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Effect of Honey Bee (*Apis cerana*) Dominated Insect Pollination on Yield and Quality of Mustard, Buckwheat and Plum in Central Himalayan Agro-ecosystem

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ABSTRACT
This paper presents the finding of pollination effects of honey bees (*Apis cerana*) on productivity outcomes of the three crops of the Himalayan agro-ecosystem: mustard (*Brassica campestris*), buckwheat (*Fagopyrum esculentum)* and plum (*Prunus domestica*). We used pollination exclusion on flowers of target crops to assess the contribution of pollinators on crop yield. The effect of pollination on various yield parameters under different treatments viz. Open pollination (OP) with supplementation of beehives and Control pollination (CP, pollinator exclusion) were quantified. The CP treatment negatively impacted crop yield variables in all the target crops contrary to the OP, where yield variables were significantly higher in all the target crops. Total yield of mustard increased by 27% (179 vs. 227 kg/ha), buckwheat by 73% (309 vs. 1141 kg/ha) and plum by 64% (0.92 vs. 2.52 kg fruits /branch) in OP than the CP. This is mainly due to higher pollinator density in the OP and supplementation of *A. cerana* bee hive. The maximum pollinator species diversity was recorded in buckwheat (16 spp.) followed by mustard (15 spp.) and plum (13 spp.). In all the target crops, honey bee (*A. cerana*) emerged as the most abundant visitor, with mean density of 24.38±0.92 in mustard, 18.56±2.00 in buckwheat and 39.45±1.45 in plum. The findings indicate that pollinators, especially honey bees can be suitably integrated with agro-ecosystems of this region for effective pollination management and to maximize the crop yield.

Key words: Himalayan agro-ecosystem; *Apis cerana;* Control pollination; Open pollination; Crop yield

INTRODUCTION

Among various types of ecosystem services, pollination is regarded as regulating service, which is crucial for food production, human livelihoods and diversity of life on earth. Pollination contributes enormous economic value to reproduction of the flowering plants, in the wild and the managed ecosystems of the world. It is estimated that fruits, vegetables or seed production of about 87% of leading global food crops rely upon animal pollination including honey bees, stingless bees, bumble bees, solitary bees, wasps, hover flies, beetles, birds and other animals (Klein et al. 2007, Ollerton et al. 2011). Globally, increased yield with animal pollination of at least 10% or higher was observed in 63 crops with varying levels of pollination dependence (Klein et al. 2007). Garibaldi et al. (2016) used a coordinated protocol across 344 small and large fields from 33 pollinator dependent crop systems globally across regions and crops reported that yield gaps for fields measuring <2 ha could be closed by a median of 24% through higher flower insect visitor density. Besides yield increment, pollination is also reported to significantly improve the quality of seeds (Free 1993), and thus the crop production might be severely impacted by pollinator loss. It is estimated that about one-third (35%) of all plants or plant products eaten by human beings are directly or indirectly dependent on bee pollination. Often the bees, including honey bees and stingless bees are known as one of the most important groups of pollinators worldwide. Studies revealed that over 25000 species of bees pollinate more than 70% of the world crops (Nabhan and Buchmann 1997), of which 15% of the world crops are pollinated by managed species of honey bees, bumble bees and solitary bees. Bees are considered significant pollinators due to their effectiveness and wide availability.

Entomophilous crops like oil seeds, fruits, fibers, condiments, spices and vegetables are the major categories directly benefitted by insect pollination in terms of increased seed production and improved efficiency of breeding system (Khalifa et al. 2021). Most studies assessing the impact of insect pollination on crop yield were conducted in Europe and North America, whereas, such studies in India are largely sparse and confined to controlled farm conditions. Pollination, chiefly from bees and other insects demonstrated to enhance plant reproduction (80%) and yield (Non-timber Forest Products-40%, crops-62%) in tropical forests of southern India (Rehel et al. 2009). Beekeeping as a traditional industry is mainly honey centric in the region (Chaudhary and Chand 2017), and its role in crop production is largely overlooked except in States of Himachal and Jammu & Kashmir, where farmers usually hire bee colonies for minimizing the crop pollination deficit and optimizing the yield outputs (Partap and Partap 2002).

Across the globe, concerns being raised that pollination of crops is on decline as a result of intensive land use change, modern agriculture practices, introduced pest and disease and climate change (Allen-Wardell et al. 1998, Kearns et al. 1998, Kremen et al. 2002). Land clearance, habitat loss, degradation and fragmentation, changing agricultural practices, use of herbicides and pesticides and the introduction of non-native exotic plants and pollinator species have resulted in "Pollination crisis" (Buchmann and Nabhan 1996), consequently linked to decline in pollinator diversity and abundance (Kearns et al. 1998, Spira 2001), thus causing subsequent reduction in pollination services (Kremen et al. 2002).

Systematic studies to reveal linkages of pollinators and crop production in Indian Himalaya are limited. However, there are few studies from Himachal Pradesh which suggest that the fruit quality and yield is influenced by insect pollinators in apple and other crops (Kumar 1997, Mattu et al. 2012, Raj et al. 2012, Partap 2010). A similar study from Sikkim Himalaya (Gaira et al. 2016) reported that the increasing bumble bee visitation resulted in higher yield of large cardamom (17-14 gm/plant). Stanley et al. (2017) reported 17% increase in yield of mustard in bee pollinated crop over control from Kumaun Himalaya.

In the central Himalayan mountains, livelihood of people is mainly dependent on agriculture, horticulture and animal husbandry supported by a variety of ecosystem services provided by surrounding forests (Joshi and Negi 2011). The agriculture is mostly practiced on tiny parcels of rainfed land and crop yield is dismally low (1 t/ha) that has imperiled the food security of the mountain people (Maikhuri et al. 1997). Usually, the farming practices include a combination of cereals, pulses, oilseeds crops, vegetables and fruit trees in their tiny farmlands, which hardly meets the year-round demand of the food for the family. The crop productivity is often impacted by variety of factors including inadequate pollination (Abrol 2012, Stanley et al. 2017). Several factors such as decline in surrounding forest vegetation and loss of habitat, land use changes, monoculture-dominated agriculture and indiscriminate use of agricultural chemicals and pesticides have contributed to decline in pollinator's population and diversity (Abrol 2012).

Among the rural populace there is lack of awareness about the crucial role of pollination services of insects and their conservation for optimizing crop production. However, Indian honey bee (*Apis cerana)* has been traditionally domesticated by rural people in wall hives and log hives for medicinally valuable honey for self-consumption and occasionally for sale in this region (Sofi and Patahnia 2017). In the past, mountain farmers grew a variety of crops, which bloomed at different times of the year and provided food for insect pollinators. In the recent years the transformation of agriculture from traditional mixed crop farming to high value cash crop farming and off-season vegetables has led to an increase in monocrop agriculture, reducing the food sources for natural insect pollinators (Partap and Partap 2002). Also introduction of European honey bee (*Apis mellifera*) in this region due to its large colony size and honey production has motivated bee keepers to opt it in place of *A. cerana,* and thus posing competition for floral resources, interference in mating and exchange of disease (Theisen-Jones and Bienefeld 2016). An increase in the ruthless hunting of the nests of wild honey bees for honey is also contributing to the decline in the population of indigenous honey bees (Partap 2010). Therefore, it is essential to assess the insect pollinator diversity, population of *A. cerana* and impact of insect visitation on crop yields to mainstream the conservation efforts of pollinators in practice and policy domains. For this, collection of data across various aspects of yield estimation and other comparable data sets in experimental (pollinator exclusion) and naturally growing crops is required. In this paper, we present the results of an experiment conducted to study the effect of pollination on various yield parameters of mustard (*Brassica campestris*), buckwheat (*Fagopyrum esculentum*) and plum (*Prunus domestica*) crops in a mountain village agro-ecosystem in Uttarakhand (Central Himalaya). The overall aim of this research was to understand the insect pollinator diversity in hill agro-ecosystems and role of bees (*Apis cerana*) as dominant pollinators to supplement the crop yield gaps to address the food and nutrition security of marginal farmers of this region.

MATERIAL AND METHODS

Study area

Present study was carried out in Jyoli village cluster located between $29^0$36’38" to 29^0 38’13"N latitude and $79^0$34’40" to $79^0$36’35"E longitude at 1268-1550 m asl in District Almora, Uttarakhand during November 2021 to September, 2022. The study area represented typical mountain topography and ecological characteristics of rural agro-ecosystems where agriculture and animal husbandry is the mainstay of the inhabitants. Most of the farming in the study area is rainfed, and in the recent years the numbers of crop varieties have declined severely due to several socio-economic and ecological reasons (Maikhuri et al. 1997). The surrounding forests and adjoining pasture lands are also facing decline in diversity of forage plants and invasion of weeds. In this area during the past 53 years (1955-2007) the average atmospheric temperature (i.e., 17.55^{o}C) has increased by 0.46^{o}C, while annual rainfall (i.e., 1060 mm) declined by 23%. This might have great impact over land use, farming practices, flora, biodiversity and water availability etc. Also, recurrent forest fires in the region have reduced the plant diversity for honey bees and consequently loss in their population. In the past there was a rich tradition of bee keeping in wall hives of mud stone built houses, which has now almost disappeared due to construction of modern cement brick houses in the study area.

Selection of crops for pollination experiment

Among the diverse crops in the region, three entomophilous crops, namely, mustard, buckwheat and plum were selected for representing different categories of oilseed, pseudo-cereal and fruit crops (Table 1). Mustard (*Brassica campestris)* is an important oilseed crop of Rabi season (winter) requiring low rainfall (80-240 mm). Being an intermediate and low input cash crop, it has long been a strategic component in integrated hill farming contributing significantly for nutritional security of human society by way of provisioning of oilseeds and winter forage for cattle and diverse pollinator assemblages.

Buckwheat (*Fagopyrum esculentum)* is a distylous crop mainly pollinated by honeybees and by many other insect species (Hisatomo et al. 2009). It is one of the important pseudo-cereals adaptive to extreme cold temperatures, water stress conditions, low soil fertility and low soil moisture and varying climatic conditions. This crop is a staple food for people in high altitude region and as a specific food for several communities while observing religious fasting. Efficacy of honey bee in buckwheat pollination growing across diverse agro-ecosystems in the world varies considerably from 5% in Japan (Namai 1986) to 97% in Belorus (Kushnir 1976) suggesting a greater role of other indigenous wild pollinators. In the present scenario of climatic change, buckwheat could be suitable candidate for climate adaptation and mitigation measures to compensate the global food security.

Plum (*Prunus domestica*) is an important cash crop of the diversified agri-horticulture landscape in the hill region because of climate suitability and economic returns. Being a self-incompatible crop, plum requires cross-pollination by insects to produce fruits but little is known about the influence of pollinator abundance on yield variables for this plant, except few studies from Kashmir on foraging behaviour, abundance and rank abundance of insect pollinators, where chief pollinators of plum crops were largely wild bees (Dar et al. 2020). In other parts of the world where plum is grown in intensive agricultural systems honey bees were recorded as the main pollinators (Hopping and Jerram 1980, Langridge and Goodman 1985).

Experimental design

To determine the effect of pollination on yield of different crops two treatments: Control pollination (CP) and Open pollination (OP) were applied in all

Table 1. General characteristics of the target crops

Parameters	Mustard (*Brassica campestris*)	Plum (*Prunus domestica*)	Buckwheat (*Fagopyrum esculentum*)
Variety	Local	Santa Rosa	VL7
Date of sowing	15-11-2021	6-7 year old trees	3 June 2022
Date of germination	01-12-2021	-	8 June 2022
Flowering period	26-1-2022 to 28-2-2022 (34 days)	2nd to11th March 2022 (10 days)	3-7-2022 to 4-8-2002 (33 days)
Date of crop harvesting	22-3-2022	20-5-2022	6-9-2022
Seed/fruit maturation period	1-3-2022 to 21-3-2022 (21 days)	12-3-2022 to 1 9-5-2022 (68 days)	5-8-2022 to 5-9-2022 (31 days)

the three target crops along with supplementation of one *Apis cerana* mature hive (strength of five frames). In case of mustard and buckwheat, the CP plot (area = 30 m^2) was closed with a transparent insect proof net (0.5 mm mesh size) before anthesis of flowers. The OP treatment crop was grown in open (area = 30 m^2) with unhindered access of pollinating insects to the flowers of mustard and buckwheat. In case of plum, 5 trees of same cultivar growing about 5 m apart from each other were selected. On each tree, two mature alternating branches (diameter = 10 cm) those bear fruits at similar height in the tree were marked and randomly assigned to CP and OP treatments, alternatively. On approaching the balloon stage, the flower buds of CP branches were covered with insect proof net (0.5 mm mesh size) to exclude pollinators (Fig. 1 a, b). The flowers on the OP branches were visited by pollinators without any obstruction.

Estimation of pollinator density

Pollinator density in OP treatment was counted by using scan sampling, which provide the most reliable way to assess the pollinator density on flowers (Levin et al. 1968, Vaissiere et al. 2011). Sampling for all the three crops was done on the onset of main

Figure 1. (a) Branches of mature trees of Plum (var. Santa Rosa) covered with nylon net for exclusion of pollinators immediately before flowering in early March 2021; (b) Fruit bearing branches of Plum trees under open pollination and control pollination

blooming period (≥10% of the plants on bloom). It suggests that the insects will be counted if it is present at the very time when the flower is first seen. Sampling in mustard and buckwheat crop was performed by walking slowly along a set path around the experimental plot margins for recording the number of pollinators (honey bees, wild solitary bees, dipterean flies, butterflies, and wasps). In each selected walk per week between 8 am to 5 pm, four readings of 100 floral units were taken along the set paths within the crop field using a binocular, thus, a total of 16 such readings were taken each for both mustard and buckwheat during the entire flowering season. In case of plum, which is a determinate crop, 250 flowers were scanned at each of the 5 marked trees by slowly walking around the marked trees and observations were made at two-day interval using a binocular. Thus, a total of four such readings were taken during the short flowering period (10 days) of plum trees. All readings of flower visiting insects were noted down in appropriate data sheet. The data on insect diversity was collected following sweep net method immediately after the recording of data on pollinator density. In this case, only the flower visiting (likely pollinators) insects were caught. Data was recorded under good weather condition for visiting insects. The handbook "Protocol to detect and assess pollination deficit in crops: A handbook of its use" by Vaissiere et al. (2011) formed the basis for data recording on pollinator abundance. All recorded insect species up to species level were identified using Taxonomic Keys and pictorials (Beeson 1941, Kehimkar 2008, Buck et al. 2009, Marshall et al. 2017, Joshi et al. 2016) and consulting an expert entomologist of Indian Council of Agriculture Research (*Vivekananda Parvatiya Krishi Anusandhan Sansthan)* situated in our study area where extensive collection of regional crop pollinators has been maintained.

Effect of pollination

In order to determine the effect of pollination on mustard and buckwheat crop yields, 100 plants were randomly selected in each treatment (OP and CP) at the time of crop harvest. In case of mustard, various yield contributing parameters such as, number of pods per plant, total number of seeds per pod and per plant, total weight of seeds per 100 plant, percentage of wrinkled seeds and test weight of 1000 seeds were recorded. In case of buckwheat, total number of grains per terminal inflorescence, total number of grains per plant, test weight of 1000 grains and grain yield (weight) per plant were recorded. In case of plum crop, data on fruit yield per tagged branch were recorded from each tree during the fruit harvesting period (May-June). Data on different parameters, such as total number of fruits, total weight of 10 fresh fruits, and percentage of unhealthy or deformed fruits were recorded for yield estimation of five branches of marked plum trees. Statistical test (t-test) was applied between the two treatments (OP and CP) for various crop yield parameters to determine the statistical significance among the difference in mean values.

RESULTS

Diversity of floral visitors

The flower visiting insect pollinators recorded during the present study are shown in Table 2. Altogether, a total of 23 insect species of five orders were recorded during the sampling period spanning over three crops in this study from January 2022 to August 2022. In case of mustard, a total of 15 insect species belonging to four insect orders (Hymenoptera, Diptera, Lepidoptera and Odonota) were recorded during the sampling period. Maximum (46.7%) insect visitors belonged to order Hymenoptera, and the rest belonged to other orders. In case of buckwheat, a total of 16 flower visiting insects were recorded from 5 insect orders (Hymenoptera, Diptera, Lepidoptera, Odonota and Hemiptera). Among the total insect visitors 43.8% species belong to order Hymenoptera,

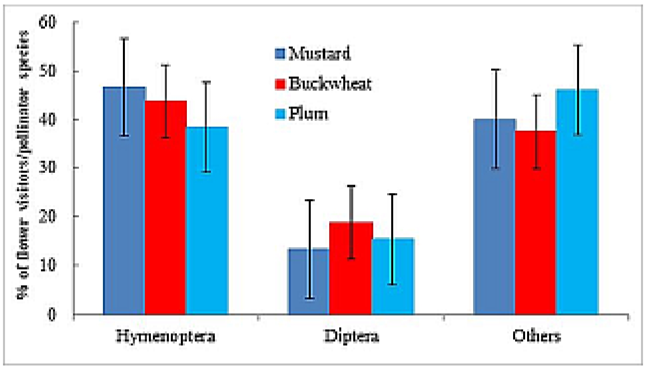

Figure 2. Insects (%) recorded from open pollination treatment in target crops

while remaining 56.2% visitors were represented by other orders. In plum crop, 13 insect species belonging to four orders visited the flowers, and percentage of Hymenoptera, and other group of orders (Diptera, Lepidoptera, Hemiptera and Odonota) was 38.5% and 61.5%, respectively (Fig. 2).

Seventeen insect species i.e., 74% of total insect visitors belonged to two orders, Hymenoptera and Lepidoptera, and constituted as the insect orders most frequent pollinator in mustard, buckwheat and plum. Among all the visitors, excluding Hymnopteran and Dipterean insects none of these can be considered potential pollinators because of their occasional presence. In order to estimate the density of pollinators recorded during the sampling period all insect visitors were further simplified and placed in three broad categories, Hymenoptera (honey bees, wild bees and wasp), Diptera (syrphid and other flies) and others (insects of Lepidoptera, Odonota and Hemiptera Orders). Out of total 8 Hymenopteran species recorded in the present study, four viz., *Apis cerana*, *Bombus haemorrhoidalis*, *Vespa velutina* and *Megascolia azurea* were common in mustard, buckwheat and plum crops. Three Hymenopterans species viz., *Ceratina* sp., *Xylocopa* sp. and *Poliste scanadensis* were common in mustard and buckwheat. Among Dipterian insects, *Calliphora sp.* was encountered in all the target crops, whereas *Episyrphus balteatus* was observed in mustard and buckwheat. One species of Lepidoptera (*Dunaus genutia*) was recorded from all the target crops, whereas three species viz., *Coladenia indrani*, *Catopsilia pomona* and *Pieris brassicae* were common in mustard and buckwheat fields. Only one species (*Neurobasis chinensis*) of Odonota order visited amongst all the three crops. Insect species such as *Eristalis arbustorum (Diptera)* and *Halyomorpha halys* (Hemiptera) were recorded only in buckwheat, and three species of Lepidoptera (i.e., *Celaenorrhinus leucocera, Aporia agathon* and *Aglaiscas chmirensis*) were found only in plum flowers (Table 2).

Population density of pollinators

Among all the insect pollinators, honey bees (*Apis cerana*) were recorded as the most prominent visitors in all the three target crops. The mean density of honey bees was highest among the visiting insect groups of mustard (24.4±0.92), buckwheat (18.6±2.00) and plum (39.5±1.45). The density of honey bee (*A. cerana*) remained high during all the sampling times in OP treatment of all the target groups (Tables 3, 4 and 5). Beside this wild bee, wasp and syrphid were also considered important pollinators despite low densities than the honey bees (*A. cerana*). Total population density (per 400 flowers in case of mustard and buckwheat and per 250 flowers in case of plum) of insect pollinators was maximum in plum (56) followed by mustard (33) and buckwheat (31).

Effect of pollinators on the yield of crops

The period of seed sowing, time taken in seed germination, flowering period and seed maturation (harvesting period) for all the three crops is given in Table 1. Blooming period of mustard and buckwheat (33-34 days) was the longest and the plum trees were in bloom only for ten days in March 2022. Whereas seed/fruit maturation period in mustard (21 days) and buckwheat (31 days) was much lower than the plum (68 days).

In mustard, the yield parameters between CP and OP for number of pods/plant (9.6 vs. 11.9), total number of seeds per plant (47.4 vs. 64.6), percentage of healthy seeds (50.1 vs. 83.7) and yield of 100 plants (9.6 vs. 12.2 gm) were significantly greater for OP as compared to CP (Table 6). The yield of mustard crop was found significantly higher for OP (227 kg/ha) than for the CP (179 kg/ha) registering an increase of 26.8% yield in OP. In buckwheat, significantly greater number of grains per inflorescence (23.3±0.61) and total number of grains per plants (123.35±0.66) were recorded in OP treatment. The mean values of test weight of 1000 grains (22.32±0.23 g) and grain yield (3.17±0.16 g) per plant were also found significantly higher in OP treatment. Thus the increase in yield of buckwheat (73%) was significantly higher for OP treatment (1141 kg/ha) than for the CP (309 kg/ha) (Table 7). Similarly, in plum the OP resulted into significant increase in average number of total fruits per branch (154±69.68), percent healthy fruits per branch (89.9±0.90), test weight (g) of 10 fresh fruits (173.0±16.78), and total yield (kg) per branch (0.92±0.53), thus registering an increase of 64% in

Table 2. Pollinator/flower visiting insect species recorded from open pollination sites of the target crops

Order/Species	Common name	Crops		
		Mustard	Plum	Buckwheat
Odonota				
Neurobasis chinensis	Stream glory	+	+	+
Hemiptera				
Halyomorpha halys	Brown mormorated sting bug	-	-	+
Diptera				
Episyrphus balteatus	The marmalade hoverfly	+		+
Calliphora sp.	Blue bottle fly	+	+	+
Calliphora sp.	Blow fly	-	+	-
Eristalis arbustorum	Drone fly	-	-	+
Lepidoptera				
Papilio bianor	Common peacock	-	+	-
Celaenorrhinus leucocera	Common spotted flat		+	
Coladenia indrani	Tricolored pied flat	+	-	+
Catopsilia pomona	Lemon enigrant	+	-	+
Aporia agathon	Great black vein		+	
Pieris brassicae	Large cabbage white	+	-	+
Danaus genutia	Stripped tiger	+	+	+
Argyreus hyperbius	India fritillary	+		
Aglaiscaschmirensis	India tortoise shell		+	
Hymenoptera				
Apis cerana	Honey bee	+	+	+
Bombus haemorrhoidalis	Bumble bee	+	+	+
Ceratina sp.	Small carpenter bee	+	-	+
Xylocopa sp.	Carpenter bee	+	-	+
Vespa velutina	Asian hornet	+	+	+
Vespa mandarinia	Asian giant hornet	-	+	-
Polistes canadensis	The red paper wasp	+	-	+
Megascolia azurea	Scolid wasps	+	+	+

+ (presence), - (absence)

Table 3. Mean density of visiting insects recorded during the sampling period in mustard (values represent mean of scan sampling of 400 flowers in OP treatment)

Sampling frequency	Hymenoptera			Diptera	Others*	Total insect density/400 flowers
	Honey bee	Wild bee	Wasp	Syrphid		
1	24.75	1.75	2.00	1.50	1.50	31.5
2	25.50	2.75	2.00	1.75	2.25	34.25
3	23.50	2.50	2.00	3.00	3.00	34
4	23.75	3.25	1.75	2.50	2.00	33.25
Average (±SD)	**24.38±0.92**	**2.56±0.63**	**1.94±0.13**	**2.19±0.69**	**2.19±0.63**	**33.26±1.24**
% population	**73.30**	**7.70**	**5.83**	**6.58**	**6.58**	**100.0**

***Others include Lepidoptera, Odonota and Hemiptera**

Table 4. Mean density of visiting insects recorded during the sampling period in buckwheat (values represent mean of scan sampling of 400 flowers in OP treatment)

Sampling frequency	**Hymenoptera**			**Diptera**	**Others***	**Total insect density/400 flowers**
	Honey bee	Wild bee	Wasp	Syrphid		
1	21.50	4.25	1.25	3.25	2.75	33
2	17.75	4.00	2.00	2.75	4.00	30.5
3	17.00	5.00	2.25	3.25	5.00	32.5
4	18.00	4.50	1.50	4.00	1.50	29.5
Average (±SD)	**18.56±2.00**	**4.44±0.43**	**1.75±0.46**	**3.31±0.52**	**3.31±1.52**	**31.37±1.65**
% population	**59.16**	**14.15**	**5.58**	**10.55**	**10.55**	**100.0**

***Others include Lepidoptera, Odonota and Hemiptera**

Table 5. Mean density of visiting insects recorded during the sampling period in plum (values represent mean of scan sampling of 250 flowers in OP treatment)

Sampling frequency	**Hymenoptera**			**Diptera**	**Others***	**Total insect density/250 flowers**
	Honey bee	Wild bee	Wasp	Syrphid		
1	39.00	4.40	6.60	2.00	4.60	56.6
2	40.40	4.40	2.80	2.40	6.00	56.00
3	40.80	5.20	4.20	2.00	6.80	59.00
4	37.60	3.80	4.20	2.40	4.80	52.8
Average ±SD	**39.45±1.45**	**4.45±0.57**	**4.45±1.58**	**2.20±0.23**	**5.55±1.04**	**56.1±2.5**
% population	**70.32**	**7.93**	**7.93**	**3.92**	**9.89**	**100.0**

***Others include Lepidoptera, Odonota and Hemiptera**

Table 6. Effect of insect pollination on mustard yield (mean±SD) components

Parameters	**CP**	**OP**	**Difference**	**Level of significance**
Total no of pods per plant	9.58±0.50	11.89±3.03	2.31	0.05
Total no. of seeds per pod	5.73±0.39	5.84±3.97	0.11	Not significant
Total no. of seeds per plant	47.35±2.55	64.59±3.79	17.24	0.02
Percent healthy seeds	50.12 ±2.22	83.73±3.51	33.61	0.02
Test weight of 1000 grains (g)	2.8	3.6	0.8	0.05
Yield of 100 plants (g)	9.6	12.2	2.6	0.05
Total Yield (kg/ha)	179	227	48	0.02

Table 7. Effect of insect pollination on buckwheat yield components

Parameters	**CP**	**OP**	**Difference**	**Level of significance**
Total no. of grains per terminal inflorescence	6.80±0.49	23.26±0.61	16.46	0.01
Total no. of grains per plant	17.89±0.49	123.35±0.66	105.46	0.01
Test weight of 1000 grains (g)	22.32±0.23	27.45±0.37	5.13	0.04
Grain yield per plant (g)	0.93±0.19	3.17±0.16	2.24	0.05
Total yield (kg/ha)	309	1141	832	0.01

Table 8. Effect of insect pollination on plum yield components

Parameters	Tree 1		Tree 2		Tree 3		Tree 4		Tree 5		Mean	Mean	Level of significance
	OP	CP	OP	CP	OP	CP	OP	CP	OP	CP	CP	OP	
Total number of fruits per branch	403.0	163.0	34.0	10.0	46.0	15.0	77.00	15.0	210.0	50.0	50.60±29.	154±69.68	0.01
Percent healthy fruits	92.75	75.46	88.24	70.00	89.13	73.33	88.31	73.33	91.43	78.00	74±1.32	89.9±0.90	0.03
Test weight of 10 fresh fruits (g)	115	155	195	210	150	130	195	155	245	215	173±16.78	180±22.13	0.05
Total yield (kg) per branch	4.39	2.90	0.71	0.24	2.60	0.23	1.61	0.13	3.28	1.12	0.92±0.53	2.52±0.63	0.03

Table 9. Diversity of pollinator/flower visiting insect species recorded in Himachal and Uttarakhand States in India

Studies	Study site	Selected crops	Number of species recorded during the sampling period							Total species
			Hymenoptera	Diptera	Lepidoptera	Odonota	Hemiptera	Coleoptera	Thysonoptera	
Paschapur et al. (2002a)	Almora Uttarakhand	Onion	19	14	17	-	-	5	-	55
Paschapur et al. (2002b)	Almora Uttarakhand	Eggplant	14	5	10	-	-	-	-	29
Goswami et al. (2013)	Pantnagar, Uttarakhand	Sunflower	9	1	1	-	-	1	-	12
Kumar et al. (2019)	Almora, Uttarakhand	Radish	9	6	4	-	-	-	-	19
Jiju et al. (2017)	Dehradun, Uttarakhand	Mango, Fenugreek, citrus carrot	4	7	4	-	1	3	-	19
Thakur and Mattu (2014)	Shimla Hills, Himachal Pradesh	Plum	8	5	5	-	-	1	-	19
		Peach	15	12	9	-	1	3	-	40
		Pear	13	11	6	-	-	3	-	33
		Apple	15	19	10	-	-	3	1	48
Mattu and Nirala, (2016)	Shimla Hills, Himachal Pradesh	Apple	13	17	8	-	-	2	1	41
Present Study	Almora Uttarakhand	Mustard	7	2	5	1	-	-	-	15
		Buckwheat	7	3	4	1	1	-	-	16
		Plum	5	2	5	1	-	-	-	13

OP treatment as compared to CP (fruit yield per branch = 2.52 kg) (Table 8).

DISCUSSION

Present study indicates that the present study area is poor in insect-pollinator species diversity that consequently results into low yield of the test crops. A comparative account of pollinator diversity between Himachal Pradesh and Uttarakhand agro-ecosystems revealed pollinator diversity is rich in the former area (Table 9), perhaps because of sowing a series of temperate fruit crops, which flowers in succession and support a diverse pollinator guild. In Uttarakhand growing of temperate fruit crops is quite intermittent and a part of larger subsistence based farming system. It also appears that the targeted agro-ecosystems are relatively poor in terms of mass flowering crops that support and attract honey bees and other wild pollinators as indicated by the diversity in nearby forested areas that support much higher insect diversity (Bhatt et al. 2020). In OP treatment, honey bee (*Apis cerana*) was a key visitor of the mustard crop than the remaining recorded insect groups, as has been reported by Paschapur et al. (2022b) in similar agro-climatic conditions in this region. Data on pollinator diversity revealed that while 15 different insect species visited the flowers of mustard crop, and 16 insect species visited buckwheat, all of them cannot be considered important pollinators because of their low numbers and infrequent and occasional visits. Also, in case of plum 13 different insect species visited the flowers but many of them cannot be considered potential pollinators. Honey bee (*A. cerana*) density was maximum in comparison to other flower visiting insect groups in OP treatment of mustard, buckwheat and plum crops. Density data indicate that *A. cerana* visited frequently on the sampled crops thus accounted for most of the pollination. Pollinator insect visitor diversity in number of crops in Uttarakhand and the neighboring Himachal Pradesh has been reported ranging from a minimum of 12 in sunflower (Goswami et al. 2013) to a maximum of 40 in peach, 48 in apple (Thakur and Mattu 2014) and 55 in onion (Paschapur et al. 2002a) in Uttarakhand state.

We recorded an increase of 27% in the yield components in mustard in the OP treatment. Large difference was found in OP in comparison to CP treatment. Similarly, the effect of pollinators on buckwheat showed that insect pollinators increased grain set in terms of total numbers of grains per terminal inflorescence, total number of grains per plant, test weight of 1000 grains and yield per 100 plants, which is in agreement with the findings of Singh (2009) in similar agro-climatic conditions in Nepal. We found significant differences among the crop parameters such as total number of grains per inflorescence and total number of grains per plant between CP and OP treatments for both mustard and buckwheat. The yield of buckwheat we recorded was nearly four times higher in the OP treatment (i.e., 1141 kg/ha), which is comparable with that reported in Himachal Pradesh (Bhardwaj and Kaur 2020). Similarly, the effect of pollination on plum yield components revealed that OP treatment resulted in 2.7 times increased yield (2.52 kg/branch) having large proportion (90%) of healthy fruits.

Our findings clearly indicate that pollinators have played a crucial role in yield increment of the mustard, buckwheat and plum crops (range = 27-73%). Our findings are in agreement with other studies conducted for assessment of pollination effects on yield of crops, such as onion and eggplant (Paschapur et al. 2022a, b), mustard (Stanley 2017), buckwheat (Singh 2008) and others in the similar mountain agro-ecosystems. Present study corroborated the findings of previous studies which have described the pollination need of mustard and buckwheat crops due to their self-incompatibility, which requires pollen transfer from plant-to-plant and where bees play an important role as pollen vector (Sihag 1986, Khan and Chaudory 1995, Bhandari and Sah 2001).

In agro-ecosystems of the study region considerable variations in yields have been reported i.e., 544 kg/ha in local variety of mustard (Singh 2017) and 800-1000 kg for VL variety of buckwheat, (Bhardwaj and Kaur 2020) and 876-1064 kg/ha for local variety of buckwheat (Babu et al. 2019) owing to differences in crop varieties, soil quality and improved agro-techniques excluding the consideration of pollination supplementation/ efficacy. In the present study the poor yield (227kg/ ha) of mustard in bee/open pollination treatment indicated the need to look for improved crop varieties along with adopting improved agro-techniques and pollination management incorporating *A. cerana* bee hives in agro-ecosystems.

The increase in yield can be attributed to the fact that honey bees from nearby hives and other insects were attracted by mass blooming in mustard, buckwheat and plum crops due to their attractive provisioning of nectar/pollen potential (Partap 1997). If attractive foraging resources are available in nearby area, it can become an immediate preferable option for insect pollinators. Supplementation of a bee hives that could have several thousand honey bees (5000-25000) would also have contributed in higher density of *A. cerana*. In winter months, there is severe shortage of foraging resources around the present study site, and the honey bees from hive placed next to experimental site might have found ideal foraging resources in blooming mustard during harsh winter and would have contributed in high percentage / density of honey bees among the visiting insects. The effect of CP on mustard and plum yield components showed less grain/fruit set, decreased yield and high proportion of unhealthy seeds/fruits that clearly indicates the inadequate pollination or pollination deficit. The little success obtained in CP would be due to anemophily as wind plays some role in dispersal of pollen grain (Marshall 1969). These observations could indicate that keeping beehives in nearby locations could increase the crop yield in these crops. The findings supported the previous researches (Williams 1994, Bartomeus et al. 2014), which concluded that inadequate pollination probably limit yield more or less in self-sterile crops, regardless of fertilizers, irrigation and cultural practices that may not give even a fraction of their potential yields unless agronomists provide adequate number of pollinating bees (Deodikar and Suyanarayana 1972, 1977). The productivity of mustard, buckwheat and plum crops can be enhanced by ensuring year round availability of foraging resources to support viable pollinator assemblage in and around farmyards through effective pollination management practices. Similar suggestions were also made in previous studies as well, which stated the need for ensuring pollination particularly through conserving pollinators and incorporating managed crop pollination (Abrol 2012).

In hill region of Uttarakhand, agriculture marred with challenges on production front which often led to increased production cost. Therefore, placing honey beehives which is a low cost investment will not only address the production challenges but also add to total farm income. Such integrated approach could greatly help in improving the insect diversity in the agro- ecosystem and would also mitigate low productivity in hill region of Uttarakhand. The honey bearing properties of mustard, buckwheat and plum could also make these crops more valuable for promotion of apiculture in the region to get additional benefits from the sale of beehive products other than the improved crop yields.

CONCLUSIONS

This study provides insight into the potential of pollinator insects especially the honey bee (*Apis cerana)*, contributing in enhancing crop yields of mustard, buckwheat and plum crops in traditional agricultural systems of Uttarakhand. Pollination greatly affected various yield parameters by way of producing healthy seeds/fruits of better quality, higher number of seeds/fruits per plant and high percentage of healthy seeds/fruits. Less number of seeds/fruits set in CP treatment means crops selected under present study required cross pollination by insect pollinators for improved gene flow and agronomic output. Therefore, it is recommended that pollination management through provisioning of honey beehives as part of crop management should be considered as an important practice to raise and diversify the farmer's income both by increasing the crop yield and harvesting beehive products. Farmers in the Central Himalayan region are gradually abandoning farming as it is turning into an input intensive avenue with less attractive returns. This indicates that productivity of crops can be enhanced through assisted/managed pollination in areas with low insect diversity and by motivating the farmers to adopt bee keeping for pollination service as well as honey and other products associated with it, thus, leading to biodiversity conservation and improved health of the agro-ecosystems.

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