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Correlation between Foraging activity and Bee Strength in *Apis mellifera ligustica* Colonies in Mid Hills of Himachal Pradesh

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ABSTRACT: The effects of different hive volume having varied bee strength on foraging activity of *Apis mellifera* were evaluated in the mid hills of Himachal Pradesh, India. There were five treatments *viz.*, Modified BIS type A hive (20 L), 5 frame hive (25 L), 6 frame hive (30 L), 8 frame hive (33 L) and Langstroth hive (42 L). The bee strength showed a positive correlation with bee activity (r=0.70, 0.72, 0.92, 0.79, 0.54). Mean outgoing bees (423.25 bees/5 min), incoming pollen foragers (161.42 bees/5 min) and nectar foragers (489.79 bees/5min) in different experimental hives were found maximum in 8-frame hive of low volume in the month of June and April at 1000-1200 hours at 1200-1400 hours which were statistically similar in standard Langstroth hive. Correlation worked out for the foraging activity with parameters showed a positive significant correlation with the external, internal hive temperature and relative humidity whereas a negative correlation with external relative humidity. This preliminary study showed that hive volume influenced the foraging activity and bee strength of *Apis mellifera* and thus resulted in high population of honeybees. To improve beekeeping in Himachal Pradesh in terms of factors like bee strength and foraging activity more research in this field is required.

Keywords: *Apis mellifera*, Colony strength, Pollen, Honey production, Foraging activity, Langstroth hive.

INTRODUCTION

The nest size, volume and space for a honey bee colony play a significant role in determining the comb construction and subsequent survival and colony productivity (Hepburn *et al*., 2014). Honey bees use nest cavity volume, or the size of the bee hive *i.e.*, bee population as one of the factors in choosing where to build their nests naturally (Villa, 2004). Honey bees raise agricultural yields by pollinating them, which ultimately boosts farm revenues (Goyal *et al*., 1989). The strength of a honey bee colony is very important for the productivity of honey bees (Jevtic *et al*., 2009). Bee foraging impacts the performance of a colony, whereas the productivity of bee hives depends on the foraging activity. The foraging habits of the bee colony determine how much pollination and honey is produced. The strength of the colony, including the number of workers, the availability of brood, pollen, and honey storage, has an impact on the foraging behavior. During the fall and winter, bee colonies kept in 8 frame hives develop bigger than those managed in 10 frame hives (Rinderer *et al*., 2010). Brood rearing depends upon the availability of pollen and nectar, as also on climate factors predominant in the locality. It is necessary to evaluate how the internal space of the hives or hive volume affects the population maintenance and determine the effect of the hive volume on bees. The colony strength influences the foraging pattern of bees. The state of Himachal Pradesh constitutes of most important bee-keeping zones in India. It bids great capabilities of beekeeping owing to its rich bee flora and is important beekeeping areas of India.

MATERIALS AND METHODS

The investigations were conducted in apiary at Department of Entomology, Dr. YSP University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India located at 33°51.607″ latitude, 077°09.95″E longitude and altitude 1262 m amsl from July 2020 to June 2021 in stationary conditions and in months December to February in migratory conditions. There were 5 treatments (Table 1) used *viz*., 5 frame hive of 25 L, 6 frame hive of 30 L, 8 frame hive of 33 L, Langstroth hive of 42 L and Modified BIS A type hive of 20 L (Fig. 1). Modified BIS type A hive used for *A. cerana* F. was provided with modified bee frames of *A. mellifera.* At the start of the experiment all the colonies have 3 frame bee strength. All the colonies were equalized relating to sealed and unsealed brood area, honey and pollen quantities. To estimate the total number of arriving pollinators carrying pollen loads and nectar, bee activity at the hive entrance was monitored. The number of outgoing and incoming bees (pollen and nectar foragers) at hive entrance were counted for 5 minutes. The bee activity was recorded at 1 week interval at 1000h, 1200h and 1400h with three

replications of each experiment hive with the help of stopwatch. Number of bees per 5 minutes going out of hive and incoming pollen and nectar foragers at 1000h, 1200h and 1400h for foraging were recorded at weekly intervals by counting the number of bees with the help of stopwatch. Incoming bees such as resin and water collectors were considered as nectar foragers. Temperature and humidity inside the hive was recorded with the help of thermo-hygrometer. External weather temperature, rainfall and humidity was procured from Department of Environmental Science, UHF Nauni, Solan and Department of Agricultural Meterology, Chaudhary Charan Singh Haryana Agricultural University Hisar, Haryana for stationary and migratory colonies, respectively.

Statistical analysis. The data was subjected to square root transformation as per need of the experiment and with the help of method described by Gomez and Gomez (1986) data was statistically analyzed by three factor analysis of variance (ANOVA) in Completely Randomized Design. The treatment effects were tested at 5 per cent level of significance.

RESULTS AND DISCUSSIONS

The foraging activity of *Apis mellifera ligustica* presented in Table 3, 4 and 5 reveals that foraging activity varied according to its colony strength (Table 2) in each hive volume. The incoming and outgoing bees (Fig. 2) at any point of time were not in equilibrium. *Apis mellifera* colonies showed a distinct foraging activity as the outgoing and incoming bees were maximum during 1000-1200 and 1200-1400 hours in all treatments. The pollen gathering activity was, however, variable in colonies having variable strength. Mean outgoing bees(423.25 bees/5 min), incoming pollen (161.42 bees/5 min) and nectar (489.79 bees/5min) foragers in experimental hives were found maximum in 8-frame hive in the month of June and April at 1000-1200 hours at 1200-1400 hours which was statistically at par with the mean number of pollen foragers in Langstroth hive (160.73 bees/5min) in May during 1000-1200 hours followed by average nectar foragers in Langstroth hive at 1200-1400 hrs (429.92 bees/5min), 1400-1600 hrs (403.42 bees/5min) and 1000-1200 hrs (398.58 bees/5min), 5-frame hive at 1400-1600 hrs (391.75 bees/5min) and in 6-frame hive at 1400-1600 hrs (390.42 bees/5min).

Significant increase in pollen and nectar foragers is related with the greater availability of pollen and nectar which is mainly due to the flowering of plant species yielding both pollen and nectar in the locality. Honeybees rely on flowering plants as a supply of nectar and pollen, and in exchange, provide pollination, which helps the area's plant species flourish. The bee strength (Table 6) showed a positive (significant) correlation with bee activity in all the treatments *viz*. 5-frame, 6-frame, 8-frame, Langstroth (r=0.70, 0.72, 0.92, 0.79) and modified BIS type A hive positive but non-significant (r=0.54). The current findings concur with those of Abou-Shaara *et al*. (2013) who reported a strong positive correlation (r=70) between foraging activity and bee populations.

Correlation between bee activity and weather parameters in hives with different volumes (Table 7) revealed that bee activity was significantly maximum in 8-frame hive (385.17 bees/5min) in the month of June when external weather parameters were 24.15°C Temperature, 61% Relative humidity and 99.50 mm Rainfall and internal hive weather parameters were 33.63°C Temperature and 61.71% Relative humidity whereas significantly minimum bee activity was recorded in BIS Type A hive (57.75 bees/5min) in the month of August when external weather parameters were 24.95°C Temperature, 64% Relative humidity and 148.60 mm Rainfall and internal hive weather parameters were 33.05°C Temperature and 55.96% Relative humidity.

The current study indicated that the number of outgoing bees, incoming pollen foragers as well as incoming nectar foragers has been found maximum in 8-frame hive with 33 L volume (Fig. 3) as compared to Langstroth hive of 42 L volume during the study period from July 2020 to June 2021. However, data was statistically similar in Langstroth hive as well. Free (1967) also reported that the number of active foragers and their foraging activities are influenced by the colony performance, including bee strength, brood area, honey, and pollen reserves. According to Barker (1971), foraging behavior is influenced by the pollen and honey reserves in the hive, and bee activity during flight is almost proportionate to colony strength (Farrar, 1937). The current research is in agreement with studies by Erickson *et al*. (1975), who found that flight activity was 1.5 and 2 times higher in more populated overwintered colonies as compared to colonies with low strength and low total foraging indices. They also noted that low temperature restricts flight activity more in a disposable pollination unit that is less populated than in more populated overwintered colonies. Individual pollen foragers from high brood colonies tend to acquire larger loads than those from low brood colonies, and individual nectar foragers from large colonies tend to work harder than those from small colonies, according to Eckert *et al*. (1994). Rueppell *et al.* (2009) concluded that workers in large hives exhibit higher foraging rates than workers in the small hives. Bee hive type also has an impact on the foraging activity of honey bees (Abou-Shaara *et al*. 2013). Bees' foraging behaviour for nectar or pollen was significantly influenced by their high and low pollen-hoarding behaviours (Pankiw *et al*. 2002). In addition to this, having access to suitable plant resources has a significant influence on foraging behaviour. Foragers of nectar and pollen prefer some resources over others. Chaand *et al*. (2017) also observed that the influence of food reserves resulted in the increase of pollen reserves of the colonies the nectar foraging of the colonies increased, and pollen foraging decreased significantly and reported pollen gathering activity was variable in colonies having variable colony strength i.e., the nectar collectors in 6 (10.56+0.01), 8 (12.23+0.01) and 10 (13.41+0.02) bee frame colonies were maximum between 1200-1400 hours.

Table 1: Measurements of different volume hives.

Sr. No.	Hive used	Hive dimensions in cm (l × b × h)	Hive volume in liters (L)	Replications
1.	5-frame hive	47.5 × 22 × 23.5	25 L	4
2.	6-frame hive	47.5 × 26.5 × 23.5	30 L	4
3.	8-frame hive	47.5 × 29.5 × 23.5	33 L	4
4.	Modified Bis A type	30 × 30 × 22.5	20 L	4
5.	Langstroth (10-frame)	47.5 × 37.5 × 23.5	42 L	4
No. of colonies examined = 20 (4 in each type of experimental hive volume)				

Table 2: Effect of hive volume on bee strength in *Apis mellifera ligustica* colonies.

Hive volume / Month	Mean bee strength					
	25 L (5-frame)	30 L (6-frame)	33 L (8-frame)	42 L (Langstroth)	20 L (Modified BIS type A)	Mean
July 2020	3.00	3.00	3.00	3.00	2.78	2.96
August	2.75	2.68	3.32	3.05	2.64	2.89
September	2.45	2.50	3.15	4.50	2.36	2.99
October	2.63	2.35	3.25	3.20	2.10	2.71
November	2.49	2.23	3.10	3.05	2.03	2.58
December*	2.00	2.04	2.86	2.81	1.75	2.29
January 2021*	2.88	2.13	2.92	2.83	1.11	2.37
February*	2.50	2.63	3.68	3.66	2.06	2.91
March	3.71	3.28	4.48	4.71	3.65	3.96
April	5.50	4.90	6.50	6.25	3.94	5.42
May	5.94	5.75	8.60	8.03	4.12	6.49
June	7.13	7.38	8.76	8.31	3.31	6.98
Mean	3.58	3.40	4.47	4.45	2.65	
$CD_{(0.05)}$	Months : 0.24 Hive volume : 0.15 Month X Hive volume : 0.53					

Table 3: Effect of hive volumes on outgoing foragers in *Apis mellifera* colonies.

Hive volume / Month	Mean no. of outgoing bees / 5 min					
	Time	25 litre (5-frame)	30 litre (6-frame)	33 litre (8-frame)	42 litre (Langstroth)	20 litre (modified BIS Type A)
July 2020	10.00-12.00	61.71 (7.92)*	61.67 (7.92)	86.66 (9.36)	74.02 (8.66)	58.67 (7.72)
	12.00-14.00	74.00 (8.66)	71.08 (8.49)	78.58 (8.91)	76.21 (8.79)	73.86 (8.65)
	14.00-16.00	61.58 (7.91)	61.91 (7.93)	82.91 (9.16)	72.25 (8.56)	58.71 (7.73)
August	10.00-12.00	90.27 (9.55)	76.46 (8.80)	76.13 (8.78)	90.72 (9.58)	52.67 (7.32)
	12.00-14.00	87.00 (9.38)	76.17 (8.78)	76.13 (8.78)	87.31 (9.40)	67.86 (8.30)
	14.00-16.00	82.42 (9.13)	74.65 (8.70)	73.75 (8.65)	84.21 (9.23)	52.71 (7.33)
September	10.00-12.00	91.02 (9.59)	74.11 (8.67)	74.61 (8.70)	151.37 (12.34)	74.36 (8.68)
	12.00-14.00	87.46 (9.41)	73.03 (8.60)	73.53 (8.63)	160.33 (12.70)	73.11 (8.60)
	14.00-16.00	84.17 (9.23)	66.99 (8.25)	67.49 (8.28)	131.25 (11.50)	67.24 (8.26)
October	10.00-12.00	115.13 (10.78)	76.29 (8.79)	97.40 (9.92)	117.25 (10.87)	55.67 (7.53)
	12.00-14.00	127.17 (11.32)	76.15 (8.78)	90.65 (9.57)	129.08 (11.41)	70.86 (8.48)
	14.00-16.00	109.18 (10.50)	74.20 (8.67)	87.56 (9.41)	111.28 (10.60)	55.71 (7.53)
November	10.00-12.00	73.61 (8.64)	116.13 (10.82)	115.25 (10.78)	103.79 (10.24)	53.67 (7.39)
	12.00-14.00	72.53 (8.57)	128.17 (11.37)	120.71 (11.03)	108.12 (10.45)	68.86 (8.36)
	14.00-16.00	66.49 (8.22)	110.18 (10.54)	108.79 (10.48)	97.75 (9.94)	53.71 (7.40)
December**	10.00-12.00	92.52 (9.67)	115.69 (10.80)	116.00 (10.82)	97.53 (9.93)	115.63 (10.80)
	12.00-14.00	88.96 (9.48)	124.44 (11.20)	124.54 (11.20)	97.97 (9.95)	127.67 (11.34)
	14.00-16.00	85.67	109.48	110.19	90.96	109.68

		(9.31)	(10.51)	(10.54)	(9.59)	(10.52)
January 2021**	10.00-12.00	88.83 (9.48)	122.23 (11.10)	116.75 (10.85)	116.50 (10.84)	59.58 (7.78)
	12.00-14.00	99.79 (10.04)	102.74 (10.18)	128.38 (11.37)	128.09 (11.36)	74.25 (8.67)
	14.00-16.00	69.63 (8.40)	94.63 (9.78)	111.59 (10.61)	111.82 (10.62)	59.58 (7.78)
February**	10.00-12.00	178.36 (13.39)	188.96 (13.78)	123.07 (11.14)	118.33 (10.92)	61.17 (7.88)
	12.00-14.00	127.57 (11.33)	109.40 (10.50)	140.65 (11.90)	130.38 (11.46)	75.59 (8.75)
	14.00-16.00	76.20 (8.78)	111.49 (10.61)	111.70 (10.62)	110.68 (10.57)	60.92 (7.87)
March	10.00-12.00	242.00 (15.59)	119.13 (10.96)	167.94 (13.00)	184.40 (13.62)	98.00 (9.91)
	12.00-14.00	208.58 (14.48)	110.70 (10.57)	207.55 (14.44)	190.28 (13.83)	100.08 (10.03)
	14.00-16.00	232.75 (15.29)	98.43 (9.96)	152.30 (12.38)	151.81 (12.36)	92.67 (9.63)
April	10.00-12.00	230.40 (15.19)	224.00 (15.00)	279.58 (16.71)	249.96 (15.83)	103.67 (10.23)
	12.00-14.00	237.08 (15.39)	237.08 (15.41)	218.07 (14.77)	192.62 (13.91)	84.00 (9.22)
	14.00-16.00	227.93 (15.09)	125.58 (11.23)	208.99 (14.48)	187.96 (13.69)	81.96 (9.11)
May	10.00-12.00	298.11 (17.29)	239.06 (15.49)	359.27 (18.96)	274.92 (16.61)	112.55 (10.65)
	12.00-14.00	238.86 (15.37)	233.63 (15.31)	268.63 (16.30)	253.66 (15.95)	100.19 (10.05)
	14.00-16.00	284.21 (16.87)	234.46 (15.34)	234.67 (15.32)	193.00 (13.87)	76.00 (8.77)
June	10.00-12.00	322.75 (17.99)	328.00 (18.14)	423.25 (20.60)	291.00 (17.09)	102.60 (10.15)
	12.00-14.00	304.33 (17.47)	330.50 (18.21)	419.50 (20.51)	311.50 (17.68)	122.00 (11.09)
	14.00-16.00	306.00 (17.52)	305.75 (17.51)	312.75 (17.71)	277.50 (16.69)	83.50 (9.19)

* Figures in parentheses are square root ($\sqrt{x+1}$) transformation of original values
** Bees were in migratory conditions in these months

Table 4: Effect of hive volumes on incoming pollen foragers in *Apis mellifera* colonies.

Hive volume / Month	Mean no. of incoming nectar foragers / 5 min					
	Time	25 litre (5-frame)	30 litre (6-frame)	33 litre (8-frame)	42 litre (Langstroth)	20 litre (Modified BIS Type A)
July 2020	10.00-12.00	80.84 (9.04) *	73.51 (8.63)	85.50 (9.28)	75.51 (8.74)	54.42 (7.44)
	12.00-14.00	118.58 (10.93)	111.25 (10.59)	108.58 (10.46)	113.25 (10.68)	57.08 (7.61)
	14.00-16.00	97.71 (9.90)	90.38 (9.52)	85.25 (9.28)	92.38 (9.62)	64.25 (8.05)
August	10.00-12.00	91.58 (9.61)	92.62 (9.67)	83.17 (9.17)	66.67 (8.21)	58.17 (7.68)
	12.00-14.00	117.92 (10.80)	116.21 (10.81)	84.58 (9.25)	116.33 (10.82)	45.17 (6.73)
	14.00-16.00	66.08 (8.18)	84.25 (9.23)	57.67 (7.63)	56.67 (7.59)	59.17 (7.76)
September	10.00-12.00	55.75 (7.49)	99.75 (10.02)	53.29 (7.37)	53.83 (7.38)	52.59 (7.28)
	12.00-14.00	110.83 (10.57)	88.00 (9.37)	62.75 (7.98)	69.33 (8.33)	49.00 (7.03)
	14.00-16.00	84.67 (9.26)	67.42 (8.26)	69.67 (8.40)	46.67 (6.87)	57.67 (7.66)
October	10.00-12.00	55.50 (7.50)	39.67 (6.36)	48.71 (7.05)	78.42 (8.90)	35.42 (6.03)
	12.00-14.00	45.58 (6.70)	43.33 (6.66)	61.50 (7.90)	72.25 (8.54)	21.83 (4.77)
	14.00-16.00	64.91 (8.05)	41.71 (6.51)	46.00 (6.85)	47.92 (6.88)	26.04 (5.17)
November	10.00-12.00	34.92 (5.97)	40.04 (6.39)	45.71 (6.82)	47.10 (6.91)	63.67 (8.01)
	12.00-14.00	41.17 (6.45)	29.04 (5.47)	48.83 (7.01)	41.51 (6.51)	29.33 (5.50)
	14.00-16.00	31.83	42.04	55.83	57.18	56.00

		(5.71)	(6.53)	(7.48)	(7.62)	(7.55)
December**	10.00-12.00	77.29 (8.84)	30.04 (5.50)	38.42 (6.26)	86.33 (9.29)	34.69 (5.96)
	12.00-14.00	86.08 (9.32)	48.71 (7.05)	44.67 (6.72)	61.75 (7.91)	33.20 (5.74)
	14.00-16.00	62.84 (7.95)	36.38 (6.05)	37.83 (6.23)	80.50 (8.94)	26.20 (5.20)
January 2021**	10.00-12.00	77.77 (8.87)	75.52 (8.74)	76.15 (8.78)	66.23 (8.19)	53.25 (7.36)
	12.00-14.00	81.04 (9.03)	81.92 (9.10)	88.86 (9.47)	79.61 (8.96)	54.92 (7.47)
	14.00-16.00	92.84 (9.68)	81.59 (9.08)	72.75 (8.59)	58.83 (7.64)	43.50 (6.64)
February**	10.00-12.00	99.64 (10.03)	93.49 (9.72)	95.45 (9.82)	85.66 (9.28)	49.13 (7.04)
	12.00-14.00	88.51 (9.46)	80.70 (9.03)	102.36 (10.16)	69.05 (8.34)	59.07 (7.74)
	14.00-16.00	92.75 (9.68)	90.21 (9.54)	77.22 (8.78)	76.80 (8.72)	62.50 (7.94)
March	10.00-12.00	120.79 (11.03)	92.67 (9.67)	116.07 (10.81)	88.90 (9.46)	80.40 (8.92)
	12.00-14.00	86.50 (9.34)	90.94 (9.57)	130.87 (11.48)	130.32 (11.43)	65.16 (8.09)
	14.00-16.00	127.58 (11.34)	82.68 (9.14)	99.87 (10.02)	125.56 (11.17)	87.71 (9.42)
April	10.00-12.00	146.17 (12.12)	101.15 (10.10)	139.17 (11.77)	120.71 (11.02)	110.34 (10.55)
	12.00-14.00	140.46 (11.88)	135.92 (11.55)	177.19 (13.33)	144.08 (12.03)	101.34 (10.12)
	14.00-16.00	206.36 (14.37)	116.19 (10.82)	153.48 (12.42)	126.99 (11.30)	96.87 (9.89)
May	10.00-12.00	236.50 (15.41)	215.79 (14.72)	248.41 (15.79)	276.15 (16.32)	109.59 (10.51)
	12.00-14.00	262.59 (16.24)	247.50 (15.76)	338.79 (18.43)	333.02 (18.26)	100.42 (10.07)
	14.00-16.00	245.38 (15.70)	211.42 (14.57)	256.89 (15.91)	240.44 (15.12)	106.87 (10.38)
June	10.00-12.00	349.92 (18.73)	348.33 (18.69)	462.54 (21.50)	398.58 (19.99)	108.67 (10.47)
	12.00-14.00	354.29 (18.85)	353.72 (18.83)	489.79 (22.15)	429.92 (20.75)	112.17 (10.64)
	14.00-16.00	391.75 (19.82)	390.42 (19.78)	457.04 (21.40)	403.42 (20.11)	100.88 (10.09)

* Figures in parentheses are square root ($\sqrt{x+1}$) transformation of original values
** Bees were in migratory conditions in these months

Table 5: Effect of hive volumes on incoming nectar foragers in *Apis mellifera* colonies.

Hive volume / Month	Mean no. of incoming nectar foragers / 5 min					
	Time	25 litre (5-frame)	30 litre (6-frame)	33 litre (8-frame)	42 litre (Langstroth)	20 litre (Modified BIS Type A)
July 2020	10.00-12.00	80.84 (9.04) *	73.51 (8.63)	85.50 (9.28)	75.51 (8.74)	54.42 (7.44)
	12.00-14.00	118.58 (10.93)	111.25 (10.59)	108.58 (10.46)	113.25 (10.68)	57.08 (7.61)
	14.00-16.00	97.71 (9.90)	90.38 (9.52)	85.25 (9.28)	92.38 (9.62)	64.25 (8.05)
August	10.00-12.00	91.58 (9.61)	92.62 (9.67)	83.17 (9.17)	66.67 (8.21)	58.17 (7.68)
	12.00-14.00	117.92 (10.80)	116.21 (10.81)	84.58 (9.25)	116.33 (10.82)	45.17 (6.73)
	14.00-16.00	66.08 (8.18)	84.25 (9.23)	57.67 (7.63)	56.67 (7.59)	59.17 (7.76)
September	10.00-12.00	55.75 (7.49)	99.75 (10.02)	53.29 (7.37)	53.83 (7.38)	52.59 (7.28)
	12.00-14.00	110.83 (10.57)	88.00 (9.37)	62.75 (7.98)	69.33 (8.33)	49.00 (7.03)
	14.00-16.00	84.67 (9.26)	67.42 (8.26)	69.67 (8.40)	46.67 (6.87)	57.67 (7.66)
October	10.00-12.00	55.50 (7.50)	39.67 (6.36)	48.71 (7.05)	78.42 (8.90)	35.42 (6.03)
	12.00-14.00	45.58 (6.70)	43.33 (6.66)	61.50 (7.90)	72.25 (8.54)	21.83 (4.77)
	14.00-16.00	64.91 (8.05)	41.71 (6.51)	46.00 (6.85)	47.92 (6.88)	26.04 (5.17)
	10.00-12.00	34.92	40.04	45.71	47.10	63.67

November		(5.97)	(6.39)	(6.82)	(6.91)	(8.01)
	12.00-14.00	41.17 (6.45)	29.04 (5.47)	48.83 (7.01)	41.51 (6.51)	29.33 (5.50)
	14.00-16.00	31.83 (5.71)	42.04 (6.53)	55.83 (7.48)	57.18 (7.62)	56.00 (7.55)
December**	10.00-12.00	77.29 (8.84)	30.04 (5.50)	38.42 (6.26)	86.33 (9.29)	34.69 (5.96)
	12.00-14.00	86.08 (9.32)	48.71 (7.05)	44.67 (6.72)	61.75 (7.91)	33.20 (5.74)
	14.00-16.00	62.84 (7.95)	36.38 (6.05)	37.83 (6.23)	80.50 (8.94)	26.20 (5.20)
January 2021**	10.00-12.00	77.77 (8.87)	75.52 (8.74)	76.15 (8.78)	66.23 (8.19)	53.25 (7.36)
	12.00-14.00	81.04 (9.03)	81.92 (9.10)	88.86 (9.47)	79.61 (8.96)	54.92 (7.47)
	14.00-16.00	92.84 (9.68)	81.59 (9.08)	72.75 (8.59)	58.83 (7.64)	43.50 (6.64)
February**	10.00-12.00	99.64 (10.03)	93.49 (9.72)	95.45 (9.82)	85.66 (9.28)	49.13 (7.04)
	12.00-14.00	88.51 (9.46)	80.70 (9.03)	102.36 (10.16)	69.05 (8.34)	59.07 (7.74)
	14.00-16.00	92.75 (9.68)	90.21 (9.54)	77.22 (8.78)	76.80 (8.72)	62.50 (7.94)
March	10.00-12.00	120.79 (11.03)	92.67 (9.67)	116.07 (10.81)	88.90 (9.46)	80.40 (8.92)
	12.00-14.00	86.50 (9.34)	90.94 (9.57)	130.87 (11.48)	130.32 (11.43)	65.16 (8.09)
	14.00-16.00	127.58 (11.34)	82.68 (9.14)	99.87 (10.02)	125.56 (11.17)	87.71 (9.42)
April	10.00-12.00	146.17 (12.12)	101.15 (10.10)	139.17 (11.77)	120.71 (11.02)	110.34 (10.55)
	12.00-14.00	140.46 (11.88)	135.92 (11.55)	177.19 (13.33)	144.08 (12.03)	101.34 (10.12)
	14.00-16.00	206.36 (14.37)	116.19 (10.82)	153.48 (12.42)	126.99 (11.30)	96.87 (9.89)
May	10.00-12.00	236.50 (15.41)	215.79 (14.72)	248.41 (15.79)	276.15 (16.32)	109.59 (10.51)
	12.00-14.00	262.59 (16.24)	247.50 (15.76)	338.79 (18.43)	333.02 (18.26)	100.42 (10.07)
	14.00-16.00	245.38 (15.70)	211.42 (14.57)	256.89 (15.91)	240.44 (15.12)	106.87 (10.38)
June	10.00-12.00	349.92 (18.73)	348.33 (18.69)	462.54 (21.50)	398.58 (19.99)	108.67 (10.47)
	12.00-14.00	354.29 (18.85)	353.72 (18.83)	489.79 (22.15)	429.92 (20.75)	112.17 (10.64)
	14.00-16.00	391.75 (19.82)	390.42 (19.78)	457.04 (21.40)	403.42 (20.11)	100.88 (10.09)

* Figures in parentheses are square root ($\sqrt{x+1}$) transformation of original values
** Bees were in migratory conditions in these months

Table 6: Pearson Correlation coefficient (r) of bee activity with bee strength in *A. mellifera* colonies hives with different volumes.

		Bee strength					Bee activity				
		5-frame	**6-frame**	**8-frame**	**Langstroth**	**M# BIS Type A**	**5-frame**	**6-frame**	**8-frame**	**Langstroth**	**M# BIS Type A**
Bee strength	**5-frame**	1.00									
	6-frame	0.98*	1.00								
	8-frame	0.97*	0.97*	1.00							
	Langstroth	0.95*	0.95*	0.98*	1.00						
	M# BIS Type A	0.76*	0.75*	0.77*	0.78*	1.00					
Bee activity	**5-frame**	0.70*	0.62*	0.69*	0.70*	0.48	1.00				
	6-frame	0.73*	0.72*	0.78*	0.76*	0.58*	0.84*	1.00			
	8-frame	0.90*	0.86*	0.92*	0.89*	0.72*	0.84*	0.91*	1.00		
	Langstroth	0.71*	0.70*	0.76*	0.79*	0.62*	0.91*	0.94*	0.89*	1.00	
	M# BIS Type A	0.50	0.46	0.61*	0.67*	0.54	0.67*	0.61*	0.70*	0.75*	1.00

*5% significance, # Modified

Table 7: Correlation between bee activity and weather parameters in hives with different volumes.

Hive volume / Months	No. of outgoing bees/5 min					Weather parameters											
						External Weather parameters			Internal Hive weather parameters								
									25 litre (5-frame)		30 litre (6-frame)		33 litre (8-frame)		42 litre (Langstroth)		20 litre (BIS Type A)	
	25 litre (5-frame)	30 litre (6-frame)	33 litre (8-frame)	42 litre (Langstroth)	20 litre (BIS Type A)	T* (°C)	RH** (%)	Rainfall (mm)	T (°C)	RH (%)	T (°C)	RH (%)	T (°C)	RH (%)	T (°C)	RH (%)	T (°C)	RH (%)
July-2020	65.76 (8.16)***	64.89 (8.11)	82.72 (9.14)	74.16 (8.67)	63.75 (8.03)	25.05	76.00	278.10	33.45	56.25	33.75	56.00	33.63	56.63	33.25	56.13	33.05	55.75
August	86.56 (9.36)	75.76 (8.76)	75.33 (8.74)	87.41 (9.40)	57.75 (7.65)	24.95	81.00	148.60	33.45	56.46	33.75	56.21	33.63	56.83	33.25	56.33	33.05	55.96
September	87.55 (9.41)	71.38 (8.50)	71.88 (8.53)	147.65 (12.18)	71.57 (8.51)	24.10	64.00	6.00	33.03	54.23	33.00	53.98	33.30	54.60	33.03	54.10	32.78	53.73
October	117.16 (10.86)	75.55 (8.75)	91.87 (9.63)	119.20 (10.96)	60.75 (7.84)	20.40	55.00	0.00	31.50	53.63	31.60	53.38	32.03	54.00	31.80	53.50	31.60	53.13
November	70.88 (8.47)	118.16 (10.91)	114.92 (10.76)	103.22 (10.21)	58.75 (7.72)	14.60	56.00	37.70	31.25	52.63	30.75	52.38	30.50	53.00	30.25	52.50	30.00	52.13
December ***	89.05 (9.49)	116.54 (10.84)	116.91 (10.86)	95.48 (9.82)	117.66 (10.89)	13.15	72.68	0.00	30.50	50.63	30.00	50.38	30.00	51.00	30.00	50.50	30.00	50.13
January 2021 ***	86.08 (9.31)	106.53 (10.35)	118.91 (10.95)	118.80 (10.94)	64.47 (8.08)	11.80	84.20	8.90	30.00	49.38	30.00	49.13	30.00	49.75	30.00	49.25	30.00	48.88
February ***	127.38 (11.17)	136.61 (11.63)	125.14 (11.22)	119.80 (10.98)	65.89 (8.17)	13.85	62.00	8.70	30.00	52.13	31.50	51.88	31.50	52.50	31.75	52.00	30.75	51.63
March	227.78 (15.12)	109.42 (15.12)	175.93 (13.27)	175.50 (13.27)	96.92 (9.86)	18.15	43.00	14.80	32.73	56.63	31.68	56.38	31.93	57.00	31.55	56.50	31.80	56.13
April	231.80 (15.22)	195.55 (13.88)	235.55 (15.32)	210.18 (14.48)	89.88 (9.52)	20.10	43.00	65.90	33.25	58.88	33.43	58.63	35.38	59.25	32.93	58.75	32.93	58.38
May	273.72 (16.51)	235.72 (15.38)	287.52 (16.86)	240.53 (15.48)	96.25 (9.82)	21.85	59.00	148.90	33.00	59.13	33.75	58.88	33.13	59.50	33.23	59.00	33.00	58.63
June	311.03 (17.66)	321.42 (17.95)	385.17 (19.61)	293.33 (17.15)	102.70 (10.15)	24.15	61.00	99.50	33.45	61.34	33.75	61.09	33.63	61.71	33.25	61.21	33.05	60.84
CD	**0.36**																	

Temperature ** Relative humidity *** Migratory conditions

a. Standard bee frame of *A. mellifera* b. Modified *A. cerana* bee frame

Fig. 1. Bee frames for BIS Type A hive.

Fig. 2. Bee activity at hive entrance.

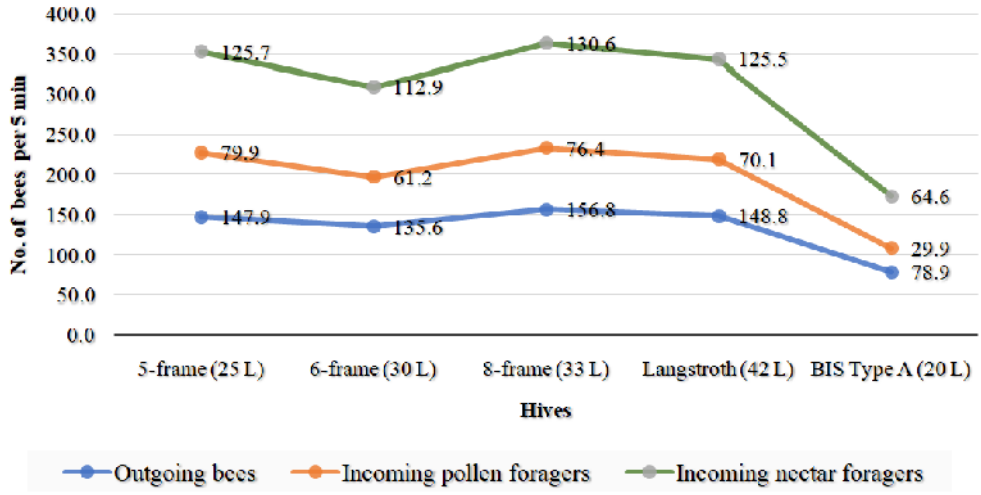

Fig. 3. Mean number of outgoing bees, incoming pollen and nectar foragers per 5 min in *Apis mellifera* colonies in hives with different volumes during July 2020 to June 2021.

CONCLUSION

As, it is evident from studies that bee strength and bee activity of *A. mellifera* colonies were significantly affected by hive volume or hive size. The bee strength showed a positive correlation with bee activity. Mean outgoing bees, incoming pollen foragers and nectar foragers in different experimental hives were found maximum in 8-frame hive of 33 L. Based on performance of colonies in different hive volumes it can be concluded that 8-frame hive is found to be optimum for keeping *A. mellifera* in mid-hills of Himachal Pradesh. It can contribute to enhance the honey production and ultimately the farmer's income in Himachal Pradesh.

FUTURE SCOPE

It is clear from studies that bee strength and foraging activity was significantly affected by hive volume or

hive size. Based on performance of colonies in different hive volumes it can be concluded that 8-frame hive is found to be optimum for keeping *A. mellifera* in mid hills of Himachal Pradesh. However, these are preliminary studies more research in this research is required to be recommend by the farmers.

Author contributions: All authors jointly designed the experiment. Simran Bhatia conducted the field trials, performed data analysis and drafted the manuscript with inputs from all authors. Dr. Kiran Rana (Major Advisor) collaborated closely in the whole process from data observation to data analysis and manuscript submission. Dr. Meena Thakur, cooperated in data interpretation and analysis. Monika, Sapna Devi and Sawraj Jit Singh read and modified manuscript paper writing according to journal format and Ojas Chauhan and Veenu Janjhua in data recording and in manuscript paper writing. All authors read and approved the final manuscript.

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