headspace collections of *S. bicolor*, *Z. mays*, *P. purpureum* and *H. tamba*. Similarly, another EAD-active compound, 2-ethyl hexanol, has been reported as an electrophysiologically active component for male fruit piercing moth, *Eudocima materna* from fruit volatiles[16]. The attractiveness of bioactive compounds that elicited antennal response in the present study through GC-EAD/EAG analyses needs to be further ascertained using detailed olfactometer bioassays. Although geranyl acetate was found to elicit maximum response from *C. partellus* males, it has been reported to reduce in male response by 34.6% *Spodoptera littoralis*. Linalool has been found to synergize the pheromone of *Spodoptera exigua* (Hubner), *Helicoverpa zea* (Boddie) and *Cydia pomonella* (Linnaeus), but not for *Spodoptera litura* (Fab.)[17] and *Spodoptera littoralis* (Boisd.)[18]. Hence, before specifying the functional role of these volatiles in behaviour manipulation of *C. partellus* males and to using them for developing synergistic lures in combination with pheromone fractions, further laboratory studies involving olfactometer and wind-tunnel assays coupled with field evaluation are needed.

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Mites: an emerging problem for bumblebees in the Indian Himalayan Region

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To increase crop yield in the high altitude ecosystem in the Indian Himalayan Region (IHR), bumblebees are highly valued insects. An unwanted mites association with bumblebees is an example of a serious threat for the conservation of high-altitude agro-forestry

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ecosystem. Mites are emerging as a serious pest for bumblebees in the IHR and cause reduction in the pollinating efficiency of bumblebees, population health and in the spread of unwanted pathogens in nests. The mite *Uropodina* sp. (Acari: Mesostigmata) attacks on queens of *Bombus simillimus*, *Bombus tunicatus* and males of *Bombus miniatus* were recorded in the present study and fitness of bumblebees attacked by the mite population was also determined. *B. simillimus* queens were heavily attacked and wide distribution of *Uropodina* sp. on the body of the bumblebees was observed in this study.

Keywords: Bumblebees, crop yield, high-altitude ecosystem, mites, pollinators.

BUMBLEBEES belong to an insect order Hymenoptera: Apidae, which is the largest parasitic order. Several families in the order Hymenoptera are known for their deadly parasitic species which attack different insects and are also frequently used as biological control agents to maintain pest populations. Bumblebees are eusocial insects which live in colonies and serve as noteworthy pollinators for uncultivated and cultivated flowering plants as well as several crops in the high-altitude ecosystem, where survival and existence are difficult for other insects due to harsh environmental conditions.

Several studies have reported that different mites species from various parts of the world are endo- and exo-parasites of colonial and solitude bees[1–3]. The exterminatory pests of bees during bee-culture/keeping are recorded as *Acarapis woodi* and *Varroa destructor* which broadly influence the bee colonies and pollination performances at a large scale globally[4–6]. The rearing of bumblebees was initiated more than 20 years ago at a commercial level, while the mite–bumblebee relationship has come under focus only recently because of the importance of bumblebees in nature and their commercial demand[7]. Different kinds of pathogens and parasites have evolved and attained a higher proliferation during the rearing of bumblebee colonies above the ground level[8,9]. Velthuis and Van Doorn[7] reported that some bumblebee colonies are imported in greenhouses of Europe from other countries and may help in the shipping of foreign pathogens, parasites and mites into Europe along with these colonies. During the last decade, protozoans have been widely studied as parasites, with a focus on the effect of the protozoans on the fitness of bumblebees[10–13]. In addition, mite attack in commercial bumblebees was recorded in Canada greenhouse bumblebee, *Bombus occidentalis*[11] and European commercial colonies of *Bombus terrestris*[14].

In this study we focus on the mite–bumblebee association in India, and mite effect on health of bumblebees. We particularly paid attention to study the fitness of bumblebees and to explore the mite–bumblebee relationship. We also studied the population of mites on particular individuals bumblebee and how these mites are associated with various parts of bumblebees. Several studies have been conducted on mite–bumblebee association and predators and parasites of bumblebees used for commercial purposes but less attention has been given to the natural enemies which are pests in the natural habitat. So a detailed study needs to be conducted in the natural habitat for pests of bumblebees.

Bumblebees were collected using swipe-net from Jammu and Kashmir and Himachal Pradesh, India (Figure 1). The collected specimens were transferred into killing jar containing ethyl acetate. The individual bumblebees with mite association were kept separately in vials (75 ml) containing ethanol. The fitness and morphological disabilities of bumblebees due to mites were recorded simultaneously. Geological data were recorded using GPS (GARMIN GPS MAP 64SC) to indicate the location of the species (Figure 1). The specimens were brought to the laboratory at Desert Regional Centre, Zoological Survey of India, Jodhpur, Rajasthan, India for further studies and deposited in the National Zoological Collection. Mites were detached from the bumblebees during the sampling period and preserved in 90% alcohol for identification. A detailed study was done in the laboratory to examine the mites associated with various body parts of bumblebees, and how they affect the fitness of bumblebees. Photographs were taken with the help of a camera (Nikon Coolpix P1000 Digital Camera) and microscope (Nikon/SMZ25). Collected bumblebee specimens were identified in the laboratory up to species level with the help of the available literature (Table 1) and the detached mite samples were sent to Punjab Agricultural University, Ludhiana and Tamil Nadu Agricultural University, Coimbatore for identification.

Mite (*Uropodina* sp.) attack was only recorded in the queens of *Bombus simillimus*, *Bombus tunicatus* and male of *Bombus miniatus* (Figure 2 *a–h*). No mites were found on other species of bumblebees in the present study, but the number of species attacked might increase in future based on sampling size in the Indian Himalayan Region (IHR). The tracheal mite in the Holarctic region has been reported to attack at least 25 bumblebee species[15–20]. A detailed observation revealed that *Uropodina* sp. prefers to attack the queen because of her large size and adequate place for feed and reproduce.

Mites are widely studied pests in commercial honey bees and a little focus has been given to bumblebees[15,19]. A detailed examination of bumblebees attacked by *Uropodina* sp. shows that the mite heavily attacked on their body parts, particularly hind legs, mid legs, compound eyes, genitalia and abdominal air sacs (Figure 2 *a–k*); only a small population was found on the dorsal side of the bumblebee body (Figure 2 *h*). Heavy infestation of *Uropodina* sp. was found on the femur of hind legs of *B. simillimus* (Figure 2 *c* and *d*) compared to mid legs. *B. simillimus* queen was recorded as intentionally attacked by *Uropodina* sp. followed by *B. tunicatus* and *B. miniatus*

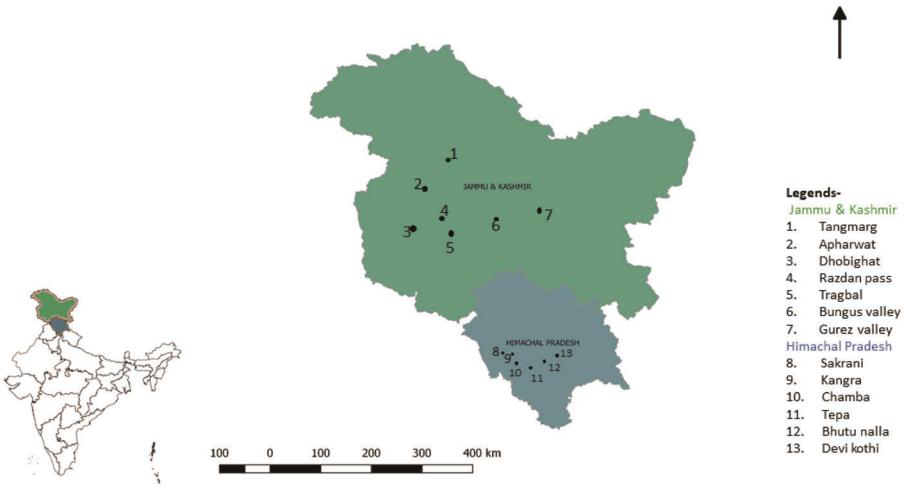

Figure 1. Sampling area.

Table 1. List of Bumblebee species attacked by *Uropodina* sp. in Indian Himalayan region

Species	District/locality/state	Mites attack
Bombus melanurus Lepeletier, 1835	Bla/Tgm (J&K)	N
Bombus rufofasciatus Smith,1852	Bla/Tgm (J&K), Cba/Skn (HP)	N
Bombus miniatus Bingham, 1897	Bla/Awt, Tbal (J&K)	Y
Bombus albopleuralis Friese, 1916	Bla/Awt (J&K), Kgr/FV (HP)	N
Bombus tunicatus Smith, 1852	Bla/Dbgt (J&K), Cba/BN (HP)	Y*
Bombus ferganicus (Radoszkowsi, 1893)	Bla/Dbgt (J&K)	N
Bombus simillimus Smith, 1852	Bndp/RP (J&K), Cba/T (HP)	Y*
Bombus keriensis Morawitz, 1886	Bndp/RP (J&K), Cba/DK (HP)	N
Bombus jacobsoni Skorikovi, 1912	Bndp/Tbal, Kpw/BV (J&K)	N
Bombus asiaticus Morawitz, 1890	Bndp/GV (J&K), Cba/T (HP)	N

Y*, Heavy mite attack; Y, mite attack; N, No mite attack; Bla, Baramulla; Tgm, Tangmarg; Cba, Chamba; Skn, Sakrani; Awt, Apharwat; Kgr, Kangra; FV, Forest vatika; Dbgt, Dhobighat; BN, Bhotu Nala; Bndp, Bandipora; RP, Razdan Pass; T, Tepa; Tbal, Tragbal; DK, Devi Kothi; Kpw, Kupwara; BV, Bungus Valley; GV, Gurez valley; J&K, Jammu & Kashmir and HP, Himachal Pradesh.

respectively, because of their large size. Mites are endo and exo-parasites of bumblebees[15], which feed and reproduce outside the body. However, in the present study we only recorded the exo-parasites. Mites affect the fecundity rate of bumblebees, leading to death. A heavy attack of *Uropodina* sp. on *B. simillimus* queen indicates that the mite individuals are dispersed everywhere on the body parts and affect the flight, reproduction, feeding and health of the queen.

B. simillimus, *B. tunicatus* and *B. miniatus* play a vital role in the conservation of wild flowers at high altitudes. They are distributed from the elevation range 1380–4180 m amsl in the IHR and serve nature by pollinating a wide range of wild flowers as well as high-altitude crops[21,22]. *B. simillimus* pollinates several flowering plants found in the IHR, viz. *Amaranthus caudatus*, *Hedera helix*, *H. nepalensis*, *Artemisia absinthium*, *Aster thomsonii*, *Carduus edelbergii*, *Carduus* spp., *Canturea iberica*, *Lavatera cashmeriana*, *Trifolium pratense*, *Trifolium repens*, *Rosa indica*, *Delphinium ajacis*, *Delphinium* spp., *Digitalis lanata*, *Lycopersium esculentum*, *Cirsium falcorneri*, *Cirsium* spp., *Cynara scolymus*, *Dahila variabilis*, *Tagetes patula*, *Taraxacum officinale*, *Impatients balsamina* and *Impatients glandulifera*, *Ipomea* sp., *Swertia petiolata*, *Althea rosea* and *Solanum nigrum*. *B. simillimus* is considered as a potential pollinator for these flowering plants and therefore plays a pivotal role in their conservation.

B. tunicatus and *B. miniatus* also pollinate different varieties of flowering plants, viz. *Allium cepa*, *C. edelbergii*, *Centaurea iberica*, *Cichorium intybus*, *Cirsium falconeri*, *Cirsium arvense*, *C. wallichii*, *C. scolymus*, *Helianthus annus*, *Scorzonera virgata*, *Tagetes patula*, *Tagetes* spp., *Zinnia elegans*, *Impatiens balsamina*, *I. edgeworthii*, *I. galdulifera*, *Campanula* spp., *Convolvulus arvensis*, *Dispsacus inermis*, *Gentiana* sp., *Hedera nepalensis*, *Aster himalicus*, *Antirrhinum majus*, *Artemisia absinthium*, *Artemisia* spp., *Swertia petiolata*, *Geranium* sp., *G. wallichianum*, *Nepata cataria*, *Prunella vulgaris*, *Stachys sericea*, *Lavatera cashmeriana*, *Astragalus* sp.,

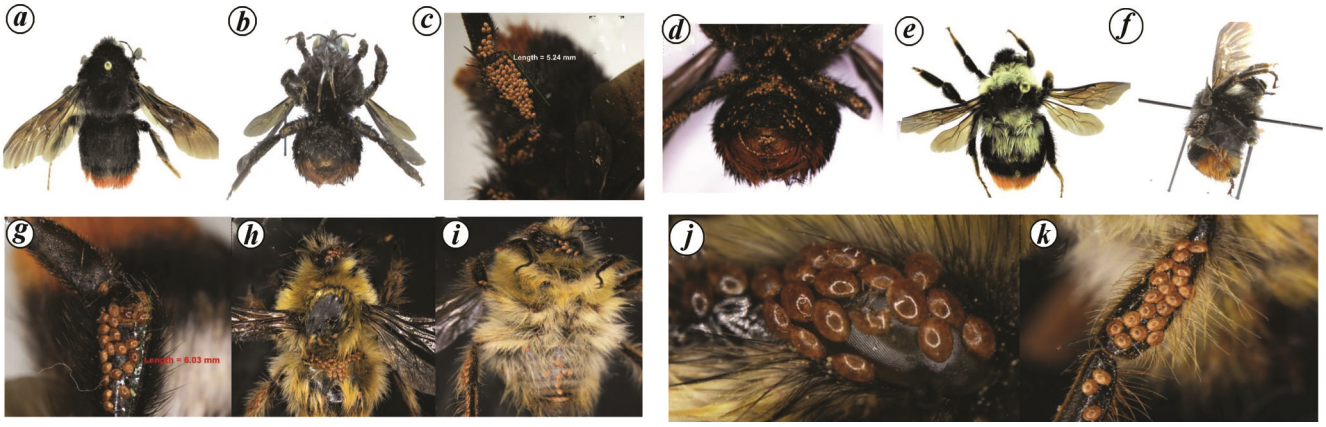

Figure 2. Mite (*Uropodina* sp.) attack on bumblebees. (***a–d***) *Bombus simillimus* Smith, 1852: (***a***) dorsal view, (***b***) ventral view, (***c***) Femur of hind leg and (***d***) ventral view showing mites attack on female genitalia. (***e–g***) *Bombus tunicatus* Smith, 1852: (***e***) dorsal view, (***f***) lateral view and (***g***) femur of hind leg. (***h–k***) *B. miniatus* Bingham, 1897: (***h***) dorsal view, (***i***) ventral view, (***j***) compound eye and (***k***) femur of hind leg.

Indigofera heterantha, *Lupinus polyphyllus*, *Robinia peusoacacia*, *Triflium pretense*, *Aconitium heterophyllum*, *Aconitium* sp., *Delpinium* sp., *Althea rosea*, *Potentilla atrosanguinea*, *Rosa webbiana*, *Digitalis lanata*, *D. purpurea*, *Pedicularis punctata* and *Pedicularis* spp.[21–24] in the IHR[21,23,24]. A mite-attacked bumblebee is not efficient like a normal bee as the IHR pollination potential may be reduced several fold after severe exploitation.

The transmission of disease-causing agents (bacteria, virus and protozoans) through mite association has been recorded in various countries, viz. The Netherlands, Japan, America, Indonesia and Europe in reared colonies of commercial bumblebees (*B. terretris*)[15]. In the present study, we did not explore this aspect but there may be some cases of pathogen transmission through queens in bumblebee nests.

To the best of our knowledge, there are no previous studies of *Uropodina* sp. attack in *B. simillimus*, *B. tunicatus* and *B. miniatus* from the IHR. The mite attack affects the pollinating efficiency of bumblebees and cause the spreading of diseases in nests from one individuals to another. *B. simillimus* queen was found to be heavily attacked and less pollen grains were recorded from its body (Figure 2 *a–d*) followed by *B. tunicatus* (Figure 2 *e–g*) and *B. miniatus* (Figure 2 *h–k*). In *B. tunicatus* and *B. miniatus*, *Uropodina* sp. was only recorded on the femur of hind and mid legs, and genital parts. However, *Uropodina* sp. was distributed on the whole ventral body parts of *B. simillimus*, including genital portion. *B. miniatus* compound eyes were mostly covered by *Uropodina* sp., which ultimately causes vision problems to find food and nest. Studies have revealed that commercial bumblebee populations affect the fauna by transferring pathogens and parasites[8,13,16,18,19]. The present study reveals that of *Uropodina* sp. attack on bumblebees can cause a wide range of problems in the IHR and can have an impact on high-altitude flora which are mainly conserved by these types of bees. The bumblebee species composition after mite attack can be reduced and this will ultimately affect pollination and crops yield in the IHR.

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