzstan, Kazakhstan, Lebanon, Lithuania, Malaysia, Moldova, Montenegro, Morocco, Netherlands, Nigeria, North Korea, Palestine, Papua New Guinea, Poland, Romania, Portugal, Russia (Eastern Siberia, Western Russia, Western Siberia), Serbia, Slovakia, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Tajikistan, Tunisia, Turkey, Ukraine, USA (introduced) (California, Great Plains, Northeast, Pacific Northwest), Uzbekistan, former Yugoslavia, (Cerretti & Ziegler, 2004; Tschorsnig et al., 2004; Vanhara & Tschorsnig, 2006; Stanković et al., 2014; O'Hara et al., 2020; Hammami et al., 2022) (Fig. 4F).

Hosts. Lepidoptera: *Hyphantria cunea* (Drury, 1773), *Lymantria dispar* (Linnaeus, 1758) *Leucoma salicis* (Linnaeus, 1758), *Euproctis chrysorrhoea* (Linnaeus, 1758); *Orgyia trigotephras* Boisduval, 1829, *Ocneria terebinthina* Stgr. (Erebidae); *Cydalima perspectalis* (Walker, 1859) (Crambidae); *Hemileuca oliviae* Cockerell, 1898 (Saturniidae); *Thaumetopoea jordana* (Staudinger, 1894, *T. solitaria* (Freyer, 1838), *T. pityocampa* (Denis & Schiffermüller, 1775), *T. ispartaensis* Doğanlar & Avcí (Notodontidae); *Euphydryas aurinia* (Rottemburg, 1775), *Nymphalis antiopa* (Linnaeus, 1758) (Nymphalidae); *Thiacidas postica* Walker, 1855, *Mythimna unipuncta* (Haworth, 1809); *Dicycla oo* (Linnaeus, 1758) (Noctuidae) (Halperin, 1990; Sabahi, 1997; Camerini & Groppali, 1999; Dehghani Zahedani et al., 2006; Farar, 2006; Al-e-Mansoor, 2008; Saeidi, 2011; Stanković et al., 2014; Ghahari, 2017; Tschorsnig, 2017; Farahani et al., 2018; Martini et al., 2019; O'Hara et al., 2020; Hammami et al., 2022).

Genus *Exorista* Meigen, 1803

***Exorista larvarum* (Linnaeus, 1758)** (Fig. 3B)

For taxonomical and morphological characters of this species see Tschorsnig and Herting (1994).

Material examined. Iran, Guilan province, Rezvanshahr, Paresar, Sandian, (37°57′22.70″ N, 49°12′82.95″ E), 02.ix.2019, 181♂, 196♀; on larvae of *Hyphantria cunea*, leg. A. Karami.

Distribution in Iran. Guilan (Ghahari, 2017; current study), Mazandaran (Ghahari, 2017), West Azerbaijan (Karimpour et al., 2005), Zanjan (Modarres Awal, 1994), Kohgiluyeh and Boyer-Ahmad (Saeidi, 2011).

General distribution. Armenia, Austria, Azerbaijan, Belarus, Belgium, British Isles, Bulgaria, Canada (introduced), China, Corse, Croatia, Czech Republic, Denmark, Egypt, Finland, France, Georgia, Germany, Greece, Hungary, India, Iran, Israel, Italy, Japan (Hokkaidō, Honshū, Kyūshū), Korean Peninsula (North Korea), Kyrgyzstan, Latvia, Lithuania, Macedonia, Moldova, Mongolia, Netherlands, New England, Palestine, Poland, Portugal, Romania, Russia (Eastern Siberia, Southern Far East, Western Russia, Western Siberia), Saudi Arabia, Scotland, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Taiwan, Tajikistan, Tunisia, Turkey, Turkmenistan, Ukraine, USA (introduced), Uzbekistan (Kara et al., 2007; El-Hawagry, 2018; O'Hara et al., 2020) (Fig. 4G).

Hosts. Lepidoptera: *Hyphantria cunea* (Drury, 1773), *Lymantria dispar* (Linnaeus, 1758), *Euproctis chrysorrhoea* (Linnaeus, 1758), *Leucoma salicis* (Linnaeus, 1758), *Arctia caja* (Linnaeus, 1758) (Erebidae); *Pieris brassicae* (Linnaeus, 1758), *P. rapae* (Linnaeus, 1758), *Colias croceus* (Fourcroy, 1785) (Pieridae); *Malacosoma castrensis* (Linnaeus, 1758), *M. neustria* (Linnaeus, 1758), *Dendrolimus pini* (Linnaeus, 1758) (Lasiocampidae); *Tortrix viridana Linnaeus, 1758 (Tortricidae*); *Cydalima perspectalis* (Walker, 1859) (Crambidae); *Mamestra oleracea* (Linnaeus, 1758), *M. brassicae* (Linnaeus, 1758), *Autographa gamma* (Linnaeus, 1758), *Spodoptera exigua* (Hübner, 1808), *S. littoralis* (Boisduval, 1833), *Agrotis segetum* (Denis & Schiffermüller, 1775), *Prodenia litura* (Fabricius, 1775), *Peridroma saucia* (Hübner, 1808), *Xestia c-nigrum* (Linnaeus, 1758), *Simyra dentinosa* Freyer, 1838, *Mythimna loreyi* Duponchel, 1827, *M. unipuncta* (Haworth, 1809), *Trichoplusia ni* (Hübner, 1803), *Lacanobia oleracea* (Linnaeus, 1758), *Orthosia gracilis* (Denis & Schiffermüller, 1775) (Noctuidae) (Herard et al., 1979; Kara & Tschorsnig, 2003; Karimpour et al., 2005; Kara et al., 2007; Cerretti & Tschorsnig, 2010; Razmi et al., 2011; Saeidi, 2011; Depalo et al., 2012; Tschorsnig, 2017; Martini et al., 2019; O'Hara et al., 2020).

Family Phoridae Latreille, 1796

Genus *Megaselia* Rondani, 1856

Megaselia scalaris (Loew, 1866) (Fig. 3C)

For taxonomical and morphological characters of this species see Disney (2008), Disney and Sinclair (2008), Brown and Oliver (2007).

Material examined. Iran, Guilan province, Rezvanshahr, Paresar, Sandian, (37°57′22.70″ N, 49°12′82.95″ E), 02.ix.2019, 5♂, 3♀; on pupae of *Hyphantria cunea*, leg. A. Karami.

Distribution in Iran. Alborz (Zamani et al., 2005), Zanjan (Ghavami & Djalilvand, 2015), Fars (Sadeghi et al., 2013), Guilan (Ejlali et al., 2008; current study).

General distribution. Albania, Andorra, Angola, Austria, Belgium, Bosnia and Herzegovina, Brazil, Bulgaria, Cameroon, Cape Verde, China, Colombia, Congo, Costa Rica, Croatia, Cuba, Egypt, France, Georgia, Ghana, Greece, India, Iran, Italy, Japan, Kuwait, Macedonia, Malaysia, Malta, Mexico, Montenegro, Netherlands, New Zealand, Norway, Pakistan, Philippines, Portugal, Puerto Rico, San Marino, Saudi Arabia, Serbia, Slovenia, South Korea, Spain, Sri Lanka, Tanzania, Thailand, Togo, Turkey, United Kingdom, United States of America, Venezuela (Brown & Oliver, 2007; Disney, 2008; Wakid, 2008; Disney et al., 2010; Seebens et al., 2017; Cham et al., 2018; Khameneh et al., 2018; Debnath & Roy, 2019) (Fig. 4H).

Hosts. Lepidoptera: *Hyphantria cunea* (Drury, 1773) (Erebidae), *Peridroma saucia* (Hübner, 1808) (Noctuidae); Diptera: *Aneomochtherus mundus* (Loew, 1849) (Asilidae), *Palaeosepsis* sp. (Sepsidae); Hemiptera: *Triatoma brasiliensis* Neiva, 1911 (Reduviidae); Hymenoptera: *Apis mellifera* Linnaeus, 1758 (Apidae); Blattodea: *Macrotermes gilvus* (Hagen, 1858) (Termitidae); Ixodida: *Dermacentor nitens* Neumann, 1897 (Ixodidae); *Rhipicephalus microplus* Canestrini, 1888 (Ixodidae); *Otobius megnini* Dugès, 1883 (Argasidae); *Amblyomma variegatum* Fabricius, 1794 (Ixodidae); Orthoptera: *Zonocerus variegatus* (Linnaeus, 1758) (Pyrgomorphidae); Coleoptera: *Curculio caryae* Horn, 1873 (Curculionidae); *Macrodactylus marinus* (Scarabaeidae); Araneae: *Brachypelma vagans* (Ausserer, 1875) (Theraphosidae); Mantodea: *Parastagmatoptera tessellata* Saussure & Zehntner, 1894 (Mantidae); Agaricales: *Agaricus bisporus* (Lange, 1946) (Agaricaceae); Scorpiones: *Mesobuthus eupeus* (Koch, 1839) (Buthidae) (Gregorio & Leonide, 1980; Harrison & Gardner, 1991; Arredondo-Bernal & Trujillo-Arriaga, 1994; Downie et al., 1995; Zamani et al., 2005; Costa et al., 2007; Ejlali et al., 2008; Disney, 2008; Abdi Goodarzi et al., 2012; Mongiardino Koch et al., 2013; Machkour-M'Rabet et al., 2015; Zhang et al., 2017; Marchiori, 2020; Noknoy et al., 2020).

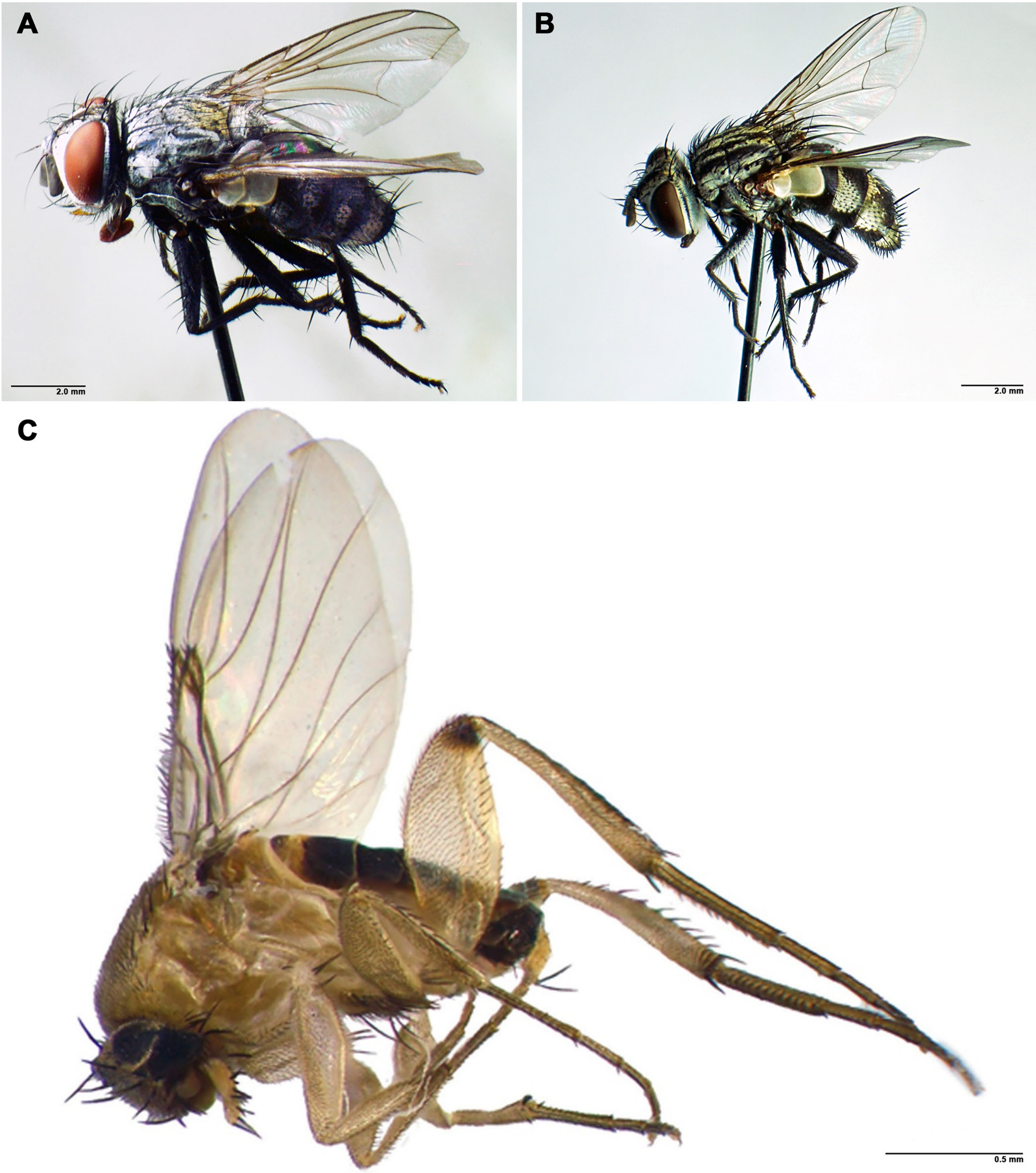

Figure 3. General habitus of the dipterous parasitoids of *Hyphantria cunea* (Drury, 1773) in North of Iran. **A.** *Compsilura concinnata* (Meigen, 1824) (female); **B.** *Exorista larvarum* (Linnaeus, 1758) (female) (Diptera, Tachinidae); **C.** *Megaselia scalaris* (Loew, 1866) (female) (Diptera, Phoridae).

Species frequency and rate of parasitism. Four parasitoid species were found as the major insect parasitoids of the fall webworm. These were *Chouioia cunea* Yang, 1989 (Hym., Eulophidae), *Psychophagus omnivorus* (Walker, 1835) (Pteromalidae), *Compsilura concinnata* (Meigen, 1824) and *Exorista larvarum* (Linnaeus, 1758)

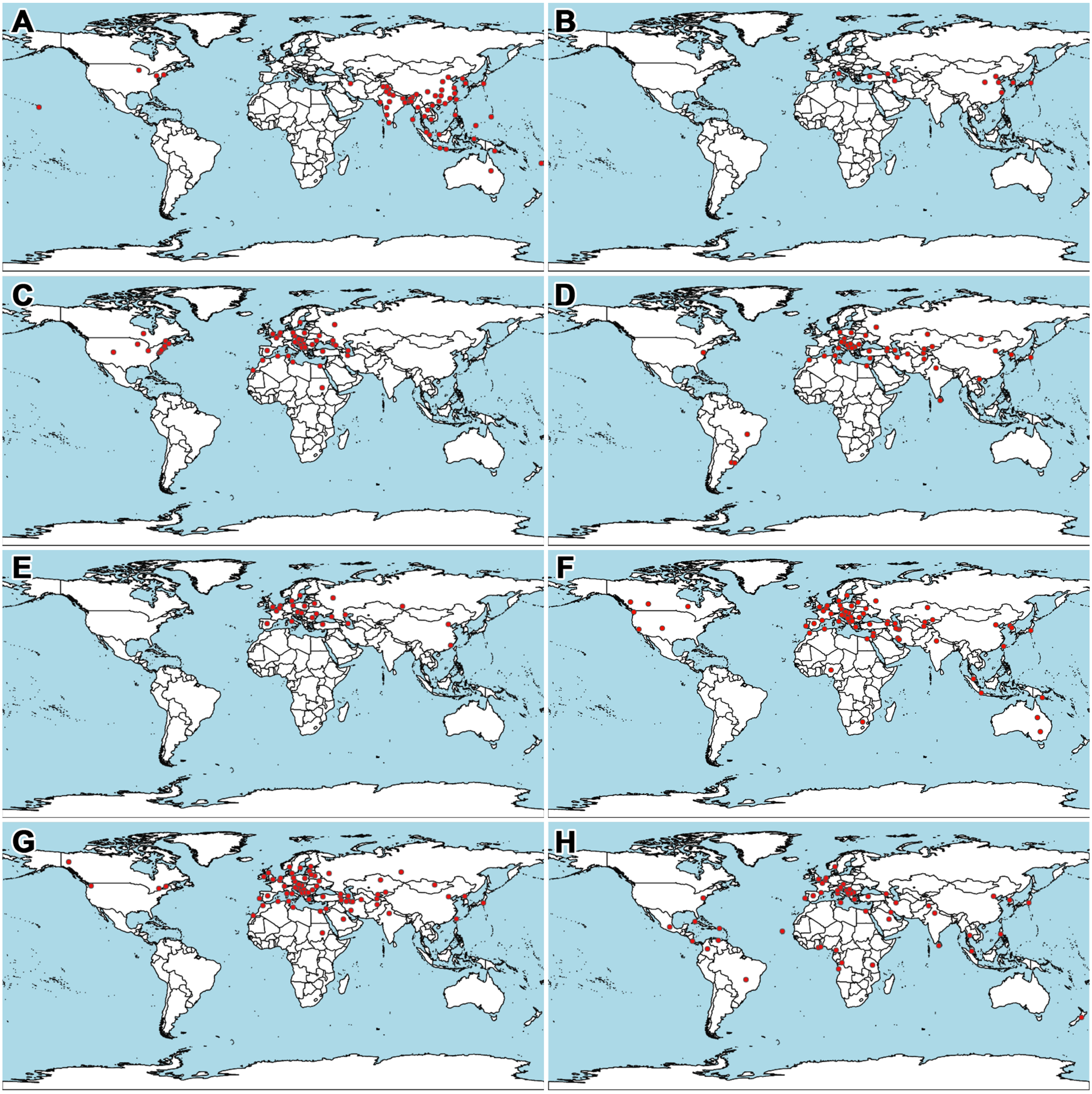

Figure 4. The worldwide distribution map for the parasitoids of *Hyphantria cunea* (Drury, 1773). **A.** *Brachymeria lasus* (Walker, 1841); **B.** *Chouioia cunea* Yang, 1989; **C.** *Psychophagus omnivorus* (Walker, 1835); **D.** *Pimpla rufipes* Brulle, 1846; **E.** *Virgichneumon dumeticola* (Gravenhorst, 1829); **F.** *Compsilura concinnata* (Meigen, 1824); **G.** *Exorista larvarum* (Linnaeus, 1758); **H.** *Megaselia scalaris* (Loew, 1866).

(Diptera, Tachinidae) which appeared to have considerable influence on the population of this pest. Among the hymenopterous parasitoid species, *C. cunea* and *P. omnivorus* showed the highest number of *H. cunea* parasitoids in the collected pupae samples. Of these, *C. cunea* was the most abundant parasitoid species and may be important in the initial regulation of moth populations. *Exoriata larvarum* and *C. concinnata* were also the dominant larval parasitoids of this pest. *Compsilura concinnata* occupied the position as the second most abundant parasitoid of *H. cunea*. The gregarious endoparasitoid *E. larvarum*, despite the lower population than *C. concinnata*, appeared to have considerable influence on the population of this moth pest. The rest of the species were in relatively low densities, with fewer than ten individuals each and did not play an important role as regulating agents of *H. cunea* (Fig. 5). There was a significant difference in the contribution of each parasitoid species to overall parasitism (66.3%) achieved by the parasitoid complex. *Chouioia cunea* was the most predominant and effective species with the highest parasitism percentage among collected parasitoids (24.33%) and is followed by *P. omnivorus* (15.5%) and *C. concinnata* (13.73%). *Exorista larvarum* was the fourth most prevalent parasitoid recovered in this study (12.57%) which can be a major factor for the population dynamics of this pest. But the remaining species were rare, with fewer than ten individuals each and overall represent 0.53% of the parasitoids reared from *H. cunea* (Fig. 6).

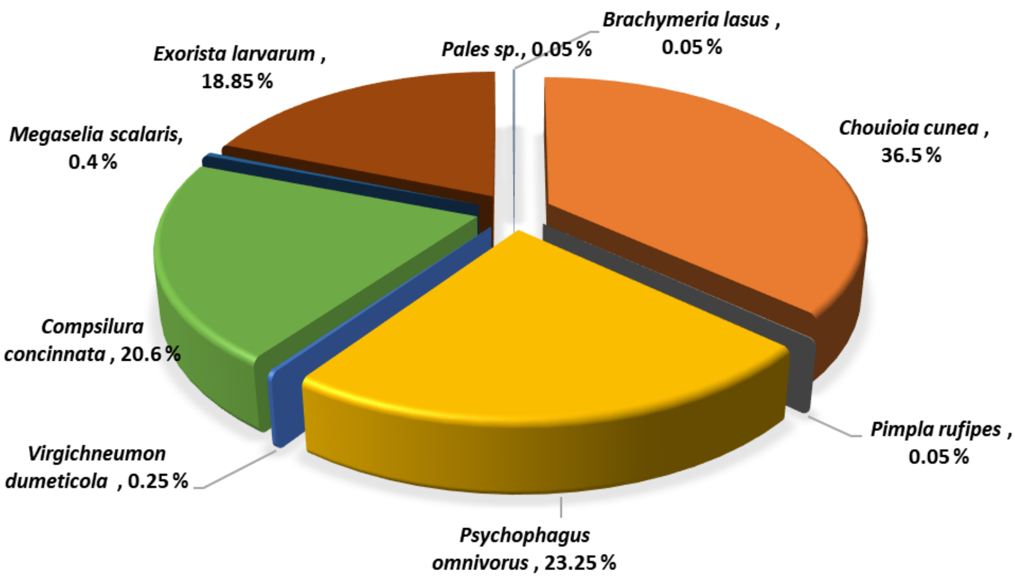

Figure 5. Frequency of the larval and pupal parasitoids of *Hyphantria cunea* (Drury, 1773) (Lepidoptera, Erebidae) in northern Iran.

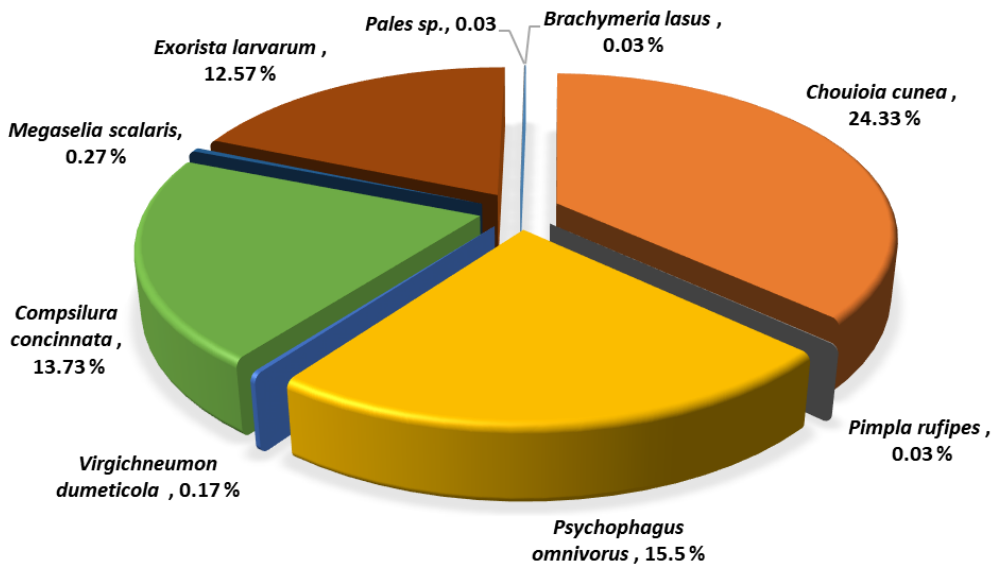

Figure 6. Parasitization rate of the larvae and pupae of *Hyphantria cunea* (Drury, 1773) (Lepidoptera, Erebidae) by native parasitoids in northern Iran.

DISCUSSION

In this research, we focused on searching for native insect enemies of the fall webworm in Hyrcanian forest in northern Iran, trying to find effective species as potential biological control agents. In this study, nine species were detedted as parasitoid of the larvae and pupae of *H. cunea,* but only those that their population was appeared to influence the population of this pest would be discussed. Accordingly, the four abundant parasitoids attacking *H. cunea* were *C. cunea*, *P. omnivorus*, *C. concinnata*, and *E. larvarum* (Fig. 5). *Chouioia cunea* was the most predominant species with the highest parasitism rate (24.33%) among the collected parasitoids and is followed by *P. omnivorus* (15.5%) and *C. concinnata* (13.73%). *Exorista larvarum* was also the fourth most prevalent parasitoid recovered in this study (12.57%).

Chouioia cunea was found as the most important parasitoid of *H. cunea* in several countries (Boriani, 1994; Japoshvili et al., 2006; Yang et al., 2006). Native natural enemies, especially *C. cunea,* seem to have significant impacts on the fall webworm populations in northern Iran (Figs 5, 6). Although no quantitative estimate of the actual reduction in numbers of this moth were made over the study period, it was apparent that the high population of this parasitoid would affect the pest population drastically. *Chouioia cunea* has more generations than the fall webworm (two generations) in a year (Yang, 1989), but since it has a broad host range can maintain its own populations in the absence of the *H. cunea* pupae. Numerous alternative hosts and the year-round availability of host makes it an ideal parasitoid for developing and implementing IPM programs which may be put into practice in the future (Yang et al., 2006; Edosa et al., 2019). On the other hand, the life cycles of the pest individuals are not identical and the phenomenon of generation overlap is particularly obvious. Therefore, there are fairly large quantities of the pest pupae between the first- and second-generation pupae and the host pupae are always available. Notwithstanding, *C. cunea* is a broad oligophagus species, the parasitization rate reported by Yang (1989) on *H. cunea* (83.2 and 68.15%) shows a remarkable fitness to this pest. This trait, along with the advantages like high reproductive capacity and fast reproduction speed seems to be reasons that makes it particularly useful as a control agent.

Among the larval parasitoid species, *C. concinnata* was found to be a common species in northern Iran. This dipterous parasitoid has generally been recorded attacking other forest lepidopterous defoliators such as *Cydalima perspectalis* (Walker, 1859) (Lepidoptera, Crambidae) (Farahani et al., 2018) in northern Iran, and *Thaumetopoea solitaria* (Freyer, 1838) (Lepidoptera, Notodontidae) in Fars province, southwest of Iran (Dehghani Zahedani et al., 2006) and was not specific in their choice of host and distribution. It was also designated as a parasitoid of other forest pests, such as *Ocneria terebinthina* Stgr. (Lepidoptera, Erebidae) (Sabahi, 1997) in Kerman province, southeast of Iran, *Thiacidas postica* Walker, 1855 in Bousher province, south of Iran (Farar, 2006) and *Dicycla oo* (Linnaeus, 1758) (Lepidoptera, Noctuidae) in Fars province, southwest of Iran (Al-e-Mansoor, 2008). This species has low parasitism rates (2.16%) on larvae of *T. solitaria* in Arsanjan region of Fars province, located in southern Iran (Dehghani Zahedani et al., 2006). Since it is a multivoltine fly, it appears to be able to have better control on *H. cunea*, however, because it attacks a wide range of pests and is not specific, it is also likely that it does not provide an acceptable percentage of parasitism. In confirmation of this conclusion, in a biological control program for the gypsy moth in Northern America, this parasitoid was imported from Europe in 1906, where the pest is native. However, during the pest outbreak, it parasitized less than 5% of the pest population and the program was ultimately not successful (Weseloh, 1984). So, this remains a subject for additional research, since host-preferences could affect parasitoid efficiency. On the other hand, because parasitism rates vary spatially and temporally (Stiling & Simberloff, 2000) more extensive data from additional sites and years are needed. Another trait that makes this parasitoid particularly useful as a control agent for the fall webworm is that *C. concinnata* overwinters inside a host caterpillar or pupa, and *H. cunea* also overwinters as a pupa which this could be cited as another reason for the preference of *C. concinnata* for *H. cunea* than for other hosts. However, this scenario can also be interpreted in other ways as the fall webworm is bivoltine and *C. concinnata* produces more generations a year (Webber & Schaffner, 1926), this parasitoid must attack alternate hosts after fall webworm larvae are no longer available (Weseloh, 1984) that this can lead to a potential negative impact on Lepidoptera in general and nontarget species in particular. On the other hand, *C. concinnata* is an extreme generalist parasitoid and although it is clear that its impact varies regionally, in recent discussions of nontarget effects of biological control, *C. concinnata* has been cited as posing risks to native species (Hawkins & Marino, 1997; Stiling & Simberloff, 2000), so the impact of this parasitoid on nontarget hosts is unpredictable and future studies should aim to explore interactions between *C. concinnata* and its lepidopteran hosts. Despite all the above mentioned explanations, there are successful examples worldwide introductions of generalist natural enemies such as *Pimpla disparis* Viereck, 1911 (Hymenoptera, Ichneumonidae), an ichneumonid parasitoid first released in the 1970s and introduced repeatedly in subsequent years to control gypsy moth in North America (Schaefer et al., 1989).

Exorista larvarum is a well-known parasitoid of forest and agricultural defoliators in many parts of the world (Sabrosky & Reardon, 1976; Sannino & Espinosa, 1999). Various lepidopteran species belonging to families Erebidae, Lymantriidae, Noctuidae, Pieridae, and Pyralidae were recognized as hosts of this parasitoid (Kara & Tschorsnig, 2003). It has been previously recorded as a parasitoid of *Lymantria dispar* (Linnaeus, 1758) (Herard et al., 1979), *Euproctis chrysorrhoea* (Linnaeus, 1758) (Lepidoptera, Erebidae), *Pieris brassicae* (Linnaeus, 1758) (Lepidoptera, Pieridae) (Razmi et al., 2011), *Malacosoma neustria* (Linnaeus, 1758) (Lepidoptera, Lasiocampidae), *Mamestra oleracea* (Linnaeus, 1758), *Spodoptera exigua* (Hübner, 1808) and *Simyra dentinosa* Freyer, 1838 (Lepidoptera, Noctuidae) (Karimpour et al., 2005) in Iran. Biological factors such as nonsynchronised development with the host make this parasitoid particularly suitable for use in the biological control of forest lepidopterous defoliators including *H. cunea*. The most important benefit of this parasitoid is the fast population build-up that enables it to control an increasing pest population in a short period of time. *Exorista larvarum* also like *C. cunea* and *C. concinnata* is polyphagous, but the fact that these parasitoids are native and partly widespread in northern Iran may minimize their impact on non-target lepidopterous species. However, the potential of this species as biocontrol agent also deserves to be investigated, in order to increase knowledge on the overall effect exerted on the fall webworm and other lepidopterous species.

The gregarious endoparasitoid *P. omnivorus* could also be a possible candidate for biological control of *H. cunea*. It was designated as a pupal parasitoid of various pest species, such as *Malacosoma neustria* (Linnaeus, 1758) (Lepidoptera, Lasiocampidae) (Özbek & Çoruh, 2010), and *H. cunea* (Rezaei et al., 2003). *Psychophagus omnivorus* is a pro-ovigenic species (Flanders, 1950). Since the complement of eggs is therefore finite, once these have been deposited, parasitoid cannot mature any more eggs and the adult wasp remains reproductively inactive until death. By contrast, *P. omnivorus* does not immediately distribute all of her eggs into host individuals, since they will not support big broods. The oviposition period is thus prolonged, as the parasitoid continues to lay into a larger number of hosts, until its egg-supply is finally exhausted. This increases the number of parasitized hosts and increases the chance of adult parasitoid emergence from the host pupae, and finally resulting in a further decrease in the pest population.

Conservation of indigenous *H. cunea* parasitoids as part of community-oriented IPM programs are practical and reasonable approaches to alleviating growing public concerns about the environment, and humans and other nontarget organisms safety in forest ecosystems. Furthermore, other mortality agents of the pest, such as predators and entomopathogenic bacteria, fungi, viruses, and nematodes should be studied in detail to enhance our understanding of the impact of all mortality factors on *H. cunea* populations (Gholami Ghavamabad et al., 2021a, 2021b; Edosa et al., 2019; Wang et al., 2020). Ultimately, it is hoped that this study will provide a general basis for study of the natural enemies of *H. cunea* in future works. Additional field surveys and detailed studies to understand the role of these and other parasitoids will be essential in implementing effective IPM programs in Hyrcanian forests of northern Iran.

AUTHOR'S CONTRIBUTION

The authors confirm their contribution in the paper as follows: A. Karami: Compiling the data, sampling, mounting preparation of the photographs, and writing the manuscript. A.A. Talebi: Supervising the work, identification of species, writing the manuscript and correspondence. E. Gilasian: Identification of species, checking the validity of the recorded data and revising the manuscript. Y. Fathipour and M. Mehrabadi: Revising the manuscript. All authors read and approved the final version of the manuscript.

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AVAILABILITY OF DATA AND MATERIAL

Datasets and specimens used to support the findings of this study are available from the corresponding author upon request.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this paper.

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پارازیتوییدهای بومی شب‌پره تارتن پاییزی *Hyphantria cunea* (Drury, 1773) (Lepidoptera: Erebidae)، آفت مهاجم غیربومی در شمال ایران

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چکیده: شب‌پره تارتن پاییزی، *Hyphantria cunea* (Drury, 1773) (Lepidoptera, Erebidae) یکی از مهمترین آفات درختان جنگلی در شمال ایران است. به منظور شناسایی پارازیتوییدهای بومی این آفت، نمونه‌برداری در سال ۲۰۱۹ در استان گیلان انجام شد. لاروها و شفیره‌های آفت از روی درختان مختلف و زیر تنه‌های خشکیده جمع‌آوری و به آزمایشگاه منتقل و در شرایط آزمایشگاهی تا زمان ظهور حشرات کامل پارازیتویید پرورش داده شدند. بر اساس نتایج بدست آمده، پنج گونه از بال‌غشاییان شامل *Brachymeria lasus* (Walker, 1841) از خانواده Chalcididae، *Chouioia cunea* Yang, 1989 از خانواده Eulophidae، *Psychophagus omnivorus* (Walker, 1835) از خانواده Pteromalidae، *Pimpla rufipes* Brulle, 1846 و *Virgichneumon dumeticola* (Gravenhorst, 1829) از خانواده Ichneumonidae و چهار گونه از دوبالان شامل *Compsilura concinnata* (Meigen, 1824)، *Exorista larvarum* (Linnaeus, 1758)، یک از گونه از جنس *Pales* از خانواده Tachinidae و *Megaselia scalaris* (Loew, 1866) از خانواده Phoridae به عنوان پارازیتوییدهای آفت، شناسایی شدند. در بین آنها شش گونه (*P. rufipes*، *V. dumeticola*، *B. lasus*، *E. larvarum*، *C. concinnata* و یک گونه ناشناخته از جنس *Pales*) برای اولین بار از ایران به عنوان پارازیتویید شب پره *H. cunea* گزارش شدند.

واژگـان کلیدی: آفت مهاجم، حفاظت، پارازیتویید، Tachinidae، Chalcidoidea، Ichneumonidae