ICIMOD Working Paper 2017/19

Honeybee Pollination and Apple Yields in Chitral, Pakistan

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Honeybee Pollination and Apple Yields in Chitral, Pakistan

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Key words: Apple, Honeybees, Bees, Pollinators, Pollination, *Apis cerana*, *Apis mellifera*, Chitral, Pakistan

Acronyms and Abbreviations

AKRSP	Aga Khan Rural Support Programme
ARC	Agriculture Research Centre
HF	Hashoo Foundation
CBD	Convention of Biological Diversity
HH	household
HKH	Hindu Kush Himalaya
ICIMOD	International Centre for Integrated Mountain Development
IPM	Integrated Pest Management
kg	kilogramme
KP	Khyber Pakhtunkhwa
LSO	local support organization
MT	metric tonne
SRSP	Sarhad Rural Support Programme

Executive Summary

Apple plays an important role in the livelihood of the farming community in Chitral, Pakistan. The commercial varieties of apple planted in orchards in Chitral, for example, Kala Kola (Red Delicious), Choupush (Royal Delicious), and Royal Gala, are reported to be partially or completely self-incompatible and require cross-pollination for commercial yield and fruit quality. Honeybees are reported to play an important role in apple pollination. However, awareness about the crucial role of honeybees and beekeeping is lacking among farmers and development workers as well as at policy level in mountain areas of the Hindu Kush Himalayas (HKH) including Chitral.

The present research was undertaken in collaboration with the Aga Khan Rural Support Programme (AKRSP), Chitral, Pakistan to demonstrate the benefits of using honeybees for apple pollination and its impact on fruit yield and quality to the apple growers, other farmers and extension workers of district horticulture/ agriculture departments, and district level decision makers. The other objective of this research was to generate evidence on the role of honeybees as significant ecosystem service (pollination) providers to help establish a mechanism on payment for ecosystem services. The research was conducted in six villages in different altitudinal locations for two consecutive years (2014 and 2015) by engaging 24 apple growers in 2014 and 27 apple growers in 2015.

A strong and healthy colony of honeybees (*Apis mellifera*) free of any signs of disease was placed in one of the two selected orchards (hence called honeybee-pollinated orchard) in each action research site. The other orchard without a bee colony was used as control. Observations on the abundance of insect visitors to the apple flowers on selected branches (number of insect visitors counted in a five-minute period) and the number of flowers visited per minute by the visitors of each species were recorded at different hours of the day in honeybee pollinated as well as control orchards. After flowering was over, data on fruit set, premature fruit drop, and fruit quality (fruit weight, shape and colour) as well as total yield per tree was recorded in the orchard having a bee colony (honeybee-pollinated orchard) and without bee colonies (control) at each site.

The findings of this study revealed that supplementary pollination by honeybees enhanced fruit set by 7.5 to 12% in 2014 and 9.8 to 14.5% in 2015, and reduced premature fruit drop by 0.5 to 7.6% in 2014 and 1.6 to 6.4% in 2015 in different sites. It enhanced the overall fruit yield by 41.9% in 2014 and 47.9% in 2015.

Similarly, the bee pollination also enhanced the quality i.e. weight, shape and colour of apple fruit. Fruits from honeybee-pollinated orchards were bigger and weighed more compared to those from control orchards. The average weight of an apple (fruit) in honeybee pollinated apple orchard was 192.3 g, as compared to 158.5 g in control orchard in 2014, revealing 21.5% increase in fruit weight as a result of honeybee pollination; whereas in 2015 an increase of 35% was observed as the average weight per fruit in honeybee pollinated orchard was 189.1 g compared to 139.5 g.

Honeybee pollination also enhanced the percentage of well-formed symmetrical fruits; the average number of well-formed fruits in honeybee-pollinated orchard was 21.9% higher in 2014 and 19.9% higher in 2015 compared to those from control orchards. Similarly, honeybee pollination also enhanced the percentage of bright coloured apples by 10.2% in 2014 and 17.5% in 2015 as compared to control orchards.

These findings proved that training farmers to properly manage bee colonies for pollination enhances yield and fruit quality in apple. Engaging farmers in this research also helped in raising awareness and enhancing their understanding about the role of honeybees as pollination service providers. The results suggested that integrating pollination into the whole production and marketing system is important to enhance farmers' resilience by bringing higher incomes and improved livelihoods. The information generated can underpin crop management and policy decisions focused on promoting insect pollination services and on conserving/protecting pollinators. This will help maintain and improve crop production in the face of ongoing environmental change.

Introduction

The people of Chitral, the northern-most district of Pakistan bordering Afghanistan, have traditionally practised subsistence agriculture focused on grain production and livestock rearing. Their diet of cereals and dairy products is supplemented with fruits and nuts, grown as single trees on marginal land along field boundaries. The primary crops grown in this region are maize, wheat, rice, potato, barley, local beans such as black gram/ mung beans (oleen, khanis). Crops are mostly grown for self-consumption. Commercial production is limited to local market. According to the field survey conducted by AKRSP Chitral in 2014, wheat is the most abundantly grown crop in the district, covering 56% of the total crops produced, followed by maize, which covers 17%. Some other crops produced in Chitral include beans, potato, rice, barley, etc.

Some valleys in Chitral district have an ecological niche for high-value agricultural products such as temperate fruits and off-season vegetables that have demand in downstream city markets and fetch high prices. Therefore, cultivation of various fruit crops has been promoted in such valleys of Chitral. In valleys such as Golain valley (Koh), Lotkoh valley i.e. Garam Chashma and Karimabad, fresh beans and potatoes are produced for market as cash crops (Figure 1). Similarly, there are around 590 hectares under fruit crops, producing around 3,970 tonnes of fruit annually (Khyber Pakhtunkhwa Bureau of Statistics, 2012). The major fruits grown in this district are apple, pear, apricot, walnut, mulberry, pomegranate, persimmon, peach, almonds and cherry (Figure 2).

Apple Cultivation in Chitral

Apple and apricot are the most important fruits produced in Chitral; they cover 26% and 19% respectively of the total fruit production (AKRSP Chitral, 2014) (Figure 2). Though the orchards are small and the average orchard size is 0.059 ha/ household, apple contributes significantly to household cash income. Some households have commercial orchards in the district while many households grow fruits around the houses.

Four varieties of apple that have demand in the market have been planted in Chitral. These include

Figure 1: **Production of different crops in Chitral, Pakistan**

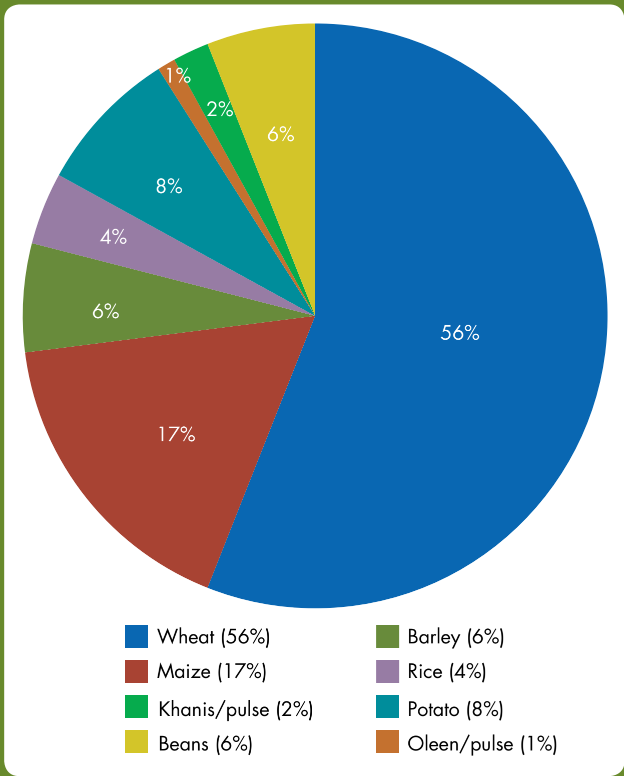
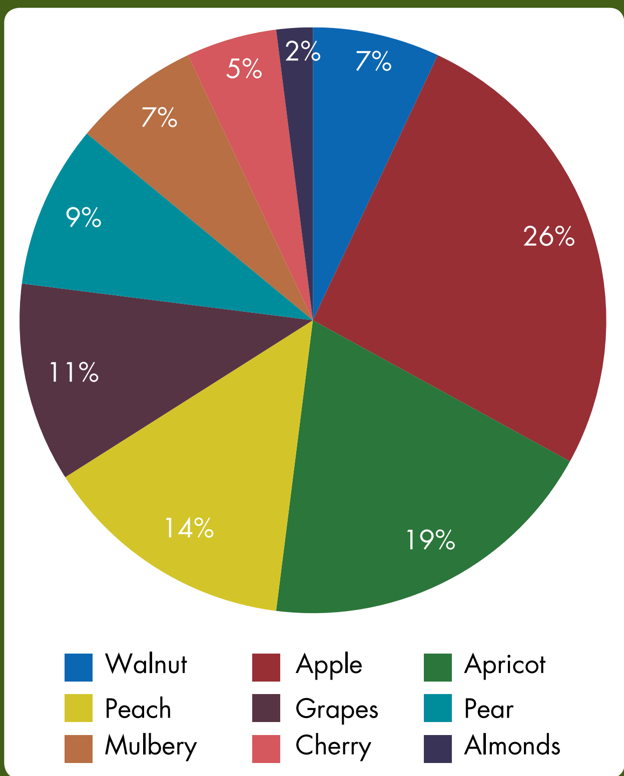


Figure 2: **Fruit production in Chitral, Pakistan**



Apple orchard in Booni, Chitral

Royal Gala, Kala Kola (Red Delicious), Khurduzhi/ Choupush (Royal Delicious) and Golden (AKRSP Chitral, 2012). Other varieties of apples are also produced in Chitral but not on a large scale e.g., Red Chief, silver spur and Basoti (local name).

From a market perspective, Royal Gala and Kala Kola varieties are considered to be of good quality due to their bright colour, pleasant aroma, high shelf life, firmness/crunchiness and uniform size. Some valleys in the district are famous for different varieties of apples. For example, Garam Chashma / Karimabad is famous for varieties like Khurduzhi, Kala Kola, Royal Gala and Golden; Booni for Choupush, Kala Kola, Royal Gala, Golden; Mastuj and Brep for Choupush, Kala Kola, and Royal Gala.

Importance of Pollinators and Pollination for Horticultural Productivity

Pollination is a vital ecosystem service that is essential to ensuring human food security as well as maintaining the productivity of agricultural and natural ecosystems (Cruden, 1976; Zimmerman, 1983; Kevan, 1991; Buchmann & Nabhan, 1996; Kearns et al., 1998; Ollerton, 2011; Kevan & Phillips, 2001; Millennium Ecosystem Assessment (MA), 2005, Eardley et al., 2006). Over 80% of plants and three-quarters of world food crops rely on animal pollinators such as bees, flies, etc. (Meeuse, 1961; Dowden, 1964; McGregor, 1976; Free, 1993; Eardley et al., 2006; Klein et al., 2007; Intergovernmental Panel for Biodiversity and Ecosystem Services (IPBES), 2016). The nature and extent of pollination benefits can vary between crops, ranging from increasing the quantity and quality of fruit or seed produced to hastening crop development and increasing genetic diversity within crop species (Free, 1993; Shipp et al., 1994; Hajjar et al., 2008).

Studies conducted in different parts of the world have shown that pollinators make a huge economic contribution to agriculture (Winston & Scott, 1984, Matheson & Schrader, 1987, Pimentel et al., 1997; Carreck & Williams, 1998; Morse & Calderone, 2001; Ruijter, 2002). Costanza et al. (1997) estimated the global annual contribution of pollinators to agriculture at USD 117 billion. More recently, Gallai et al. (2009) estimated the global annual contribution of pollinators to the agricultural crops at USD 161 billion. Partap et al. (2012) estimated that insect pollinators contribute USD 2.69 billion to the agricultural economy in parts of the Hindu Kush Himalaya (HKH) in Bangladesh, Bhutan, China, India, and Pakistan. The value of insect pollination on which humans can exert much influence is not limited to cultivated crops. Baker & Hurd (1968) also recognized this important ecological relationship and stated that insect pollination was extremely important in grasslands, temperate forests and deserts.

Realizing its contribution to agriculture and biodiversity, the Convention of Biological Diversity (CBD) recognized pollination as a key driver in the maintenance of biodiversity and ecosystem function.

However, a range of factors such as excessive chemical pesticide application, habitat loss as a result of ongoing land use changes, spread of pathogens, competition from alien species, and climate change, have led to an alarming decline in pollinator abundance and diversity, both globally and in the Hindu Kush Himalayan (HKH) region (Williams, 1982; Crane & Walker, 1983; Aizen & Feinsinger, 1994; Allen-Wardell et al., 1998; Partap & Partap, 2002; 2009; Partap et al., 2001; Partap, 2003a,b; 2011; Berezin & Beiko, 2002; Biesmeijer et al., 2006; Eardley et al., 2006; Potts et al., 2010; Cameron et.al., 2011; Partap & Tang 2012; IPBES, 2016). Climatic factors, particularly inclement weather conditions, are known to limit production of fruit crops, especially in plant species that bloom early in the year due to frequent inclement weather, affecting crop pollination in temperate areas (Gould, 1939). Climatic conditions strongly affect the foraging activity of pollinating insects. Spells of unfavourable weather can significantly limit the reproductive success of both pollinating insects and plants that depend on them for pollination (Eisikewitch & Galil, 1971; Martiner del Rio & Burqquez, 1986; Bergman et al., 1996). Especially susceptible are many solitary bee species with short seasonal activity period (Larsson & Tengo, 1989; Vicens, 1997). Foraging activity of *Apis mellifera* is low at temperature below 12 to14°C and solar radiation under 500lux condition (Burrill & Dietz, 1981; Kevan & Baker, 1983; Winston, 1987; Free, 1993; Vicens & Bosch, 2000 a; b), which frequently occurs in late winter and spring. Similarly, most native bees reproduce in late spring and summer when natural floral sources are flushing so that competition for floral nectar and pollen may be reduced. The serious implications of this decline were uncovered by an extensive ICIMOD study by Partap and Partap (2002) carried out in the apple farming areas of the Himalayas (China, India, Pakistan, Bhutan, Nepal). The study showed a severe decline in apple yield and quality as a result of inadequate pollination.

Although many species of insects are known to provide pollination services, honeybees have been reported to be one of the most efficient providers of crucial and high-value pollination services and play an indispensable role in enhancing production of many economic crops (Breeze et al., 2011). Studies conducted in different parts of the world have proven the role of honeybee pollination in improving the yield and quality of various crops such as fruit and nuts, vegetables, pulses, oilseeds, spices, and fibre and forage crops (McGregor 1976; Batra 1985; Vithanage & Ironside, 1986; Free, 1993; Partap & Verma, 1994; Verma & Partap, 1994; Singh et al., 2000; Sekita, 2001; Mattu et al., 2012). Further, as the diversity and abundance of naturally occurring pollinators' declines, the role of domesticated bees – one of the greatest providers of pollination services – has become increasingly important.

Why this Research?

Apple is an important source of cash income for farmers in Chitral. It constitutes 26% of the total fruit production and is widely used as a commercial crop followed by apricot, which covers 19% of total production and is also used commercially (AKRSP Chitral, 2014). Of the four major varieties planted in Chitral, Kala Kola or Red Delicious are self-incompatible; Royal Gala is partially self-fertile; and Golden Delicious is self-fertile and capable of self-pollination, though this variety too produces more when cross pollinated with a suitable pollinizer by pollinators (Ahmad, 1987). Self-incompatible varieties of apple require pollen from a compatible pollinizer variety to be deposited on the stigmatic surface of the flower for ovule fertilization, and seed and fruit development (Volz. et al., 1996).

Apple blooms in spring and flowers occur in clusters (Khan & Khan, 2004). Literature on the pollination of apple suggests that different species of bees (including honeybees *Apis cerana* and *Apis mellifera*, bumblebees, and horn faced bees - *Osmia cornifrons* and *Osmia lignaria* and flies – *Eristalis* spp and *Syrphus* spp) serve as pollinators of apple in different parts of the world (Mc Gregor, 1976; Verma & Chauhan, 1985; Free, 1993; Sekita, 2001; Sheffield, 2014). Studies conducted in apple farming areas in the Indian Himalayas revealed that honeybees play an important role in apple pollination, enhancing its yield and fruit quality (Dulta & Verma, 1987; Gupta et al., 1993; Partap & Partap, 2002; Verma & Rana, 1994; Mattu et al., 2012).

Beekeeping has been practised for many generations in Chitral. It plays a significant role in the livelihoods of the rural communities in the district. Southern Chitral is the main source of honey that was used for medicinal purposes (AKRSP Chitral, 2014). Although beekeeping is common in the area, the majority of the population is not aware of the importance of honeybees as pollination service providers. This is because studies on the role of honeybees and other pollinators in apple production in mountain areas of Pakistan, in particular Chitral, are lacking. Thus, there is little or no awareness of this crucial role of honeybees/beekeeping among farmers and development workers as well as at policy level in Chitral.

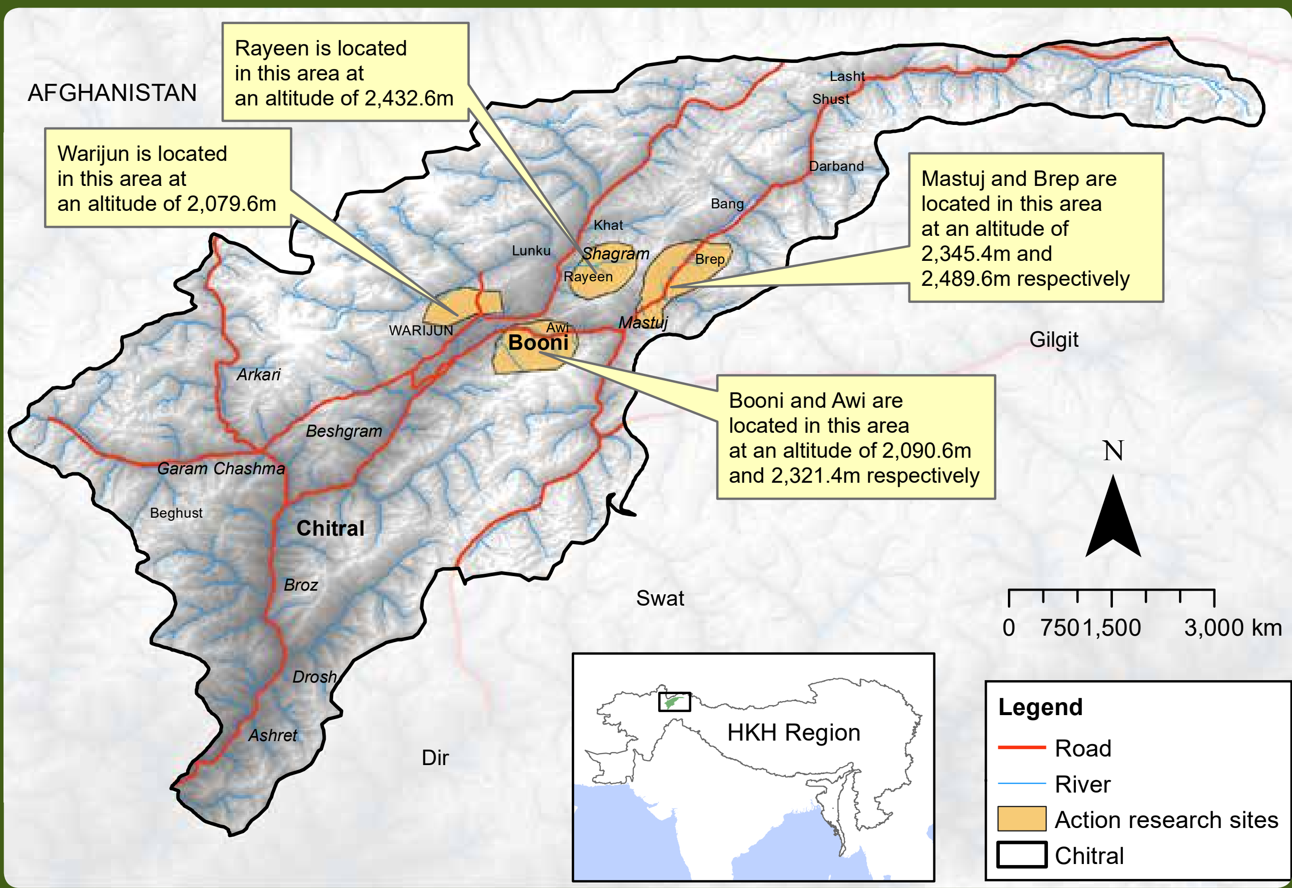
This collaborative action research was undertaken in collaboration with the Aga Khan Rural Support Programme (AKRSP), Chitral, Pakistan to demonstrate the benefits of using honeybees for apple pollination and its impact on fruit yield and the quality of apple. The aim is to promote honeybees and beekeeping primarily for their pollination services. The overall objective of this action research was to raise awareness among fruit growers and other farmers, extension workers of district horticulture/ agriculture departments, and decision makers at the district level about the importance of beekeeping for apple production. The other objective was to generate evidence on the role of honeybees as significant ecosystem service (pollination) providers to help establish a mechanism for payment for ecosystem services. The apple growers in different villages in different valleys and other stakeholders (beekeepers, community based organizations, government departments of agriculture and horticulture, and the agriculture university) were engaged in this action research right from the designing phase to implementation and monitoring.

Methodology

Study Sites

The action research on the role of honeybees in apple pollination was conducted in six villages including Booni, Awi/Parwak, Mastuj, Warijun/Kosht (Mulkho valley), Rayeen/Shagram/Istaru (Torkhow valley) and Brep. These villages fall in six distinct geographical and altitudinal locations of upper Chitral (northern part of the district) and are separated from each other by a distance of 100 to 300 km (Figure 3).

Figure 3: **Map of district Chitral showing action research sites (indicated by the green lines)**



Main criteria for the selection of villages were:

- Villages where apple is an important cash crop and is important to people's livelihoods
- Farmers are interested in participating in action research and using honeybees for apple pollination
- Beekeeping is commonly practiced in the area and beekeepers are interested in providing bee colonies for pollination action research

Characteristics of the study sites including the details of the selected villages, such as geographic coordinates, altitude, aspects and number of households involved in apple production are provided in Table 1.

The study villages Booni and Warijun/Kosht are located at almost the same altitude, i.e., 2,070–2,100 m; Awi/Parwak and Rayeen at 2,300–2,450 m; and Mastuj and Brep at 2,400–2,500 m (Table 1). These are the highest apple-producing areas in the district. The number of apple producers varies from 102 (lowest) in Awi/Parwak and 1,400 (highest) in the Mastuj area.

Table 1: **Characteristics of study sites**

Name of the village	Geographic coordinates	Altitude (m)	Aspect (whether north facing or south facing)	No. of households engaged in apple production
Booni	36° 16′ 20″N 72° 15′ 01″E	2,090.9	North	850
Awi/Parwak	35° 15′ 52″N 72° 20′ 32″E	2,321.4	North	102
Mastuj	36° 16′ 44″N 72° 30′ 56″E	2,345.4	North	1,400
Warijun/Kosht	36° 18′ 12″N 72° 25′ 17″E	2,079.6	North	823
Rayeen/Shagram/Istaru	36° 27′ 23″N 72° 25′ 17″E	2,432.6	North	600
Brep	36° 25′ 27″N 72° 39′ 19″E	2,489.6	North	350

Research design

The study adopted action research methodology i.e., engaging apple farmers in on-farm experimental research in their orchards. The research instruments were jointly developed by ICIMOD and AKRSP and were contextualized with the technical support of Khyber Pakhtunkhwa Agriculture University (KPAU), Peshawar. The Agriculture Research Centre (ARC), Seen Lasht, Chitral helped with the selection of apple orchards for on-farm research in different villages.

Farmers who had apple orchards of nearly the same age, containing the same variety of apple, and similar orchard management practice and inputs were selected for action research to have a good balance of confounding covariates between honeybee-pollinated and control groups. To create a comparable counter factual, we selected some apple orchards for control group and some apple orchards for honeybee-pollinated group in each village selected for action research. The apple growers were engaged in the whole process of research, from setting up field experiments to data collection.

Engaging Farmers in the Action Research

We planned to select 30 orchards – i.e., five apple farmers/orchards for action research in each village/area. The criteria for selection of farmers were – farmers who grow apple as a cash crop and produce larger quantities of apples for the market, are interested in participating in the research, and are interested in using honeybees for apple pollination. However, in the first year of research (2014) we had to drop two orchards each from Awi/Parwak and Warijun/Kosht and one each from Brep and Rayeen/Shagram/Istaru as these orchards did not have enough flowering. Thus, there were 24 action research orchards/ farmers in 2014. This included three orchards each in Awi/Parwak and Warijun/Kosht; two were used for honeybee-pollinated and one as control in each village; four orchards in Brep and Rayeen/Shagram/Istaru (two each for honeybee-pollinated and control); and five orchards in Booni and Mastuj (three honeybee-pollinated and two control) in each village (Table 2). Similarly, in 2015 we had 27 farmers/ orchards including 5 each in Awi/Parwak, Warijun/Kosht, Brep and Rayeen/Shagram/Istaru, 4 in Booni, and 3 in Mastuj villages, as shown in Table 2.

To reduce the variation in size, shape, colour and weight of fruits, orchards that had the same variety of apple were used in this action research. Thus all the orchards included in the action research had Kala Kola (Red Delicious) variety of apple. This variety was selected because the Kala Kola apple orchards in Chitral are of nearly the same age; also Kala Kola has great market value because consumers prefer this variety. Further this variety is self-incompatible and requires pollinators such as honeybees for cross pollination. Thus it was a suitable choice for showing the impact of honeybee pollination on yield and fruit quality.

Table 2: **Number of farmers/apple orchards selected for action research**

Village/Research Site	Year 2014			Year 2015		
	No. of apple orchards selected	No. of honeybee pollinated orchards	No. of control orchards	No. of apple orchards selected	No. of honeybee pollinated orchards	No. of control orchards
Booni	5	3	2	4	2	2
Awi/Parwak	3	2	1	5	3	2
Mastuj	5	3	2	3	2	1
Warijun/Kosht	3	2	1	5	3	2
Rayeen/Shagram/Istaru	4	2	2	5	3	2
Brep	4	2	2	5	3	2
Total	**24**	**14**	**10**	**27**	**16**	**11**

Engaging Beekeepers in the Action Research

Beekeepers in the area were engaged in the action research. They provided and managed their bee colonies placed in honeybee pollinated (treatment) orchards. However, in some action research sites we couldn't find local beekeepers. In these villages we rented the bee colonies from Himalayan Natural Honey - a commercial beekeeping enterprise in Green Lasht.

Orientation of Farmers, Beekeepers and Related Staff of AKRSP Chitral in Managing Bees for Pollination and Data Recording

Farmers and beekeepers were provided orientation training on managing bees for pollination. Initially all 30 selected apple growers/action research farmers in six villages were trained to participate in action research. They were introduced to different tools of specific research and bee management techniques. Finally only 24 of these were engaged in action research. The remaining six could not participate because their orchards did not produce flowers in 2014 due to the alternate bearing nature of apple. We also arranged a refresher training in 2015 for the farmers who were already engaged in action research in 2014. A separate training was organized for beekeepers on the provision of healthy bee colonies and proper colony management during the apple flowering season for pollination. The research staff of AKRSP and the participating farmers were also trained on data collection during apple pollination, post flowering up to the harvesting stage for action research. An expert entomologist and pollination researcher from the KP Agriculture University, Peshawar gave the training. A step-by-step summary of the whole action research process is provided in Figure 4.

Apple farmers and research team being trained in managing honeybees for apple pollination

a. Classroom session

b. Field session

Experimental Setup

Two experimental groups i.e. control and honeybee-pollinated groups were used in each research site. In each village some apple orchards were placed in control group and some in honeybee-pollinated groups (Table 2). Colonies of honeybee (*Apis mellifera*) were placed in some of the orchards (hence called 'honeybee-pollinated' orchards) while orchards used as control (control orchards) had no honeybees colonies. In control orchards pollination took place by naturally occurring pollinators including free ranging honeybees. The team ensured that control orchards were located at a distance of 100–150m from the honeybee-pollinated orchards so that no bees from the honeybee-pollinated orchards would visit the flowers in the control orchard following Verma (1990) and Free (1993).

In each orchard five trees of the same age and in similar health were selected. On each of the selected trees three branches of the same dimensions (with respect to their spread, phase of flowering, exposure to sunlight and height above the ground) having an equal number of pink buds/ flowers were selected for data collection following Dulta (1986) and Mattu and Raj (2013).

After the training of the farmers, beekeepers and research staff, strong, healthy and disease-free colonies of *Apis mellifera* were placed (@ five colonies per hectare) in each honeybee pollinated orchard at the time of 5–10% of flowering. The colonies were placed at an almost equal distance from the selected trees to ensure that almost the same number of bees visited the flowers in each selected tree. Bee colonies used for action research in each orchard had an almost equal number of foraging bees. The bee colony was left in the orchard until the flowering was over.

A honeybee colony placed in the research orchard.

In total 120 trees in all the villages were marked for data collection. On each of these trees three branches were selected for recording the data. This means 360 apple branches were under observation in 2014 and 405 branches in 2015 for data collection. All data on the number of flowers per selected branch, number of insects on flowers during each five-minute period, number of flowers visited by the floral visitors of different pollinator species per minute, mean number of fruits formed (i.e., initial fruit set) two weeks after petal fall, and number of fruits after one month of initial fruit were recorded.

Data Recording

Data on the characteristics of the study sites was gathered from secondary sources. Data on floral biology of the crop (i.e. flowering time, and the number of flowers per selected branch), pollinator species and their numbers on selected branches, and the number of flowers visited by each pollinator species per minute, and the impact of bee pollination on yield and quality of fruit was recorded in each orchard.

The number of flowers, fruit set, fruit drop and final fruit set and fruit quality (shape, weight, and colour of fruits) were recorded on each of these flowers.

Information about the crop in each action research orchard

- Main variety of the apple
- Number of flowers per branch selected for research

Abundance of insect pollinators

Insect visitors (pollinators including bees, flies, butterflies, and honeybees, etc.) to the flowers in each selected branch and the number and frequency of their visits (during each five-minute period at different hours of the day) were recorded at about 50% flowering of the crop three times a day – morning (between 9:00 and 10:00), noon (between 12:00 and 13:00) and afternoon (between 15:00 and 16:00) for five sunny days in the honeybee-pollinated and control orchards.

Number of flowers visited by a bee per minute

Data on the number of flowers visited per minute by a bee/insect at different hours of the day in the honeybee pollinated and control orchard were recorded at about 50% flowering of the crop. These data were also recorded three times a day – morning (between 9:00 and 10:00), noon (between 12:00 and 13:00) and afternoon (between 15:00 and 16:00) for five sunny days.

Fruit set

To assess the impact of bee pollination on fruit set the number of flowers was counted at pink bud stage on each selected branch in control as well as honeybee pollinated. For fruit set data the number of fruits on each of these branches were counted two weeks after the petal fall (two weeks after flowering was over) and the fruit set was calculated in percentage using the following Dulta (1986) and Mattu and Raj (2013).

$$\text{Percentage of fruit set} = \frac{\text{Number of fruits}}{\text{Number of pink buds/flowers}} \times 100$$

Fruit drop

To assess the impact of honeybee pollination on fruit drop, the number of fruits was counted again four weeks later on the same selected branches that were used for assessing the fruit set in honeybee pollinated and control orchards in each site. The fruit drop was calculated from the ratio of fruits dropped to the total number of fruits set. The fruit drop was calculated in terms of percentages following Dulta (1986) and Mattu and Raj (2013).

$$\text{Percentage of fruit drop} = \frac{\text{Number of fruits dropped}}{\text{Total number of fruits set}} \times 100$$

The number of fruits dropped was calculated by subtracting the number of fruits after six weeks of petal fall from the number of fruits set two weeks after the petal fall.

Impact of honeybee pollination on fruit yield

The increase in fruit yield as a result of honeybee pollination was calculated by harvesting and weighing the fruits from each experimental tree in honeybee-pollinated and control orchards in each site.

Impact of honeybee pollination on fruit quality

Improvement in the quality of fruit as a result of honeybee pollination was measured in terms of increase in weight and improvement in the shape and colour of the fruit. Weight of the fruit was measured in grams with the help of a top pan digital balance. Observations on other quality parameters of the fruits such as shape (well-formed/ symmetrical or lopsided) and colour (bright or dull) were recorded visually. Hundred randomly selected fruits from treatment and control orchards at each action research site were taken to obtain the mean value for each parameter.

Statistical Analysis of Data

A difference analysis between control and honeybee-pollinated apple orchards was performed to measure the impact of honeybee pollination on the above-mentioned indicators. Two independent sample t-test with a p value of 0.05 and 95% confidence level were used for the difference analysis. SPSS 16 and STATA 12 software were used for data analyses.

The key steps in the methodology have been summarised in Figure 4.

Figure 4: **Summary of key steps in action research implementation**

Step 1: Identify study sites, action research farmers and beekeepers: A total of 24 farmers in year 2014 and 27 farmers in 2015 having orchards of the same variety and same age were engaged in action research in 6 villages located at different altitudes. The villages and farmers were selected based on the following criteria: 1) apple is an important crop contributing to household cash income; 2) farmers are interested to participate in action research; 3) village is representative in terms of landscape, farming practices and socio-economic characteristics.

↓

Step 2: Identify and contact beekeepers interested to participate in action research and provide bee colonies for action research. In villages where beekeepers were not available, bee colonies were rented from Himalayan Natural Honey – a commercial beekeeping enterprise in Green Lasht (Reshun).

↓

Step 3: Orientation for farmers and beekeepers on managing bees for pollination; and for project staff/researcher and action research farmers on data collection

↓

Step 4: In each village two experimental groups including honeybee pollinated and control were used. Some orchards were used as honeybee-pollinated orchards and some as control. In honeybee-pollinated orchards bee colonies @ 5 colonies per hectare were placed at 5–10% of flowering; no colony was placed in control orchards to compare the impact of bee pollination on apple yield and quality.

↓

Step 5: Five trees in each action research orchard in each village were selected and marked for observation and data collection at the study sites.

↓

Step 6: On each of these trees three branches were marked for data collection

↓

Step 7: Data on the number of flowers/pink buds per selected branch, number of pollinators (including bees, flies, butterflies, moths, honeybees, etc.) visiting the flowers during each five-minute period, types/ species of pollinators, number of flowers visited by foragers of each pollinator species per minute, fruit set after two weeks of petal fall, fruit drop, fruit set after six weeks of petal fall, overall yield/ tree and quality of fruit (fruit weight, shape, colour, etc. in all the orchards with or without bee colonies) were recorded in each of the six villages. Data on the number of insects during each five-minute period was recorded at three different times of the day (i.e. between 09:00 and 10:00; 12:00 and 13:00; and 15:00 and 16:00) for five sunny days.

↓

Step 8: Statistical analyses of data

↓

Step 9: Repeat the action research in 2015 by incorporating any experiences, feedback, lessons learnt during the first year of research.

Results and Discussion

Apple Flowering and Floral Biology in Chitral

Apples bloomed during early May in research sites at lower altitudes (Booni and Warijun/Kosht); mid-May in Awi/Parwak, and Mastuj; and end of May at high altitudes (Brep and Rayeen/Shagram/Istaru) in both 2014 and 2015. Flowering period of apple lasted about two to three weeks in research orchards in each site.

Early flowering in lower altitude villages has been attributed to warmer temperature at lower altitudes in the beginning of May. In higher altitude research sites, the weather was still cold at the beginning of the month and warm enough for flowering only at the end of the month. Earlier studies have already shown that weather is a key factor for flowering and effective pollination of crops, e.g., apples and other fruit crops (Fitter & Fitter, 2002; Miller et al., 2007). Air temperature of 17–18°C is thought to be appropriate for apple flower blooming (Fitter & Fitter, 2002). Temperature has significant impact on pollinator interactions and is known to affect flowering in crops and plants. In cold areas the response of plants to warming is the production of increased number of flowers (Arft et al., 1999), though some studies (Inouye et al., 2003) have shown that increased spring temperatures may decrease flower abundance in plants.

Common pollinators of apple flowers in different action research orchards in Chitral

a. *Apis cerana*

b. *Apis mellifera*

c. *Eristalis* spp

d. Butterfly

Abnormal weather during the fruit trees' blooming period can have considerable negative effect on the pollination of fruit trees, as reported by Partap & Partap (2002); Tang et al. (2003), who found that frequent rains, low temperature and cloudy weather as observed in the Maoxian County during apple flowering season delay flowering and affect pollination service by natural pollinators; pollination of fruit trees is affected most and the yield decreases considerably.

Observations of the number of pink buds/flowers (Table 3) show that the number of flowers per branch varied across research sites and was different in honeybee-pollinated and control orchards in 2014 as well as 2015. In honeybee-pollinated orchards the mean number of pink buds/flowers was highest (366.5) in Brep in 2014 and (386.3) in Awi/Parwak in 2015 and lowest (172.4 and 215.3) in Rayeen/Shagram/Isrtaru in 2014 and 2015 respectively. In control orchards the highest number (369.6) of pink buds/ flowers was observed in Mastuj in 2014 and Booni (403.1) in 2015 while the lowest (172.4) in Rayeen/Shagram/Isrtaru in 2014 and Awi/Parwak (286.6) in 2015 (Table 3). This difference in the number of flowers per branch was due to a difference in the size of branches selected for the research though care was taken to select branches of the same dimensions (with respect to their spread, phase of flowering and height above the ground) and with equal number of flowers in control and honeybee-pollinated orchards in all sites.

Apple flowers were borne in groups of four to six as reported already by several studies (McGregor, 1976; Free, 1993; Verma 1990). Each flower consisted of five greenish sepals, five pinkish white petals, 20–25 stamens surrounding the carpel having a single ovary, a style and five stigmas (McGregor, 1976; Free, 1993).

Table 3: **Number of flowers/branch in honeybee-pollinated and control orchards. Values are mean±SE.**

Research site	Number of flowers/m²/selected branch			
	2014		2015	
	Honeybee pollinated orchards	Control orchards	Honeybee pollinated orchards	Control orchards
Booni	272± 25.1 (n=45)	367.7±21.3 (n=30)	279±13.4 (n=30)	403.1±23.2 (n=30)
Awi/Parwak	258.5± 21.3 (n=30)	122.3±23.03 (n=15)	386.3±21.6 (n=45)	286.6±14.2 (n=30)
Mastuj	335.8±32.6 (n=45)	369.6± 29.9 (n=30)	336.0±14.4 (n=30)	356.5±14.3
Warijun/Kosht	282.9± 23.02 (n=30)	195.0±22.8 (n=15)	258.0±14.1	289.2±15.4 (n=15)
Rayeen/Shagram/Isrtaru	172.4± 25.5 (n=30)	172.4.0±14.2 (n=30)	215.3±12.5 (n=45)	317.4±19.7 (n=30)
Brep	366.5± 35.5 (n=30)	236.2±30.4 (n=30)	305.3±17.5 (n=45)	392.5±22.0 (n=30)

Floral Visitors

Our observations on floral visitors revealed two species of honeybees – *Apis cerana* and *Apis mellifera*, bumblebees, different species of butterflies and other insects (other bees, flies, etc.) as common visitors to apple flowers across all action research orchards. Similar results on flower visitors in apple are available in different countries of the HKH region. Studies conducted by Verma and Chauhan (1985) in apple orchards in the hills of Shimla, Himachal Pradesh, India reported 44 species of insects belonging to 14 families including honeybees *Apis cerana* and *Apis mellifera*, bumblebees, halictid bees, butterflies and dipteran flies including *Metasyrphus* spp and *Eristalis tenax* on apple flowers; *Apis cerana* made 24.01 to 43.03 per cent of total pollinator population in different orchards.

Foraging Behaviour of Insect Visitors in Relation to Apple Pollination

Foraging habits of different pollinators

Foraging bees of all species i.e., honeybees (*Apis cerana* and *Apis mellifera*), bumblebees and other bees began their foraging activities early in the morning. Bumblebees and *Apis cerana* started visiting flowers earlier than *Apis mellifera*, butterflies and other bees. Peak foraging activity (highest number of bees/ pollinators returning to hive per minute) was observed during mid-day i.e., between 12:00 and 13:00. Similar findings of the foraging activity of *Apis cerana* and *Apis mellifera* on apple flowers in Kullu valley of Himachal Pradesh, India were reported by Mattu and Bhagat (2016). These authors revealed that *Apis cerana* foraged for a significantly longer time in a day and visited more flowers per minute than *Apis mellifera*, while *Apis mellifera* took a longer time to complete a single forging trip and spent significantly more time per flower than *Apis cerana*. Peak foraging activity for *Apis cerana* occurred at 10:00 to 13:00 and for *Apis mellifera* between 12:00 and 13:00.

Abundance of insect visitors on apple flowers

The observations of the number of insects of different species visiting the apple flowers/branch during each five-minute period at three different hours of the day (09:00-10:30, 12:00-1:30 pm, and 15:00-16:30) in honeybee-pollinated and control orchards at all research sites during 2014 and 2015 (Table 4) show the highest number of *Apis mellifera* bees on apple flowers/per branch in the morning, noon, and afternoon hours in honeybee-pollinated orchards. This was followed by other bees and *Apis cerana*, while the number of butterflies was consistently lower throughout the day in both the years of study. However in control orchards the highest number of other bees visited the flowers, followed by *Apis mellifera* (Table 4). The differences in the number of insect visitors of different species were significant, while the differences in the number of insect visitors of the same species on flowers at different times of the day was not significant within the treatment. Further there was significant difference in the number of insect visitors of same species between the treatments, except for butterflies.

The site/village-wise descriptive statistics on the abundance of different insects in apple orchards (honeybee pollinated and control) during different time of the day are presented in Annex 1.

Table 5 summarises the overall average number of different species of insect pollinators on apple flowers during each five-minute period on the selected branches in honeybee-pollinated and control orchards in all sites in 2014

Table 4: **The number of insects/branch during each five-minute period in honeybee-pollinated and control orchards at different times of the day. Values represent the mean of observations gathered from all sites±SE**

Insect visitors	Number of insects/branch/5 minutes							
	Honeybee-pollinated orchards			Values of 'F' and degrees of freedom (*df*)	Control orchards			Values of 'F' and degrees of freedom (*df*)
Year 2014								
	09-10:30	12-13:30	15-16:30		09-10:30	12-13:30	15-16:30	
Apis cerana	1.3±0.2	1.3±0.2	1.3±0.2	F=0.04; df=206	0.6±0.7	0.6±0.6	0.6±0.6	F=0.15; df=149
Apis mellifera	3.6±0.5	3.6±0.5	3.4±0.4	F=0.05; df=206	1.2±0.1	1.2±0.2	1.2±0.2	F=0.0; df=149
Butterflies	0.6±0.1	0.5±0.1	0.5±0.1	F=0.2; df=206	0.7±0.09	0.6±0.1	0.7±0.07	F=0.2; df=149
Other bees	1.7±0.2	1.7±0.2	1.7±0.2	F=0.0; df=206	3.5±0.5	3.6±0.5	3.7±0.6	F=0.05; df=149
Year 2015								
Apis cerana	3.3±0.7	3.9±0.8	3.5±0.7	F=0.24; df=178	0.8±0.1	0.9±0.1	0.7±0.1	F=0.5; df=225
Apis mellifera	5.2±1.2	5.9±1.6	4.9±1.2	F=0.5; df=178	1.4±0.2	1.58±0.2	1.4±0.2	F=0.6 df=225
Butterflies	0.6±0.2	0.6±0.3	0.6±0.3	F=0.08; df=178	0.2±0.06	0.3±0.06	0.2±0.04	F=0.7; df=225
Other insects	2.3±0.3	2.3±0.3	2.2±0.3	F=0.24; df=178	1.9±0.3	2.0±0.3	1.8±0.3	F=0.1; df=225

Differences between the number of insect foragers of the same species at different times of the day were not significant; however the number of foragers of different insect pollinators varied significantly.

Table 5: **Average number of insects visited apple orchards/5 min/selected branch in 2014 and 2015 in all sites. Values represent the mean of all observations from all research sites±SE.**

Insect visitors to flowers	Honeybee pollinated orchards	Control orchards	Value of 't'	Degrees of freedom (*df*)
Year 2014				
Apis cerana	1.3±0.09	0.6±0.05	-5.4*	358
Apis mellifera	3.5±0.2	1.2±0.1	-8.4*	358
Butterflies	0.5±0.06	0.6±0.4	1.4	358
Other insects	1.7±0.3	3.6±0.1	6.5*	358
Year 2015				
Apis cerana	3.6±0.3	0.8±0.06	-6.9*	403
Apis mellifera	6.5±0.6	1.4±0.1	-7.1*	403
Butterflies	0.5±0.08	0.2±0.02	-3.9*	403
Other insects	2.3±0.1	1.9±0.1	-1.8*	403

*Differences are significant at $P < 0.05$

and 2015. The data reveals that in the orchards with honeybee colonies, the number of *Apis mellifera* bees was highest, followed by other bees, *Apis cerana* and butterflies in both the years. In control orchards the number of other bees was highest, followed by *Apis mellifera*, *Apis cerana* and butterflies.

The number of *Apis cerana* and *Apis mellifera* was significantly higher in honeybee-pollinated orchards in 2014 and 2015 as compared to control orchards, while the number of other bees was significantly higher in control orchards in 2014; the differences were not significant for butterflies. Reverse was true for butterflies and other bees in 2015 and the number of these foragers was significantly higher in honeybee-pollinated orchards.

The finding that *Apis mellifera* bees were dominant among insect visitors of apple bloom in honeybee-pollinated orchards in all study sites for both the years could be linked to the placement of the bee colony in the honeybee-pollinated orchards. Observations also revealed that the number of *Apis mellifera* bees per flowering branch during each five-minute period was much higher in all the orchards in 2015 compared to year 2014. The reason for this could be the use of stronger colonies of bees in 2015. Free (1993), Verma (1990) and Ahmad (1987) have already proved that a strong colony of bees has a higher number of foraging bees compared to a weak colony.

The average number of *Apis cerana* visiting honeybee-pollinated apple orchards in 2014 and 2015 was 1.3/5 min/branch and 3.6/5 min/branch respectively, while the average number of *Apis cerana* visiting control apple orchards in 2014 and 2015 was 0.6/5 min/branch and 0.8/5 min/branch respectively. These findings are also consistent with the study of Sharma et al. (2012), who reported a significantly higher (1.93 bees/m^2/5 min) number of *Apis cerana* in orchards where additional bee colonies were kept in comparison to the orchard with natural insect pollination (0.83 bees/m^2/5 min) in an orchard in Nainital. Similarly, Sharma and Gupta (2001) reported the increase in bee visits in apple orchards in Kullu valley of Himachal Pradesh. On the other hand studies by Herbertsson et al. (2016) found that adding honeybees suppressed bumblebee densities in homogeneous landscapes.

The number of butterflies and other insects (syrphid flies, bumblebees etc) was higher in control orchards as compared to the honeybee-pollinated orchards throughout the day in all the sites except in Awi/Parwak, where there were more butterflies and other insects than honeybees (Annex 1). This means that as the number of *Apis mellifera* increased after a colony of bees was placed, the number of *Apis mellifera* foragers on the flowers increased, outcompeting other insects. Honeybee foragers, being higher in number, displaced the other insects, leading to a reduction in the number of these insects. Partap (2000) reported that an increase in the number of one species per unit area leads to a decline in the number of insects of the other species on flowers. Similar results of flower visitors in apple are available in different countries of the HKH region; one example is studies conducted by Verma and Chauhan (1985) in the apple orchards of Shimla hills of Himachal Pradesh, India.

Number of flowers visited by different insects per minute

Observations on the number of number of flowers visited by different insect pollinators per minute recorded during different hours of the day in honeybee-pollinated and control orchards at all research sites are presented in Table 6. Data revealed that the foraging bees of *Apis mellifera* visited a comparatively higher number of flowers than bees of *Apis cerana*, other bees and the butterflies throughout the day in honeybee-pollinated and control orchards in 2014 while in 2015 *Apis cerana* visited more flowers per minute. Other bees showed no specific pattern in the number of flowers visited per minute. These bees visited a comparatively higher number of flowers per minute in control orchards during different hours of the day in 2014 and lower number of flowers in 2015 as compared to the orchards with honeybee colonies (Table 6).

Table 6: **Number of flowers visited by different species of insects per minute at different times of the day. Values are mean±SE**

Insect visitors	Number of flowers visited/minute by different insects							
	Honeybee pollinated orchards			' Values of 'F' and Degrees of freedom (*df*)	Control orchards			Values of 'F' and Degrees of freedom (*df*)
Year 2014								
	09-10:30	12-13:30	15-16:30		09-10:30	12-13:30	15-16:30	
Apis cerana	4.5±0.4	4.8±0.5	4.7±0.5	F=0.13; df=209	3.05±0.9	3.1±0.1	3.1±0.2	F=0.05; df=149
Apis mellifera	6.03±0.5	6.3±0.5	5.6±0.4	F=0.19; df=209	2.3±0.41	2.4±0.4	2.7±0.5	F=0.25; df=149
Butterflies	3.02±0.3	3.06±0.3	3.2±0.3	F=0.16; df=209	2.9±0.11	2.9±0.1	3.01±0.1	F=0.27; df=149
Other insects	4.9±0.5	5.2±0.5	4.9±0.5	F=0.12; df=209	5.9±0.5	6.7±0.6	6.85±0.6	F=0.97; df=149
Year 2015								
Apis cerana	7.4±0.7	8.2±0.8	8.3±0.7	F=0.29; df=238	3.4±0.3	3.48±0.2	3.2±0.2	F=0.37; df=149
Apis mellifera	6.3±0.8	7.2±0.9	6.3±0.7	F=0.64; df=238	4.73±1.3	6.34±1.7	5.38±1.4	F=0.33; df=149
Butterflies	3.2±0.3	3.1±0.3	3.7±0.2	F=0.07; df=238	2.20±0.1	2.21±0.05	2.20±0.04	F=0.05; df=149
Other insects	5.5±0.4	5.8±0.5	5.9±0.5	F=0.33; df=238	4.14±0.3	4.37±0.3	3.79±0.3	F=1.08; df=149

Differences between the number of flowers visited by the foragers of the same species at different times of the day were not significant within the same treatment but the differences were significant between the number of flowers visited in different treatments; also significant differences ($P<0.05$) were found between the number of flowers visited by the foragers of different insect pollinators.

The differences between the number of flowers visited by different species per minute was significant ($p<0.01$) while the difference in the number of flowers visited by the same species during different hours of the day was not significant. Generally, the number of flowers visited per minute by the foragers of different honeybees, butterflies and other insects was higher in noon hours between 12:00 and 13:30 in both honeybee-pollinated as well as control orchards (Table 6). Earlier studies by Mattu et al (2016) conducted in Kullu and Shimla hills of Himachal Pradesh showed a higher number of flowers visited by insects during mid-day hours.

Data on the number of flowers visited by different insect pollinators at different research sites during different hours of the day are presented in Annex 2. The annex shows that the foraging bees of *Apis mellifera* visited a comparatively higher number of flowers than bees of *Apis cerana*, other bees and the butterflies throughout the day in all research orchards except at Rayeen/Shagram/Istaru. In Rayeen/Shagram/Istaru the foraging bees of *Apis cerana* visited more flowers per unit time compared to the foraging bees of *Apis mellifera* in morning and noon hours, whereas in the afternoon bees of *Apis mellifera* visited a comparatively higher number of flowers per minute, followed by the other bees, whereas butterflies visited the least number of flowers per unit time.

Table 7 summarises the overall number of flowers visited by different species of insects per minute in honeybee-pollinated and control apple orchards in 2014 and 2015. The table shows that the number of flowers visited by the foraging bees of *Apis cerana*, *Apis mellifera*, butterflies and other insects was higher in honeybee-pollinated

Table 7: **Number of flowers visited by different species of insects per minute. Values represent the average of all research sites±SE**

Insect visitors	Number of flowers visited by different species of insects per minute			
	Honeybee pollinated orchards	Control orchards	Value of '*t*'	Degrees of freedom (*df*)
Year 2014				
Apis cerana	4.7±0.2	3.1±0.1	-5.8*	df=358
Apis mellifera	6.0±0.3	2.5±0.4	-2.4*	df=358
Butterflies	3.1±0.1	2.9±0.1	-0.8	df=358
Other bees	5.04±0.2	6.5±0.3	3.6*	df=358
Year 2015				
Apis cerana	8.1± 0.5	3.6±0.1	-7.0*	df=402
Apis mellifera	8.1±0.4	2.7±0.8	-1.3	df=402
Butterflies	3.06±0.4	2.4±0.8	-6.1*	df=402
Other insects	5.4±0.3	4.6±0.2	-5.6*	df=402

*Differences are significant at $P < 0.05$

orchards as compared to control orchards. The data further revealed that the number of flowers visited by *Apis mellifera* foragers in honeybee-pollinated apple orchards was significantly higher than the number of flowers visited in control apple orchards. The number of flowers visited by *Apis cerana*, butterflies and bees in honeybee-pollinated apple orchards was slightly higher than the number of flowers visited in control apple orchards, but the differences were not significant.

The higher number of flowers visited by insect pollinators in honeybee-pollinated orchards could be due to the competition, as reported earlier by Partap (2000 d), who found that in the presence of *Apis mellifera* in the same plot, *Apis cerana* bees spent less time on each flower and visited more flowers per unit time. On the contrary Gorasm et al. (2016) reported that the average time wild bees spent on *Cistus creticus* increased (and the number of flowers visited per unit time decreased) with the introduction of honeybee colonies.

There is no explanation as to why other insects including bumblebees, syrphid flies and flies visited slightly fewer flowers in honeybee-pollinated orchards than in control orchards in 2014, though the difference is not significant. Earlier studies reported that insect groups differed greatly in their rate of flower visits (Couvillon et al., 2015). These authors also reported that bumblebees and honeybees visit significantly more flowers per time (11.5 and 9.2 flowers/minute, resp.) than the other insect groups. A study by Rader et al. (2016) showed that though non-bees were less effective pollinators than bees per flower visit, they made more visits; thus these two factors compensated for each other, resulting in pollination services rendered by non-bees that were similar to those provided by bees. Moreover, with more flowers visited per unit time, the chances of pollinating them are higher. Therefore, these authors concluded that it is important to take measures for pollinator protection for effective pollination and higher yield and fruit quality. Thus, placing a bee colony in the orchard increases the number of flower visitors while also making them visit a higher number of flowers by increasing the competition for resources.

Data on the number of apple flowers visited by different insects per unit time is lacking except for *Apis cerana* and *Apis mellifera*. Studies by Verma and Dulta (1986) reported that foraging bees of both *Apis cerana* and *Apis mellifera* visited an equal number of flowers per minute (i.e., 3.09 and 3.33) respectively. However, studies by Mattu et al. (2016) reported that *Apis cerana* visited a higher number of flowers (9.7 to 8.08) as compared to *Apis mellifera*, which visited 6.8 to 5.6 flowers per minute in different orchards in Kullu valley of Himachal Pradesh, India. Similarly, Joshi (2010) reported similar observations on the number of flowers visited by *Apis cerana* and *Apis mellifera* in apple orchards in Nainital, Uttarakhand, India.

Impact of Honeybee Pollination on Apple Yield

Improvement in fruit set

Table 8 presents the data on the impact of honeybee pollination on fruit set in honeybee-pollinated and control orchards after two weeks of petal fall during 2014 and 2015. The data showed that the fruit set was significantly higher in honeybee-pollinated orchards as compared to control orchards at all sites in 2014 as well as in 2015 (Table 8). In 2014, honeybee-pollinated orchards had the highest fruit set (29.9%) in Warijun/Kosht, followed by Booni (28.7%), Awi/Parwak (28.3%), Mastuj (27.7%), Rayeen/Shagram/Istaru (27.5%), and lowest (26.3%) in Brep. In control orchards Warijun/Kosht had the highest fruit set (22.2%), followed by Booni (18.4%), Mastuj (16.9%), Rayeen/Shagram/Istaru (16.7%), Awi/Parwak (28.3%), Mastuj (16.9%), and lowest (15.4%) in Brep.

Among the orchards with honeybee colonies in 2015 Rayeen/Shagram/Istaru had the highest fruit set (30.7%), followed by Mastuj (30.5%), Brep (29.6%), Awi/Parwak (29%), Booni (28.7%) and lowest (28.4% in Warijun/Kosht. In control orchards Brep had the highest (19.8%) fruit set and Warijun/Kosht had the lowest (13.9%) (Table 8).

The differences in fruit set were significant between the honeybee-pollinated and control orchards in each site in both the study years. However, the differences in fruit set within each treatment in different sites were not significant. The results clearly indicated that using honeybees for pollination increases fruit set in apple at different altitudes.

Table 8: **Impact of honeybee pollination on fruit set (%) as observed after two weeks of petal fall in honeybee-pollinated and control orchards at different research sites**

Research sites	Fruit set after two weeks of petal fall (%)		Increase in fruit set due to honeybee pollination (%)	Level of significance Pr (T<t); degrees of freedom
	Honeybee-pollinated orchards	Control		
2014				
Booni	28.7	18.4	10.3	t =0.03**; df= 44
Awi/Parwak	28.3	16.3	12.0	t =0.01**; df=29
Mastuj	27.7	16.9	10.8	t =0.01*; df= 29
Warijun/Kosht	29.9	22.2	7.5	t =0.005**; df= 29
Rayeen/Shagram/Istaru	27.5	16.7	10.8	t =0.09; df= 29
Brep	26.3	15.4	10.9	t =0.001**; df= 29
Year 2015				
Booni	28.7	17.3	11.4	t =0.02* ; df= 44
Awi/Parwak	29.0	16.0	13.0	t =0.004**; df=29
Mastuj	30.5	17.0	13.5	t =0.02**; df=29
Warijun/Kosht	28.4	13.9	14.5	t =0.3; df=29
Rayeen/Shagram/Istaru	30.7	16.4	14.3	t =0.002**; df=29
Brep	29.6	19.8	9.8	t =0.002**; df=29

**Differences are significant at P < 0.01; and * significant at P<0.05

Reduction in premature fruit drop

Observations on the impact of honeybee pollination on premature fruit drop during 2014 and 2015 are presented in Table 9. Data revealed significant differences in premature fruit drop between honeybee-pollinated and control orchards, with higher fruit drop in control orchards as compared to the honeybee-pollinated orchards. This means that honeybee pollination significantly reduced premature fruit drop. The difference in premature fruit drop between the honeybee-pollinated and control orchards was significant in Awi/Parwak, and Rayeen/Shagram/Istaru in 2014; and Awi/Parwak, Mastuj and Rayeen/Shagram/Istaru in 2015. In other sites there was no significant difference in fruit drop between honeybee-pollinated and control orchards.

Table 9: **Impact of honeybee pollination on premature fruit drop (%) as observed after six weeks of fruit set in honeybee-pollinated and control orchards at different research sites**

Research site	Premature fruit drop (%)		Reduction in fruit drop due to honeybee pollination	Level of significance Pr (T<t); degrees of freedom
	Honeybee pollinated orchards	Control		
Year 2014				
Booni	21.8	29.1	7.3	t = 0.06; df= 44
Awi/Parwak	27.4	35.0	7.6	t =0.01**; df=29
Mastuj	25.7	30.3	4.6	t =0.09; df=44
Warijun/Kosht	29.7	30.2	0.5	t =0.28; df=29
Rayeen/Shagram/Istaru	21.4	25.2	4.2	t =0.02**; df=29
Brep	32.3	33.3	1.0	t =0.1; df=29
Year 2015				
Booni	18.8	22.0	3.2	t =0.8; df=29
Awi/Parwak	15.5	21.9	6.4	t =0.03**; df=44
Mastuj	16.3	21.2	4.3	t =0.04**; df=29
Warijun/Kosht	20.5	22.1	1.6	t =8.1; df=44
Rayeen	20.8	25.9	5.1	t =0.05*; df=44
Brep	18.6	22.2	3.6	t =0.7; df=44

**Differences are significant at $P < 0.01$; and * significant at $P<0.05$

There was no set pattern of fruit drop in honeybee-pollinated and control orchards at different sites during the research years. Among honeybee-pollinated orchards, Brep showed the highest fruit drop (32.3%) and Rayeen/Shagram/Istaru had the lowest (21.4%) premature fruit drop in 2014 (table 9). In 2015 Rayeen/Shagram/Istaru had the highest fruit drop (20.8%) and Awi/Parwak the lowest (15.5%).

In control orchards the highest fruit drop was observed in Awi/Parwak (35%) and lowest in Rayeen/Shagram/Istaru (25.2%) in 2014. Similarly in 2015, the highest fruit drop was found in Rayeen/Shagram/Istaru (25.9%) and lowest in Mastuj (21.2 (table 9).

Adequate pollination results in fertilization of more ovules, thus properly pollinated flowers develop better fruits. On the other hand an earlier study by McGregor (1976) and Free (1993) reported that poor pollination results in fertilization of fewer ovules, and fruits with fewer fertilized ovules are more likely to drop. The increased percentage of fruit drop in control orchards was because of inadequate pollination of flowers due to the insufficient number of pollinators.

Higher fruit set, lower fruit drop, increased yield and higher percentage of better quality fruit in honeybee-pollinated orchards were due to the fact that in addition to naturally occurring insect pollinators including free-ranging honeybees, these orchards also had additional bee colonies to supplement pollinator numbers. More recently, similar experimental studies by Mattu and Raj (2015) and Bhagat and Mattu (2013) reported that pollination by honeybees significantly increased fruit set and reduced fruit drop in Royal Delicious variety of apple in Kullu valley and Shimla hills of Himachal Pradesh, India.

This finding – that pollination by honeybees resulted in an increase in fruit set – was also consistent with the study of Sharma et al. (2012), Dulta and Verma (1987), and Gupta et al. (2000). Sharma et al. (2012) found that fruit set in honeybee-pollinated orchards was 42.32%, while in control apple orchards it was 27.98%. Partap (2000 b) reported similar findings on the impact of bee pollination on fruit set for peach and plum, while Partap and Verma (1994) reported the same for radish, and Verma and Partap (1994) for cabbage and cauliflower. Similarly, our finding that pollination by honeybees helped in reducing premature fruit drop in all research sites was in line with the study of Rana et al. (1998), Gupta et al. (1993), Sharma and Gupta (2001), and Sharma et al. (2004), who have also reported increased fruit set and low fruit drop in orchards with managed pollination.

Improvement in fruit yield

The data on fruit yield in honeybee-pollinated and control apple orchards (Table 10) show that in the year 2014 the average apple yield per tree in control apple orchards was 40.6 kg, while in honeybee-pollinated orchards it was 57.6 kg. Similarly, in 2015 the average apple yield per tree in control apple orchards was 99.3 kg, while the average apple yield in honeybee-pollinated orchards was 146.9 kg. This means that pollination by honeybees enhanced the apple yield by 41.9% in 2014 and by 47.9% in 2015.

The findings also suggest that the apple yield in honeybee-pollinated orchards was significantly higher than the apple yield in control orchards in each research site in 2014 and 2015; the findings are significant at 95% level of confidence (Table 10).

Impact of honeybee pollination on fruit production (compare the number)

a. Honeybee pollinated orchard

b. Control orchard

Table 10: **Impact of honeybee pollination on fruit yield in apple**

Year	Fruit yield/tree (kg)		Increase in fruit yield due to honeybee pollination (%)	Values of 't' and degrees of freedom	Level of significance Pr (T<t)
	Honeybee pollinated orchards	Control orchards			
2014	57.6	40.6	41.9	t= -1.53; df=22	0.06*
2015	146.9	99.3	47.9	t= -1.93; df=25	0.03**

The results of the independent sample t-test of control and honeybee pollinated orchards to check the mean difference. *, and ** denotes significance at 10, and 5 percent confidence level respectively. The t-test has been performed on the mean difference i.e. control-honeybee pollinated < 0.

Besides, the table shows that the fruit yield in 2015 was more than double compared to 2014. This was due to apple trees' tendency to bear in alternate years in Chitral. The yield in 2015 was thus much higher than in the preceding year.

Data on the fruit yield in honeybee-pollinated and control orchards in individual research sites are provided in Annex 3 (i).

Impact of Honeybee Pollination on Fruit Quality

Improvement in fruit weight

The findings on the impact of honeybee pollination on fruit weight show that pollination by honeybees significantly enhanced the fruit weight in all research sites during 2014 and 2015 (Table 11). In 2014 the average weight of randomly selected apples in honeybee-pollinated orchards was 192.6 g per fruit, while the average weight per fruit in control orchards was 158.5 g. The results also suggested that the weight of apples in honeybee-pollinated orchards was 21.4% more than the weight of apple in control orchards. Similarly, in the year 2015 the average weight of randomly selected apples in honeybee-pollinated apple orchards was 189.1 g per fruit, while the average weight of apple fruit in control orchards was 149.5 g per fruit. The results also suggested that the weight of apples in honeybee-pollinated orchards was 35% greater than the weight of apple in control orchards. Statistical analysis suggested that the results are significant at 99% level of confidence (Table 11).

Table 11: **Impact of honeybee pollination on fruit weight in apple**

Year	Fruit weight/fruit (g)		Increase in fruit weight due to honeybee pollination (%)	Values of 't' and degrees of freedom	Level of significance Pr (T<t)
	Honeybee pollinated orchards	Control orchards			
2014	192.6	158.5	21.4	t= -2.21; df=22	0.02**
2015	189.1	149.5	35.0	t= -6.91; df=25	0.00***

The results of the independent sample t-test of control and honeybee-pollinated orchards to check the mean difference. *, **, and *** denote significance 10, 5, and 1 percent confidence level respectively. The t-test has been performed on the mean difference i.e., control-honeybee pollinated < 0.

Honeybee pollination also showed a positive impact on the weight of apples in all study sites. Site-specific data on the impact of honeybee pollination on fruit weight has been presented in Annex 3 (ii).

Our findings are in agreement with those of Khan et al. (2012) and Volz et al. (1996). Khan et al. (2012) reported that pollination of apple by *Apis mellifera* resulted in an increase of 138.44% in fruit weight compared to natural pollination in Murree hills near Islamabad, Pakistan. Mattu and Raj (2013) made similar findings in Shimla hills and Bhagat and Mattu (2015) in Kullu valley of Himachal Pradesh in India. Partap (2000b) made similar findings for peach and plum in the Kathmandu valley of Nepal.

Improvement in fruit shape

Observations on the impact of bee pollination on the shape of fruit were recorded by carefully observing the shape of 100 randomly selected fruits from each treatment (honeybee-pollinated and control) orchard in all study sites. The findings (Table 12) reveal that both in 2014 and 2015 a significant percent (over 90%) of all fruits in honeybee-pollinated apple orchards were well formed while less than one-tenth were lop-sided/asymmetrical. In control orchards more than a quarter of fruits were lop-sided. The findings are significant at 99% level of confidence as the *p* value that shows the level of significance is less than 0.01.

Table 12: **Impact of honeybee pollination on fruit shape in apple. The proportion of asymmetrical or lop-sided fruits is given in parentheses**

Year	Symmetrical vs asymmetrical (in parentheses) fruits (%)		Increase in the proportion of symmetrical fruits due to honeybee pollination (%)	Values of 't' and degrees of freedom	Level of significance Pr (T<t)
	Honeybee pollinated orchards	Control orchards			
2014	92.8 (7.2)	71.7 (28.3)	21.1	t= -2.91; df=22	0.0040***
2015	94.0 (6.0)	75.25 (24.7)	19.9	t= -6.67; df=25	0.0000***

The results of the independent sample t-test of control and honeybee-pollinated orchards to check the mean difference. *, **, and *** denote significance 10, 5, and 1 percent confidence level respectively. The t-test has been performed on the mean difference i.e., control-honeybee pollinated < 0.

The table shows that pollination by honeybees enhanced the proportion of well-formed fruits by 29.38% in 2014 and by 25% in 2015. The p-value is less than 0.01, which suggests that the findings are significant at 99% level of confidence.

Honeybee pollination increased the proportion of well-formed fruits and reduced the proportion of asymmetrical fruits in all study sites. Site-specific data on the impact of honeybee pollination on fruit weight has been presented in Annex 3 (iii).

Although fertilization of the ovule is not necessary for fruit development in apple, for large, perfectly shaped fruit, it is important that a large number of ovules are fertilized (McGregor, 1976; Free, 1993). Inadequate pollination leads to fertilization of fewer ovules and results in lop-sided fruits with fewer seeds. The increased proportion of well-formed symmetrical fruits in honeybee-pollinated orchards was due to adequate pollination of flowers as a result of increased number of pollinators. On the other hand increased proportion of lop-sided fruits in control orchards was due to inadequate pollination of flowers owing to insufficient pollinators. Similar findings on the impact of honeybee pollination on fruit shape have been reported by Bhagat and Mattu (2015) in Kullu valley and by Mattu and Raj (2013) in Shimla hills of Himachal Pradesh, India.

Improvement in fruit colour and brightness

The data on the impact of honeybee pollination on fruit colour in 2014 and 2015 is presented in Table 13. The table shows that in 2014, a large proportion (over 90%) of fruits in honeybee-pollinated orchards were uniform and bright coloured, while a small proportion (less than one-tenth) was dull looking. In contrast, in control orchards a little more than 80% of the fruits were bright coloured and nearly one-fifth were dull. This shows that honeybee pollination increased the proportion of bright coloured fruit by10%. The results are statistically significant at 99% confidence level.

In 2015 the percentage of bright coloured fruits was 90% in honeybee-pollinated orchards whereas in control orchards a little over three-quarters of the fruit were of bright colour. The data shows that honeybee pollination increased the proportion of bright coloured fruit by 17.5%. The differences were significant at 99% level of confidence as the p value is less than 0.01.

Honeybee pollination increased the proportion of bright, uniform coloured fruits and reduced the proportion of dull looking fruits in apples in all study sites. Site-specific data on the impact of honeybee pollination on fruit colour has been presented in Annex 3 (iv).

The findings of the study suggest that honeybee pollination improved the shape and colour of the fruit, resulting in bright and uniform coloured and well-formed fruits. Our findings corroborate the earlier findings of Mattu and Raj (2013) and Bhagat and Mattu (2015), who reported that bee pollination also enhanced fruit quality by enhancing fruit weight, length, breadth, and volume and number of seed per fruit.

The findings are also consistent with the studies by Murneek & Scohwengerdt (1935), Kozin (1972), Childers (1976), Dulta & Verma (1986). These researchers have observed a positive relation between honeybee pollination and the quality of apple crop, i.e., weight, colour and shape. Moreover, Sihag (1997) and Rana et al. (2010) also reported a similar impact on fruit quality and yield in different crops.

Table 13: **Impact of honeybee pollination on fruit colour and brightness**

Year	Bright vs dull (in parentheses) fruits (%)		Increase in the proportion of bright and uniform coloured fruit due to honeybee pollination (%)	Values of 't' and degrees of freedom	Level of significance Pr (T<t)
	Honeybee pollinated orchards	Control orchards			
2014	91.8 (8.2)	82.4 (17.6)	10.2	t= -2.31; df=22	0.004***
2015	94.8 (6.0)	77.5 (22.5)	17.5	t= -9.38; df=25	0.000***

The results of the independent sample t-test of control and honeybee-pollinated orchards to check the mean difference. *, **, and *** denote significance 10, 5, and 1 percent confidence level respectively. The t-test has been performed on the mean difference i.e., Control-honeybee pollinated < 0.

Garrett et al. (2014) made similar findings about the impact of insect pollination on fruit quality in apple in the United Kingdom. They reported that insect pollination not only affects the quantity of production but can also have marked impacts on the quality of apples, influencing their size and shape and affecting their classification for the market. Their research further shows that continued pollinator decline could have serious financial implications for the apple industry. However, Partap and Partap (2002) and Partap et al (2001) have reported – in the context of apple farming areas of the Hindu Kush Himalaya – that there is considerable scope for improving the quality of production through the management of wild pollinators or using managed pollinator augmentation.

Conclusions and Recommendations

Pollination is an essential ecosystem service and can become a limiting factor in crop productivity. Insects including honeybees play a crucial role in fruit crop pollination. However, a range of factors such as excessive chemical pesticide application, land use changes resulting in loss of habitat, spread of pathogens, competition from alien species, and climate change have led to an alarming decline in the abundance and diversity of pollinators both globally and in the Hindu Kush Himalaya. There is increasing evidence of global and localised declines in the diversity and abundance of both wild and managed pollinators (Biesmeijer et al., 2006; Potts et al., 2010; Potts, Roberts et al., 2010). This has led to a decline in crop yield and quality, and even total crop failure in crops like apples, almonds, cherries and pears, as several ICIMOD studies have shown (Partap & Partap, 2001; 2002; Partap et al., 2001; Partap & Tang, 2012). In this context the role of domesticated bees – one of the greatest providers of pollination services – has become increasingly important.

The present research was undertaken in Chitral district in the northern part of Pakistan for two consecutive years i.e., 2014 and 2015. The purpose of the research is to raise awareness among apple growers and other farmers about the importance of pollination services provided by honeybees (beekeeping) for apple production. A total of 24 apple growers in the year 2014 and 27 apple growers in 2015 were engaged in this action research. The research was carried out in collaboration with the KP Agriculture University, government departments of agriculture and horticulture, Chitral Beekeepers Association, as well as the action research farmers and AKRSP-Chitral during the design, implementation and monitoring phases. The findings of this action research have generated evidence that honeybee is a significant ecosystem service provider with respect to pollination service, which demands payment for the service.

The key findings of this study include a decrease in premature fruit drop, increase in yield, and improvement in fruit quality (shape, colour and weight) as a result of pollination of apple flowers by honeybees. For example, in control apple orchards (orchards without bees), fruit set was 44% less than in honeybee-pollinated apple orchards (orchards where honeybee colonies were placed). Findings also suggest a 22% decrease in premature fruit drop in honeybee-pollinated orchards compared to control apple orchards. The apple yield in honeybee-pollinated apple orchards was 41.9% higher than the apple yield in control apple orchards.

Use of honeybees for pollination has also shown a positive impact on the quality of apple, i.e., weight, shape and color. The average weight of 100 randomly selected fruits (apples) from honeybee-pollinated apple orchards was 19.3 kg, while in control apple orchards the average weight of apple was 15.9 kg. This means that as a result of honeybee pollination services, the weight of apple increased by 21.4%. Similarly, the average number of well-formed fruit in honeybee-pollinated apple orchards is 21.1% higher than in control apple orchards. Finally, the average number of bright coloured apples in honeybee-pollinated orchards is 10.2% higher than in control orchards. The action research repeated in 2015 also yielded similar results.

It has been shown empirically that insect/honeybee pollination is essential to apple production in Pakistan, both in terms of yield and quality. But growers need to understand the true value of this service before they can make economically justifiable management decisions to arrest potential pollinator declines and also to manage pollination services to increase the production above current levels.

The results of this research clearly indicate that insect/honeybee pollination service should be treated as one of the many ecosystem and agronomic inputs necessary for a grower. Therefore, pollination needs to be integrated into the whole production and marketing system. The methodologies used in the study incorporated quality parameters into the valuation of pollination services to understand the importance of pollination service of honeybees in agricultural and horticultural production. Information generated can underpin farm management and policy decisions focused on promoting insect pollination services. This can help maintain and improve crop production in the face of ongoing environmental change. Understanding the multiple benefits of an ecosystem service such as pollination is critical for ensuring food security and nutritional security, as it is not only the yield but also the quality and value of produce which are important.

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Annex 1: Number of Insects of Different Species that Visited Apple Orchards/5 min in Different Research Sites during Different Hours of the Day

Booni

Insect visitors	Number of pollinating insects/ flowering branch/ 5 min											
	Year 2014						Year 2015					
	Honeybee-pollinated orchards			Control orchards			Honeybee-pollinated orchards			Control orchards		
	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30
Apis cerana	1.68	2.31	2.41	0.33	0.24	0.22	3.21	3.31	3.47	0.69	0.56	0.66
Apis mellifera	6.85	8.72	7.29	2.31	2.55	2.75	3.57	3.73	3.56	1.46	1.50	1.39
Butterflies	0.69	0.30	0.39	0.90	0.16	0.16	0.69	0.73	0.72	0.27	0.28	0.30
Other	1.60	1.69	1.25	2.13	2.79	2.73	2.91	2.95	2.84	0.51	0.30	0.29

Awi/Parwak

Insect visitors	Number of pollinating insects/ flowering branch/ 5 min											
	Year 2014						Year 2015					
	Honeybee-pollinated orchards			Control orchards			Honeybee-pollinated orchards			Control orchards		
	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30
Apis cerana	1.06	0.97	0.89	0.76	0.96	0.97	0.97	0.79	1.00	1.49	1.19	0.73
Apis mellifera	3.62	3.41	3.29	0.01	0.01	0.04	5.12	5.32	4.44	3.46	3.76	3.05
Butterflies	0.67	0.52	0.56	1.15	1.12	1.09	0.00	0.01	0.00	0.01	0.01	0.01
Other	2.66	2.54	2.59	0.96	1.03	1.09	1.23	0.98	1.12	4.76	4.46	3.53

Mastuj

Insect visitors	Number of pollinating insects/ flowering branch/ 5 min											
	Year 2014						Year 2015					
	Honeybee-pollinated orchards			Control orchards			Honeybee-pollinated orchards			Control orchards		
	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30
Apis cerana	1.57	1.60	1.70	0.65	0.65	0.55	0.81	1.13	0.56	1.40	1.50	1.39
Apis mellifera	5.19	5.03	4.81	1.14	1.14	1.26	26.87	41.65	32.09	0.55	0.69	0.59
Butterflies	1.50	1.40	1.62	0.64	0.80	0.98	0.07	0.03	0.05	0.55	0.75	0.42
Other	2.34	2.27	2.20	7.27	7.85	10.08	3.92	4.25	2.52	3.99	4.44	4.61

Warijun/Kosht

Insect visitors	Number of pollinating insects/ flowering branch/ 5 min											
	Year 2014						Year 2015					
	Honeybee-pollinated orchards			Control orchards			Honeybee-pollinated orchards			Control orchards		
	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 -10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30
Apis cerana	1.71	1.50	1.85	0.62	0.54	0.43	4.55	7.47	7.77	0.50	0.49	0.32
Apis mellifera	3.75	2.40	3.85	1.93	1.66	1.22	2.95	4.35	3.94	1.86	1.96	1.43
Butterflies	0.13	0.14	0.15	1.03	1.57	0.12	0.05	0.08	0.12	0.04	0.04	0.03
Other	2.11	2.37	2.89	1.02	1.21	1.00	1.31	1.86	1.83	0.84	1.22	1.02

Rayeen/Shagram/Istaru

Insect visitors	Number of pollinating insects/ flowering branch/ 5 min											
	Year 2014						Year 2015					
	Honeybee-pollinated orchards			Control orchards			Honeybee-pollinated orchards			Control orchards		
	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30
Apis cerana	2.05	1.70	1.55	1.22	1.05	0.80	9.39	10.44	8.10	0.70	1.26	1.05
Apis mellifera	1.90	2.33	1.60	0.58	0.51	0.45	9.95	11.07	8.82	0.67	0.91	0.89
Butterflies	0.27	0.28	0.23	0.74	0.68	0.62	1.99	1.77	1.42	0.38	0.49	0.36
Other	1.61	1.60	1.32	2.45	2.37	2.73	4.22	4.08	3.72	0.81	0.76	0.72

Brep

Insect visitors	Number of pollinating insects/flowering branch/5 min											
	Year 2014						Year 2015					
	Honeybee-pollinated orchards			Control orchards			Honeybee-pollinated orchards			Control orchards		
	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30
Apis cerana	0.11	0.15	0.13	0.56	0.71	0.77	0.65	0.15	0.68	0.13	0.13	0.11
Apis mellifera	1.15	1.11	1.00	1.82	1.64	1.31	0.96	1.11	0.82	1.01	0.79	0.77
Butterflies	0.20	0.19	0.16	1.03	0.87	1.11	0.64	0.19	0.73	0.13	0.14	0.15
Other	0.43	0.38	0.47	5.20	4.38	2.66	1.88	0.38	1.83	0.27	0.25	0.27

Annex 2: Number of Flowers Visited by Different Insects per Minute in Different Research Sites during Different Hours of the Day

Booni

Insect visitors	Number of flowers visited (pollinated)/ branch/ insect/ min											
	Year 2014						Year 2015					
	Honeybee-pollinated orchards			Control orchards			Honeybee-pollinated orchards			Control orchards		
	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30
Apis cerana	6.04	7.13	7.53	2.76	2.79	2.88	5.20	3.78	4.46	5.93	4.73	3.97
Apis mellifera	7.40	8.57	8.17	0.00	0.23	0.07	9.21	11.21	9.45	6.08	7.11	6.85
Butterflies	4.11	4.01	3.77	4.11	3.04	3.13	2.28	2.01	2.01	2.01	2.01	2.03
Other	7.49	9.41	8.84	2.96	2.97	2.05	2.28	2.01	2.01	2.01	2.01	2.03

Awi/Parwak

Insect visitors	Number of flowers visited (pollinated)/ branch/ insect/ min											
	Year 2014						Year 2015					
	Honeybee-pollinated orchards			Control orchards			Honeybee-pollinated orchards			Control orchards		
	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30
Apis cerana	5.70	6.83	5.95	2.73	2.54	2.55	7.61	3.58	3.64	4.72	4.54	4.39
Apis mellifera	14.79	16.43	13.35	6.32	6.48	7.69	6.07	1.54	1.58	3.88	3.41	3.35
Butterflies	2.27	2.47	2.33	2.62	2.35	2.40	2.40	3.09	3.34	2.45	2.37	2.43
Other	4.00	4.02	3.89	6.99	7.83	8.02	3.40	3.09	3.34	2.45	2.37	2.43

Mastuj

Insect visitors	Number of flowers visited (pollinated)/ branch/ insect/ min											
	Year 2014						Year 2015					
	Honeybee-pollinated orchards			Control orchards			Honeybee-pollinated orchards			Control orchards		
	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30
Apis cerana	5.00	5.07	5.60	3.64	3.92	3.79	2.76	3.15	2.53	4.49	5.25	4.91
Apis mellifera	7.95	7.38	7.64	2.89	2.86	3.36	26.05	41.75	32.71	1.20	1.67	1.43
Butterflies	4.68	4.67	5.30	3.50	3.63	4.21	2.07	2.01	2.04	3.30	3.29	2.96
Other	6.27	6.05	6.32	8.95	10.19	10.80	2.07	2.01	2.04	3.30	3.29	2.96

Warijun/Kosht

Insect visitors	Number of flowers visited (pollinated)/ branch/ insect/ min											
	Year 2014						Year 2015					
	Honeybee-pollinated orchards			Control orchards			Honeybee-pollinated orchards			Control orchards		
	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30
Apis cerana	3.54	3.01	4.19	2.56	2.61	2.53	11.95	19.20	19.80	2.46	2.46	2.33
Apis mellifera	3.62	2.44	3.17	1.98	1.27	1.50	4.80	6.65	5.54	2.02	1.97	1.50
Butterflies	2.13	2.23	2.67	2.80	2.09	2.22	2.05	2.09	2.17	2.07	2.04	2.02

Other	4.91	4.21	4.62	2.80	2.19	2.42	2.05	2.09	2.17	2.07	2.04	2.02

Rayeen/Shagram/Istaru

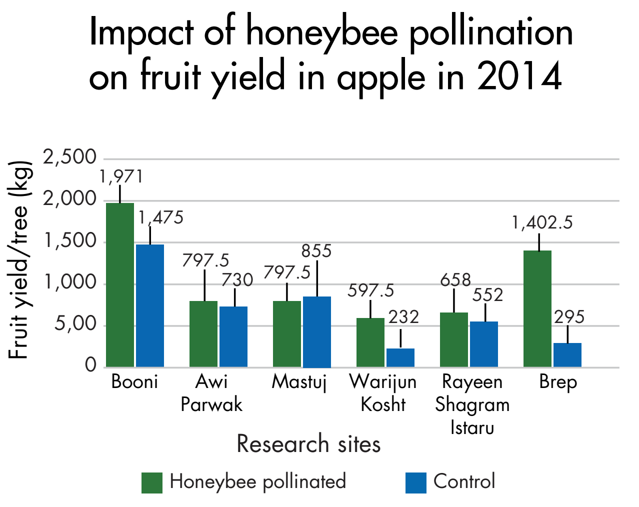
Insect visitors	Number of flowers visited (pollinated)/branch/insect/min											
	Year 2014						Year 2015					
	Honeybee-pollinated orchards			Control orchards			Honeybee-pollinated orchards			Control orchards		
	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30
Apis cerana	5.79	6.02	3.77	4.01	4.07	3.67	13.86	14.62	13.98	2.80	3.26	3.12
Apis mellifera	3.68	4.69	2.48	0.87	0.81	0.68	13.03	14.50	12.13	0.75	0.97	0.87
Butterflies	2.43	2.47	2.65	3.05	2.95	3.01	5.16	4.92	5.17	2.39	2.53	2.39
Other	4.45	5.36	3.54	6.44	6.00	6.68	5.16	4.92	5.17	2.39	2.53	2.39

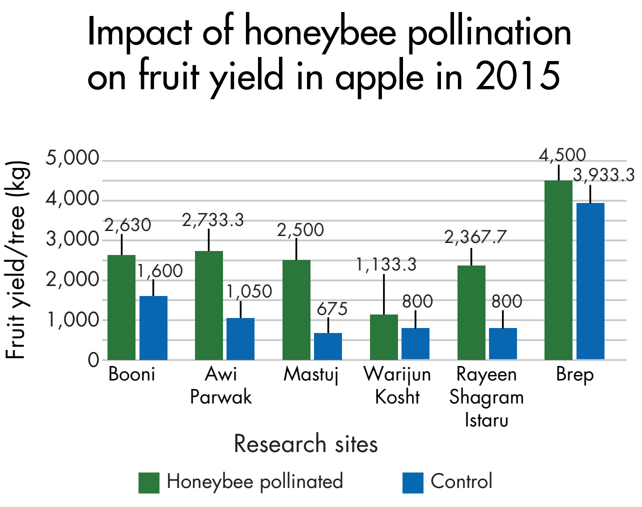
Brep

Insect visitors	Number of flowers visited (pollinated)/branch/insect/min											
	Year 2014						Year 2015					
	Honeybee-pollinated orchards			Control orchards			Honeybee-pollinated orchards			Control orchards		
	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30	09:00 - 10:30	12:00 - 13:30	15:00 - 16:30
Apis cerana	2.14	2.07	2.15	2.54	2.69	2.83	3.82	3.58	3.64	2.35	2.29	2.26
Apis mellifera	0.83	0.94	0.87	1.26	1.86	1.75	1.60	1.54	1.58	1.93	2.05	1.92
Butterflies	2.21	2.29	2.18	3.02	3.01	2.87	3.07	3.09	3.34	2.32	2.31	2.35
Other	2.48	2.49	2.36	4.51	7.01	6.27	3.07	3.09	3.34	2.32	2.31	2.35

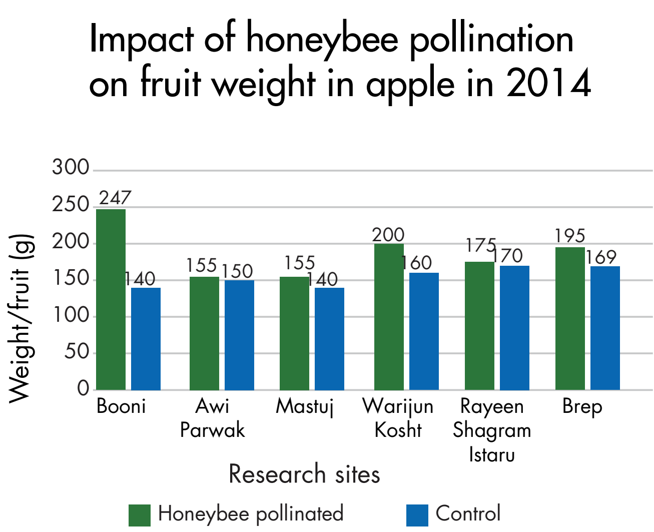
Annex 3: **Impact of Honeybee Pollination on Fruit Yield and Quality**

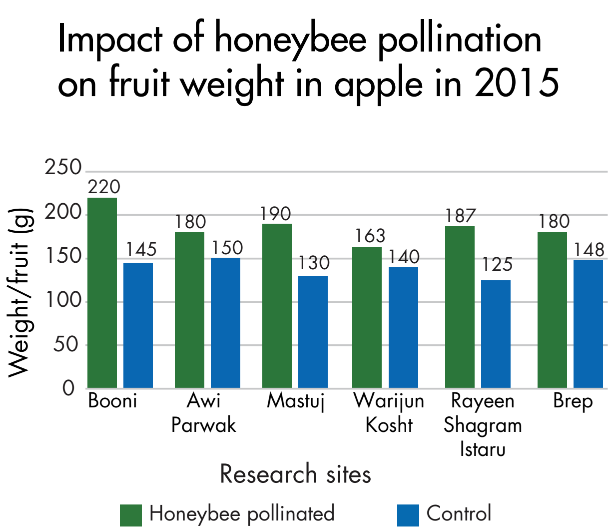
i. Fruit yield



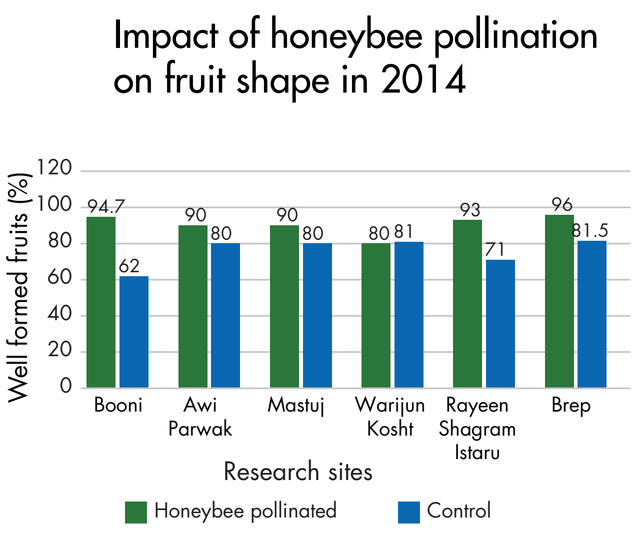


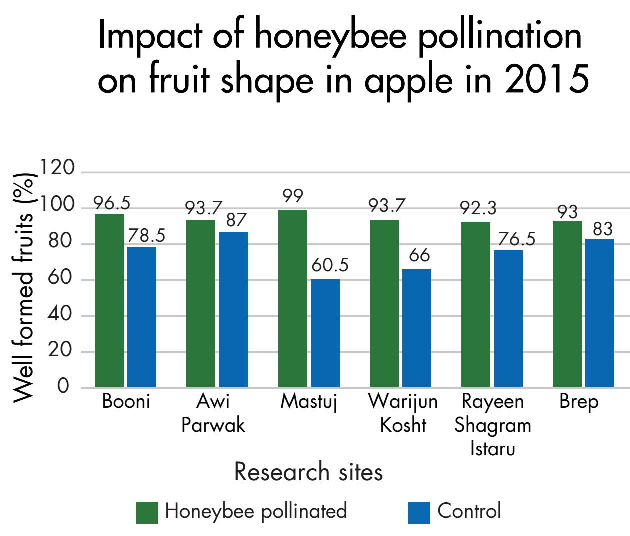
ii. Fruit weight



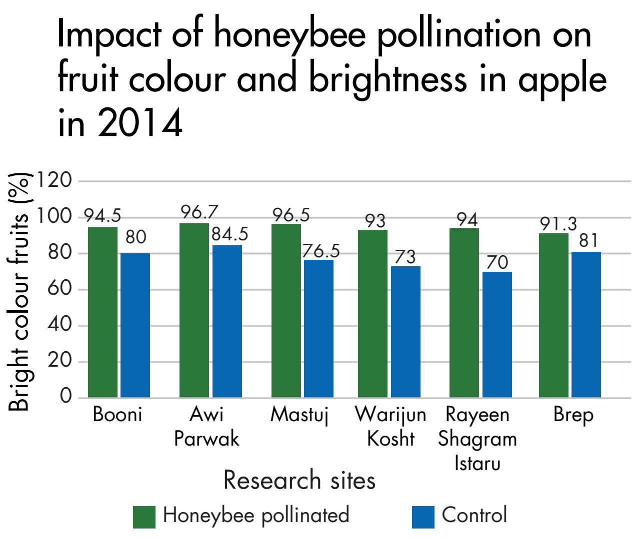


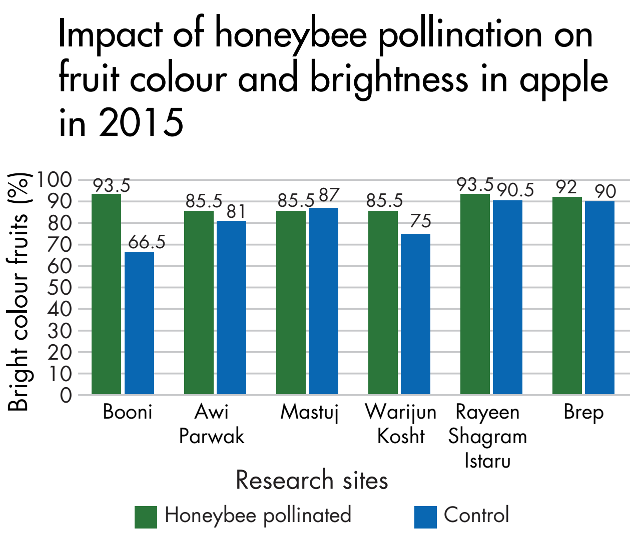
iii. Fruit shape





iv. Fruit colour and brightness





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