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The Asian Hive Bee, *Apis cerana*, as a Pollinator in Vegetable Seed Production

(An Awareness Handbook)

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Cover photograph: Beehives among mustard flowers in bloom

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Foreword

The Asian hive bee, *Apis cerana* F, is widely distributed throughout the Hindu Kush-Himalayan range. Beekeeping with this native bee species has been an important part of natural and cultural heritage amongst the mountain communities as a traditional household activity. Hive products, such as honey, beeswax, and pollen, provide both nutritious food and cash income. Yet another significant, but not widely recognised, role is that honeybees help to increase productivity levels and the quality of agricultural, horticultural, and fodder crops through cross-pollination activities. However, this aspect has not yet been developed on the modern scientific lines that are followed in the developed countries of the West where the European hive bee, *Apis mellifera*, is extensively used for the pollination of agricultural crops. For example, the value of bee pollination in crop production in the USA has been estimated at more than 20 billion U.S. dollars per annum and one third of the food consumed in the world is produced by insect-pollinated plants.

Keeping in mind the above, ICIMOD has identified the beekeeping and pollination research and development programme as one of the essential components of mountain farming systems. Within this context, ICIMOD earlier published two books, "Beekeeping in Integrated Mountain Development" and "Honeybees in Mountain Agriculture". These books focussed on government strategies and interventions, research and development efforts, farmers' strategies and responses, and replicable experiences for the development of beekeeping in the Hindu Kush-Himalayan Region. The present handbook follows on directly from the success of these earlier publications which identified the urgent need for practical information on bee-pollination methods, especially through the native *Apis cerana*, for increasing the yield and quality of vegetable seed production in the Kathmandu Valley of Nepal. The present awareness handbook is in response to the need to provide a much needed guide for those involved in the scientific and practical aspects of bee pollination, including extension workers, beekeepers, growers, pesticide applicators, consultants, environmentalists, and others.

This handbook describes the general scientific principles involved in using the native hive bee, *Apis cerana*, for pollination purposes and documents the results of scientific research carried out at ICIMOD and elsewhere on this important aspect. It also discusses the comparative role of the native hive bee, *Apis cerana*, and the exotic hive bee, *Apis mellifera*, as pollinators of vegetable crops under the ecological conditions of the Kathmandu Valley and offers a positive set of solutions to the problems of protecting honeybees from pesticides.

The excellence of this report is due to the painstaking efforts of Professor L.R. Verma, the Apicultural Expert at ICIMOD, who was ably assisted by his project staff, especially by Dr. Uma Partap, the co-author.

E.F. Tacke
Director General
ICIMOD

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Chapter 1

Bee Pollination and Crop Productivity

Introduction

The sustainable development of agriculture in the 21st century will necessitate a reorientation of the present crop production technologies. Instead of making extensive use of chemical fertilisers, biocides, irrigation facilities, and heavy machinery for yield enhancement, a shift towards biologically-based agriculture, which includes increased photosynthetic efficiency, biological nitrogen fixation, efficient nutrient uptake and biological cross-pollination, will become necessary to increase food productivity. In future, the full use of such underutilised resources, which are environmentally more friendly, should be emphasised. For example, the yields of different cultivated crops could be increased through cross-pollination by honeybees.

The vital role that honeybees play in enhancing the productivity levels of different crops, such as fruits, nuts, vegetables, pulses, oils, and forage crops, has often been underestimated, especially in developing countries all over the world. Most of the research work on crop pollination has been carried out in developed countries where the European honeybee, *Apis mellifera*, has been used extensively to increase the yield of different cultivated crops. The non-consumptive benefits of increasing crop yields through cross-pollination by honeybees are difficult to quantify, yet these far outweigh the direct benefits of these social insects as producers of honey and other hive products. The value of bee pollination in crop production in the U.S. dollars has been estimated at 20 billion US dollars per year (USDA-ARS 1991). A recent FAO report indicated that the direct contribution of pollination to increase in farm harvests in 20 mediterranean countries was 5.2 billion US dollars per year; 3.2 billion in developing countries in the region, and two billion in the others (Cadoret 1992). These estimates suggest that there is a need to create awareness amongst policy-makers, planners, aid agencies, researchers, and extension workers about promoting bees and beekeeping as an important component of present day strategies for sustainable agriculture and integrated rural development programmes.

Pollination Mechanisms

Pollination is the transfer of pollen grains from the anther (male part of the flower) to the stigma (the female part) of the same or another flower of the same plant species. This is the first step towards fertilisation which is the union of the male nucleus of germinated pollen grains with the female nucleus (oosphere) of the egg or ovule. The ovule, after fertilisation, develops into the seed.

A plant is considered to be self-pollinated/self-fertile when its flower is pollinated by its own pollen. In this case, pollen grains from the anthers fall on the stigma of the same flower. Some self-fertile species are automatically pollinated by pollen from their own flowers but often the construction of the flowers is such that wind or insects are needed to transfer pollen from the anthers of the flowers to their stigmas.

However, in many other plants, the flower cannot be fertilised with pollen from the same plant (self-sterile) but needs pollen from another plant of the same species for fertilisation. This phenomenon is known as cross-pollination (Fig. 1.1).

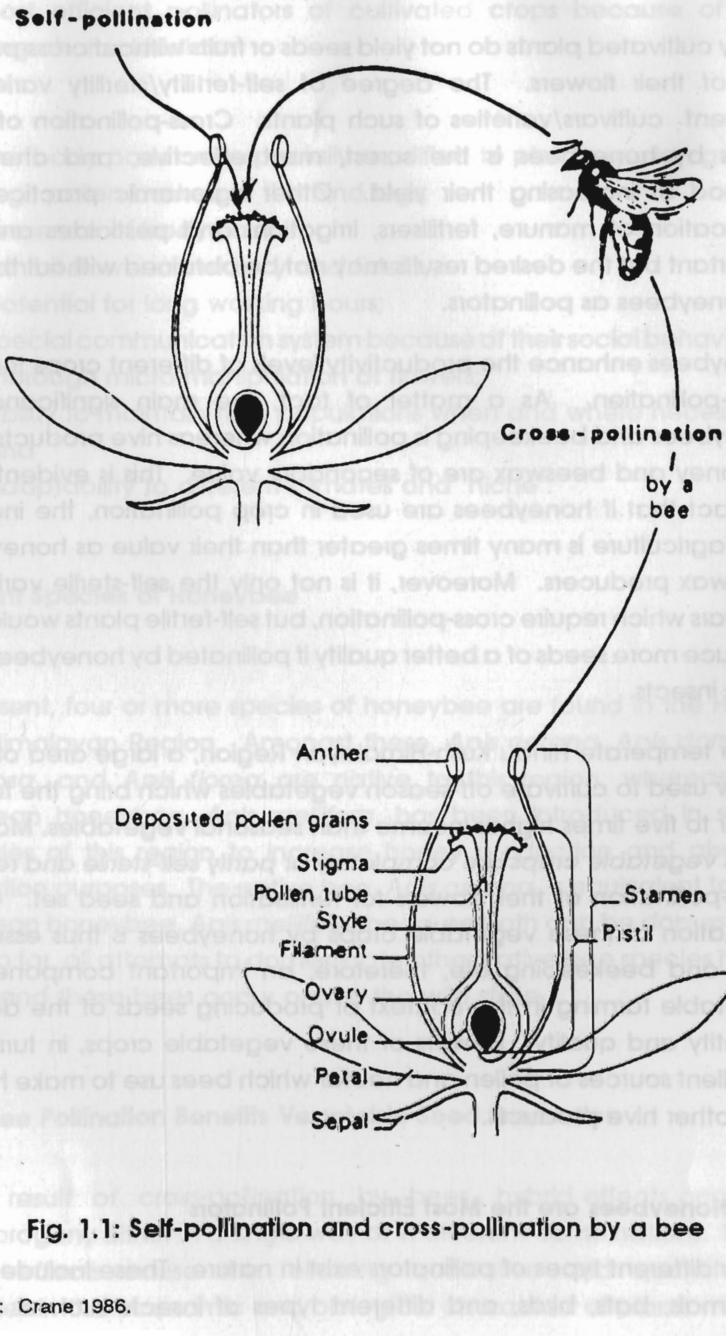

Fig. 1.1: Self-pollination and cross-pollination by a bee

Source: Crane 1986.

Honeybees as Pollinators

Many cultivated plants do not yield seeds or fruits without cross-pollination of their flowers. The degree of self-fertility/sterility varies in different cultivars/varieties of such plants. Cross-pollination of such crops by honeybees is the surest, most effective, and cheapest method of increasing their yield. Other agronomic practices like application of manure, fertilisers, irrigation, and pesticides are also important but the desired results may not be obtained without the use of honeybees as pollinators.

Honeybees enhance the productivity levels of different crops through cross-pollination. As a matter of fact, the main significance of honeybees and beekeeping is pollination whereas hive products such as honey and beeswax are of secondary value. This is evident from the fact that if honeybees are used in crop pollination, the income from agriculture is many times greater than their value as honey and beeswax producers. Moreover, it is not only the self-sterile varieties/cultivars which require cross-pollination, but self-fertile plants would also produce more seeds of a better quality if pollinated by honeybees and other insects.

In the temperate Hindu Kush-Himalayan Region, a large area of land is now used to cultivate off-season vegetables which bring the farmer a four to five times higher income than seasonal vegetables. Many of these vegetable crops are completely or partly self-sterile and require cross-pollination of their flowers for fertilisation and seed set. Cross-pollination of these vegetable crops by honeybees is thus essential. Bees and beekeeping are, therefore, an important component of vegetable farming in the context of producing seeds of the desired quantity and quality. Flowers of these vegetable crops, in turn, are excellent sources of pollen and nectar which bees use to make honey and other hive products.

Why Honeybees are the Most Efficient Pollinators

Many different types of pollinators exist in nature. These include small mammals, bats, birds, and different types of insects such as bees, wasps, flies, butterflies, moths, and beetles, out of which honeybees are the most efficient pollinators of cultivated crops because of the following characteristics:

- the body parts are especially modified to pick up pollen grains, e.g., pollen baskets in the hind legs;
- presence of body hairs;
- exhibit flower constancy and fidelity;
- potential for long working hours;
- special communication system because of their social behaviour;
- thorough micro-manipulation of flowers;
- ability to maintain high populations when and where necessary; and
- adaptability to different climates and 'niche'.

Different Species of Honeybee

At present, four or more species of honeybee are found in the Hindu Kush-Himalayan Region. Amongst these, *Apis cerana*, *Apis dorsata/laboriosa*, and *Apis florea* are native to this region, whereas the European honeybee, *Apis mellifera*, has been introduced in some countries of this region to increase honey production and also for pollination purposes. The native bee, *Apis cerana*, is equivalent to the European honeybee, *Apis mellifera*, because both can be domesticated. So far, all attempts to domesticate other native bee species have failed and these bees occur only in the wild state.

How Bee Pollination Benefits Vegetable Seed Production

As a result of cross-pollination by bees, hybrid effects occur in plant progeny either in a single way or in different combinations. Such hybrid effects cause the following qualitative and quantitative changes in the economic and biological characters of plants:

- stimulate the germination of pollen grains on the stigma and improve selectivity in fertilisation;
- increase the viability of seeds and embryos;
- increase the number and size of seeds;
- enhance resistance to diseases and other adverse environmental conditions;
- increase nectar production in the nectaries of plants; and
- ensure well-filled seeds, tight clusters, and uniform seed set.

Managing Honeybee Colonies for Pollination

The efficiency of a bee colony as a pollinator of a vegetable seed crop depends upon a number of factors.

Colony Strength

Larger and stronger colonies are four to five times better pollinators than smaller and weaker ones because the former have a higher percentage of older bees as foragers. Thus, good honey-yielding colonies are better and more efficient pollinators also. It has been estimated that one colony of *Apis mellifera*, with 60,000 worker bees, produces one-and-a-half times more honey than four colonies with 15,000 bees each. The same can be true for pollination activity also.

The strength of a colony depends upon the season. In the Hindu Kush-Himalayan countries, during winter the colony strengths are poor because of low temperatures and a dearth of bee flora. In the early spring season, when honeybee colonies are required for the cross-pollination of vegetable crops in this region, these colonies do not possess enough strength for effective pollination.

Keeping in mind this constraint, farmers in certain regions migrate their colonies to lower altitudes where the winters are warmer and where there is no dearth of bee flora, so that, in spring, when vegetable crops are in bloom, an adequate number of bees is available for effective pollination.

Number of Colonies Required for Pollination

The number of colonies required for pollination of different cultivated crops would depend upon the following factors:

- density of plant stand;
- total number of flowers in each plant;
- duration of flowering;
- strength of bee colonies; and
- number of flowers per hectare of land.

In general, two colonies of *Apis mellifera* per hectare of crops in bloom are recommended for sufficient and efficient pollination. Considering the smaller colony size of the *Apis cerana* colony, and also its shorter flight range, four to five colonies per hectare are recommended.

Distribution of Colonies in the Fields

Honeybees as a rule visit primarily those sources of nectar flow which are within a radius of 0.3 to 0.5km from the apiary. At a distance of more than 0.5km, the pollination activity decreases significantly.

In the Hindu Kush-Himalayan countries, because of the small size of farm holdings, and also due to the practice of mixed cropping, spacing of the colonies and their optimum arrangement do not pose a serious problem as in developed countries where monoculture is a common practice in farming systems.

For effective pollination, *Apis cerana* hives should be placed singly instead of in groups. Honeybees always tend to forage in the area which is closest to their hive, particularly when the weather is not very favourable.

The Appropriate Time for Placement of Colonies

Bee colonies should be placed in the field when five to 10 per cent of the crop is in bloom. Earlier placement of colonies results in the bees foraging on other weeds and wild plants in the vicinity and later the bees ignore the crop in bloom. If the bees are moved in too late, they can only pollinate the late and less vigorous flowers.

Weather Conditions

Weather plays an important role in determining the success or failure of a pollination programme, as it affects both bee activities as well as seed/fruit setting. For example, in the temperate climate of the Hindu Kush-Himalaya, some vegetable crops bloom in early spring when the temperature is low. Flower buds may die due to frost injury. Weather also adversely affects the foraging activities of bees. Wind velocity of 15 miles per hour or more also adversely affects the foraging behaviour of bees. It is, therefore, recommended that a wind break should be constructed around the crop field.

Attracting Bees to a Crop in Bloom

A crop that requires cross-pollination can be made more attractive to honeybees if nectar production in the nectaries is increased by breeding techniques or by improving other agronomic practices such as application of fertilisers and manure, and by providing better irrigation facilities. Another method of attracting bees to a particular crop in bloom is by sowing high nectar-yielding crops amongst the other crops which secrete low amounts of nectar. For example, sweet clover requires cross-pollination by bees for good seed yield. But this crop is not very attractive to bees due to poor or very low quantities of nectar in the nectaries of this plant. However, if other nectariferous plants, such as buckwheat, are sown, a larger number of bees would be attracted to this crop.

Isolation Distance In Relation to Pure Vegetable Seed Production

It is now well-known that cross-pollination by honeybees helps to increase the yield and quality of vegetable seeds. This activity of honeybees also hampers pure seed production in such crops due to intercrossing. This problem can be solved by providing the necessary isolation distance between different cultivars of the same crop in order to avoid crossing and contamination. The foraging areas where the adult worker bees forage are always limited, and they confine their foraging activities to a particular area only during their successive field trips to collect pollen, nectar, or both. If fields with compatible varieties/cultivars are adjacent, there are more chances of intercrossing or contamination. However, in distant fields with compatible varieties or cultivars, the foraging areas of bees will not overlap, and pure seed production is possible. The actual isolation distance would depend upon the degree of seed purity required, i.e., whether the seed is being produced as foundation seed or certified seed by the grower. The actual distances required for different vegetable crops to produce pure seeds are given in Table 1.1.

In Britain, the isolation distance required varies from 193 to 214m for different crops. In Canada, isolation distances for certified, registered, and foundation seeds are 46m, 91m, and 183m respectively. However, these data have been collected from experiments carried out in western countries, and related information on this issue collected under the local ecological conditions of the Hindu Kush-Himalayas is unavailable.

Beekeeping Demonstration to Potential Beekeepers

Table 1.1: Pollination Requirements and Mechanisms for Main Vegetable Crops

Crop	% of cross-pollination	Total blooming period	Peak receptivity period of stigma to pollen	Nectar or pollen potentials	Chief pollinators	Honeybee pollination requirements (number of hives per hectare)	% increase in yield due to honeybee pollination over self-pollination	Isolation distance required for pure seed production (in metres)
Cole Crops: Cauliflower, Cabbage	72-95	1 month	3-4 days	N^2P^3	Honeybees, bumblebees, wildbees, flies	5	100-300	3000 for breeder seeds and 1500 for certified seeds
Tomato	Less than 2	12-15 days	4-8 days	N^2P^3	Solitary bees, thrips, honeybees	No specific recommendation	No specific data	250-400
Chillies: Green Pepper, Chilli Pepper	7-36	2-3 weeks	2 days	N^3P^3	Honeybees, ants	No specific recommendation	No specific data	200 for foundation seeds and 100 for certified seeds
Radish	85	22-30 days	3-4 days	N^3P^3	Honeybees only	5	22-100	1600 for foundation seeds and 1000 for certified seeds
Carrot	Mainly cross pollinated	1 month	One week or longer	N^3P^3	Honeybees, house flies	8 bees per square metre	9-135	1000
Turnip	Mainly cross pollinated	1 month	2-3 days	N^2P^2	Honeybees	2-5	100-125	1600 for foundation seeds and 1000 for certified seeds
Cucurbits	60-80	1 month	2 hours	N^2P^2	Honeybees *Halictus*	2-4	21-6700	800-1000
Okra	4-42	22-30 days	2 days	N^3P^3	Honeybees, bumblebees	None	No specific data	No specific recommendations

Source: Compiled by author from different sources.

N^1 = Major source of nectar P^1 = Major source of pollen
N^2 = Medium source of nectar P^2 = Medium source of pollen

Chapter 2

The Asian Hive Bee, *Apis cerana*, as a Pollinator of Vegetable Crops

Vegetable seed production offers an opportunity for the commercialisation of agriculture. Sufficient or adequate pollination of vegetable crops is essential for the production of good quality seeds. Many of these vegetable crops are completely or partially self-incompatible and incapable of pollinating themselves, therefore, the cross-pollination of their flowers by insects, especially honeybees, is essential.

Under the USAID/ADB-funded beekeeping research and development programme at ICIMOD, detailed investigations have been conducted on the use of the native Asian hive bee, *Apis cerana,* to enhance yields and improve the seed quality of important vegetable crops grown in the Kathmandu Valley. The results of these investigations are summarised below.

Cauliflower

The cauliflower is an important vegetable crop widely grown in temperate and sub-tropical regions. Since most of its cultivars are self-incompatible, cross-pollination of its flowers is essential for seed production. Cross-pollination of the cauliflower is mostly carried out by insect pollinators, especially honeybees which are the most efficient pollinators, because they can be managed in sufficient number and exhibit flower constancy.

Cauliflower

The floral biology of the plant, the foraging behaviour of honeybees in relation to pollination, and the qualitative and quantitative effects of *Apis cerana* pollination on cauliflower seed production have been researched at ICIMOD. For this, cauliflower plants (*Brassica oleracea*, var. *botrytis*, sub-var Kathmandu Local) were raised on experimental plots at the HMG/FAO Vegetable Seed Production Farm, Khumaltar, during August 1991. (See plate above). The plant to plant distance was 50-60cm and the row to row distance was 80-90cm. Three sets of experiments were performed when the cauliflower crop started blooming in the first week of March, 1992 (1) control (no insect pollinators), (2) open-pollinated (only natural insect pollinators), and (3) bee-pollinated.

Data on the floral biology of cauliflower plants are given in Table 2.1. The results suggest that the average number of branches per plant was seven and that each branch contained an average of 600 flowers. The average diameter of each flower was 15mm and the buds were about

Table 2.1: Floral Biology of Cauliflower, Cabbage, Radish, and Lettuce Plants Grown in the Kathmandu Valley, Nepal

Parameter	Cauliflower	Cabbage	Radish	Lettuce
No. of flowers per branch	M 600 RV 500-700	M 94 RV 84-106	M 153 RV 104-201	M 75 RV 15-175
No. of flowers per plant	M 4,000 RV 3,000-5,000	M 1,128 RV 900-1,500	M 1,500 RV 1,000-2,000	M 1,500 RV 1,000-2,300
Time of flower opening	Opens in the morning and remains open for about 2-3 days	Same as in Cauliflower	Same as in Cauliflower	M 0822h RV 0800-0900h
Time of flower closing				M 1,135 RV 1,100-1,200
Diameter of flower/head* (mm)	M 15 RV 12-16	M 14 RV 12-15	M 14 RV 12-16	M 15 RV 12-16
Length of bud (mm)	M 9 RV 8-10	M 8 RV 7-9	M 11 RV 10-12	M 7 RV 6-9
Total flowering period	One month (mid Feb to mid Mar)	One month (mid March to mid April)	One month (1st week of March to the last week)	One month (mid June to mid July)

* In Lettuce small flowers cluster in the form of a head (or capitulum) surrounded by an involucre of bracts. Each head contains 15-25 small flowers (or florets).

M = Mean
RV = Range of variation

9mm long. The flowers opened in the morning and remained open for about two to three days. The total blooming period of the crop lasted for about one month.

Observations on the foraging behaviour of *Apis cerana* on this plant are given in Table 2.2. The results suggest that *Apis cerana* started foraging at 0702 h in the morning and ceased their foraging activity at 1805 hours in the evening. The total duration of foraging activity was

Table 2.2: Foraging Behaviour of *Apis cerana* on Cauliflower, Cabbage, Radish, and Lettuce Plants in Kathmandu Valley, Nepal
(Values are mean ± S.E.)

Parameter	Cauliflower	Cabbage	Radish	Lettuce*
Initiation of foraging (time of day)	0702 ± 0.02	0630 ± 0.02	0640 ± 0.02	0830 ± 0.05
Cessation of foraging (time of day)	1805 ± 0.02	1835 ± 0.03	1830 ± 0.02	1130 ± 0.05
Duration of foraging activity (h)	11.03 ± 0.03	12.05 ± 0.05	11.50 ± 0.04	3.00 ± 0.05
Peak foraging hours (time of day)	1100 - 1300	1100 - 1300	1100 - 1300	0900 - 1100
Duration of foraging trip (min)	26.87 ± 0.81	23.87 ± 0.42	22.13 ± 0.03	15.66 ± 0.04
Time on flower (sec) at 0900 h 1200 h 1500 h	 5.83 ± 0.3 6.69 ± 0.5 5.14 ± 0.2	 4.33 ± 0.21 4.63 ± 0.32 6.90 ± 0.24	 4.34 ± 0.06 5.31 ± 0.03 12.79 ± 0.03	3.84 ± 0.02
Time taken to shift from flower to flower (sec) at 0900 h 1200 h 1500 h	2.51 ± 0.1 3.35 ± 0.3 2.15 ± 0.1	3.33 ± 0.50 3.63 ± 0.30 3.43 ± 0.30	3.08 ± 0.10 2.83 ± 0.30 3.31 ± 0.80	2.69 ± 0.07
Distance covered from flower to flower (cm) at 0900 h 1200 h 1500 h	9.43 ± 2.0 9.25 ± 1.1 9.04 ± 1.5	09.80 ± 2.25 21.83 ± 1.50 22.00 ± 3.02	20.97 ± 1.20 21.56 ± 0.90 20.47 ± 1.90	9.86 ± 2.21
No. of flowers visited per min at 0900 h 1200 h 1500 h	7.0 ± 0.5 6.0 ± 1.0 8.0 ± 0.5	7.00 ± 0.40 7.00 ± 0.50 5.00 ± 0.50	8.00 ± 0.50 9.00 ± 0.40 5.00 ± 0.50	13.00 ± 1.00
Pollen load (mg) at 0900 h 1200 h 1500 h	7.0 ± 0.5 9.0 ± 0.3 5.0 ± 0.5	08.00 ± 0.03 10.00 ± 0.01 08.00 ± 0.49	11.00 ± 0.20 10.00 ± 0.50 7.00 ± 0.50	8.00 ± 0.10
Ratio between pollen collectors and nectar collectors (P:N) at 0900 h 1200 h 1500 h	7:3 5:5 3:7	6:4 5:5 4:6	6:4 5:5 3:7	Bees collect only pollen
Top vs side workers at 0900 h 1200 h 1500 h	6:4 5:5 4:6	9:1 7:3 4:6	9:1 6:4 2:8	No side worker observed
No. of bees per plant at 0900 h 1200 h 1500 h	9 8 4	3 4 3	5 9 4	4
Non-*cerana* pollinators	Insects such as *Eristalis*, stingless bees, butterflies, ladybird beetles, etc.	Insects such as *Eristalis*, stingless bees, butterflies, ladybird beetles, etc.	Insects such as *Eristalis*, stingless bees, butterflies, ladybird beetles, etc.	Insects such as *Eristalis*, stingless bees, butterflies, ladybird beetles, etc.
Pollen+Nectar collectors (P+N) at 0900 h 1200 h 1500 h	nil nil nil	nil nil nil	4% 7% nil	nil

* In lettuce, flowers open in the morning for three to four hours only (i.e., from 0822 h to 1135 h). Observations on foraging behaviour were recorded during these hours only.

11.03 hours and peak foraging activity occurred between 1100-1300 hours (Fig.2.1). The duration of each foraging trip was 26.87 min. Each worker bee spent an average time of five to seven seconds on a flower, visited an average of six to eight flowers per minute, carried an average pollen load of five to eight miligramme per trip, and the number of bees per plant varied from four to nine during different times of the day. An interesting aspect of their behaviour was that, at 0900 hours, pollen collectors outnumbered nectar collectors. This ratio was equal at 1200 hours and at 1500 hours nectar collectors outnumbered pollen collectors. *Apis cerana* collected either pollen or nectar but not both during a single foraging trip.

The qualitative and quantitative effects of honeybee pollination on seed production are given in Table 2.3. These results suggest that bee pollination significantly increased fruit set by 57 and 20 per cent compared to control and open-pollinated plants. Similarly, the number of seeds per siliqua increased by 500 and 33.8 per cent compared to control and open-pollinated plants. *Apis cerana* pollination increased the seed weight increase by 62.9 and 37.4 per cent and enhanced seed germination by 16 and 12 per cent compared to control and open-pollinated plants.

Cabbage

Like cauliflower, many varieties of this crop are self-incompatible and require cross-pollination of their flowers for seed production. In order to study the effects of *Apis cerana* pollination on cabbage seed production, cabbage plants (*Brassica oleracea*, var *capitata*, subvar. Pride of India) were raised on experimental plots in HMG/FAO Vegetable Seed Production Farm, Khumaltar, during the second week of September, 1991, in the same way as the cauliflower plants. (See plate, page 17). The crop started blooming during mid-March 1992 and, at that time, three sets of experiments, similar to those in the case of cauliflower plants, were performed -(1) control, (2) open-pollinated, and (3) bee-pollinated.

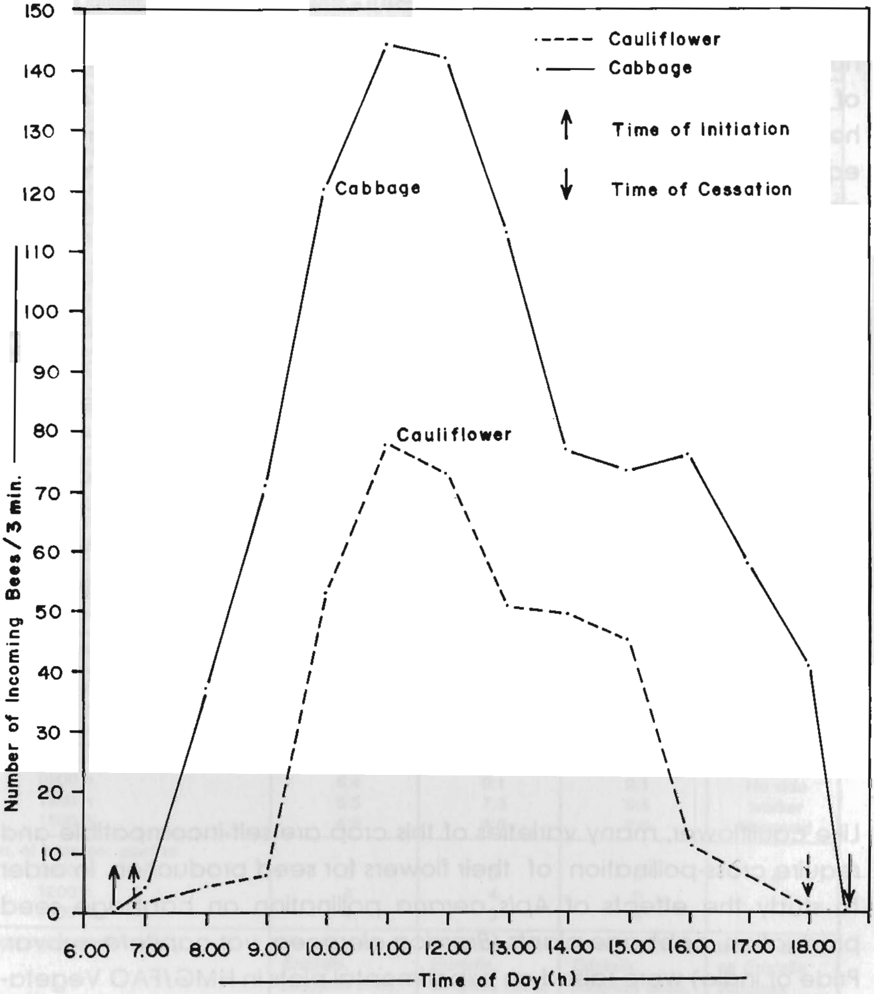

Fig. 2.1: Peak hours of foraging activity (number of incoming bees/3 min.) of *Apis cerana* on cauliflower and cabbage plants in Kathmandu Valley

Cabbage

Table 2.3: Quantitative and Qualitative Effects of *Apis cerana* Pollination on Cauliflower Seeds

(Values are mean ± S.E.)

Parameter	Control	Open-pollinated	Bee-pollinated	Per cent Increase[1]	Per cent Increase[2]
Per cent fruit set	21.0	58.0	78.0	57.0	20.0
No. of seeds per siliqua	3.3 ± 1.4	14.8 ± 0.6	19.8 ± 0.5	500**	33.8**
100 seed weight (mg)	264 ± 7	313 ± 8	430 ± 12	62.9**	37.4**
Per cent germination	80.0	84.0	96.0	16.0	12.0

1. Increase compared to control
2. Increase compared to open-pollinated

** Significant (P = 0.01)

Observations on the floral biology of cabbage plants are recorded in Table 2.1. The results show that each plant had an average of 13 branches and each branch bore an average of 94 flowers. Each flower was 14mm in diameter and its bud was eight milimetres long. Flowers opened in the morning and remained open for about three days like those of cauliflower. The total blooming period of the crop lasted for about a month, i.e., mid-March to mid-April.

Data on foraging behaviour (Table 2.2) suggest that *Apis cerana* worker bees began foraging at 0630 hours in the morning and ceased their foraging activities at 1835 h in the evening; thus the total duration of foraging activity was 12.05 hours. Peak foraging activity was observed between 1000-1300 hours, and the duration of each foraging trip was 23.87 min. Each bee made an average of 10 foraging trips per day (Fig. 2.1).

Apis cerana worker bees either collected pollen or nectar but never both during the same foraging trip. During morning hours (at 0900 hours), pollen collectors outnumbered nectar collectors (P:N=6:4). This ratio was equal at 1200 hours (P:N=5:5) and, at 1500 hours, nectar collectors outnumbered pollen collectors (P:N = 4:6). Each worker bee spent an average of four to seven seconds on a flower and collected eight to 10mg of pollen load during different hours of the day.

The qualitative and quantitative effects of *Apis cerana* pollination (Table 2.4) suggest that bee pollination significantly enhanced the fruit and seed set by 27 and 52.9 per cent respectively compared to open-pollinated plants. Control plants did not set any fruit indicating that the crop is self-incompatible and required cross-pollination. Bee pollination significantly increased the weight of the seeds by 51 per cent and germination by 28 per cent compared to open-pollinated plants. It also decreased the time required for the initiation of germination.

Radish

Radish is also an important vegetable and salad crop. Many varieties of radish are self-incompatible and almost entirely cross-pollinated.

Table 2.4: Quantitative and Qualitative Effects of *Apis cerana* Pollination on Cabbage Seeds

(Values are Mean ± S.E.)

Parameter	Control	Open-pollinated	Bee-pollinated	Per cent Increase
Per cent fruit set	No Fruit Set	52.0	79.0	27.0
No. of seeds per siliqua	-	18.5 ± 0.1	28.3 ± 0.7	52.9**
100 seed weight (mg)	-	278.0 ± 4.0	420.0 ± 3.0	51.1**
Per cent germination	-	56.0	84.0	28.0

** Significant (P = 0.01)

Cross-pollination of its flowers by honeybees and other natural insect pollinators is, therefore, of great significance in seed production. In order to study the effect of bee pollination on radish seed production, some field experiments were carried out. Radish plants (*Raphanus sativus*, var Meno Early) were raised at the HMG/FAO Vegetable Seed Production Farm, Khumaltar, during the last week of September (see plate, page 20). The plant to plant distance was 50cm and the row to row distance was 75cm. Three sets of experiments were performed, similar to those in the case of cauliflower plants, when the crop started blooming in the first week of March - (1) control, (2) open-pollinated, and (3) bee-pollinated.

Table 2.1 shows the floral biology of the crop. Each radish plant had an average of 10 branches and each branch bore an average of 155 flowers which opened in the morning and remained open for about three days. Each bud was 11mm long and each flower was 15mm in diameter. The crop started blooming from the first week of March until the last week of March, thus the total flowering period of the crop was one month.

Observations on the foraging behaviour of *Apis cerana* are summarised in Table 2.2. *Apis cerana* worker bees started foraging early in the morning at 0640 h and ceased their foraging activities at 1830 hours in the evening. Thus the total duration of foraging activity was 11.50 hours per day. Peak foraging activity was observed between 1100-1300 hours. Each bee made an average of nine trips in a day and the duration of each foraging trip was 22.13min.

Radish

Each bee spent four to 12 seconds on a flower and carried seven to 11mg of pollen load during different hours of the day. Most of the bees collected either pollen or nectar during a single foraging trip but a few bees (4% during the morning and 7% during the noon hours) collected both pollen as well as nectar during the same foraging trip. Pollen collectors outnumbered nectar collectors at 0900 hours (P:N=6:4), the ratio was equal (P:N = 5:5) at noon and during the afternoon at 1500h, nectar collectors outnumbered pollen collectors (P:N=3:7).

The effects of *Apis cerana* pollination on the quality and quantity of radish seeds are summarised in Table 2.5. It shows that bee pollination significantly enhanced fruit set by 23 per cent compared to open-pollinated plants. Bee pollination also significantly increased the number of seeds per siliqua by 42.3 per cent and seed weight by 44.5

Table 2.5: Quantitative and Qualitative Effects of *Apis cerana* Pollination on Radish Seeds

(Values are Mean ± S.E.)

Parameter	Control	Open-pollinated	Bee-pollinated	Per cent Increase
Per cent fruit set	No Fruit Set	51.0	74.0	23.0
No. of seeds per siliqua	-	5.2 ± 0.4	7.4 ± 0.3	42.3**
100 seed weight (mg)	-	1276.0 ± 4.0	1844.0 ± 7.0	44.5**
Per cent germination	-	44.0	76.0	32.0

** Significant (P = 0.01)

per cent compared to open-pollinated plants. Control branches did not set any fruit indicating that the crop was self-incompatible and required cross-pollination. Bee pollination enhanced seed germination by 32 per cent and decreased the time required for initiation of germination compared to open-pollinated plants.

Lettuce

Lettuce is grown for its succulent leaves which are used in salads and also as a vegetable. The lettuce flower, however, is usually self-pollinated and the plants are self-compatible. Cross-pollination has also been observed. The plants are cross-pollinated by insect pollinators which visit lettuce flowers for pollen, and honeybees are the chief pollinators of this flower.

To study the effect of *Apis cerana* pollination on lettuce seed production, lettuce plants (*Lactuca sativa var Atlanta*) were raised during the first week of February 1992 (see plate, page 22). The crop came into bloom during mid-June 1992. Three sets of experiments similar to those for the other three crops (i.e., cauliflower, cabbage, and radish) were per-formed - (1) control, (2) open-pollinated, and (3) bee-pollinated.

Lettuce

Observations on the floral biology of lettuce plants are summarised in Table 2.1. Each lettuce plant had 20 (15-25) branches and each branch bore 75 yellow flowering heads (capitula). Each head was about 15mm in diameter. It opened at 08.22 hours in the morning (i.e., between 0800-0900 hours depending upon the weather) and closed at 11.35 hours (i.e., between 1100-1200 hours depending upon weather conditions), thus it remained open for 3.13 hours only.

Each head was surrounded by a series of overlapping bracts (involucre). On an average it contained 22 (20-25) florets that developed simultaneously. The total flowering period of the crop was one month, i.e., from mid-June to mid-July.

Table 2.2 shows the foraging behaviour of honeybees on lettuce flowers. The bees started foraging on lettuce soon after the flowering heads opened, i.e., at 0830 hours, and ceased their activity only when the heads closed, i.e., at 1130 hours. Peak foraging activity was observed between 0900-1100 hours and the average duration of each foraging trip was 15.66 minutes. Each bee spent an average time of 3.84 seconds on a flower, collected 8.0mg of pollen load, and visited 13.0 flowers per minute. The number of bees per plant was four. Bees collected only pollen because the plant did not secrete nectar.

The qualitative and quantitative effects of *Apis cerana* pollination on lettuce are given in Table 2.6. This table shows that bee pollination significantly increased the number of seeds per capitulum (flowering head) by 31.8 and 21.05 per cent compared to control and open-pollinated plants respectively. Seed weight also increased by 16.03 per cent due to bee-pollination compared to control plants and 15.15 per cent compared to open pollinated plants. Bee pollination also increased the seed length by 23.88 and 11.26 per cent and breadth by 13.25 and 3.29 per cent respectively in comparison to control and open-pollinated plants. Germination of seeds was enhanced by 20 per cent compared to control plants and 12.83 per cent compared to open-pollinated plants. Moreover, seeds from bee-pollinated plants also showed resistance to fungal attack.

Table 2.6: Quantitative and Qualitative Effects of *Apis cerana* Pollination on Lettuce Seeds

(Values are Mean ± S.E.)

Parameter	Control	Open-pollinated	Bee-pollinated	Per cent Increase	Per cent Increase[2]
No. of seeds per capitulum	15.70 ± 0.63	17.10 ± 0.30	20.70 ± 0.75	31.80**	21.05**
100 seed weight	109.57 ± 0.46	110.41 ± 0.39	127.14 ± 0.85	16.03**	15.15**
Size of seeds (mm) Length Breadth	3.35 ± 0.10 0.83 ± 0.06	3.73 ± 0.09 0.91 ± 0.05	4.15 ± 0.10 0.94 ± 0.02	23.88** 13.25	11.26* 3.29
Per cent germination	76.66	83.33	96.66	20.20	12.83
Resistance to fungal attack	Susceptible (6 out of 25 seeds were attacked by fungus)	Less resistant (2 out of 25 seeds were attacked by fungus)	More resistant (none of the seeds were attacked by fungus)	-	-

* = Significant (P = 0.05)
** = Significant (P = 0.01)
1. = Increase compared to control
2. = Increase compared to open-pollinated

Chapter 3

The Asian Hive Bee (*Apis cerana*) Compared to the European Hive Bee (*Apis mellifera*) As a Crop Pollinator

Currently there is a movement in Asia to import the European honeybee, *Apis mellifera*, for commercial exploitation, and this has become a controversial subject amongst biologists and beekeepers. The pros, cons, and unanswered questions concerning the development of beekeeping with *Apis mellifera* and *Apis cerana* are summed up in the following passages.

Exotic *Apis mellifera*: Problems and Prospects

As a result of continuous research efforts in the area of genetic diversity, selective breeding, and improved management practices, *Apis mellifera* produces three times more honey than *Apis cerana*. Further, *Apis mellifera* is superior to *Apis cerana* because of its maintenance of prolific queens and because of less swarming and absconding tendencies. However, many importations of exoitic *Apis mellifera* into the HKH Region have proved disastrous. When kept sympatrically, *Apis cerana* and *Apis mellifera* colonies frequently rob each other. Another cause of failure in the coexistence of the two species is attempted intermating which produces lethal off-spring. A new problem is the transfer of parasites from one species to another.

A parasitic mite of brood and adults, *Varroa jacobsonii*, can co-exist with *Apis cerana* and causes no serious damage to this native bee species. In several parts of Asia, where these bee species are now kept together, the parasite has infested *Apis mellifera* colonies and has become a serious pest to this unadapted host. There is now apprehension that importation of *Apis mellifera* will lead to the decline of *Apis cerana* populations in their native habitat to a level that threatens their existence as a valuable genetic resource. In Japan and China, *Apis cerana* is now largely replaced by imported *Apis mellifera* colonies. Other Asian countries, such as Pakistan and India, are now following this trend.

Apis cerana: Problems and Prospects

Apis cerana has many valuable characteristics of biological and economic importance. These include their docile and industrious nature, their being less prone to attacks from wasps, and a high level of resistance to nosema disease and the parasitic Asian mites, *Varroa jacobsonii* and *Tropilaelaps clarae*, which plague *Apis mellifera*. *Apis cerana* can coexist with other native bee species and little chemical treatment of colonies is required to control epidemics. However, as yet, this native bee species has not become popular amongst beekeepers because of several behavioural characteristics. These inlcude their frequent swarming and absconding, their tendency to rob, their production of a large number of laying workers, and their lower honey yields. These negative traits show eco-geographical variations, depending upon the sub-species, geographic ecotype, and management efficiency of the beekeepers, and are amenable through research.

Some of these undesirable behavioural traits, from a beekeeping point-of-view, emerged in *Apis cerana* during the process of evolution as a result of harmful exploitation of this bee species by man. For example, through traditional methods of beekeeping, which are in vogue even today, most of the bees during honey harvesting were killed and no honey store was left behind in the nest for consumption by bees during dearth periods. As a result of this, the colonies of *Apis cerana* that survived and propagated in nature have developed the traits of frequent migration and absconding to safer and better pastures. In order to reverse such trends, a strategy through development and promotion of beekeeping with *Apis cerana* in modern movable hives is needed where moderate honey harvests are collected in a timely manner without harming the bees. In order to make such strategies successful, the foremost requirement is exploration and evaluation of different sub-species/geographic ecotypes of *Apis cerana*, which is now a major research focus at ICIMOD.

A recent survey conducted in ICIMOD by the authors revealed that *Apis cerana* is suffering a precipitous decline and is threatened with extinction throughout its entire range. The major threat comes from its replacement with the exotic and more prolific *Apis mellifera* and the recurrence of sacbrood virus disease which earlier had killed more than 95 per cent of the colonies in the region. While the consequences of a decline in *Apis cerana* in its native habitat can be speculated upon, it is clear that such a decline is undersirable in terms of economic development, maintenance of biodiversity in natural ecosystems, and productivity of farming ecosystems.

Comparative Foraging Behaviour of *Apis cerana* and *Apis mellifera* on Indian Mustard (*Brassica juncea*, var Khumal Broad Leaf)

The investigations carried out by our research group at ICIMOD on the foraging behaviour of these two species are summarised below (see plates of these species, page 30).

Apis cerana began foraging earlier in the morning (mean time 0626) than *Apis mellifera* (mean time 0649). In the evening *Apis mellifera* stopped earlier (mean time 1811) than *Apis cerana* (mean time 1821). The average duration of foraging activity was 11.55 for *Apis cerana* and 11.22 hours for *Apis mellifera*. Differences in all three parameters were significant at P= 0.01.

The duration of an individual foraging trip by *Apis cerana* was 23.24 ± 0.22, significantly shorter (P = 0.01) than the time of 25.29 ± 0.57 for *Apis mellifera* (Table 3.1).

Table 3.1: Comparative Foraging Behaviour of *Apis cerana* and *Apis mellifera* on Indian Mustard flowers during February/March in the Kathmandu Valley, Nepal

(Values are Mean ± S.E.)

Parameter	*Apis cerana*	*Apis mellifera*
Initiation of foraging (time of day)	0626 ± 0.65	0649 ± 0.65**
Cessation of foraging (time of day)	1821 ± 0.36	1811 ± 0.35**
Duration of foraging activity (h)	11.55 ± 0.92	11.22 ± 0.57**
Peak foraging hours (time of day)	1200 - 1300	1300 - 1400**
Duration of foraging trip (min)	23.24 ± 0.22	25.29 ± 0.57**
Time spent on flower (sec)		
0900 h	3.23 ± 0.15	3.22 ± 0.22
1200 h	2.75 ± 0.16	3.06 ± 0.16
1500 h	2.75 ± 0.15	2.74 ± 0.16
Time taken to shift from flower to flower (sec)		
0900 h	1.96 ± 0.17	1.81 ± 0.17
1200 h	1.75 ± 0.13	1.61 ± 0.13
1500 h	1.64 ± 0.13	1.61 ± 0.11
Number of flowers visited per min.		
0900 h	11.65 ± 0.29	12.20 ± 0.37
1200 h	11.68 ± 0.57	13.43 ± 0.52
1500 h	13.75 ± 0.52	14.23 ± 0.39
Pollen loads (mg)		
0900 h	13.05 ± 0.48	21.14 ± 1.00
1200 h	12.05 ± 0.62	23.58 ± 0.62
1500 h	13.57 ± 0.46	25.74 ± 0.70
Number of bees per plant.		
0900 h	2	2
1200 h	3	4
1500 h	3	3
Top vs side workers	A few, about 1-5% of side workers of both species were observed during morning hours.	

For times of initiation; cessation and duration of foraging activity, duration of foraging trip; and weights of pollen loads, differences between species are significant (P = 0.01).

Both species of honeybee did not differ significantly in behavioural characteristics such as time spent while foraging on each flower, time taken to shift from one flower to another, number of flowers visited on each plant at a time and the ratio between top versus side workers (Table 3.1).

Nectar collectors outnumbered pollen collectors (P = 0.01) for both species throughout the day, except at 1200h in *Apis mellifera* when pollen collectors were significantly more than nectar collectors. The ratio of nectar collectors to pollen collectors varied considerably with the time of day and between species at different times of the day (Table 3.2). For *Apis cerana*, more bees were collecting nectar than pollen at 1500 and 1200h; whereas, for *Apis mellifera,* nectar collectors were more numerous at 0900 and 1500h, pollen foragers of *Apis mellifera* outnumbered those of *Apis cerana* at 0900, 1200, and 1500h.

Table 3.2: Percentage of *Apis cerana* and *Apis mellifera* Honeybees Collecting Pollen, Nectar and Both from Indian Mustard Flowers during Different Hours of the Day in March in the Kathmandu Valley, Nepal

(The data are based on ten observations)

	0900 h		1200 h		1500 h	
Forager	*cerana*	*mellifera*	*cerana*	*mellifera*	*cerana*	*mellifera*
P	17	39	29	60	11	38
N	38	61	71	40	89	62
PN	0	0	0	0	0	0
P:N	1.0:4.9	1.0:1.6	1.0:2.4	1.5:1.0	1.0:8.1	1.0:1.6

P<N at 0900h, 1200h, and 1500h for *Apis cerana* and at 0900h and 1500h for *Apis mellifera* (at P=0.01)

P<N at 1200 h for *Apis mellifera* (at P=0.01)

P = Pollen collectors
N = Nectar collectors
PN = Pollen plus nectar collectors
P:N = Ratio between pollen and nectar collectors

The peak of activity for *Apis cerana* (mean number of incoming bees/ three minutes) occurred between 1200 - 1300 hours when the temperature was 25.8 to 27.4°C; relative humidity range 52.2 to 58.4; and, for *Apis mellifera*, it occurred between 1300 to 1400 hours when the mean outside temperature was 25.6 to 27.4°C and the relative humidity ranged from 52.2 to 56.6 per cent (Table 3.1).

Apis mellifera

Apis cerana

The mean pollen load of *Apis mellifera* workers was consistently heavier (P = 0.01) than that of *Apis cerana* (Table 3.1). *Apis mellifera* bees on the average visited slightly more flowers per minute than *Apis cerana* but the difference was not significant.

Based on the above data on the foraging behaviour of *Apis cerana* and *Apis mellifera*, and on data collected by other investigators, it can be established/concluded that *Apis cerana* has several distinct advantages over *Apis mellifera* for the pollination of agricultural crops. These are described below.

Initiation of Foraging Activity

Apis cerana begins foraging activties earlier in the morning and at lower temperatures than *Apis mellifera*. According to reports, the foraging activities of *Apis cerana* take place at temperatures from three to five degrees centigrade lower than those known to initiate *Apis mellifera* foraging activities. Further, the peak foraging activities of *Apis cerana* are observed at temperatures from five to six degrees centigrade lower than those of *Apis mellifera*. Thus, *Apis cerana* could be used for crops in early spring and at latitudes at least as far north (or south) as those where *Apis mellifera* are used.

Flight Range

The flight range of *Apis cerana* is less than half that of *Apis mellifera*. This is of particular interest, especially in the case of pollination, because the foraging activity of *Apis cerana* is more focussed on a smaller area and thus this bee species is better suited to the pollination of specific crops grown on smaller plots. An *Apis cerana* hive placed in the vicinity of a specific crop will pollinate that crop without wandering/escaping to different areas. Because of its shorter flight range, it will forage in areas closer to the hive than *Apis mellifera*.

Duration of Foraging Activity

The average duration of foraging activity per day of *Apis cerana* is more than one hour longer than *Apis mellifera*. This is because of the early initiation and late cessation of foraging activity. *Apis cerana* may thus ensure adequate pollination of the crop in bloom in a lesser period of time, particularly during adverse weather conditions, e.g., during the monsoon or frosty spring seasons when honeybee activities become severely limited.

Competition for Food and Nesting Site

The exotic species, *Apis mellifera*, may compete for food, i.e., nectar and pollen sources with the *Apis cerana* and other native pollinators. The exotic, *Apis mellifera*, will also take away nesting and resting space from the *Apis cerana* and other native pollinators, including birds. As a result of the habitat loss caused by severe deforestation and rapid agricultural transformation, both food sources (nectar and pollen) as well as nesting sites are becoming an increasingly limiting factor throughout the range of *Apis cerana*. Thus, the introduction of *Apis mellifera* will reduce the populations of native pollinators or cause them to be maintained at much lower levels than if these exotic honeybees were not present. The deletrious effects of such competition are more likely to be found in the case of *Apis mellifera* and *Apis cerana* as both these honeybee species occupy the same ecological 'niche' and are also more closely related to each other in habits, constitution, and structure. Since the *Apis mellifera* is more aggressive and prolific than the *Apis cerana*, according to the competitive exclusion principle, this exotic species of honeybee will completely displace *Apis cerana*.

Co-evolution of Native Bees and Crops

A large number of native plants in the Asian region (for example native fruits and vegetable crops) and *Apis cerana* evolved together. It is also true that honeybees collect nectar and pollen from a large number of these plants. Thus the plants that have evolved closely with *Apis cerana* as vectors of pollen have developed symbiotic relationships with them and they are thus indispensable one to the other. Exotic *Apis mellifera* may inefficiently pollinate such native crop plants and reduce their reproductivity.

Low Cost of Colony Maintenance

Beekeeping with *Apis cerana* requires low maintenance costs in comparison to beekeeping with *Apis mellifera* which requires expensive technology, and small and marginal farmers in the developing countries of Asia cannot afford it. *Apis mellifera* colonies also require chemical treatment to control epidemics, and this is undesirable for both economical and environmental reasons. In contrast, colonies of *Apis cerana* require a lesser degree of chemical treatment to control epidemics.

Native Bees are an Integral Part of the Cultural and Natural Heritage

Beekeeping with *Apis cerana* is a traditional occupation which forms an integral part of the cultural and natural heritage of rural communities in Asia. Such an environmentally - friendly craft may soon be discontinued as a result of the introduction of the exotic *Apis mellifera*.

Chapter 4

Pesticides and Honeybees

Pesticide Poisoning of Honeybees

Beekeeping and the use of pesticides are both essential inputs for modern techniques of vegetable seed production. Vegetable seed production will be seriously impaired if either of these two is ignored. Since the advent of synthetic pesticides several decades ago, the beekeeping industry, both in developed and developing countries, has been incurring heavy losses. In developed countries, large-scale monocultural cultivation of crops and a high degree of mechanisation has greatly amplified the problem of honeybee poisoning by pesticides. On the other hand, in developing countries, the basic problem is the lack of information about the harmful effects of pesticides on honeybees. Conflicts often arise when pesticides are applied to a crop at the inappropriate time, or by inappropriate means, or when unsafe pesticides are used.

In recent years, pest control problems are becoming more serious and difficult to manage. This is because large areas of land are being used to cultivate exotic cultivars of vegetable crops which, under the new environmental conditions, are more susceptible to pests and diseases. In some cases, pests and diseases affecting exotic cultivars/varieties are also introduced either accidently through human error, or lack of proper quarantine facilities. Such pests and diseases multiply and spread more rapidly in their new environment, because of the absence of their natural enemies such as predators or parasites. Chemical pest control measures are absolutely essential under such circumstances.

The increasing reliance on chemical methods for the control of pests and diseases is also creating serious environmental pollution problems, including health hazards to human beings and decline in other non-target, beneficial insect populations. Amongst the latter, natural insect predators, parasites, and insect pollinators, especially honeybees, are the primary victims. These beneficial insects are facing extinction in their natural habitat where they greatly contribute to the conservation of biological diversity and render essential ecological services, i.e., pollination and maintaining the population levels of different insects-pests below economic thresholds.

In developing countries, the basic problem is lack of information and lack of awareness about the harmful effects of biocides to honeybees along with the indiscriminate prescription of pesticides by agricultural scientists and extension workers and blanket and erratic application of pesticides by farmers due to lack of knowledge regarding what, how much to use, and when.

The practice of using honeybees to enhance the productivity levels of different agricultural and horticultural crops has not become very popular among farmers because indiscriminate use of biocides kills large numbers of bees. However, now other methods are available and these ensure the selective use of biocides at some right time and in the appropriate formulation and concentration. As a result of this, the hazards of bee poisoning by pesticides can be reduced to a minimum.

Effects of Pesticides

Pesticides may be absorbed by bees in one or more of the following ways - oral, respiratory, and dermal. Oral intake is likely to occur when nectar and/or pollen are contaminated. For a pesticide to be toxic via this route, it must be absorbed and the efficiency of absorption depends upon the characteristics of the pesticide. For example, bees could carry lethal doses of organophosphate dimethoate in their honey stomachs without showing signs of intoxication.

Contamination of nectar occurs in a number of plants treated with systemic insecticides. However, there is a little danger of contamination through nectar. But, on the other hand, several scientists have reported that dimethoate applied at the rate of 1 kg/ha killed the bees as a result of nectar contamination.

The major cause of bee poisoning is the contamination of pollen by microencapsulated insecticides. For example, when Penncap-M[R] capsules are applied to agricultural crops, the capsules are carried by foraging bees to their hives and stored in the brood frames together with pollen; hive bees feed the contaminated pollen to the developing brood which results in loss of the total colony. Foraging bees are killed while collecting and transporting this pollen, young hive bees are killed while storing and feeding the contaminated pollen, and the brood is killed by the poisoned food.

Insecticides such as DDVP, some organochlorine pesticides such as chlordane, and compounds such as nicotine can be present in sufficient concentration in the air to be toxic to bees by way of their tracheal system. Another possible problem in this regard is the absorption and subsequent release of volatile pesticides with fumigant properties. Beeswax has excellent absorptive properties. Combs exposed to DDVP for 48 hours absorb sufficient pesticide to kill bees that are exposed to these combs within two to six minutes.

Direct contact is probably the major way in which pesticides are absorbed by bees. Interception of pesticide droplets in the air during spraying operations and contact with sprayed surfaces are the most likely sources of contamination. The toxicity of the airborne droplets varies according to the method of application, and the amount of pesticide available to bees decreases with increasing absorption of pesticide by the surface.

Bees lose their sense of time when exposed to sub-lethal doses of pesticides like parathion. However, it is not clear whether this phenomenon is the result of changes in the "internal clock" of the poisoned bees or in the manner in which they communicate this "time" to other bees. Disruption in the communication of distance also occurs due to pesticide poisoning.

Outbreaks of European Foulbrood and Sacbrood Virus infections were observed to follow applications of Carbaryl insecticide in the foraging area of the affected colonies. The first records of the occurrence of Chalkbrood disease came from colonies that were exposed to fenetrothion spray.

Symptoms of Bee Poisoning

One of the obvious signs of poisoning is the presence of a large number of dead or dying bees at the hive entrance. These adult bees are foragers who have been exposed to pesticides sprayed on flowering plants. The mortality figures in Table 4.1 are used as guidelines to assess the extent of bee poisoning by pesticides.

Table 4.1: Extent of Bee Poisoning by Pesticides

Number of dead bees per day at entrance	Level of poisoning
100	Normal death rate
200-400	Low
500-1000	Medium
Over 1000	High

Source: FAO Bulletin 68/3 1988.

As a result of organophosphorous poisoning, dying bees extend their tongues through which nectar is regurgitated and a moist and sticky mass of dead bees is often found at the hive entrance. Fast-acting insecticides kill foraging bees in the field itself, and only a small number of such bees manage to return to the hive. Sometimes, the whole bee colony may die instantly. Strong bee colonies suffer greater losses due to pesticide poisoning than weaker ones because the former have a larger number of foraging bees.

Foraging bees often carry residual pesticides in their pollen loads while returning to the hive. The behaviour of bees in the hive changes abruptly as a result. Honeybees in such colonies become more agitated or aggressive. As and when the hive with pesticide-affected forager bees is opened, they often fly off the top bars of the hive and sometimes straight into the face of the beekeeper handling them. Other symptoms of pesticide poisoning include stupefaction; paralysis; and abnormal, jerky, or spinning movements. Carbaryl poisoning causes bees to crawl around at the hive entrance, they lose their ability to fly and ultimately die in two to three days after poisoning.

Nurse bees in pesticide-affected colonies lose their ability to clean dead bees from the hive, as a result of which the hive entrance is completely blocked.

Pesticide poisoning also affects the colony strength because there is a break in the brood-rearing cycle and often dead or deserted colonies cease foraging, as a result of which there is a sharp decline in food storage, and incoming foragers are attacked at the hive entrance by other bees.

Protective Measures

i) As far as possible, biocides should not be applied during the blooming period.

ii) Pesticides that have short residual effects and those that are less hazardous to honeybees should be selected.

iii) Ignorance and the absence of extension programmes to educate farmers about the harmful effects of pesticides are the biggest problems in developing countries. Both vegetable growers and beekeepers should be properly informed regarding pesticide application schedules and how to reduce poisoning in a particular area.

iv) Broad-spectrum pesticides should be avoided as they are much more hazardous than selective pesticides which are safer for bees and other beneficial insects.

v) Night or early morning application of pesticides is always desirable because foraging honeybees are in the hive at that time and thus out of danger. Night application of pesticides allows adequate time for the pesticide to dissipate or break down into substances that are non-toxic to bees.

vi) It has been recognised that spray or liquid formulations are safer than dust or wettable powder formulations. The death rate is six times higher if powder formulations are used in comparison to liquid formulations. The addition of solvents or oily substances to sprays significantly reduces bee losses.

Insecticide formulations can be classified in order of their toxicity:

dust>wettable powder>flowable> emulsifiable concentrate or soluble powder or liquid solution>granular formulation.

vii) It is always advisable to keep bee colonies as far away as possible from the pesticide-treated fields. Even a distance of one kilometre from the sprayed site will reduce honeybee mortality ninefold.

ix) Remove all the flowering weeds from the fields by either mowing or beating so that they do not become a source of poison to the bees. This practice will force the bees to forage over longer distances, free from the adverse effect of pesticides.

x) In the temperate regions of the Hindu Kush-Himalayas, residues will remain toxic for a longer time due to lower temperatures. But, at the same time, low temperatures delay the initiation of the foraging activities of honeybees in the morning. Keeping this in mind, the time of pesticide application should be shifted accordingly.

xi) Primary emphasis should be placed on an integrated pest management programme which mainly relies on biological or cultural methods of insect-pest control and minimises the use of poisonous chemicals.

Relative Toxicity of Some Pesticides to the Asian Hive Bee, *Apis cerana*

In several developing countries of southeast Asia, beekeeping with *Apis cerana* has been sustaining heavy losses since the advent of synthetic pesticides several decades ago. Such widespread and careless use of toxic pesticides during the blooming periods of agricultural and horticultural crops not only kills bees but also contaminates hive products.

Several research workers have compared the relative toxicities of commonly used pesticides on *Apis cerana* and these have been classified as highly toxic, moderately toxic, and non-toxic. Application of highly toxic pesticides on blooming crops or weeds may cause severe damage to bees. Beekeepers should be warned in advance by the growers when these insecticides are to be used so that they can temporarily move the colonies to safer locations. Even 10 hours after spraying, these pesticides are still highly toxic to bees. Moderately toxic pesticides should be applied during the late evening when bees are not foraging actively. Bee hives should not be directly exposed to these pesticides. For minimal hazards to honeybees, the dose, the timings, and the methods of application of these moderately toxic pesticides are very important. Relatively non-toxic pesticides cause minimum damage to the bees. These should be applied during late evening, night, or early morning. The list of pesticides is given in Appendix I and Appendix II gives instructions regarding their safe usage.

Appendix I:

List of Pesticides with High, Moderate, and Least Toxicity to *Apis cerana*

Group 1: Highly Toxic Pesticides

Carbaryl 50% WP
Carbophenothion 20 EC
Cypermethrin 10 EC
Decamethrin 20 EC
Dichlorvos 100 EC
Dimethoate 30 EC
DDVP 100 EC
Monocrotophos 36 WSC
Oxydemeton-methyl 25 EC
Parathion
Phosphamidon 100 EC
Phorate
Permethrin 25 EC
Quinalphos 25 EC
Sumithion 50 EC
Thiometon 25 EC

Group 2: Moderately Toxic Pesticides

BHC 50 per cent
Carbyl 50 WP
DDT 50 per cent
Dieldrin
Endrin
Hinosan 50 EC
Heptachlor 10 WP
Malathion 50 EC
Methyl demeton
Monocrotophos 40 EC
Trichlorfan 50 EC
Diazinon 20 EC
Ethyl parathion 46%
Fenitrothion 100 EC
50 EC
Fenthion 100 EC
Formothion 25 EC
Gamma BHC 20%
Lindane
Metacid 50 EC
Metasystox 50 EC
25 EC
Mevinphos
Methyl Parathion 50 EC
Dithane M-45 75 WP
Foltaf 80 WP
Difolitan 50 WP
Hexacap 50 WP
Bavistin 50 WP

Group 3: Relatively Non-toxic Pesticides

Endosulfan 35 EC
Menazon 70 DP
Phosalone 35 EC

Appendix II:

Safe Pesticide Use for Human Beings

1. **General**

   i. Pesticides should be applied only when it is really necessary.

   ii. Instructions given on the label of the pesticide container should be read carefully and followed accordingly.

2. **Reducing the Incidence of Pesticide Poisoning in Human Beings**

   i. Protective clothing such as a hat, long sleeved shirt, long trousers, face mask, goggles, and rubber or neoprene gloves and shoes should be worn while handling pesticides.

   ii. When handling and applying pesticides, one should not eat, drink, or smoke. After applying pesticides, hands and face should be washed thoroughly with soap.

   iii. Children should never be allowed to apply/use pesticides. Pesticides should not be kept within the reach of children.

iv. Leaking and defective equipment should never be used.

v. Dust or powdered pesticides should not be applied on windy days because these can blow back on to the person applying them.

vi. Contact with recently sprayed crops should be avoided.

vii. If pesticide contamination does occur, one should change the clothing and thoroughly wash the contaminated area of the skin with soap as soon as possible.

viii. Pesticide containers should not be washed in ponds, streams, or other water sources. Waste pesticides and their containers should be carefully disposed of in a way that will not endanger people and other living beings.

ix. Empty pesticide containers should not be used for any other purpose, such as for food, water, or as cooking pots, because it is not possible to clean them thoroughly enough to render them safe.

x. Pesticides should always be kept in their original labelled containers and should never be poured into drinking bottles.

xi. Before harvesting the crops, the recommended safety intervals should be observed.

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Glossary

Anther: part of the stamen which bears pollen grains. 2

Bee Poisoning: the accidental killing or debilitation of bees caused by the use of insecticides. 36,37,38

Brood: a collective term for the eggs, larvae, and pupae of bees. 26,37

Biocide: please see pesticide. 36,39

Biodiversity: all species of plants, animals, and micro-organisms and the ecosystems and ecological processes of which they are components. 27

Breeding: techniques of producing young ones by the selection of parents. 25

Colony: a social community of several thousand worker bees usually containing a queen and with or without drones. 6,33,37

Embryo: the offspring of an individual in the early stages of its development. 6

Exotic: individual (plant/or animal) introduced from other countries. 25,27,32

Fertilisation: union of the male nucleus of a pollen grain with the female nucleus of the egg of an ovule. 2,4,6

Forage: food (pollen and nectar) for the bees. 1,7,9

Foraging Bees: worker bees which collect pollen/nectar/water. 37,39

Formulation: a mixture of an active pesticide chemical with carriers, diluents, or other materials. 36,40

Hazard: is the possibility of a chemical producing adverse effects in special circumstances. 36,41

Hybrid: individuals (plants/animals) born from unrelated parents, i.e., parents from different varieties/species. 5

Insecticide: any substance that prevents, destroys, repels, or mitigates insects. 38,40

Intercrossing: crossing between two different varieties/cultivars. 8,9

Isolation Distance: necessary distance required between different cultivars of the same crop to avoid crossing between them in order to produce pure seeds. 8,9

Label: all written, printed, or graphic matter on or attached to the pesticide or the immediate container as required by law. 44

Mixed Cropping: practice of growing more than one crop in the same field at the same time. 7

Monoculture: practice of growing only one crop (one plant species) in a particular field/area. 7

Native Species: indigenous species occurring naturally in a locality/area/region. 5,26

Nectar: sugary liquid secreted by a special gland (called nectary) of a flower. 4,6,7

Nectary: a nectar secreting gland, often associated with the petals of a flower. 6,8

Niche: the functions (both biotic and abiotic) of a particular organism in its environment. 5,32

Nucleus: an organelle of plant or animal cell which contains the genetic material. 2

Organophosphates: a synthetic organic pesticide containing carbon, hydrogen, and phosphorous. 37

Glossary

Ovule: forerunner of the seed present inside the ovary. 2

Parasite: an organism that draws a portion or the whole of its food from another living organism and gives nothing in return. 26

Pest: any organism that harms livestock or crops is a pest. 26,35,36

Pesticide: a poisonous chemical used to control pests or to prevent them from multiplying. 35,36,37

(i) Broad Spectrum Pesticide: a pesticide that kills many different species of pests. 40

(ii) Selective Pesticide: a pesticide that kills some specific species of pests. 40

Pollen: granular mass present in the anther of a flower. 2,4,5

Pollen Load: amount (weight) of pollen pellets carried by a honeybee on its hind legs. 14,15,18

Pollination: the transfer of pollen grains from the anther to the stigma of the same or a different flower. Pollination is of two types. 1,2,3

(i) Self-Pollination: transfer of pollen grains from the anther to the stigma of the same flower. 3

(ii) Cross-Pollination: transfer of pollen grains from the anther of one flower to the stigma of another flower of the same plant species. 1,2,3

Pollinator: an external agent that transfers the pollen grains from the anther of one flower to the stigma of another flower. 4,5,6

Predator: an animal that preys upon other animals of different species. 36

Residue: the remainder of the pesticide material on the treated surface after spraying. 41

Residual Effect (of pesticides): harmful effects of these poisonous chemicals if they remain after a certain period. 39

Resistance: ability of an organism to suppress or retard the injurious effects of a pesticide. 6,23

Selectivity: choice of superiority. 6

Self-compatible/self-fertile varieties: varieties in which fertilisation and fruit/seed set is carried out by its own pollen. 2,4,21

Self-incompatible/self-sterile varieties: varieties in which fertilisation and fruit/seed set is not by its own pollen. The plant is not receptive to its own pollen but needs pollen from another plant of the same species. 2,4,11

Species: an interbreeding population which is reproductively isolated from other similar but morphologically different(distinguishable) populations. 2,5,25

Stigma: part of the pistil (female part of a flower) which receives pollen. 2,6

Toxic: poisonous. 36,37,41

Toxicity: degree of poisoning, i.e., how poisonous the chemical (pesticide) is. 40,41

Variety/Cultivar: individuals of a species differ from one another regarding their size, form, colour, etc. Such variations are called varieties. Thus variety is the classification below species' level and the variety that is cultivated is called a cultivar. 11

Viability of seeds/embryos: ability of a seed or embryo to remain capable of germination (lifespan of a seed or embryo). 6

Weed: an unwanted plant that interferes with the growth of the favoured species. 8,40

About the Authors

Professor L.R. Verma is a senior professional staff member of ICIMOD where he is the project leader for the USAID-funded Himalayan Honeybee Genetic Diversity Regional Project. Earlier, he was Dean and Head of the Biosciences Department of Himachal Pradesh University, Shimla, and Scientific Advisor in Apiculture to the Government of Himachal Pradesh, India. He obtained his Ph.D degree in 1972 from the University of Guelph, Canada, and was also an Alexander von Humboldt Research Fellow at J.W. Goethe University, Frankfurt, West Germany, from 1976-1978. In India, he has been principal investigator and coordinator of several research projects in the area of apiculture, pollination ecology, insect pests in mountain crops, and mountain biodiversity. Professor Verma has published more than 100 research papers in scientific journals of international repute, has been a member on the editorial board of different research journals, and has authored/edited three books on Apiculture.

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