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Hymenopteran dominance in pollination of *Adhatoda vasica* (l.) nees and *Woodfordia fruticosa* (L.) kurz.: A study from Jogindernagar, Himachal Pradesh

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Abstract
Insect pollinators are crucial in maintaining ecosystem balance and ensuring the reproduction of flowering plants, including medicinal plants. This study investigated the diversity, distribution, and relative abundance of insect pollinators visiting two medicinal plants, *Adhatoda vasica* (L.) Nees and *Woodfordia fruticosa* (L.) Kurz, in Joginder Nagar, Himachal Pradesh, India, from 2019 to 2023. A total of 31 insect species were recorded, with 26 species visiting *A. vasica* and 16 species visiting *W. fruticosa*. The insect pollinators belonged to four orders: Hymenoptera, Diptera, Lepidoptera, and Coleoptera. Hymenopterans were the most abundant pollinators for both plant species, with *Apis dorsata* being the most frequent visitor to *A. vasica* and *Apis cerana* being the predominant visitor to *W. fruticosa*. The relative abundance of insect pollinators on *A. vasica* revealed that hymenopterans (78.61%) were the most abundant, followed by dipterans (15.01%), lepidopterans (4.94%), and coleopterans (1.42%). On *W. fruticosa*, hymenopterans (76.78%) were the most abundant, followed by dipterans (21.02%), lepidopterans (1.79%), and coleopterans (0.38%). The findings highlight the importance of insect pollinators in the reproductive biology of these medicinal plants and emphasize the need for conservation strategies to protect pollinator diversity and ensure the sustainability of pollination services in natural ecosystems and agriculture.

Keywords: Diversity, Distribution, Relative abundance, Insect pollinators, *Adhatoda vasica* (L.) Nees, *Woodfordia fruticosa* (L.) Kurz.

Introduction

Insect pollinators are essential for maintaining ecosystem balance, ensuring food security, and helping the reproduction of flowering plants. They pollinate more than 80% of the world's flowering plants, including many important crops (Nath *et al*., 2022) [12]. While bees, particularly honeybees and bumblebees, are often recognized as the primary pollinators, other insect groups such as beetles (Coleoptera), flies (Diptera), and butterflies and moths (Lepidoptera) also play significant roles in pollination (Weiss, 2001) [23]. The diversity of insect pollinators and their crucial functions in both natural ecosystems and agriculture underscore the importance of conservation. However, threats such as habitat destruction, pesticide use, and air pollution (Ryalls *et al*., 2022) [14] have led to declines in pollinator populations, which could have serious consequences for global biodiversity and food production. To sustain pollination services, it is vital to adopt strategies that protect both managed and wild pollinators. This includes providing suitable habitats and reducing harmful environmental factors (Kevan *et al*., 1990) [7].

Adhatoda vasica (L.) Nees, also known as Vasaka or Adosa, are medicinal shrubs extensively used in traditional Ayurvedic and Unani medicine for over 2500 years (Shoaib, 2022) [17]. This plant, which belongs to the Acanthaceae family, is found throughout the tropical regions of Southeast Asia (Chakraborty and Brantner, 2001) [2]. It has been used to treat various ailments, including respiratory disorders, infections, and inflammatory conditions. *A. vasica* is known for its wide range of pharmacological activities, particularly its effectiveness against respiratory issues, such as bronchitis, asthma, and cough (Hossain & Hoq) [5]. It also exhibits antibacterial, antifungal, hepatoprotective, anti-ulcer, antiviral, anti-inflammatory, thrombolytic, hypoglycemic, anti-tubercular, antioxidant, and antitussive properties (Shamsuddin *et al*., 2021) [15]. Vasicine, the primary active alkaloid in *A. vasica*, along with other compounds such as l-vasicinone, deoxyvasicine, and vasicinol, contributes to its medicinal value (Shoaib, 2022) [17] and become scarce successively in winter. The flowering period for *Adhatoda* is from March to April, offering a valuable alternative for foraging pollinators when resources begin to dwindle.

Woodfordia fruticosa (L.) Kurz (Syn. *Lythrum fruticosum* L.) of the Lythraceae family, commonly referred to as Fire flame bush, Shiranjitea, Dhai, Dhataki, Dawi, is a plant native to tropical and subtropical regions. It is found in most Southeast Asian countries, including Malaysia, Indonesia, Sri Lanka, China, Japan, Pakistan, and tropical Africa. The plant is reported to be present throughout India up to an altitude of 1500 m. *W. fruticosa* has long been used as traditional medicine by practitioners in the Southeast Asian region, particularly in India. Ayurvedic and Unani medicinal systems extensively use the flower parts of plants as herbal remedies (Das *et al*., 2007) [3]). *W. fruticosa* exhibits a broad spectrum of medicinal benefits, such as antioxidant, antidiabetic, antidepressant, antimicrobial, anti-inflammatory, and antiviral properties (Kafle *et al*., 2021) [6] These observations indicate that this may serve as a promising source of dietary supplements and therapeutic agents for various health problems (Najda *et al*. 2021; Tayab *et al*. 2021) [11] [20]. In the context of Indian medicinal systems, flower is described as pungent, acrid, cooling, toxic, alexiteric, uterine sedative, and antihelmentic, and is beneficial for conditions such as dysentery, leprosy, erysipelas, blood disorders, leucorrhea, and menorrhagia

(Gupta *et al*. 2008) [4]. Flowers of *Woodfordia fruticosa* bloom from April to May and are bright red.

Further research focusing on the reproductive biology and pollination ecology of these medicinal plants is essential to identify their pollinators and comprehend their roles in the plant lifecycle. Conserving medicinal plants is a vital responsibility for any nation, especially to meet local healthcare needs. An effective long-term conservation plan will protect and restore endangered medicinal plants while maintaining their diversity, which is crucial for preserving the natural gene pool dependent on pollination.

Methodology

Studies on the diversity, distribution, and relative abundance of various insect pollinators of *Adhatoda vasica* (L.) Nees and *Woodfordia fruticosa* (L.) Kurz was conducted by collecting insect pollinators from *Adhatoda* and *Woodfordia* flowers during March-April from 2019 to 2023. This research was conducted in the herbal garden of the Research Institute in the Indian System of Medicine, located in Joginder Nagar, District Mandi of Himachal Pradesh. This region, situated between 31° 50' North and 76° 45' East, boasts rich and diverse flora owing to its favorable climate. Joginder Nagar is located at altitudes ranging from 900 to 2,800 meters above sea level, with a significant portion of its area covered by forests. Studies on the relative abundance of various insect visitors were conducted by randomly selecting plants based on their size, age, flowering stage, and number of branches and determining their visits per 500 flowers/10 min (Verma and Chauhan, 1985) [22]. Observations were recorded at regular intervals between 0900-1700 hours each day, and the average count during these hours provided the abundance of insect pollinators for that specific day (Southwood 1978) [19]. Species diversity and relative abundance were statistically analyzed from the collected data (Snedcor and Cochran, 1993) [18]. Similarly, the family number, family percentage, order number, and order percentage were calculated for all insect collection sites, and the results were tabulated. The relative abundances of different pollinator species were calculated using the following formula and expressed as percentages.

$$\text{Relative abundance of species} = \frac{\text{Total number of individual of species A}}{\text{Total number of individuals of all species}} \times 100$$

Results and Discussion

The present insect pollinator's diversity and distribution studies, which were conducted on two medicinal plants, revealed that *Adhatoda vasica* (L.) Nees and *Woodfordia fruticosa* (L.) Kurz was visited by 31 species during the entire flowering period, in Jogindernagar District Mandi, Himachal Pradesh (Table I, Figure I, Figure II). Among 31 insect species, 26 species have been collected from *Adhatoda vasica* (L.) Nees, belongs to 4 orders and 9 families. Among these 26 insects, 12 species of Hymenoptera, 6 species of the order Diptera, 5 from Lepidoptera, and 3 from Coleoptera. Hymenoptera was represented by 3 families, i.e. Apidae, Vespidae, Halictidae, with species like *Apis cerana, Apis melllifera, Apis dorsata, Bombus haemorrhoidalis, Bombus trifasciatus, Xylocopa tenuiscapa, Ceratina* sp., *Vespa velutina auraria, Polistes delhiensis, Polistes rothneyi, Ropalidia brevita,* and *Halictus* sp. Six species of dipterans i.e. *Episyrphus (Episyrphus) balteatus, Eupeodes* sp., *Melanostoma orientale, Sphaerophoria (Sphaerophoria) indiana*, *Asarkina* sp. and *Ischiodon scutellaris* belong to the family Syrphidae. Five species of lepidopterans were reported, which belong to Pieridae (*Pieris canidia indica, Pieris brassicae*), Nymphalidae (*Ypthima baldus baldus*), Hesperidae (*Pseudocoladenia dan*), and Riodinidae (*Dodona durga*). However, in the order Coleoptera, only 3 insect pollinator species of the family Coccinellidae were recorded, i.e., *Coccinella septempunctata*, *Oenopia kirbyi* Mulsant, and *Harmonia dimidiata.*

During this study, 16 species of insect pollinators were recorded and collected on *Woodfordia fruticosa* (L.) Kurz, belongs to 5 families and 4 orders. Among these 16 species, 8 species belong to Hymenoptera, 6 to Diptera and one each to Lepidoptera and Coleoptera. Hymenoptera was represented by 2 families, i.e., Apidae and Vespidae, with species like *Apis cerana, Apis dorsata, Ceratina* sp., *Vespa velutina auraria, Polistes delhiensis, Polistes rothneyi*, *Ropalidia brevita,* and *Parapolybia varia*. Dipterans were represented by *Eristalis cerealis, Eristalis tenax, Eristalinus (Eristalinus) arvorum, Episyrphus (Episyrphus) balteatus, Melanostoma orientale* and *Ischiodon scutellaris* of the family Syrphidae. Only one species of Lepidoptera, *Aglais caschmirensis* of family Nymphalidae and one from Coleoptera, *Coccinella septempunctata* of Coccinellidae.

Various studies have documented the presence of insect pollinators in numerous medicinal plants across India. Mishra *et al*. (1987) [10] identified *Apis dorsata, Apis cerana indica,* wasps, ants, and flies as the primary pollinators of *Woodfordia floribunda* Salisb. in Solan, Himachal Pradesh. In Thovinakere, Karnataka, India, Shivanna (2009) [16] discovered five insect species that visited the flowers of the medicinally significant plant *Adhatoda vasica* Nees. (Acanthaceae). These species are part of the Hymenoptera and Lepidoptera orders, with Hymenopterans including *Xylocopa verticalis*, *Xylocopa* sp., and *Apis cerana*, while Lepidopterans comprise *Pseudoborbo bevani* (Moore) and *Amegilla* sp. Kumari and Thakur (2021) [8] noted 25 insect pollinator species on *Punica granatum* L., with 13 species from Hymenoptera, 6 from Diptera, 2 from Lepidoptera, and 1 from Coleoptera. Thakur and Katoch (2022) [21] recorded 29 insect pollinators on two medicinal plants, *Bergenia ciliata* (Haw.) Sternb. and *Vinca major* (Linnaeus) at various Shimla hill locations. Of these, 8 species were found on *Bergenia ciliata* (Haw.) Sternb., spanning three orders: Coleoptera, Hymenoptera, and Diptera, whereas 24 species were identified on *Vinca major* (L.). Madhu and Thakur (2023) [13] observed that *Valeriana jatamansi* Jones flowers attracted 51 insect pollinator species from five orders and 12 families of the class Insecta in Shimla Hills. Among these, 33 species belonged to Diptera, four to Hymenoptera, nine to Lepidoptera, three to Coleoptera, and two to Hemiptera.

The relative abundance studies which were conducted on insect pollinators of *Adhatoda vasica* (L.) Nees revealed that hymenopterans (78.61%) were the most abundant insect pollinators, followed by dipterans (15.01%), lepidopterans (4.94%) and coleopterans (1.42%) respectively. Among hymenopterans, *Apis dorsata* (16.83±1.36, 15.39%) is most abundant insect pollinators followed by *Apis cerana* (12.33±0.89, 11.28%), *Bombus haemorrhoidalis* (10.41±1.09, 9.52%), *Apis mellifera* (9.83±0.76, 8.99%), *Bombus trifasciatus* (9.41±0.58, 8.61%), *Ceratina* sp. (8.00±0.53, 7.31%), *Xylocopa tenuiscapa* (5.41±0.63, 4.95%), *Vespa velutina auraria* (3.25±0.44, 2.97%),

Polistes rothneyi (3.25±0.41, 2.97%), *Polistes delhiensis* (2.58±0.43, 2.36%), *Ropalidia brevita* (2.50±0.45, 2.28%) and *Halictus* sp. (2.08±0.19, 1.90%) respectively.

Among dipterans *Episyrphus (Episyrphus) balteatus* (5.66±0.65, 5.18%) was the most abundant pollinators followed by *Sphaerophoria (Sphaerophoria) indiana* (2.66±0.44, 2.43%), *Eupeodes* sp. (2.33±0.43, 2.13%), *Asarkina* sp. (2.25±0.44, 2.05%), *Melanostoma orientale* (1.75±0.35, 1.66%) and *Ischiodon scutellaris (*1.75±0.21, 1.66%) respectively. *Pseudocoladenia dan* (1.75±0.17, 0.17%) was the most abundant lepidopterans followed by *Pieris canidia indica* (1.25±0.25, 1.14%), *Pieris brassicae* (0.91±0.19, 0.83%), *Dodona durga* (0.91±0.19, 0.83%), and *Ypthima baldus baldus* (0.58±0.19, 0.53%) respectively. Among coleopterans, *Oenopia kirbyi* (0.90±0.25, 0.83%) was most abundant, followed by *Coccinella septempunctata* (0.33±0.18, 0.30%) *and Harmonia dimidiate* (0.33±0.18, 0.30%) (Table II).

Table I: Diversity of insect pollinators visiting *Adhatoda vasica* (L.) Nees and *Woodfordia fruticosa* (L.) Kurz with their taxonomic status

Order	Family	Fauna
Hymenoptera	Apidae	1. *Apis cerana* Fabricius, 1793 2. *Apis mellifera* Linnaeus, 1758 3. *Apis dorsta* Fabricius,1793 4. *Bombus haemorrhoidalis* Smith, 1852 5. *Bombus trifasciatus* Smith, 1852 6. *Xylocopa tenuiscapa* Westwood, 1840 7. *Ceratina* sp.
	Vespidae	8. *Vespa velutina auraria* Smith, 1852 9. *Polistes rothneyi* Cameron, 1900 10. *Polistes delhiensis* Das and Gupta, 1984 11. *Ropalidia brevita* Das and Gupta, 1989 12. *Parapolybia varia* (Fabricius, 1787)
	Halictidae	13. *Halictus* sp.
Diptera	Syrphidae	14. *Episyrphus (Episyrphus) balteatus* (De Geer, 1776) 15. *Eristalis tenax* (Linnaeus, 1758) 16. *Eristalis cerealis* Fabricius,1805 17. *Eristalinus (Eristalinus) arvorum* (Fabricius,1787) 18. *Eupeodes* sp. 19. *Melanostoma orientale* Wiedemann, 1824 20. *Sphaerophoria (Sphaerophoria) indiana* Bigot, 1884 21. *Asarkina* sp. 22. *Ischiodon scutellaris* Fabricius, 1805
Lepidoptera	Pieridae	23. *Pieris canidia indica* Evans, 1926 24. *Pieris brassicae* Linnaeus, 1758
	Nymphalidae	25. *Ypthima baldus baldus* Fabricius, 1775 26. *Aglais caschmirensis* (Kollar, 1848)
	Hesperidae	27. *Pseudocoladenia dan* Fabricius, 1787
	Riodinidae	28. *Dodona durga* (Kollar & Redtenbacher, 1844)
Coleoptera	Coccinelliade	29. *Coccinella septempunctata* (Linnaeus, 1758) 30. *Oenopia kirbyi* Mulsant, 1850 31. *Harmonia dimidiata* (Fabricius, 1781)

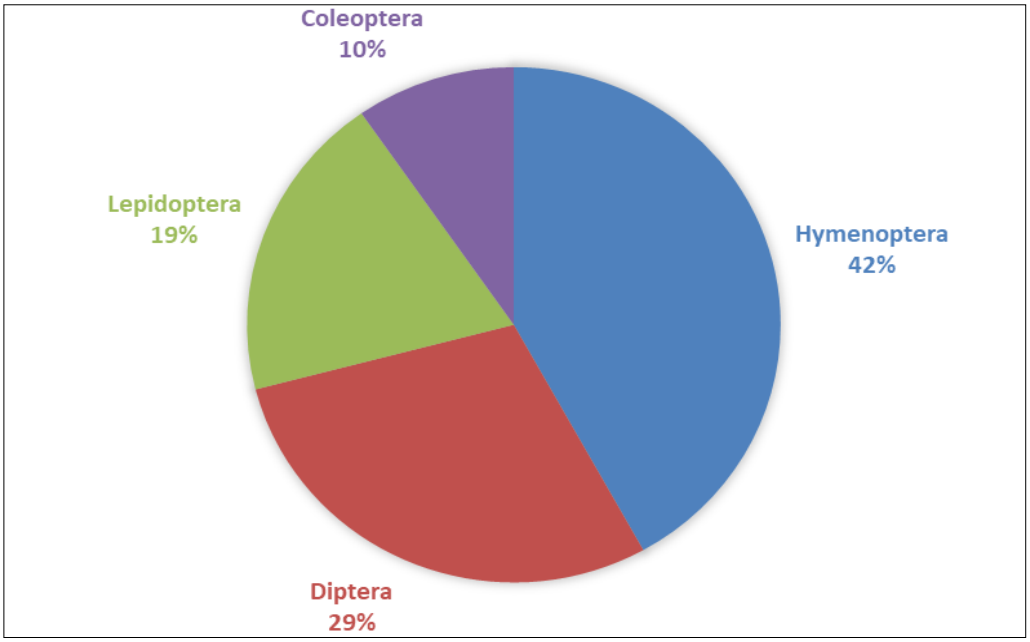

Fig 1: Diversity of insect pollinators visiting flowers of *Adhatoda vasica* (L.) Nees and *Woodfordia fruticosa* (L.) Kurz

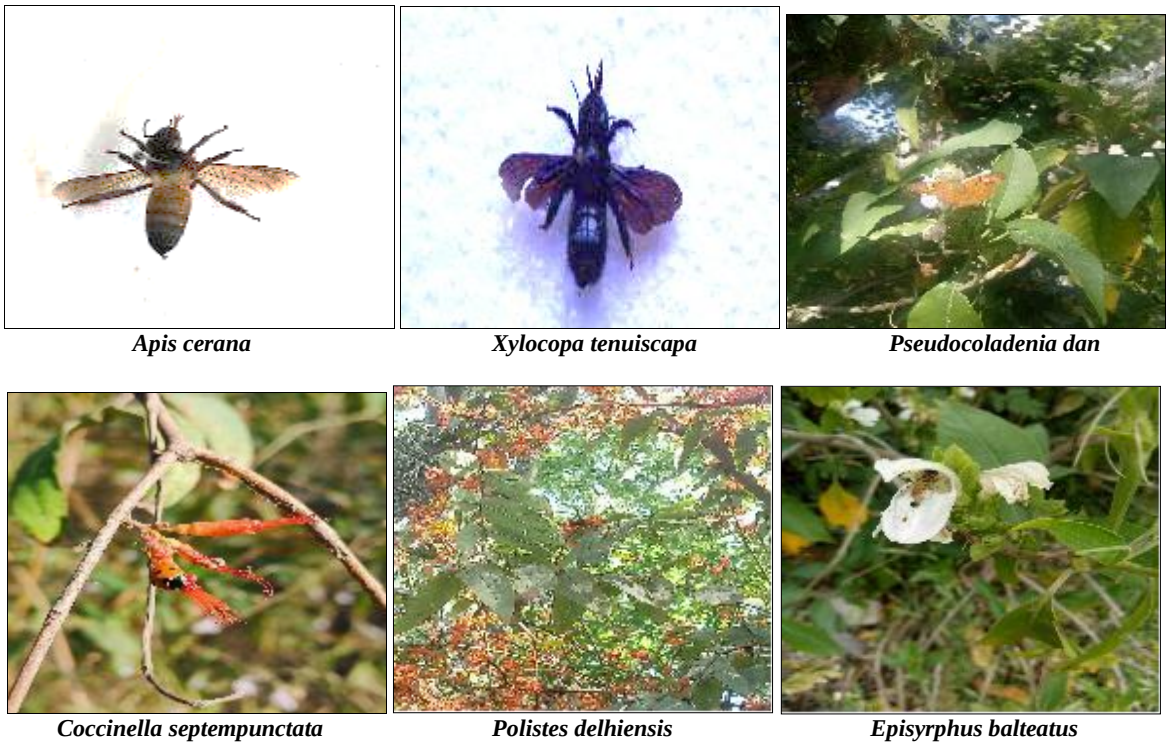

Fig 2: Insect pollinators of *Adhatoda vasica* (L.) Nees and *Woodfordia fruticosa* (L.) Kurz

While studying the relative abundance of insect pollinators of *Woodfordia fruticosa* (L.) Kurz, it has been reported that *Apis cerana* (9.75±1.56, 15.09%) was the most abundant pollinator followed by *Ropalidia brevita*(7.58±1.39, 11.74%), *Parapolybia varia* (7.41±1.41, 11.48%), *Vespa velutina auraria* (6.75±1.33, 10.45%), *Polistes rothneyi* (6.66±1.19, 10.32%), *Polistes delhiensis* (5.91±0.95, 9.16%), *Apis dorsata* (3.08±0.71, 4.77%) and *Ceratina* sp. (2.41±0.39, 3.74%) among hymenopterans. Among dipterans, *Episyrphus (Episyrphus) balteatus* (4.75±1.03, 7.35%) was most abundant folowed by *Eristalis cerealis* (4.16±0.76, 6.45%), *Eristalis tenax* (3.08±0.79, 4.77%), *Eristalinus (Eristalinus) arvorum* (0.58±0.14, 0.90%), *Melanostoma orientale* (0.5±0.15, 0.77%), and *Ischiodon scutellaris* (0.5±0.15, 0.77%). *Aglais caschmirensis* (1.16±0.20, 1.80%) and *Coccinella septempunctata* (0.25±0.13, 0.38%) were the only pollinators of order Lepidoptera and Coleoptera, respectively (Table III).

Current research indicates that hymenopterans are the most prevalent insect pollinators for these two medicinal plants. Although there are limited studies on the relative abundance of these specific plants, existing reports on other medicinal plants align with these findings. Bharti *et al.* (2015) [1] documented 25 insect species from 5 orders that forage on the medicinal plant fennel (*Foeniculum vulgare*) in Hisar, Haryana, India. The study identified that among these 25 insects, 7 were from the order Lepidoptera, 9 from Hymenoptera, 5 from Diptera, 3 from Coleoptera, and 1 from Odonata. The most frequent insect pollinators included *Apis florea*, *A. cerana indica*, *A. mellifera*, and *A. dorsata*. Mattu and Kumar (2016) [9] found that *Cassia fistula* flowers attracted 16 species of solitary bees from 4 families within the order Hymenoptera in the Sirmour and Solan hills, Himachal Pradesh. The study concluded that *Adhatoda vasica* (L.) Nees and *Woodfordia fruticosa* (L.) Kurz flowers were highly appealing to a diverse range of insects. The primary insect orders visiting these medicinal plants were hymenopterans, dipterans, lepidopterans, and coleopterans. Among all insect pollinators, hymenopterans, particularly *Apis* dorsata, were the most common visitors to *Adhatoda vasica* (L.) Nees. In contrast, *Apis cerana* was the predominant flower visitor to *Woodfordia fruticosa* (L.) Kurz, followed by other hymenopterans.

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Table 2: Relative abundance of different insect pollinators visiting *Adathoda vasica* Nees. Flowers in Jogindernagar, District Mandi, Himachal Pradesh (No. of insects/500 flowers/10 minutes)

Order	Family	Insect Species	Mean±SE	Percent Population	Family Percent	Order Percent
Hymenoptera	Apidae	1. *Apis cerana* Fabricius	12.33*±0.89	11.28	66.11	78.61
		2. *Apis mellifera* Linnaeus	9.83±0.76	8.99		
		3. *Apis dorsta* Fabricius	16.83±1.36	15.39		
		4. *Bombus haemorrhoidalis* Smith	10.41±1.09	9.52		
		5. *Bombus trifasciatus* Smith	9.41±0.58	8.61		
		6. *Xylocopa tenuiscapa* Westwood	5.41±0.63	4.95		
		7. *Ceratina* sp.	8.00±0.53	7.31		

	Vespidae	8. *Vespa velutina auraria* Smith	3.25±0.44	2.97	10.60	
		9. *Polistes rothneyi* Cameron	3.25±0.41	2.97		
		10. *Polistes delhiensis* Das and Gupta	2.58±0.43	2.36		
		11. *Ropalidia brevita* Das and Gupta	2.50±0.45	2.28		
	Halictidae	12. *Halictus* sp.	2.08±0.19	1.90	1.90	
Diptera	Syrphidae	13. *Episyrphus balteatus* De Geer	5.66±0.65	5.18	15.01	15.01
		14. *Eupeodes* sp.	2.33±0.43	2.13		
		15. *Melanostoma orientale* Wiedemann	1.75±0.35	1.60		
		16. *Sphaerophoria indiana* Bigot	2.66±0.44	2.43		
		17. *Asarkina* sp.	2.25±0.44	2.05		
		18. *Ischiodon scutellaris* Fabricius	1.75±0.21	1.60		
Lepidoptera	Pieridae	19. *Pieris canidia indica* Evans	1.25±0.25	1.14	1.97	4.94
		20. *Pieris brassicae* Linnaeus	0.91±0.19	0.83		
	Nymphalidae	21. *Ypthima baldus baldus* Fabricius	0.58±0.19	0.53	0.53	
	Hesperidae	22. *Pseudocoladenia dan* Fabricius	1.75±0.17	1.60	1.60	
	Riodinidae	23. *Dodona durga* (Kollar and Redtenbache)	0.91±0.19	0.83	0.83	
Coleoptera	Coccinelliade	24. *Coccinella septempunctata* Linnaeus	0.33±0.18	0.30	1.42	1.42
		25. *Oenopia kirbyi* Mulsant	0.90±0.25	0.83		
		26. *Harmonia dimidiata* Fabricius	0.33±0.18	0.30		

* Each value is an overall average for an insect species S.E. = Standard error about the mean

Table 3: Relative abundance of different insect pollinators visiting *Woodfordia fruticosa* (L.) Kurz flowers in Jogindernagar, District Mandi, Himachal Pradesh (No. of insects/500 flowers/10 minutes)

Order	Family	Insect Species	Mean±SE	Percent Population	Family Percent	Order Percent
Hymenoptera	Apidae	*Apis cerana* Fabricius	9.75*±1.56	15.09	23.61	76.78
		Apis dorsta Fabricius	3.08±0.71	4.77		
		Ceratina sp.	2.41±0.39	3.74		
	Vespidae	*Vespa velutina auraria* Smith	7.58±1.39	11.74	53.16	
		Polistes rothneyi Cameron	7.41±1.41	11.48		
		Polistes delhiensis Das and Gupta	6.75±1.33	10.45		
		Ropalidia brevita Das and Gupta	5.91±0.95	9.16		
		Parapolybia varia Fabricius	6.66±1.19	10.32		
Diptera	Syrphidae	*Episyrphus balteatus* De Geer	4.16±0.76	6.45	21.02	21.02
		Eristalis tenax (Linnaeus)	3.08±0.79	4.77		
		Melanostoma orientale Wiedemann	4.75±1.03	7.35		
		Eristalis cerealis Fabricius	0.58±0.14	0.90		
		Eristalinus (Eristalinus) arvorum Fabricius	0.5±0.15	0.77		
		Ischiodon scutellaris Fabricius	0.5±0.15	0.77		
Lepidoptera	Nymphalidae	*Aglais caschmirensis* (Kollar)	1.16±0.20	1.80	1.79	1.79
Coleoptera	Coccinelliade	*Coccinella septempunctata* Linnaeus	0.25±0.13	0.38	0.38	0.38

* Each value is an overall average for an insect species S.E. = Standard error about the mean

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