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Studies on Nest Architecture and Pollination Potential of Bumble Bee (*Bombus haemorrhoidalis*)

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Abstract: Pollination potential of bumble bee *Bombus haemorrhoidalis* Smith was studied along with their rearing. Bumble bee q were trapped from different flora during spring. During 2009-2010, eleven queens raised their progeny successfully in confin (incubator) and three colonies raised their progeny for the first time under room temperature (control). Domiciles 16x12x10cl 15x12x8cm with different nesting materials (cotton, moss and filter paper with bottle lid) were accepted to the level of 75 per cent, ho the per cent acceptance was 41.66 for the domiciles having 25x20x15cm dimensions. Hoarding cages were not accepted by the q The average time for wax secretion and development from egg to adult was 6.7 days and 26.21 days. Reared bumble bee colonie successfully used for pollinating cucumber grown under polyhouse in increased fruit set, healthy fruits, fruit length, diameter, seed number and weight with reduction in crooked fruits. The cost benefit ratio was 1:2.02 and an increase of 22 per cent in t returns from bumble bee pollinated crop over non-pollinated crop.

Key Words : Bumble bees, nest architecture, pollination, cucumber, protected conditions

In horticulture and agriculture, honey bees are mainly utilized for the pollination of crops. Over the last few decades, the trend of cultivating crops has shifted towards protected cultivation. Besides, due to changing climatic conditions and increased *Varroa* mite infestation, the apiculture industry received a setback. Under such critical situations, it becomes obvious to take into account the immense role and utility of native pollinators in pollinating various economically important crops. Bees can be used for the pollination of crops under protected conditions. Bumble bees are found to be the most efficient and reliable pollinators under protected conditions and work well under adverse conditions of temperature and cool weather. It is also valuable in buzz pollinating the crops such as tomato (Corbet *et al.*, 1982; Erikson and Buchmann, 1983). Bumble bees lives either underground in pre-existing small, mammal nests or above ground in dry vegetation comprising of thick dry leaves and wooden twigs. Several attempts have been made earlier by different workers to raise bumble bee colonies in captivity by artificial methods and utilize them for pollination in both open and protected conditions (Plowright, 1996). But in India, no attempts were made till first decade of this century.

Attempts to rear bumble bees were started in 2002 and were successfully reared in captivity during 2005-2008 (Kashyap, 2008). To avoid several problems such as increased humidity and moisture, several advances have been made. Techniques have been developed to rear bumble bees for pollination of high value crops under protected conditions to increase productivity (Berezin and Belko, 2000; Anonymous, 2009). As the Indian agriculture is shifting towards protected cultivation to make av the crops throughout the year with quality produ present study was formulated to know the poll efficiency of bumble bee with the refinement of its technology for the successful domestication of this pollinator, which is a highly commercial pollinato protected cultivation conditions in the Eastern and countries.

MATERIALS AND METHODS

The studies were carried out in the Depart Entomology and Apiculture (February to June an to October in 2009-2010) and Experimental Far Department of Vegetable Science (June to August 2010); Dr. Y.S. Parmar University of Horticul Forestry, Nauni, Solan, Himachal Pradesh.

Natural nest architecture studies: These stu conducted at Sarot, Jubbal (2300 meters above level, 31.1094667°N; 77.662996°E) and Nauni (12 above mean sea level) at a longitude of 77° 11' 3 latitude of 30°52'30 N°. Nests of bumble bees we at different altitudes by listening to the buzzing the bumble bees in the forest and field areas (cult barren lands). The bumble bee nests were regularly till the activity ceased. The nests were out and brought to the laboratory for stu composition, structure, nesting materials and typ the nests. The outer covering of the composi nesting material was isolated from the brood a the composition of nests. The nests were

line the variations in the shape of the nests collected ifferent altitudes. Different cells of bumble bee nests eparated to study the dimensions of different cells cells, worker cells and honey-pots) with digital calliper. The average of cells was taken to know the nce in the dimensions of different cell types.

efinement of bumble bee rearing technique: Four of boxes each with three different nesting materials three replications for each box were taken. The les had different dimensions with different nesting als. The domiciles were made up of ply-wood, divided o equal chambers viz., brood chamber and defecating er and had a sliding glass at the top to observe the onstruction and brood activity without disturbing the The glasses were covered with inner covers from to avoid the entry of direct light. The base of the ting chamber was made sliding and perforated for emoval of debris from the colony and to maintain e in the nest along with removing excess moisture to tside. Two holes were provided in the side wall for ventilation. The dimensions of different domiciles 5x12x 8cm, 16x12x10cm and 25x20x15cm. Hoarding had dimensions of 33x20x10cm. All cages had a ole in the centre, which provided a free space for the and workers for movement between brood and ling chambers.

th the onset of spring, the bumble bee queens were d in the early morning and evening during foraging n and nectar with the help of insect collecting nylon e queens were brought to the laboratory in plastic ving perforated lids and were placed in refined s with proper feeding provisions. Spring captured bee queens were put in the wooden domiciles having nesting materials (moss, thermo-cole, cotton, filter d sponge sheets) and kept in controlled conditions cubator at 26.9°C temperature and 65 per cent umidity. Queens were fed with honey bee-collected nd 50 per cent sucrose solution. Similarly, queens at room temperature to know the success of rearing le bees under room temperature ranging between nd 50-60 per cent relative humidity. These queens with both 50 per cent sugar/sucrose solution and ltir pollen pellets. Time taken by the queens for wax and emergence of workers was recorded.

ation of bumble bee under protected conditions

ollination of cucumber: For pollination studies ected conditions, the experiment was conducted plastic greenhouse using randomized block tal 32 blocks were made out of which 24 blocks were exposed to bumble bee pollination while eight blocks were left out for control treatment. The cucumber (Punjab Naveen) crop was sown in the first week of April. In each block, twelve plants were planted, thus making a total of 384 plants in three replications. An insect proof net was placed between the experimental and control plots to avoid pollination in control plots. Cucumber plants were also planted in open conditions during the last week of February in randomized block design to know the effect of natural pollination on cucumber productivity under open conditions. A total of sixty blocks were made and in each block twelve plants were planted. The plants came to bloom during the month of June.

Artificially reared bumble bee colony was introduced in blooming cucumber crop (with 5-10% flowers opened) in the polyhouse by placing it inside a big box (30x30x30cm) to which a plastic tube was attached, which served as a passage for entry and exit for bumble bee foragers. Foraging activity of bumble bees was recorded on cucumber grown inside polyhouse from early morning hours (0600h) till late evening (1800h) at two hour interval for 20 days continuously. For comparative studies, similar data were recorded under open conditions.

For studying the crop productivity, the female flowers per vine were pre-counted. Ten plants from each treatment viz., bumble bee pollinated, control and open pollinated were selected randomly. The fruit set on these plants were then recorded and total yield was calculated on fruit set basis. The per cent healthy fruits crooked fruits were calculated by counting the number of healthy/crooked fruits from the total fruit set. Fruit length, fruit diameter and fruit weight were measured using scale, digital Vernier calliper and digital weighing balance, respectively.

The average of 10 fruits was taken for each pollination treatment. The seeds from each fruit were removed and kept separately in water for 24 hours. After washing, the seeds were dried by keeping them in temperature controlled chambers for 24 hours, and then counted. One thousand dried seeds from each treatment were taken separately in the petriplate and weighed. Per cent increase in the fruit set, healthy fruits, crooked fruits, length, diameter, weight, number of seeds, weight of 1000 seeds was calculated as per cent increase in bumble bee pollinated cucumbers over control.

Cost-benefit ratio was worked out for cucumber grown under polyhouse conditions and the per cent increase in total returns was calculated for increase in the cucumber productivity and production in bumble bee pollinated plants over control.

RESULTS AND DISCUSSION

Nest architecture: The nest located at Sarot, Jubbal (Nest 1) was dug out in the month of November when the activity of bumble bees ceased before snowfall. The nest was built inside the abandoned, old rodent burrow having one small opening. Nest was attached to the roots of an adjoining apple tree. An involucrum made of waxy substance was found covering the nest from top. Some pine needles were found in the tunnel and the tunnel end, leading into a wide cavity where the brood having different scattered cells were found. The nest was circular with diameter and height of 12.56 and 6.8cm (Table 1). The nest located at Nauni (Nest 2) was dug out in the month of December. It was located in the abandoned nest of some rodent beneath heap of big stones with broad opening and was interwoven with long grass. Single entrance of nest was found bifurcated into a number of tunnels. The nest was found at a depth of 90cm and the length of the tunnel was found to be 150cm. Nest was rested on the flat surface and was attached to roots of nearby tree. It was built with interwoven dry grass, leaves, small wooden twigs and some plastic material. The involucrum of wax covered the nest. The nest had three entrances from the involucrum. The diameter and height of the nest were found to be 17.25 and 7cm, respectively. Beneath the involucrum the worker, queen and honey pot cells were observed. The brood filled most of the cavity beneath the nest canopy. The surface of nest was completely dry and free of mold. The nest contained both sealed and unsealed brood. The brood batches were arranged in circular manner. Some beetles were found in the colony at Nauni and were identified as *Antherophagus* sp., which was found to be pollen feeder. The dimensions of the different brood cells (queen, worker and honey pots) observed in the natural nest are presented in Table 1.

Similar observations were recorded by Thakur (2002) who reported bumble bee *B. haemorrhoidalis* nests underground. Taylor and Cameroon (2003) also studied the nest construction and architecture of *B. Vancouverensis*. They found that nests were constructed from soil, pine and grass which kept the nest dry during high humidity. In similar studies, Katayama *et al.* (1995) observed nest of Japanese bumble bee (*B. deuteronymus schrenckii maruhanobachi)* and found that the honey pots were found on the periphery and worker cells on the inner side of nest.

At higher altitude (2300m), the average length of queen cells, honey pots and worker was 16.56±2.1 12.55±0.27; 15.31±0.25 and 12.91±0.23, and 13.16±0.78 and 10.15±1.07 mm, while at lower altitude (1250m) above measurements were 20.57±0.75 and 15.20±0.86; 20.35±0.68 and 16.32±0.83; and 14.24±0.86 and 10.01±1.03mm, respectively (Table 2). Honey pots located at the periphery of both the nests. Gonzalez (2004) also found the similar observations in the architecture of bumble bees. Hoffmann *et al.*, (2004) recorded similar dimensions of worker cells, queen and honeypots of *B. melaleucus* to the size of 15.0± 23.9±0.33 and 20.6±4.24mm, respectively.

Refinement of bumble bee rearing technique rearing of bumble bees under laboratory conditions with the capturing of fecundated bumble bee queens came out of hibernation and searched for new habitats during collection of pollen and nectar at the onset of Spring. During February–March, the major flora sustaining bumble bee queen population was found to be *Caryopteris farly*, *Scutellaria linearis*, *Salvia moorcroftiana*, Lavendula, *Lupinus mutabilis*, *Delphinium* sp. and Jasminum (Table 2). During April-May, the queens were found to pollen from *Salvia moorcroftiana*, *Nicotiana* sp., *Punica granatum* and *Jakaranda mimmosaefolia*. queens were trapped while foraging on these plants. queens were also collected when they were search

Table 1. Observations on different features and dimensions of the nests at different altitudes

Features	Nest 1 (2300m) Jubbal	Nest 2 (1250m) Nauni	
Dimension of nest (cm)	12.x 6.8cm	17.25cm (diameter) and 7cm (height.)	
Shape	Circular	Oval	
Nesting material	Pine leaves and small twigs	Grass, leaves, small wooden pieces and some plastic m	
Water Saturation	Wet at bottom (saturated)	Dry at bottom	
Compactness	Scattered	Compact	
Nest depth	62cm	90cm	
Tunnel length	139.4cm	150cm	
Queen cell length	16.56±2.1	12.55±0.27	20.57±0.75
Worker cells	13.16±0.78	10.15±1.07	14.24±0.86
Honey pots	15.31±0.25	12.91±0.23	20.35±0.68

Table 2. Important flora harbouring bumble bee queens during different months

Botanical Name	Common name	Trapping Time	No. of queens collected
Caryopteris bicolor	Caryopteris	Evening	2
Rosmarinus officinalis, Lupinus mutabilis	Rosemary, Lupin	Morning, Evening	2, 4
Caryopteris bicolor, Lavendula sp.	Lavendula	Evening, Morning	5,1
Delphinium sp.	Larkspur	Morning	4
Scutellaria linearis	Scutellaria	Evening, Morning	2
Jasminum humile	Chameli	Evening	1
Salvia moorcroftiana	Salvia	Evening	3
Salvia moorcroftiana Nicotiana tobaccum	Wild tobacco	Morning, Evening	2, 2
Punica granatum	Wild pomegranate	Evening	3
Jakranda mimmosaefolia	Gulmohar	Morning	5

new home sites by chasing them. The flora enlisted
e was found to play an important role in sustenance of
ble bee population in nature (Table 2). Similar results
observed by Kashyap (2008) who also observed
ble bee queens on these flora during the months of
uary, March and April, respectively. Refined domiciles
itiation of bumble bee colonies revealed (Table 3) that
chambered boxes with sliding base and top D1 and D2
preferred as all the spring collected queens initiated
colonies. The acceptance (100 per cent) was
icantly higher as compared to D3 and D4 with partial
tance. Colony rearing, wooden two-chambered box
erforated base (25 ×20×15cm) have no acceptance
g February while during March, April and May, it was
to be 66.66, 33.33 and 66.66 per cent, respectively.
rly, hoarding cages with sliding perforated base having
g provisions (33x20x10cm) had zero per cent
tance in February, 33.33 per cent in March, 66.66 per
n April and no acceptance during May. The wax
ion was earlier in queens captured during April and
5.91 and 4.25 days, respectively) than February and
(6.58 days), while the queens captured during early
(February-March) had more acceptability for artificial
iles (Table 4), which is in conformity with the observations of Kashyap (2008). Domiciles with dimensions 15x12x8cm (D1) and 16x12x10cm (D2) were found to be most acceptable by the queens captured during early spring and the acceptances for these domiciles were found to be 100 per cent but the mean difference was found non-significant (Table 4). Horber (1961) observed that small boxes of size 7.5x7.5x5cm can be successfully utilized for the domestication of bumble bees with 60-100 per cent acceptability.

Queens collected during February-March took more time for wax secretion and have cent percent acceptance for the domiciles D1 and D2. However, during April-May, partial acceptance of domiciles D1 and D2 was observed and queens took less time for acceptance of domiciles at this time (Table 4). Similarly, domiciles D3 and D4 did not showed any acceptance during February, whereas showed partial acceptance during March, April and May. Acceptance was found to be early in the domiciles D3 and D4 during April-May than in February-March collected queens. During May, the workers emergence took place earlier (24.44 days) while in April, March and February the time for emergence after wax secretion was observed to be 26.77, 27.22 and 26.44 days, respectively. Similar results were observed by Kashyap (2008). During the rearing experiment, the queens

3. Acceptance of artificial bumble bee rearing boxes during different months

	Acceptance (%) of bumble bees for different refined domiciles*				
	D1	D2	D3	D4	Mean
	100	100	0	0	50
	100	100	66.66	33.33	75
	33.33	33.33	33.33	66.66	41.66
	33.33	66.66	66.66	0	41.66
	66.66	75	41.66	25	
	=	35.11			
	=	37.15			

*Domicile 1 (15x12x8cm); D2 = Domicile 2 (16x12x10cm); D3 = Domicile 3 (25x20x15cm); D4 = Domicile (33x20x10cm)

Table 4. Time required (days) for initiation and emergence of bumble bee after captivating queens during different months

Months	Initiation					Emergence				
	D1	D2	D3	D4	Mean	D1	D2	D3	D4	Mean
February	9.33	9.00	9.66	8.67	9.16	25.67	25.67	28.00	Nil	26.
March	5.66	7.00	7.00	6.66	6.58	27.67	26.67	27.33	Nil	27.
April	6.00	5.33	7.00	5.33	5.91	27.33	27.33	25.67	Nil	26.
May	3.66	5.00	4.00	4.33	4.25	24.67	24.67	24.00	Nil	24.
Mean	6.16	6.58	6.91	6.25		26.33	26.25	26.25	Nil	
CD(P=0.05)										
Domiciles					1.34					2.
Month					2.04					2.

*Mean of D_1, D_2 and D_3

captured fed with pollen pellets/ powder and sucrose/ sugar solution. During February-March required more amount of pollen (10g), whereas the queens captured during April-May required 5g pollen. With an increase in activity of queen and the emergence of workers, the quantity of pollen and sucrose fed to the queen was increased (5-12g pollen and 2-10ml sucrose solution) under laboratory conditions (Table 5). Similarly under room temperature, the average quantity of sugar solution and pollen fed 5-15g and 2-10ml per three days, respectively. These results were found to be in conformity with the results of Thakur *et al.* (2005) and Pridal and Hofbaeur (1998).

Utilization of bumble bee under protected conditions for the pollination of cucumber: The fruit length was significantly longer (20.75cm) from vines pollinated by bumble bees being on a par with the open pollinated ones (20.00cm), followed by 16.44cm length in control block.

Bumble bee pollination resulted in significant increase in fruit weight (413.62g) and diameter (11.01cm) being on a par with the fruit weight (548.88g) and diameter (11.89cm) of fruits obtained in open pollination conditions. In control pollination, the fruit weight (262.75g) and diameter (8. were significantly lower as compared to open and b bee pollination (Table 8). Similar results were obser Stanghellini *et al.* (2000) who noticed an increase weight and diameter of cucumber when bumble bees utilized for the pollination. Bumble bees and open poll flowers yielded fruits having significantly more seed number of seeds per fruit were 331.20 from control which were significantly less as compared to treatments. Similarly, the weight of 1000 seeds significantly higher (31.50g) in fruits of bumbl pollinated plots, followed by 29.20g and 27.55g ext from open pollinated and control plots, respectively 6).

The fruit yield (76.97%) in bumble bee-pollinate open pollinated crop (66.16%) was significantly highe in the plants excluded from pollinators (control).

Bumble bee pollinated plants had significantly crooked fruits (16.18%), followed by 25.20 per cent i pollinated plants, whereas, significantly highest num crooked fruits (36.45%) were observed in plots de

Table 5. Feeding of bumble bees under artificial conditions

	Feeding material	Quantity
Laboratory conditions (26.9°C; 65%RH)	Sucrose (50%)	2-10ml sucrose (50%)
	Pollen pellets	5-12g pollen pellets
Room Temperature conditions (32-36°C and 50-60%RH)	Sugar (50%)	2-10ml sugar (50%)
	pollen pellets	5-15g pollen pellets or pollen powder

Table 6. Effect of different modes of pollination on cucumber grown under protected conditions

Pollination Type	Length (cm)	Diameter (cm)	Weight (g)	Seeds/fruit (No.)	Weight (1000 seed g)	Fruit yield (%)	Crooked fruits (%)	Heal fruits
Bumble bee	20.75	11.01	413.62	422	31.50	76.97	16.18	83.
Open	20.00	11.89	548.88	434	29.20	55.10	36.45	64.
Control	16.44	8.39	262.75	331.20	27.55	66.16	25.20	74.
CD(P=0.05)	2.39	0.88	165.387	45.44	0.54	9.97	5.78	5.

...ators. The results are in conformity with the results of ...nghellini *et al.* (1997) who reported less abortion of ...mber fruits in bumble bee pollination. Similarly, Hodges ...Bakendale (1991) reported less crooked fruits in bee-...nated plants because of proper pollination of flowering ...plants and observed more number of crooked fruits in ...ol and open conditions due to inappropriate pollination.

...n bumble bee pollinated plants, the per cent increase ...e fruit set and healthy fruits were 27.64 and 22.81 over ...ontrol (Table 7). However, percentage of crooked fruits ...reduced to 65.62 per cent in bumble bee-pollinated ...s than the plants which were excluded of pollination.

Similarly, an increase in the percentage of fruit length, ...ter and weight of cucumber fruits was recorded in the ...mber vines pollinated by bumble bees was 20.78, 23.80 ...36.48 per cent, respectively as compared to the plants ...no pollination (control). Simultaneously, per cent ...se in the seed number and weight (1000 seeds) was ... and 12.54 per cent, respectively in bumble bee ...nated plants. Similar results were observed by Stanghellini *et al.* (2000) who noticed an increase in the weight and diameter of cucumber when bumble bees were utilized for the pollination resulting in increased fruit set and yield.

Table 7. Effect of bumble bee pollination on fruit and seed parameters of cucumber grown under polyhouse conditions

Parameters	Per cent increase (%)
Fruit set	27.64
Healthy fruits	22.81
Crooked fruits*	65.62
Fruit length	20.78
Fruit diameter	23.80
Fruit weight	36.48
Seed number	21.52
Weight (1000 seeds)	12.54

*Reduction in per cent of crooked fruits

There is an increase in the cost benefit ratio in poly house and was found to be 1: 2.02 with 22% increase in the total returns in bumble bee pollination cucumbers than

...8. Cost-benefit ratio of cucumber grown under protected conditions

...meter	Cost/100sq m	Fixed Costs (Rs.) per polyhouse (100m²)	
...n labour	2400	Rental value of polyhouse @Rs. 800/month	4000
...preparation	150	Management cost	1000
...Raising	40	Risk margin	500
...planting	40	Total fixed cost	5500
...ng	600		
...on	400		
...ulture operations	300		
...ling	240		
	50		
...er	1000		
...rotection	400		
...aneous	1000		
...rable cost	6620		
	12,120		
...tput	1228.8 kg		
...rns @ Rs. 20/kg	24,576		
...fit	12,456		
...efit ratio	1:2.02		

...pollination

...d from bumble bee pollinated plots = 1175.04 kg
...rns @ 20Rs/kg = 23,500

...d from control plots = 302.7 kg
...rns @ 20Rs/kg = 6054

...cally, if number of control (no pollination) plots taken equal to bumble bee pollinated plots (24) then,
= 921.6 Kg (total plants yield)
...rns@20Rs/kg = 18,432 Rs

...between Bumble bee pollinated and control returns = 5068 Rs (23,500-18,432=5068 which is 22 per cent more than returns ...ol blocks).