Role of Bumblebees (Hymenoptera: Apidae) in Pollination of High Land Ecosystems: A Review

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ABSTRACT
Bumblebees are one among the anthophilous form and play a significant role in the pollination of major agricultural crops like medicinal, aromatic, ornamental and various other horticultural plants. They are abundant and mostly confined to flowers present in the temperate, alpine and arctic climates of the northern continents. The bumblebees are considered as most important pollinators and are mainly responsible for the conservation of high altitude vegetation germplasm where other insect pollinators are very much limited. They are more successful pollinators and can visit large number of flowers per minute than other bees and are perfect for picking up and transferring appreciable amount of compatible pollen to flowers and thus perform buzz pollination. It is quite evident that the population of bumblebee is gradually declining throughout the globe for the last 7 decades due to agricultural intensification, habitat loss, deforestation, overgrazing, pesticide poisoning and climate change. The present paper addresses this issue on the basis of literature survey.

Key words: Agricultural, Aromatic, Bumblebees, Ecosystems, High-land, Medicinal, Pollination.

INTRODUCTION
There are 265 species of Bumblebees (Hymenoptera: Apidae) reported worldwide, (Williams et al. 1998; updated online at http://www.nhm.ac.uk/research curation/research/projects/bombus/index.html). They are very important and efficient pollinators capable of foraging outside even in harsh and unfavorable conditions as compared to other types of bees (Abak et al. 2000; Semida and Elbanna, 2006). Kearns and Thomson, 2001 studied that the bumblebees occurring at different altitudinal level starting from 1000m and up to 5500 m ASL. These bees build their nests either in uninhabited rodent burrows or in the ground or in tall grasses. O’Toole, 1994 showed that the bumblebees are significant component of an agro-ecosystem and are completely depend on nectar and pollen resources. Hence, bumblebees are considered as important group to study the link between pollinator and floral diversity and playing an essential role in conserving the high altitude vivid vegetation. Goulson, Lye and Darvill, 2008a made a detailed study and reported that these insects inhabit distinct ecological habitat with their flower-patterned foraging activity. In addition Williams and Osborne, 2009 confirmed that at least a few important species of bumblebees are required to preserve the natural flora and fauna.

Bumblebees are also considered as keystone species in most terrestrial ecosystems because the nests of bumble bees support a wide range of commensal and parasitic animals (Goulson, Lye and Darvill, 2008b). These insects are able to pollinate by producing vibration with their flight muscles rapidly and thus dislodge pollen from anthers (Wahengbam et al. 2019). Unlike bumblebees, Honeybees vibrate their flight muscles slowly, therefore, they are considered to be incompetent pollinators for plants which need buzz pollination (Averill et al. 2018). In 1998 Goulson et al., found that these bees left fragrance after visiting flowers and prevents other insects from visiting that flower again until the fragrance diminishes. These insects use signals for rewarding different types of flowers they visit or identify the visit performed by other insect pollinators (Saleh and Chittka, 2006; Saleh et al. 2007 and Pearce et al. 2017). The foraging activity of bumblebees is usually from 9:00 to 11:00 am as reported by Abak et al. 2000 and Chauhan 2011. However, they extend their foraging activity with reduced vigour from 13:00 to 14:00 pm.

The bumblebee pollinators favour brightness and dry climate as compared to rainy, cloudy and moist weather conditions and choose those flowers, which develop on the unlocked slopes of hill (Raina et al. 2019). Heinrich, 1979a

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reported that bumblebees are able to forage at moderate temperature and light intensity in various agricultural crops. Dramstad, 1996 and Osborne et al. 1999 studied that the bumblebees frequently forage from their nests at a very significant distance. Westrich, 1996 studied that the minimum requirements for the survival of bees including nest sites and other nest building materials and availability of floral resources like nectar and pollen.

Most of the wild plants are mainly pollinated by different species of bumblebees (Goulson, 2003a). Waser et al. 1996 stated that the major insect-pollinated plants use different groups of pollinators and most species of bumblebees are generalist pollinators. The consequences of elimination of extremely linked individual pollinators such as bumblebees from pollination networks created the maximum decline with respect to plant diversity (Memmott et al. 2004). Bumblebees have always been a matter of fascination for humankind because of their attractive colours and potential to carry out indispensable pollination services in several agricultural crops among the insect pollinators (Free and Butler, 1959; Plowright, 1996; Michener 2000; Abrol and Shankar, 2013). Bumblebees are widely studied insect groups among other bees (Hymenoptera: Apoidea) and have been evaluated worldwide for its status as a threatened species (Winfree, 2010).

Westrich, 1996 reported that the species of bumblebees are polylectic, which means they can forage on a number of floral species and well-tailored to live in human conquered scenery as compared to other oligolectic or oligolege bees pollinators. In addition to this, bumblebees are found to forage in different mountain regions and are directly associated with different varieties of wild and cultivated flowers. They are capable of recognizing the flowers through floral temperature (Harrap et al. 2017) and detection of electric field. (Clarke et al. 2013). They have also been noticed that these insects relatively favour symmetrical flowers than asymmetrical ones (Moler, 1995; Moller and Sorci, 1998). And from the symmetry the bilateral symmetry is chosen over radial symmetry (West and Laverty, 1998).

Raina et al. 2019 observed that in the upper Indian Himalayas predominantly the trees of less alpine meadows between 3500m to 5400m asl and the vegetation that is conserved predominantly by the species of bumblebees include wide range of herbs, shrubs, grasses and medicinal plants having small flowers. The hostile and extremely severe environment of these snow clad mountains, predominantly the Apharwat range, Leh-Ladakh of Jammu and Kashmir and Lahaul-spiti regions of Himachal Pradesh where only some preferred species of medicinal plants are maintaining their existence, therefore bumblebees play incredibly a positive and decisive role in developing and conserving them. The common vegetation existing at these ranges and mostly pollinated by these bees include Anaphalis busua DC, Cirrbita cineria Linn., Senecio chrysanthemoides DC, Taraxacum officinale, Saussurea jacea (Klotz) Cl., S. albescens, S. auriculata, S. lappa, S. costus, S. fastuosa, Scorzonera virgata, Senecio chrysanthemoides, Lactuca orientalis, Rudbeckia laciniata, Leontopodium alpinum, Tanacetum dolicophyllum (Asteraceae), Potentilla atrosanguinea Lodd. (Rosaceae), Thymus serpyllum Linn., Mentha longifolia Linn., Phlomis bracteosa Royle, Stachys serecia Wall. Ex Benth., Nepeta discolor Linn., Hyssopus officinalis Linn., Dracocephalum heterophyllum Benth., Nepeta laevigata (D. Don) Hand-Mazz. (Lamiaceae), Polygonum amplexicaule D. Don. (Polygonaceae), Pedicularis pectinata Wall., Euphrasia officinalis (Scrophulariaceae), Gypsophila cerastioideis D.Don (Caryophyllaceae), Melilotus officinalis (L.) Pall (Leguminosae), Myosotis sylvatica Ehrh. Et Hofm. (Boraginaceae), Cyanthus lobatus Wall. (Campanulaceae), Gypsophila cerastioideis (Caryophyllaceae), Rhodiola crenulata Linn., Sedum ewersii Ladeh (Crassulaceae) and Hyoscyamus niger Linn. (Solanaeaceae). Hence, this long list of plants above clearly shows that the most of the high-altitude vegetation is mostly conserved by the bumblebees.

Abak et al. 1997; Kwon and Saeed, 2003 and Velthius and Van Doorn, 2006 studied that in worldwide some important bumblebee species viz., B. impatiens, B. occidentalis and B. terrestris were employed for the commercial pollination of major agricultural cropping system. They have made a detailed study that the systematic hydroponics and polytunnel farming require such pollinators for Crops like tomato, cucumber, Pepper, strawberries etc. The Pollination performed by different species of bumble bees helps in the fruit quality with respect to weight, size, color and improved fruit set, to get cost effectual seed production (Klein et al. 2007 and Aizen et al. 2008). It has been established that bumblebees are vital and effective insect pollinators than honey bees for cucumber, watermelon and Apples (Stanghellini et al. 1997; 1998 and Thomson and Goodell, 2001).

Bumblebees have fewer tendencies to swarm as compared to honey bees and visit extra numbers of flowers per minute with a fly speed of 64 km/h, hence it is more suggested for pollination in green house cultivation (Wahengbam et al. 2019). The body of bumblebees is furry than honey bees, therefore, it makes them relatively more perfect for collecting and transferring the pollen, i.e., while bumblebees are foraging on flowers of raspberry plants and perfectly deposited extra pollen on the stigma than honeybees (Willmer et al. 1994). Klein et al. 2007 revealed that globally honeybees are significantly important for crop pollination as it is supposed to contribute 80% of insect pollination (Robinson et al. 1989). Pollination is very important for the conservation of natural ecosystem and for the production of wide range of horticultural and agricultural crops (De Groot et al. 2002; Hein et al. 2006 and Eardley et al. 2006). The agricultural crops such as tomatoes, vegetables, peppers, cucumbers, seed crops, blueberries, cane berries, strawberries, squash and melons are more convenient with bumble bee pollination (Anonymous, 2019).
Henrich, 1979b demonstrated that the bumblebees are economically important insect pollinators and play an important role as pollinators of wild flowers and some important agricultural crops. In North America it is estimated that 30% of the food for human being originate from plants pollinated by bees. Honey bees are generally considered as most frequent pollinators and have been studied extensively worldwide although bumblebees are the main pollinators of alfalfa, clover, (*Trifolium* spp.), plum and raspberries blossoms. While honey bee pollination in Norwegian orchards is mainly restricted due to low temperature, therefore pollination is mainly caused by bumblebees (Faegri and Vanderpijl, 1979). Some species of bumblebees are being reared on commercial scale and put up for sale to farmers in various parts of the globe for the pollination of major cropping systems (Pratap and Pratap, 1997, 2000).

Raina *et al.* 2019 extensively studied and confirmed that some species of bumble bees feed overwhelmingly on some plants such as *Cirsium falconeri*, *Cirsium arvensis*, *Nepeta* spp., *Carduus* spp., *Saussurea* spp., *Impatiens balsamina*, *Prunella vulgaris*, *Trifolium pratense* and *Trifolium repens*. On the other hand, there are several other plants like, *Swertia* spp., *Artemisia* spp., *Indigofera* spp. and *Pedicularis pectinata*, which inspite of that occur in close vicinity to the above mentioned plants, they are occasionally visited by bumble bees.

Osborne *et al.* 1999; Walther and Frankl, 2000 and Dramstad *et al.* 2003 studied that bumble bees with a ground speed of 54km/h are able to forage up to 1-2 km from their colony and have been known for their flower constancy. The flowers identified by long-tongued bumble bees inserted lapping tongue for collection of nectar, while short-tongued bumble bees does not help in pollination as they rob nectar from flowers with a long corolla tube by biting at the base of the corolla (Malof, 2001). In Colorado, a sharp decline in the population of honey bees had apparently led to the short tongued bumblebee's population (Plowright and Laverty, 1984). Leach and Drummond, 2018 made a detailed study that the opus of pollen and nectar plays an indispensable role for the nutrition and foraging behavior of bees.

Corbet *et al.* 1993 studied that bumblebees are very competent pollinators to work at very low temperature due to their thermoregulatory abilities and are found to be sufficient throughout the season. Therefore, they act as significant pollinators, particularly in the early blossoming period as well as in high land ecosystem (Kevan and Baker, 1993; Yu *et al.* 2012). Velthius and Van Doorn, 2006 projected that bumblebee colonies at large scale level are being commercially exploited and are large number of colonies are being marketed per year in the developed countries of the world for pollination purposes. Hence, bumble bees become ecologically and economically valuable insect pollinators. Dias *et al.* 1999; Winter *et al.* 2006 and Goulson, 2010 estimated that many species of bumblebees are commercially utilized for the glass house cultivation throughout the world and that has resulted to provide billions of dollars annually. *Bombus terrestris* one of the major pollinator among bumblebees having highest pollination potential has been introduced in many countries viz., Japan, Argentina, New Zealand and Chile for green house pollination (Goulson, 2003b, Winter *et al.* 2006).

Velthius and van Doorn, 2006 reported that the hothouse tomatoes mainly pollinated by bumblebees in the mid-1980s were found to be extremely productive, economical and put back effort demanding perfunctory process of pollination. Furthermore, they also reported that in 2004, pollination by bumblebees has yielded ca 99,000 acres of tomato production under the green house farming with an estimated cost of $ 15 billion worldwide. Bumblebees more adequately perform vibration to shed pollens from anther to stigma in tomato pollination as compared to honey bee (Van Heemert *et al.*, 1990). Free and Butler, 1959 stated that bumblebees are more frequently used in glass house farming, e.g. Kiwi fruits, tomatoes and cabbage pollination in Holland. The authors also studied that due to the wide spread of *Varroa jacobsoni* and augmentation of poly house farming, resulted in a sharp decline in honey bee population and consequently the economic importance of bumblebees will possibly enhance. Griffiths and Robberts, 1996 noticed that the increased human population worldwide emphasizes the utilization of bumblebees to pollinate agricultural crops grown under intensive cultivation.

Maclarlame *et al.* 1985 made a detailed study on bumble bees and honeybees as pollinators of *Trifolium pratense* in New Zealand. They observed that long-tongued bumblebees and pollen collecting honeybees act as main pollinators of *red Trifolium pratense*. It was also observed by them that a single species of bumblebee could pollinate enough flowers to produce 0.3-0.6kg crop seed in reasonable growing conditions. Abrol, 1991 made a comprehensive studies on bumblebees in association with pollination of brinjal flowers in J&K. He recorded 7 species of bees distributed over 4 families, attracting the brinjal flower. Of these, bumblebees, viz. *Bombs asiaticus*, *B. albopleuralis* and *B. simillimus*, were not only predominant visitors, but also efficient pollinators, whereas honeybees (*Apis cerana*, *A. mellifera*), the carpenter bee (*Xylocopa valga*) and the halictine bee (*Lassioglossum* sp.), visited less frequently and in few numbers. In European Countries crops such as red clover, oilseed, alfalfa, field beans and other squashy and hard fruits are mainly pollinated by different species of bumblebees (Corbet *et al.* 1991).

Arbetman *et al.* 2013 confirmed that bumblebees were exploited commercially beyond their inhabitant range, ensuing the increase of diseases to indigenous bumblebee populations and augmentation of exotic bumblebees (Morales *et al.* 2013). Padilla *et al.* 2017 deliberated that in many countries, proper methodology is being developed for the commercial exploitation of the indigenous bumblebees of the respective region. Two species of bumblebees viz., *Bombus breviceps* and *Bombus haemorrhoidalis* in Vietnam.
Role of Bumblebees (Hymenoptera: Apidae) in Pollination of High Land Ecosystems: A Review

and India are being reared (Chauhan et al. 2014 and Thai and Van Toan, 2018) and is first step to produce native species of bumblebee population for commercial pollination. Deka et al. 2011 studied that both species of bumble bees are common in the north-eastern states and will prove very remarkable pollinators for several crops.

Gallai et al. 2009 estimated that the pollination service extended by insect pollinators and mostly by bees to agriculture worldwide has economic value of nearly USD 193 billion. In Ontario’s economy, commercially reared bumble bees are the principal pollinators in glasshouses and the crops they aid to pollinate contribute roughly USD 502 million each year (Pindar et al. 2017). The pollination of crops through bumblebees was found to be cheaper as compared with perfunctory pollination in Belgium and Netherland (Roulston and Julier, 2009).

Goulson, 2003b studied that bumblebees are responsible for maintaining the seed production of the crops and fruit trees. In Europe crops like beans are mostly pollinated by long tongued bumblebees resulting in good yields (Free and Williams, 1976). The most important factors responsible for population decline of bumblebees in different regions of Asia, Europe and North America are manipulation of agricultural practices, pesticide poisoning and loss of habitat (Free and Williams, 1973; Rasmont, 1988).

CONCLUSION

Bumblebees are efficient and important pollinators and have the capability to pollinate diverse field crops and certain medicinal plants. These insects play significant role in conserving high altitude vegetation germplasm in the Indian Himalayan region. Indigenous bumblebees can be employed for pollination of many crops, glass house cultivation, poly house farming, other vegetables, fruits, medicinal plants and herbs and shrubs of high-altitude regions of the various continents of the world over. However, the declining of bumblebee population in recent years had led to reducing agricultural and horticultural productivity with the result that bumblebee population in the entire Himalayan ecosystem is being mercilessly got beneath absurd environmental pressure, stress and strain. Therefore, to enhance the role of bumblebees to maximize the crop productivity and their economic contribution to the agricultural economy and food security, efforts must be taken to conserve and protect them from the harmful impact of various agro-chemicals and other environmental factors causing their decline in various continents of the globe. Management strategies by encouraging the wild flowering plants and establishment of artificial nesting habitat model for conserving the target species for their survival, so that it will underpin the support for biodiversity of bumblebee population and their pollination efficiency.

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Role of Bumblebees (Hymenoptera: Apidae) in Pollination of High Land Ecosystems: A Review

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