

Effect of Honeybee Pollination on Quantity and Quality of Apple Crop in Kullu Hills of Himachal Pradesh, India

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Abstract: The experiment on quantitative and qualitative effects of honeybee pollination on apple crop were carried out on European bee *Apis mellifera* L. and Indian hive bee *Apis cerana* F., by placing two colonies of each species in experimental apple orchards located at Bhalogi (1400 m), Baskhola (1580 m) and Dhamadhar (1810 m) areas in Kullu hills of Himachal Pradesh. There was no significant difference ($P>0.01$) in the fruit set in different experimental designs (honeybees pollinated flowers, open pollinated flowers and in control) in self-compatible varieties of apple (Golden Delicious and Red Gold), but the differences in these experimental designs were significant ($P<0.01$) in self-incompatible varieties like Royal Delicious and Red Delicious. There was some difference in the fruit drops of self-incompatible varieties between open and honeybees pollinated flowers but it was not significant ($P>0.01$). In Golden Delicious and Red Gold, the qualitative pollination data showed that weight, length, breadth, volume and number of seeds per fruit developed were significantly maximum in honeybee pollinated flowers ($P<0.01$) and minimum in fruits developed under control experimental conditions in all the three orchards. Whereas, in Royal Delicious and Red Delicious varieties, the weight, length, breadth, volume and number of seeds per fruit were significantly more ($P<0.01$) in fruits developed from honeybees pollinated flowers than in fruits from open pollinated flowers.

Keywords: Honeybee pollination, quantitative and qualitative effects, apple crop, Kullu hills

1. Introduction

Insect pollinators play a vital role in the production of many fruits, vegetables and field crops (13) and various studies have valued insect pollination as an important ecosystem service for agricultural food production at global level (12). However, there is increasing evidence of global and localized declines in the diversity and abundance of both wild and managed insect pollinators (3, 21, 22) threatening the stability of this ecosystem service. The proper management of insect pollination services can reduce risks in production and increase rewards by addressing pollination deficits within cultivated areas (1).

Globally, apple (*Malus domestica*) is one of the most important fruit crops with 2010 production across 93 countries worth US\$ 64bn (11). Apple cultivars are self-incompatible to varying extents and require pollen transfer from polliniser cultivar to set fruit in marketable quantities (8). Insects, such as bees and hoverflies, are the predominant pollination vector for apple and thus their activity in orchards is essential for apple production (13). Increasing insect pollinator numbers in apple orchards has shown improved fruit set and yield (16) and there is some evidence that levels of pollination affect seed number with associated impacts on size and calcium concentration (18).

Honeybees are considered as the most efficient pollinators of cultivated crops because of their potential for long working hours, presence of pollen baskets, floral fidelity, micromanipulation of flowers, maintainability of high population and adaptability to different climatic conditions (29). Further, honeybees can be domesticated, marketed and transported from place to place (7). The vital role which

honeybees play in the pollination of large number of cultivated crops is often under estimated in developing countries. As a matter of fact, the main significance of honeybees and beekeeping is pollination. Therefore, income from agriculture by the use of honeybees in crop pollination is many times higher than their value as honey and beeswax producers (30). In the absence of honeybee pollination, the important factors that lacked in the complex of agronomical practices in apple cultivation were the total cross-pollination and fertilization of flowers and this led to the flower as well as fruit drop and a higher fruit drop in Golden Delicious and Red Gold cultivars (14, 10) but pollination by *Apis cerana* enhanced increase in fruit setting and quality of fruit set in apple crop (25).

2. Methodology

Quantitative and qualitative effects of honeybee pollination on apple crop were investigated on European bee, *Apis mellifera* L. and Indian hive bee, *Apis cerana* F., by placing two colonies of each species in experimental apple orchards located at Bhalogi (1400 m), Baskhola (1580 m) and Dhamadhar (1810 m) areas in Kullu hills of Himachal Pradesh.

2.1 Effect of Honeybee Pollination on Fruit Set

The following experimental designs were set to study the effect of honeybee pollination on fruit set at the time of bloom in the apple orchards located at different altitudes.

2.1.1 Experiment A (Honeybee pollinated flowers)

In honeybee pollinated flowers, four trees, one each of Golden Delicious, Red Gold, Royal Delicious and Red

Delicious were enclosed in an insect proof net in which two colonies of honeybees (one of *A. mellifera* and one of *A. cerana*) were placed as pollinators of apple bloom. In this experiment, four branches of each variety, containing approximately eight hundred pink buds were chosen at random. These branches of experimental trees were chosen in such a way that they were of same dimensions with respect to their spread, phase of flowering and height above the ground. The bees were kept inside the net till the last flower on experimental trees. Fruit set was observed after ten days of petal fall and the percentage was measured as below:

$$\text{Percentage of Fruit Set} = \frac{\text{Number of Fruits}}{\text{Number of Pink Buds}} \times 100$$

2.1.2 Experiment B (Open, besides honeybees other natural insect pollinators were present)

In open pollinated flowers, honeybees and other natural insect pollinators could visit the apple flowers freely. In this experiment also, equal number of branches of ten experimental trees, two trees each of Golden Delicious and Red Gold and three trees each of Royal Delicious and Red Delicious were chosen in the same way as in case of honeybees pollinated experiment and each branch contained approximately eight hundred pink buds. The results were expressed in terms of percentages of fruit set and calculated as honeybee pollinated flowers.

2.1.3 Experiment C (Control, where no insect pollinator was present)

In control experiment ten trees, two each of self-compatible varieties (Golden Delicious, Red Gold) and three each of self-incompatible varieties (Royal Delicious and Red Delicious) were selected and in each tree four branches, each containing approximately five hundred flowers at pink bud stage were chosen at random and covered with muslin bags so that no insect pollinator could enter the bag for pollination. These branches of experimental trees were chosen in the same way as in case of honeybee pollinated experiment. Before covering with muslin bags, the numbers of pink buds were counted in each experimental branch. The fruit set was observed after ten days of the petal fall, calculated as honeybee pollinated flowers.

Similar experimental designs were set up in all the three orchards and the percentage of fruit set was calculated.

2.2 Effect of honeybee pollination on fruit drop

After calculating the fruit set in different experimental designs, the number of fruits dropped in the month of June, was also noted in different experimental designs i.e. open, honeybee pollinated and control. The fruit drop was observed from the ratio of fruits dropped to the total number of fruits set. This fruit drop was also calculated in terms of percentage (9).

2.3 Quality improvement in the apple fruit due to honeybee pollination

Quality improvement in the fruit due to pollination was assessed in terms of increase in weight, length, breadth, volume and number of seeds per fruit. Weight of fruit in grams was measured with the help of a top pan electric balance; length and breadth in centimeter with the help of

Vernier callipers; volume in ml on the line of the principle that the volume of an object is equal to the amount of water displaced by it. Finally, the number of seeds in a fruit was counted by cutting it. For each parameter, ten fruits were taken to get the mean values of weight, length, breadth, volume and number of seeds (9, 16).

3. Results and Discussion

3.1 Effect of insect pollinators on fruit set of apple

In apple orchard at Bhalogi (1400 m), self-compatible varieties like Golden Delicious and Red Gold, the fruit sets in control experiment were 17.21% and 15.31% respectively, whereas, in open pollinated flowers of Golden Delicious and Red Gold the fruit set was 20.44% and 17.04% respectively. In honeybees pollinated flowers, the fruit set in Golden Delicious and Red Gold were 30.60% and 23.20% respectively. However, in case of self-incompatible varieties of apple, such as Royal Delicious and Red Delicious, the role of honeybees in pollination was very significant. For example, the fruit set in Royal Delicious were 0%, 15.62% and 22.42% percent in control, open and honeybee pollinated flowers respectively. Similarly, at the same orchard, the fruit set in Red Delicious were 0%, 13.73% and 20.84% in control, open and honeybee pollinated flowers respectively (Table 1).

At Baskhola, (1580 m) in Golden Delicious, Red Gold, Royal Delicious and Red Delicious the fruit set in control experiment were 16.30%, 15.51%, 0% and 0% respectively. In open pollinated flowers fruit set were 18.22%, 16.52%, 15.31% and 11.05% in Golden Delicious, Red Gold, Royal Delicious, Red Delicious respectively, whereas, in honeybees pollinated flowers the fruit set in Golden Delicious, Red Gold, Royal Delicious and Red Delicious were 29.46%, 22.34%, 21.52% and 20.07% respectively (Table 1).

In Golden Delicious, Red Gold, royal Delicious and Red Delicious the fruit set were 17.20%, 16.65%, 0% and 0% respectively in control experiment, whereas, the fruit set was 19.02%, 19.42%, 8.48% and 8.32% respectively in open pollinated flowers at Dhamadhar (1810 m). Moreover, at the same height, the fruit set in honeybee pollinated flowers of Golden Delicious, Red Gold, Royal Delicious and Red Delicious was 22.20%, 21.62%, 16.90% and 16.80% respectively (Table 1). In self-compatible varieties of apple (Golden Delicious and Red Gold) there was no significant difference ($P>0.01$) in the fruit set in different experimental designs (honeybees pollinated flowers, open pollinated flowers and in control) but the differences in these experimental designs were significant ($P<0.01$) in self-incompatible varieties like Royal Delicious and Red Delicious.

3.2 Effect of insect pollinators in apple fruit drop

In the present study it has been found that fruit drop was significantly higher ($P>0.01$) in self-compatible varieties of apple under controlled experiment as compared to the fruits from open and honeybees pollinated flowers. At Bhalogi, Baskhola and Dhamadhar in Golden Delicious, the fruit

drops were maximum (37.32%, 38.37% and 39.23% respectively) under control experiment and minimum (25.32%, 26.20% and 28.31% respectively) in honeybee pollinated flowers. In open pollinated flowers of Golden Delicious, the fruit drops were 28.40%, 28.25% and 30.41% at Bhalogi, Baskhola and Dhamadhar respectively (Table 2). Similarly at Bhalogi, Baskhola and Dhamadhar in Red Gold, the fruit drops were maximum (36.40%, 38.40% and 37.70% respectively) under control experiment and minimum (24.40%, 25.46% and 27.88% respectively) in honeybee pollinated flowers. In open pollinated flowers of Red Gold, the fruit drops were 30.60%, 32.43% and 31.64% respectively. No significant difference ($P>0.01$) was observed in fruits drops of self-compatible varieties between open and honeybees pollinated flowers. In self-incompatible variety like Royal Delicious, the fruit drops in open pollinated flowers were 29.61%, 30.74% and 30.14% at Bhalogi, Baskhola and Dhamadhar respectively, whereas, in honeybees pollinated flowers the fruit drops were 25.37%, 25.53% and 27.80% respectively. In other self-incompatible variety of Red Delicious, the fruit drops in open pollinated flowers at Bhalogi, Baskhola and Dhamadhar were 29.30%, 29.04% and 30.71% respectively, whereas, in honeybees pollinated flowers of Red Delicious, the fruit drops were 24.62%, 26.54% and 27.70% respectively. The difference observed in the fruit drops of self-incompatible varieties between open and honeybees pollinated flowers was without any significant difference ($P>0.01$).

3.3 Quality improvement in the apple fruits due to insect pollination

Quality improvement in the apple fruit was observed in terms of increase in weight (gm), length and breadth (cm), volume (ml) and number of seeds per fruit. In apple orchard at Bhalogi, the mean weights of apple fruit in honeybee pollinated Golden Delicious, Red Gold, Royal Delicious and Red Delicious were 190.06 ± 1.22 gm, 150.00 ± 4.50 gm, 173.60 ± 4.20 gm and 170.60 ± 8.03 gm respectively. Whereas, at Baskhola the mean weights in honeybees pollinated Golden Delicious, Red Gold, Royal Delicious and Red Delicious were 179.22 ± 2.50 gm, 165.02 ± 2.30 gm, 213.00 ± 1.20 gm and 188.08 ± 4.20 gm respectively. At Dhamadhar, the mean weights of Golden Delicious, Red Gold, Royal Delicious and Red Delicious in honeybee pollinated fruits were 287.02 ± 6.01 gm, 203.00 ± 1.10 gm, 301.60 ± 1.30 gm and 290.20 ± 3.02 gm respectively (Table 3).

The mean lengths of Golden Delicious, Red Gold, Royal Delicious and Red Delicious under this set of experiment at Bhalogi were 7.32 ± 0.04 cm, 6.70 ± 0.50 cm, 6.97 ± 0.50 cm and 6.48 ± 0.11 cm respectively, while at Baskhola the mean lengths of Golden Delicious, Red Gold, Royal Delicious and Red Delicious were 6.80 ± 0.15 cm, 6.40 ± 0.06 cm, 7.00 ± 0.40 cm and 6.60 ± 0.24 cm respectively. The mean lengths of fruit in honeybees pollinated flowers of Golden Delicious, Red Gold, Royal Delicious and Red Delicious were 7.60 ± 0.08 cm, 6.80 ± 0.14 cm, 8.90 ± 0.29 cm and 8.92 ± 0.16 cm respectively at Dhamadhar (Table 3).

In apple orchard at Bhalogi, the mean breadths of Golden Delicious, Red Gold, Royal Delicious and Red Delicious in

honeybee pollinated flowers were 7.80 ± 0.21 cm, 7.30 ± 0.06 cm, 7.82 ± 0.30 cm and 7.40 ± 0.26 cm respectively. The mean breadths of Golden Delicious, Red Gold, Royal Delicious and Red Delicious in Honeybees pollinated flowers were 7.90 ± 0.10 cm, 7.05 ± 0.10 cm, 7.80 ± 0.22 cm and 7.14 ± 0.11 cm respectively at Baskhola, whereas, the mean breadths were 8.80 ± 0.10 cm, 7.90 ± 0.06 cm, 8.78 ± 0.04 cm, and 8.80 ± 0.07 cm, in Golden delicious, Red Gold, Royal Delicious and Red Delicious respectively at Dhamadhar. The mean volumes of Golden delicious, Red Gold, Royal delicious and Red Delicious were 170.20 ± 4.12 ml, 158.10 ± 6.80 ml, 160.50 ± 3.45 ml and 135.12 ± 6.10 ml respectively at Bhalogi, whereas, 140.00 ± 3.01 ml, 100.04 ± 2.30 ml, 240.02 ± 2.50 ml and 150.06 ± 5.20 ml respectively at Baskhola and 250.60 ± 2.30 ml, 201.20 ± 1.25 ml, 320.60 ± 1.28 ml and 270.02 ± 3.32 ml respectively at Dhamadhar (Table 3).

At Bhalogi, the mean number of seeds per fruit in honeybee pollinated flowers of Golden Delicious, Red Gold, Royal Delicious and Red Delicious were 9.00 ± 0.25 , 8.91 ± 2.50 , 7.00 ± 0.61 and 6.30 ± 0.92 respectively whereas, the mean number of seeds per fruit were 6.42 ± 0.25 , 6.20 ± 1.12 , 7.40 ± 0.52 and 6.00 ± 1.20 , respectively at Baskhola and these were 9.00 ± 0.32 , 8.60 ± 0.41 , 7.30 ± 0.70 and 7.20 ± 0.80 respectively at Dhamadhar (Table 3).

In self-incompatible varieties like Royal Delicious and Red Delicious there was not any fruit set in control experiment but in self-compatible varieties like Golden Delicious and Red Gold the quality of apple fruit was noticed. It was noticed that weight, length, breadth, volume and number of seeds per fruit in Golden Delicious and Red Gold at all the three orchards were significantly maximum ($P<0.01$) in fruits which developed from honeybees pollinated flowers and minimum in fruits under control experimental conditions, whereas, in Royal Delicious and Red Delicious the weight, length, breadth, volume and number of seeds per fruit were significantly more ($P<0.01$) in fruits from honeybees pollinated flowers than in fruits from open pollinated flowers.

In honeybee pollinated flowers the fruits were larger in size than fruits from open pollinated flowers which were in turn larger than the fruits from control experiment. Observations on fruit quality were made by some earlier workers (27, 19) who reported that honeybee pollination increased quality and quantity of apple fruits. The better pollinating efficiency of honeybees help in the fertilization of maximum number of ovules and thereby more number of seeds are formed in this way maximum amount of auxin (a growth hormone) is produced which results in better size of fruits. Fruits obtained by self pollination had a lower average weight, size and poor colour and contained a small number of seeds as compared to the fruits obtained from cross pollination (20, 15, 6). It was reported that greater number of seeds depended upon greater number of bees involved in cross pollination (4). There was positive relation between honeybee pollination and quality of apple crop (9, 26, 2). Fruit set in peach (*Prunus persica* L.) was maximum (6.5 fruit/branch) with placement of honeybee colonies at the closet distance of 20 m (5). Similar results on fruit quality and yield due to

honeybee pollination was also observed in different crops (22, 23).

4. Conclusion

Present study revealed that pollination by honeybees increased the fruit set and decreased the fruit drop in apple crop. Moreover quality of apple fruit (in terms of weight, length, breadth, volume and number of seed) was improved by honeybee pollination. We hope that our study will be useful for promoting awareness among people regarding the importance of honeybee pollination in horticulture and agriculture.

5. Conflict of Interest

The authors confirmed that this article content has no conflicts of interest.

6. Acknowledgment

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Table 1: Percentage of fruit set in three different experimental designs

Sr. No.	Apple Variety	Bhalogi (1400 m)			Baskhola (1580 m)			Dhamadhar (1810 m)		
		Honeybees pollinated flowers (H)	Open pollinated flowers (O)	No insect pollinator (Control) (C)	Honeybees pollinated flowers (H)	Open pollinated flowers (O)	No insect pollinator (Control) (C)	Honeybees pollinated flowers (H)	Open pollinated flowers (O)	No insect pollinator (Control) (C)
1.	Golden delicious	30.60	20.44	17.21	29.46	18.22	16.30	22.20	19.02	17.20
2.	Red Gold	23.20	17.04	15.31	22.34	16.52	15.51	21.62	19.42	16.65
3.	Royal Delicious	22.42	15.62	0	21.52	15.31	0	16.90	8.48	0
4.	Red Delicious	20.84	13.73	0	20.07	11.05	0	16.80	8.32	0

For honeybee pollination two colonies, one *Apis mellifera* and one *Apis cerana* with 6 frames each were placed inside the net.

S.E. = Standard error about the mean.
 For fruit set: $H > O > C$ ($P < 0.01$).

Each percentage is an average of twelve observations.

Table 2: Percentage of fruit drop in three different experimental designs

Sr. No.	Apple Variety	Bhalogi (1400 m)			Baskhola (1580 m)			Dhamadhar (1810 m)		
		Honeybees pollinated flowers (H)	Open pollinated flowers (O)	No insect pollinator (Control) (C)	Honeybees pollinated flowers (H)	Open pollinated flowers (O)	No insect pollinator (Control) (C)	Honeybees pollinated flowers (H)	Open pollinated flowers (O)	No insect pollinator (Control) (C)
1.	Golden delicious	25.32	28.40	37.32	26.20	28.25	38.37	28.31	30.41	39.23
2.	Red Gold	24.20	30.60	36.40	25.46	32.43	38.40	27.88	31.64	37.70
3.	Royal Delicious	25.37	29.61	0	25.53	30.74	0	27.80	30.14	0
4.	Red Delicious	24.62	29.30	0	26.54	29.04	0	27.70	30.71	0

For honeybee pollination two colonies, one *Apis mellifera* and one *Apis cerana* with 6 frames each were placed inside the net.

S.E. = Standard error about the mean.
 For fruit drop: $H < O < C$ ($P < 0.01$).

Each percentage is an average of twelve observations.

Table 3: Effect of insect pollinators on the quality of apple fruit in terms of weight (gm), length (cm), breadth (cm), volume (ml) and number of seeds per fruit

Apple Variety	Honeybees pollinated flowers (H)					Open pollinated flowers (O)					No insect pollinator (C) control					
	Weight W(H)	Length L(H)	Breadth B(H)	Volume V(H)	No. of Seeds SH	Weight W(O)	Length L(O)	Breadth B(O)	Volume V(O)	No. of Seeds SO	Weight W(C)	Length L(C)	Breadth B(C)	Volume V(C)	No. of Seeds SC	
Bhalogi (1400 m)																
1.	Golden delicious	190.06 ±1.22	7.32 ±0.04	7.80 ±0.21	170.20 ±4.12	9.00 ±0.25	152.00 ±2.18	6.30 ±0.08	7.02 ±0.04	158.60 ±3.30	7.50 ±0.29	90.00 ±2.40	6.04 ±0.04	6.80 ±0.05	70.60 ±5.08	6.40 ±0.29
2.	Red Gold	150.00 ±4.50	6.70 ±0.50	7.30 ±0.06	158.10 ±6.80	8.91 ±2.50	123.30 ±5.90	5.50 ±0.06	6.20 ±0.04	127.00 ±3.80	6.00 ±0.42	108.44 ±4.30	5.00 ±0.02	5.80 ±0.04	60.30 ±1.40	4.90 ±0.22
3.	Royal Delicious	173.60 ±4.20	6.97 ±0.50	7.82 ±0.30	160.50 ±3.45	7.00 ±0.61	161.21 ±4.01	6.08 ±0.22	7.20 ±0.30	140.23 ±3.45	5.40 ±0.22	No fruit set				
4.	Red Delicious	170.60 ±8.03	6.48 ±0.11	7.40 ±0.26	135.12 ±6.10	6.30 ±0.92	104.70 ±4.51	5.00 ±0.14	5.50 ±0.22	90.20 ±8.30	5.00 ±0.25	No fruit set				
Baskhola (1580 m)																
1.	Golden	179.22	6.80	7.90	140.00	6.42	152.30	6.20	6.40	160.00	7.48	120.60	5.42	5.90	70.00	5.82

	delicious	±2.50	±0.15	±0.10	±3.01	±0.25	±2.02	±0.03	±0.16	±4.50	±0.80	±0.51	±0.03	±0.09	±2.70	±0.20
2.	Red Gold	165.02 ±2.30	6.40 ±0.06	7.05 ±0.10	100.04 ±2.30	6.20 ±1.12	140.00 ±0.42	5.80 ±0.03	6.21 ±0.06	148.30 ±4.40	7.32 ±0.29	101.01 ±0.56	4.00 ±0.11	4.90 ±0.02	62.60 ±1.02	5.71 ±0.67
3.	Royal Delicious	213.00 ±1.20	7.00 ±0.40	7.80 ±0.22	240.02 ±2.50	7.40 ±0.52	180.06 ±3.52	6.40 ±0.42	7.47 ±0.22	188.40 ±3.97	7S.00 ±0.41	No fruit set				
4.	Red Delicious	188.08 ±4.20	6.60 ±0.24	7.14 ±0.11	150.06 ±5.20	6.00 ±1.20	154.22 ±9.90	6.50 ±0.12	6.29 ±0.28	160.32 ±2.25	6.72 ±0.30	No fruit set				
Dhamadhar (1810 m)																
1.	Golden delicious	287.02 ±6.01	7.60 ±0.08	8.80 ±0.10	250.60 ±2.30	9.00 ±0.32	242.62 ±1.14	7.00 ±0.04	7.91 ±0.02	240.00 ±4.54	7.80 ±0.23	225.02 ±4.12	7.20 ±0.10	7.11 ±0.42	215.30 ±3.00	7.30 ±0.80
2.	Red Gold	203.00 ±1.10	6.80 ±0.14	7.90 ±0.06	201.20 ±1.25	8.60 ±0.41	188.60 ±2.50	6.00 ±0.02	7.40 ±0.09	142.24 ±4.00	6.60 ±0.29	130.21 ±5.61	5.90 ±0.08	6.10 ±0.11	80.02 ±2.12	6.00 ±0.08
3.	Royal Delicious	301.60 ±1.30	8.90 ±0.29	8.78 ±0.04	320.60 ±1.28	7.30 ±0.70	260.70 ±3.40	7.63 ±0.10	8.17 ±0.18	250.20 ±1.30	7.00 ±0.40	No fruit set				
4.	Red Delicious	290.20 ±3.02	8.92 ±0.16	8.80 ±0.07	270.02 ±3.32	7.20 ±0.80	220.51 ±3.12	7.91 ±0.15	7.30 ±0.11	253.32 ±5.41	6.10 ±0.66	No fruit set				

For honeybee pollination two colonies, one *Apis mellifera* and one *Apis cerana* with 6 frames each were placed inside the net.

Each percentage is an average of twelve observations.
 S.E. = Standard error about the mean.

In all the orchards:

1W(H) > 1W(O) > 1W(C) : 1L(H) > 1L(O) > 1L(C) : 1B(H) > 1B(O) > 1B(C) : 1V(H) > 1V(O) > 1V(C) : 1S(H) > 1S(O) > 1S(C) (P<0.01)

2W(H) > 2W(O) > 2W(C) : 2L(H) > 2L(O) > 2L(C) : 2B(H) > 2B(O) > 2B(C) : 2V(H) > 2V(O) > 2V(C) : 2S(H) > 2S(O) > 2S(C) (P<0.01)

3W(H) > 3W(O) : 3L(H) > 3L(O) : 3B(H) > 3B(O) : 3V(H) > 3V(O) : 3S(H) > 3S(C) (P<0.01)

4W(H) > 4W(O) : 4L(H) > 4L(O) : 4B(H) > 4B(O) : 4V(H) > 4V(O) : 4S(H) > 4S(C) (P<0.01)

References

- Abson, D.J., Termansen, M., (2011). Valuing ecosystem services in terms of ecological risks and returns. *Conservation Biology* 25, 250–258.
- Belavadi, V.V., Anwarulla, M.S., Shadakshari, Y.G. and Dinesh Kumar, M. (2005). Rice research in the hill zone of Karnataka (Zone 9). In: *Five decades of Rice Research in Karnataka* (Eds.: Prabhakara Setty, T.K., Purushotham, S. and Nagamani, M.K.), Directorate of Research, UAS, Bangalore, 82-89.
- Biesmeijer, J.C., Roberts, S.P.M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., Schaffers, A.P., Potts, S.G., Kleukers, R., Thomas, C.D., Settele, J. and Kunin, W.E. (2006). Parallel Declines in Pollinators and Insect-Pollinated Plants in Britain and the Netherlands. *Science* 313 (5785): 351-354.
- Bornus, L., Zamarlicki, C., Krol, S. and Jablonski, B. (1977). Influence of increased bee visitation to apple flowers on fruit size and yield. *Pszczelnicze Zesz. Nauk.* 21: 77-86.
- Chaudhry, O. P. (2008). Influence of Different colony placement distances on yield and quality parameters of peach (*Prunus persica* L.). *Korean Journal of Apiculture*, 23 (2): 89-95.
- Childers, N.F. (1976). Flower bud formation, pollination and fruit set in the apple. In: *Modern fruit science* (Ed.: Childers, N.F.). Horticultural Publications, Rutgers University, N.J. 128-145.
- Crane, E. (1990). *Bees and Beekeeping-Science, Practice and World resources*. Heineman Newners, Oxford.
- Delaplane, K.S., Mayer, N.F. (2000). *Crop Pollination by Bees*. CABI Publishing, Walling-ford.
- Dulta, P. C. (1986). Comparative morphometric and biochemical studies on flight muscles of genus *Apis* and its role in apple pollination. Ph.D. Thesis H.P. University Shimla-5.
- Dulta, P. C. and Verma, L.R. (1987). Role of insect pollinators on yield and quality of apple fruit. *Indian J. Hortic.* 44: 274-279.
- FAOStat,(2013).Crops.http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID= 567#ancor.
- Gallai, N., Salles, J.M., Settele, J. and Vaissiere, B.E. (2009). Economic valuation of the vulnerability of world agriculture confronted with pollinator decline, *Ecological Economics*, 68: 810 - 821.
- Klein, A.M., Vaissiere, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., and Kremen, C. (2007). Importance of pollinators in changing landscapes for world crops. *Proc. R. Soc. Lon. B. Biol. Sci.* 274: 303-313.
- Kolesnikov, V.A. (1972). Role of honeybees as pollinators in orchards. In: *pollination of entomophilous agricultural crops by bees* (Ed.: Kozin, R.B.). Amrind Pub. Co. Ltd., New York.
- Kozin, R.B. (1972). *Pollination of entomophilous crops by bees*. Amrind Pub. Co. Pvt. Ltd., New York.
- Kumar, L. (1997). Foraging ecology and behaviour of *Apis cerana* F. and *Apis mellifera* L. in pollinating apple and cherry flowers. Ph.D Thesis, Himachal Pradesh University, Shimla, India.
- Ladurner, E., Recla, L., Wolf, M., Zelger, R., Burgio, G. (2004). *Osmia cornuta* (Hymenoptera Megachilidae) densities required for apple pollination: a cage study. *Journal of Apicultural Research* 43, 118–122.
- Matsumoto, S., Soejima, J., Maejima, T. (2012). Influence of repeated pollination on seed number and fruit shape of 'Fuji' apples. *Scientia Horticulturae* 137,131–137.

- [19] Morse, R.A. (1976). Efficient use of honeybees in the orchard. *Proc. Annu. Meet. N.Y. Hortic. Soc. 1021: 61-64.*
- [20] Murneek, A.E. and Schowengerdt, G.C. (1935). A study of the relation of size of apples to number of seeds and weight of the spur leaves. *Proc. Am. Soc. Hort. Sci. 33: 4-6.*
- [21] Potts, S.G., Biesmeijer, J.C., Kremen, C., Neumann, P., Schweiger, O. and Kunin, W.E. (2010 a). Global pollinator declines: trends, impacts and drivers. *Trends in Ecology and Evolution 25, 345–353.*
- [22] Potts, S.G., Roberts, S.P.M., Dean, R., Marris, G., Brown, M., Jones, R. and Settele, J. (2010 b). Declines of managed honey bees and beekeepers in Europe. *Journal of Apicultural Research 49: 15-22.* DOI: 10.3896/IBRA.1.49.1.02.
- [23] Raj, H. (2012). Studies on conservation and management of pollinators for sustainable horticulture in Himachal Himalaya. Ph.D. Thesis, Himachal Pradesh University, Shimla, India.
- [24] Rana, R.S., Sharma, H.K., Rana, K. and Rana, B.S. (2010). Studies on *Apis mellifera* L. pollination in apple and its economics. *Proc. Nat. Sym. Persp. Challeng. Integ. Pest Manag. Sustian. Agric. Solan, 100.*
- [25] Sharma, H.K., Partap, U., Bisht, K., Tewari, P. and Phartyal, P. (2010). Impact of honeybee pollination in enhancing apple production in Nainital district of Uttarakhand. *Proc. Nat. Sym. Persp. Challeng. Integ. Pest Manag. Sustian. Agric. Solan, 83.*
- [26] Sihag, R.C. (1997). *Pollination Biology: Basic and Applied Principles.* Rajendra Scientific Publishers, Hisar, 213 pp.
- [27] Singh, S. (1962). *Beekeeping in India* (Ed.: S. Singh). Indian Coun. Agric. Res., New Delhi.
- [28] Tschardtke, T. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences 274,303–313.*
- [29] Verma, L.R. (1990). *Beekeeping in integrated mountain development: Economic and Scientific perspectives.* Oxford and IBH Pub. Co. Ltd. New Delhi.
- [30] Verma, L.R. (2003). Conservation and management of Asian Hive bee *Apis cerana*. *Asian Bee J. 5 (1 &2): 1-10.*