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Pollination Management in Apple Orchards Of Himachal Pradesh

A Manual for Trainers

in Shimla and Kullu Districts in Himachal Pradesh

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Pollination Management in Apple Orchards Of Himachal Pradesh

A Manual for Trainers in Shimla and Kullu Districts in Himachal Pradesh

Foreword from GIZ

The global programme “Green Innovation Centres for the Agriculture and Food Sector (GIC)”, commissioned by the German Federal Ministry of Economic Development and Cooperation (BMZ), is being implemented in India by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, in cooperation with the Ministry of Agriculture & Farmers Welfare (MoA&FW).

The project has been working on the integrated development of the tomato, potato and apple value chains, focusing on identifying and scaling innovations that enhance the productivity and income of smallholder farmers and small-scale farming enterprises, promoting good agricultural practices and supporting FPO development. In this way the project lays the groundwork that allows farmers to adopt agroecological practices and contribute to the transformation towards sustainable and climate-resilient food systems.

Apple farmers are confronted with multi-dimensional problems, such as climate change and a decrease in chilling hours, post-harvest losses, lack of alternatives to chemical inputs, and decline in pollinator populations. These challenges keep productivity low which negatively influences the farmers’ income. To address this, the project has introduced many innovations such as manuals on good agricultural practices with scientific backstopping, pollination as an ecosystem service, solar-powered cold storage and solar dryers, trainings in food processing, and efficient irrigation techniques. Overall, the project has adopted sustainable agriculture practices to protect the soil and environment.

In Himachal Pradesh, the GIC project has been working in the apple value chain in Shimla and Kullu districts. The project is being implemented in close cooperation with the Department of Horticulture (DoH) Himachal Pradesh, Dr. Y S Parmar University of Horticulture and Forestry, (UHF) Nauni, and the Krishi Vigyana Kendra, and other implementing and private partners. The project has successfully demonstrated several innovations to achieve the key objectives.

GIC India promotes ‘innovation bundles’, which combine individual interventions to tackle multi-dimensional eco¬nomic, social, and environmental challenges. Innovation bundles build evidence and promote proven solutions for upscaling through regional and national strategies and policies.

The project has worked towards disseminating the promoted good agricultural practices by training master trainers. These technical manuals on various aspects of apple production are useful tools for expanding the project’s efforts. This document is prepared with the involvement of UHF and the DoH Shimla. I sincerely thank these organisations for contributing their learnings and hope that this technical manual will help to scale up sustainable agricultural practices in apple cultivation in Himachal Pradesh.

Ms. Regina Sanchez Sosa
Project Director
Green Innovation Centres for the Agriculture and Food Sector – India

Message from Department of Horticulture, Himachal Pradesh

Since 2016, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) India, under the project Green Innovation Centres for the Agriculture and Food Sector (GIC) India has been focusing on the apple value chain in the Kullu and Shimla districts of Himachal Pradesh. With an ever-growing demand for sustainable agricultural practices and the need to enhance the livelihoods of farmers, this project stands as a beacon of innovation and collaboration.

The Memorandum of Understanding signed between our department and GIZ underscores our commitment to fostering agriculture innovation and promoting holistic development in the horticulture sector. Through this partnership, we aim to leverage climate -smart technologies and best practices, and knowledge exchange to empower apple farmers and uplift the entire apple value chain.

The joint goal of the Himachal Pradesh State Department of Horticulture (DoH) and GIZ is to create scalable models, processes, technologies, and knowledge management systems that can be effectively implemented by the DoH. Our aim is to enhance the income and productivity of smallholder farmers while ensuring the sustainability of the apple industry. Through innovative approaches and scalable solutions, we seek to address the challenges posed by climate change and foster resilience. By collaborating closely with stakeholders, leveraging expertise, and embracing a spirit of innovation, we are committed to realizing these goals and making a meaningful impact on the livelihoods of apple farmers in Shimla and Kullu districts.

The manuals, which compiles sustainable farming practices for apple crop, will undoubtedly help all extension functionaries and farmers as a practical knowledge source. It is the result of combined efforts by GIZ India, the Department of Horticulture, and scientists from the Dr. Y S Parmar University of Horticulture and Forestry, Solan and will help make apple farming more sustainable and profitable.

As we embark on this journey, I extend my heartfelt gratitude to all the partners, stakeholders, and collaborators who have contributed their expertise, resources, and unwavering support to make this project a reality. Together, we can cultivate a greener, more prosperous future for the apple growers of the state of Himachal Pradesh, while ensuring environmental sustainability and socio-economic progress.

Mr C. Paulrasu, IAS
Principal Secretary, Horticulture
Government of Himachal Pradesh

Message from Dr. YS Parmar University of Horticulture & Forestry

Apple fruit is the oldest, commercially the most important, and high value temperate horticultural crop of Himachal Pradesh. With its unique climatic conditions, the state has been blessed with some of the finest varieties of apples in India. However, to ensure the sustainability and profitability of apple farming in face of multiple challenges including climate change, it is imperative to adopt climate-smart practices and technologies.

Through the Green Innovation Centers for the Agriculture and Food Sector (GIC) project implemented by GIZ India, we aim to empower apple farmers with the necessary skills and knowledge to enhance their productivity, quality, and marketability. We want to create a conducive environment for the growth of the apple industry, benefiting not only the farmers but also the entire community.

It is with great pleasure that I introduce the collaborative efforts of the GIC project and Dr. Y.S. Parmar University of Horticulture and Forestry (UHF), which aim to promote Good Agricultural Practices (GAP) in the region and provide essential knowledge through these manuals.

In this context, the research accomplishments and Good Agricultural Practices of apple cultivation practices have been compiled in the form of manuals. They serve as a comprehensive guide, covering various aspects of apple cultivation, from orchard management to post-harvest handling. These manuals are designed to be accessible and practical, catering to the needs of all kinds of farmers. I am sure this manual will help different stakeholders of the farming community to improve their knowledge, resulting in better income and sustainable horticulture development.

These manuals aim to enhance the skills of farmers, officials, and members of Farmers Producer Organizations (FPOs), creating a cadre of trainers equipped to disseminate knowledge and best practices within their communities. These barefoot trainers will sustain the capacity building process by providing farmers with the necessary skills in apple cultivation practices and creating a multiplier effect.

I am confident that through these collaborative efforts, we will foster a culture of continuous learning and improvement within the apple farming community. Together, we can create a sustainable and prosperous future for apple farming in Himachal Pradesh.

My best wishes and congratulations to whole team.

Dr. Rajeshwar Chandel
Vice-Chancellor,
Dr. Y S Parmar University of Horticulture and Forestry,
Solan, Himachal Pradesh

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Introduction

Apple Production in Himachal Pradesh

Apple *(Malus domestica)* belongs to the genus Malus in the Rose (Rosaceae) family. Apple trees are generally small when cultivated, with a height between 2 and 4.5 meters. If left untrimmed, a tree grown with standard rootstock can reach a height of 9 meters (30 feet) with an equally large crown diameter. The bark is usually brown and scaly. The simple leaves are roughly oval in shape and usually have serrated margins. Apple flowers are showy with five white petals, often tinged with pink, and numerous stamens. Bees and other insects pollinate the flowers, and most varieties require cross-pollination for fertilisation.

The apple fruit is a pome (fleshy) fruit in which the ripened ovary and surrounding tissue become fleshy and edible. When harvested, apples are usually roundish, 5–10 cm (2–4 inches) in diameter, and some shade of red, green, or yellow in colour; they vary in size, shape, and acidity depending on the variety of which there are thousands.

In India, the total area under apple cultivation in 2020-21 was 3,12,620 Ha, with a total production of 22,75,840 MT. The average productivity was 7.28 MT/Ha. Jammu and Kashmir is the most important apple-producing state, followed by Himachal Pradesh and Uttarakhand. Both the area under cultivation and the total production are on an increasing trend. India ranks fifth in terms of production amongst apple-producing countries in the world. In 2020-21, India exported 30,680 MT of apples worth Rs. 106.65 Crores, which has more than doubled in 4 years between 2017 and 2021.

While the apple is a temperate fruit crop, the apple-growing areas in India do not fall in the temperate zone. However, the prevailing temperate climate of these apple-growing regions is due to the Himalayan ranges and high altitudes. The average summer temperature for apples should be around 21-24°C during active growth. Apple succeeds best in areas where the trees experience uninterrupted rest in winter and abundant sunshine for good colour development. It can be grown at an altitude of 1500- 2700 m above sea level. Well-distributed rainfall of 1000-1250 mm throughout the growing season is most favourable for optimum growth and fruitfulness of apple trees.

Himachal Pradesh is called India’s fruit basket, with a total area of 2,34,780 Ha under fruit cultivation, and a production of 6,24,490 MT in the year 2020-21. Apple accounts for 1,14,650 Ha area with a total production of 4,81,060 MT in 2020-21. Apple contributes about Rs. 5000-6000 crores to the state economy, contributing more than 80% of the total fruit production in Himachal Pradesh. Shimla and Kullu districts together constitute approximately 65% of the total area under cultivation in apples and rank the highest and second highest among all districts in the state in production, respectively.

Apple production is susceptible to climate change, which will cause an increase in temperature and variability in precipitation. The excessive use of chemical fertilisers and pesticides has decimated the populations of most pollinators (bees, butterflies, and insects); poor pollination has, in turn, compromised apple production. Any negative impact on apple production due to climate change will impact the horticultural economy which provides livelihoods and income for hundreds of thousands of families and other value chain actors from production to consumption.

About Green Innovation Centres for the Agriculture and Food Sector - India

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH is a public-benefit federal enterprise of the German Government. In its projects, GIZ works with partners in national governments as well as actors from the private sector, civil society and research institutions. GIZ's main commissioning party is Germany's Federal Ministry for Economic Cooperation and Development (BMZ). Other commissioners include the European Union, the UN, the private sector, and governments of third countries.

The global programme "Green Innovation Centres for the Agriculture and Food Sector (GIC)" is funded through the Special Initiative "Transformation of Agricultural and Food Systems" of the BMZ. Since 2016, the project is implemented in India by GIZ in cooperation with the Ministry of Agriculture & Farmers Welfare (MoA&FW). In Himachal Pradesh, the project works in collaboration with the Department of Horticulture, Himachal Pradesh.

Working in the Rohru and Chirgaon regions of Shimla district and the Naggar and Kullu regions of Kullu district, the GIC project identified, tested, and introduced various innovations in a participatory manner involving the farmers.

Why we developed this Training of Trainers Module

GIC India, in partnership with the Department of Horticulture, Himachal Pradesh (DoH) and Dr. YS Parmar University of Horticulture and Forestry, Nauni (UHF), is creating a pool of Master Trainers in Good Agriculture Practices in apple cultivation in Himachal Pradesh. These Good Agriculture Practices cover canopy management, pollination management, nutrition management, and integrated pest management. This pool of master trainers is being created through Training of Trainers (ToT).

This Training of Trainers (ToT) manual provides technical information on canopy management and follows the flow of the field training.

This manual is meant as a tool during the ToTs for Master Trainers and horticulture extension officers to enable them to train farmers and transfer agronomic knowledge on integrated disease and insect-pest management. This will enhance the farmers' skills and knowledge. This manual addresses principles of learning and training design for adults, provides technical information on integrated disease and insect-pest management, and provides references for further reading.

The manual seeks to convey an interactive, well-designed and facilitative approach to learning for the target group of farmers. The inclusion of women trainers is essential in the ToTs. Women with suitable profiles and interest who can become master trainers should be included in the trainings.

This manual aims to provide insights into the integrated disease and insect-pest management practices in apple farms. It provides an overview of the main concepts of integrated disease and insect-pest management and its importance in apple orchards. It also includes information on various methods and practices to ensure adequate pollination, as well as the importance of conservation of bees and wild insect pollinators, along with chemicals to avoid that are harmful to the pollinators, to make a balance between improving productivity and ecological biodiversity and health. Its objective is to provide extension officers, members of Farmer Producer Organisations (FPO), and progressive youth with the necessary information and skills to become trainers and deliver technical capacity sessions on this topic.

Acknowledgements

Various institutions and individuals have contributed to the technical content of these manuals, which are acknowledged below.

- Scientists from Dr. Y S Parmar University of Horticulture and Forestry, Nauni, Solan
- Agriculture experts of the GIC India Project, GIZ
- Experts from the Kompetenzzentrum Obstbau Bodensee
- Senior consultants - Dr. Joginder Singh Chandel, Retired Head of Fruit Science, Dr. YS Parmar UHF Nauni and Dr. Shamshar Singh Rana, Retired Associate Director, RHRTS Nurpur UHF Nauni.
- Training design by The Training Shift

ToT Manual

POLLINATION MANAGEMENT

1 Day Field Training

Topic 1 | Fertilisation process

Objectives and key messages

Topic objectives	• Explore the vital role of pollination in enabling plant reproduction and biodiversity. • Discover how fertilization transforms seeds into fruits
Key messages to bring out	Pollination is the process of transferring pollen grains from the male anther of a flower to the female stigma to create offspring for the next generation. The fertilisation process begins with successful pollination. Animals or insects that transfer pollen from plant to plant are known as pollinators. If apple orchards do not have an adequate fertilisation process, apple fruits will not be well developed during the crop cycle or may drop early.

Pollination

Pollination is the process of transferring pollen grains from the male anther of a flower to the female stigma. The goal of every living organism, including plants, is to create offspring for the next generation. One of the ways that plants can produce offspring is by making seeds. Seeds contain the genetic information to produce a new plant.

Flowers are the tools that plants use to make their seeds. The basic parts of a flower are shown in the diagram below.

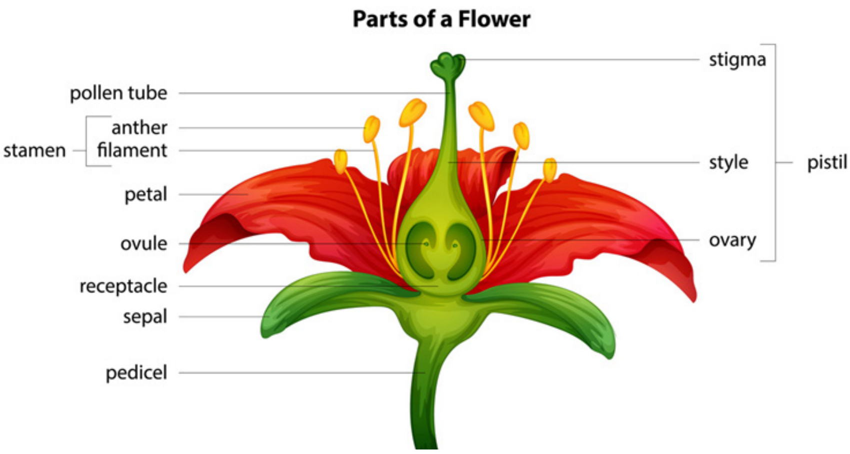
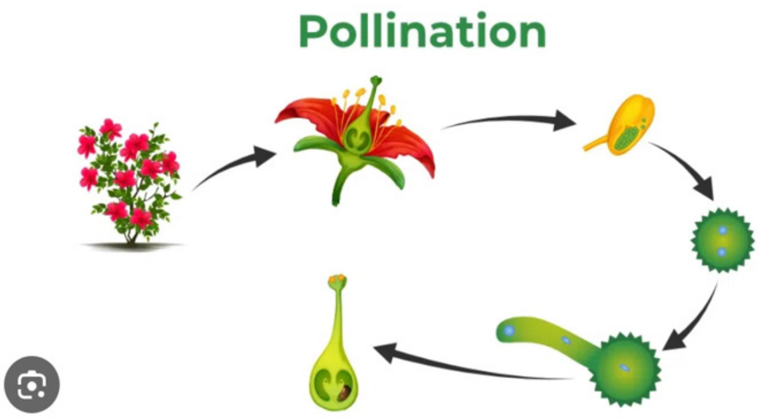


Fig. 1: Parts of a flower.



Fertilisation

Fig. 2: Fertilisation lifecycle.

As with all generative reproduction in nature, a successful fruit set requires pollination and then successful fertilisation with a fusion of the male and female germ cells. Pollination is part of the fertilisation process. The term “pollination” refers to the transport of the male pollen from the anthers of one flower and the contact of the pollen with the female stigma of the other flower.

The fertilisation process begins with successful pollination. At this point, the fruit grower can hardly influence these processes; the temperatures are now decisive. The prerequisite is a blossom that has not been damaged by frost and, if favourable, is well nourished from the previous year.

After pollination, the transfer of pollen to the stigma, the pollen germinates into pollen tubes. These penetrate the pistil of the flower. The reserve substances stored in the pollen grain are not sufficient for the entire growth of the pollen tubes up to the ovules and must, therefore, also be nourished from the pistil tissue. A well-nourished flower bud or flower, therefore, offers advantages.

Depending on the temperature, the pollen tubes reach the pistil base in two to three days and grow further into the ovary tissue to fertilise the ovules. The period between pollination and fertilisation in apples is five to seven days, depending on the temperature.
This is followed by the fertilisation process, which involves the germination of this pollen, which fertilises the ovules contained in the ovary. The fertilised ovule develops into a seed, and the tissue that develops around the seed forms the fruit.

Flowers must rely on vectors to move pollen. These vectors can include wind, water, birds, insects, butterflies, bats, and other animals that visit flowers. We call animals or insects that transfer pollen from plant to plant **“pollinators”**. A good fertilisation process and fruit set is important to produce fruit successfully. The importance of a good fertilisation process in apple orchards is shown by:

- Larger Fruit Size (e.g., small fruit can get price Rs 40/Kg while large fruit size gets Rs. 80/Kg)
- Avoid June drop (20% more fruit)
- Uniform shape
- Proper fruit set
- Better Fruit Quality

If apple orchards do not have an adequate fertilisation process, apple fruits will not be well developed during the crop cycle or may drop early. A fully fertilised apple contains 10 seeds; however, a minimum of 6-7 seeds per apple leads to good fruit development.

Topic 2 | Pollination in apple orchards

Objectives and key messages

Topic objectives	• Identify some critical pollination problems faced in apple orchards.
Key messages to bring out	The pollination process is determined by various factors, some of which can be influenced and supported by the fruit grower. Pollination is very important in apple orchards as all apple varieties are not self-pollinated. Apple varieties are self-infertile, so they require fertilisation by another apple variety for a better yield and higher production. Some critical problems faced in apple orchards regarding pollination include: • Inappropriate ratio of pollinator varieties in orchards. • Limited availability of beehives at the time of pollination. • Unfavourable weather conditions during the pollination stage. • Use of chemicals that affect the pollination by insects. • Lack of awareness of different methods of pollination in orchards.

The starting point is pollination with the successful transport of pollen to the stigma of a flower. The pollination process is determined by various factors, some of which can be influenced and supported by the fruit grower.

Pollination is very important in apple orchards as all apple varieties are not self-pollinated. Like most other temperate fruits, Apple varieties are self-infertile, so they require fertilisation by another apple variety for a better yield and higher production. Therefore, the farmers must consider various potential problems:

Some critical problems in apple orchards regarding pollination:

- Inappropriate ratio of pollinator varieties in orchards.
- Limited availability of beehives at the time of pollination.
- Unfavourable weather conditions during the pollination stage.
- Use of chemicals that affect the pollination by insects.
- Lack of awareness of different methods of pollination in orchards.

Topic 3 | Factors responsible for better pollination

Objectives and key messages

Topic objectives	• Calculate the Effective Pollination Period (EPP) to result in a successful fruit set. • Understand how the weather influences pollination. • Assess flower quality. • Understand chilling requirements for apple varieties.
Key messages to bring out	The Effective Pollination Period (EPP) refers to the timeframe when pollination can result in a successful fruit set. If an ovule remains fertilisable for ten days and the pollen tubes require six days to grow, the EPP is four days. An optimal fruit set occurs within a moderate temperature range with an extended flowering period, thereby ensuring a longer pollination period. Flower quality is hard to assess but can be indicated by fewer than 10–15 stamens, fewer than five pistils, small petals, or sparse flower clusters, often signalling inadequate nutrition from the previous year. If an apple variety's chilling requirement is not met, it may not produce a good crop or may struggle to flourish.

Effective Pollination Period

The Effective Pollination Period (EPP) refers to the timeframe following the onset of flowering when pollination can still result in a successful fruit set. If an ovule remains fertilisable for ten days and the pollen tubes require six days to grow, the EPP is four days. Hence, pollination up to the fourth-day post-flowering can still lead to fertilisation and subsequent fruit set.

For apples, EPP values of three to five days have been determined. Achieving a corresponding fruit set necessitates prompt pollination after flowering commences. Therefore, the required number of bee colonies should already be present in the orchards at the start of flowering, as delayed pollination only transports pollen to flowers but fails in fertilisation due to the unavailability of receptive ovules.

Pollination that is too late brings pollen to the pistil, but fertilisation no longer takes place, regardless of the type and method of transport.

Influence of Weather

The growth of pollen tubes and the ageing process of ovules are both temperature-sensitive. An optimal fruit set occurs within a moderate temperature range with an extended flowering period, thereby ensuring a longer pollination period. In excessively high temperatures, ovules age rapidly, impeding the growth of pollen tubes. Meanwhile, at temperatures around 5 to 10°C, the growth of pollen tubes halts, yet the ageing process of ovules persists. Prolonged cool spells similarly hamper fruit set due to ongoing ovule ageing.

Unfavourable weather conditions often lead to low fruit set, attributed to the limited viability of ovules and slower pollen tube growth, exacerbated by reduced bee flight.

Flower quality

The capability of an apple blossom to be fertilised depends on its quality. This can be determined by the previous year's cultivation and weather conditions. Frost temperatures below -2 degrees Celsius during flowering destroy the blossom organs, and fertilisation cannot take place. Furthermore, there are favourable and unfavourable combinations of varieties of self-sterile apple blossoms for successful fertilisation after pollination (sterility).

It is relatively difficult to judge flower quality. Flowers with fewer than 10 to 15 stamens and fewer than five pistils indicate insufficient supply in the previous year. If the flower clusters also have few flowers and only small transitional petals, this usually also means that the quality of the flower is impaired. The king flower is usually the best-supplied of all the flowers in the flower cluster.

If there was severe leaf damage (spider mites, hail, etc.) or heavy fruit set/yield in the previous year, or if the harvest was very late, the plant would lack the reserves to ensure optimum flower bud quality. In spring, the low carbohydrate reserves often result in small, weak flowers with shorter stems and low vigour. High-quality flowers, i.e. those that can draw on good carbohydrate reserves, are characterised by the long viability of their ovules, i.e., they are capable of fertilisation. In addition, their pistils are equipped with sufficient carbohydrate reserves, which support the growth of the pollen tubes.

Chilling requirements

Chilling requirements in apple trees refer to the cumulative exposure to cold temperatures during the dormant period necessary for the tree to break dormancy and resume normal growth and development in the spring. Different apple varieties have varying chilling requirements, which are measured in chilling hours or chilling units.

Chilling hours are the number of hours between 0°C (32°F) and 7.2°C (45°F) during the dormant period. The accumulation of these hours over the winter months is essential for the apple tree's physiological processes and the subsequent bloom and fruiting. Insufficient chilling can lead to delayed or uneven bud break, reduced flowering, and poor fruit set.

Apple varieties have different chilling requirements, with some needing fewer chilling hours to break dormancy and others requiring more. Breeders and orchardists consider these requirements when selecting varieties suitable for specific climates. If an apple variety's chilling requirement is not met, it may not produce a good crop or may struggle to flourish.

Topic 4 | Forms of sterility

Objectives and key messages

Topic objectives	• Identify the various forms of sterility that prevent fertilisation in apples.
Key messages to bring out	Apples are self-sterile or self-infertile and they cannot set fruit with its own pollen or that of another tree of the same variety. Consequently, another variety must be used as a pollinator.

As with other fruit trees, fertilisation in apples is prevented by a number of forms of sterility.

Self-sterility

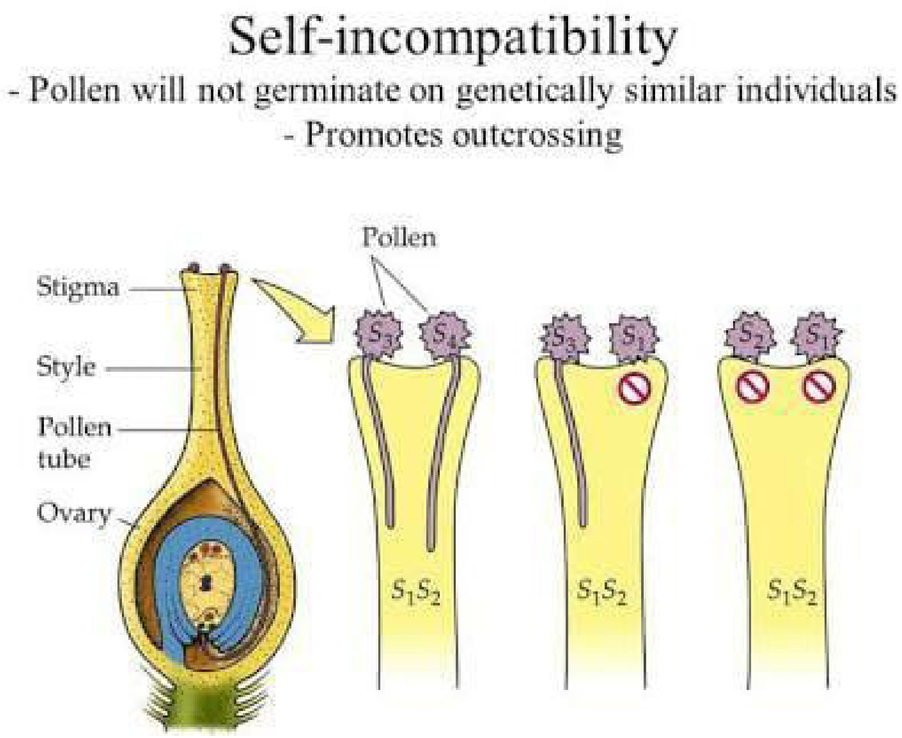


Fig. 3: Self-sterility.

Like many fruit species in temperate climates, apples and pears are self-sterile or self-infertile. The variety cannot set fruit with its own pollen or that of another tree of the same variety. Consequently, another variety must be used as a pollinator.

The several mutants of a variety behave like the parent varieties in terms of flower biology. The mutants are not capable of fertilising each other or the parent variety. Mutants of 'Golden Delicious', such as 'Smoothie', 'Reinders' and 'Type B', cannot fertilise each other or the parent variety 'Golden Delicious'. The same applies to mutants of other varieties, such as Gala, Fuji, etc.

Some scientific background: Genetically, this incompatibility is determined in different forms of a gene, the so-called alleles (S1, S2, S3.... Sn). Each apple variety is characterised by 2 alleles. If the alleles are identical, the varieties cannot fertilise each other. Therefore, no fertilisation can take place within a variety. If two varieties have only one different allele, they are 50% compatible, and the chance of successful fertilisation is 50%. If two varieties have 2 different alleles, they are 100% compatible. Their combination leads to optimal pollination, as each pollen is capable of fertilisation. Genetically related varieties such as Golden Delicious (= 1 of 2 parents) and Gala (bred descendant) are often only partially compatible. Knowing the different genotypes for the incompatibility alleles makes it possible to optimise natural pollination between the trees in an orchard.

Pollen based sterility

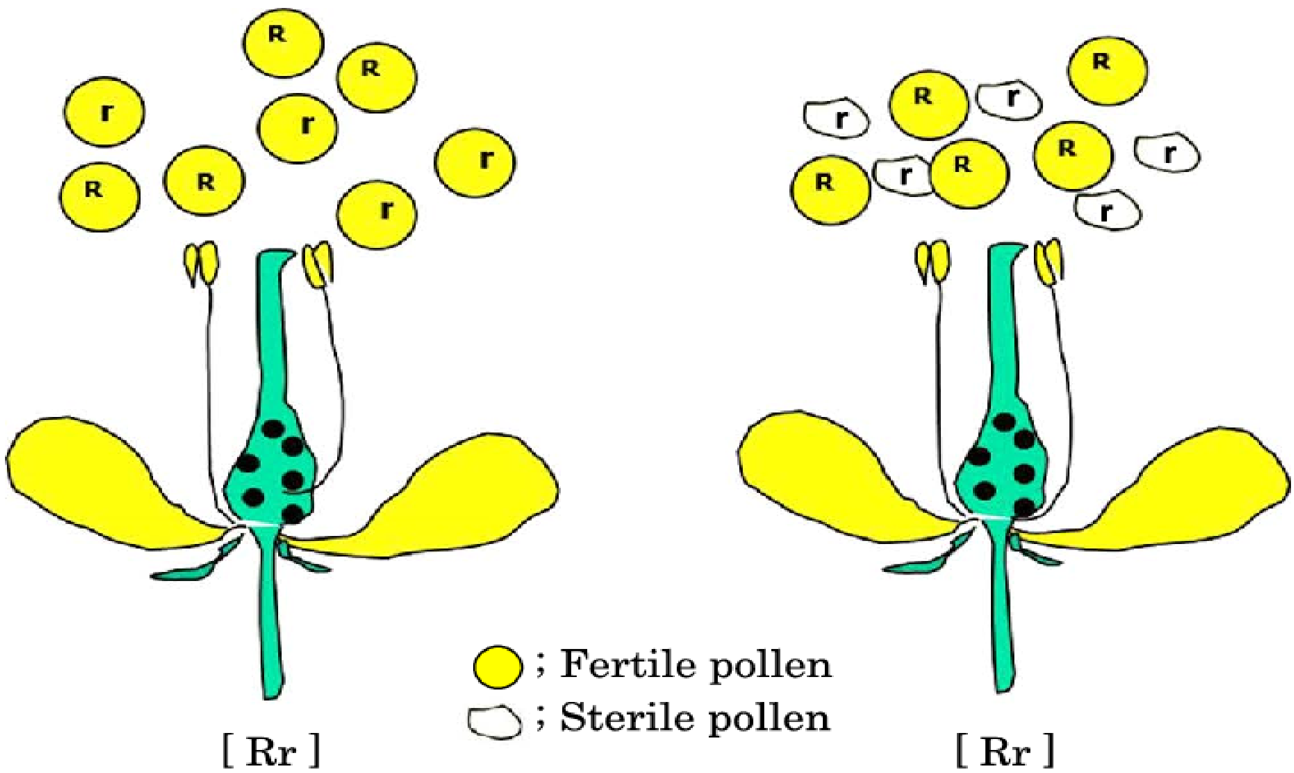


Fig. 4: Pollen based sterility.

Pollen formation is irregular in the rather rare triploid (3n = 51) apple varieties (e.g. Jonagold), i.e. apple varieties with a triple instead of a double set of chromosomes. The pollen of these varieties cannot fertilise other varieties and are not cross-pollinated.

Pollen-based sterility refers to a condition in plants where the pollen produced by the male reproductive organs (anthers) is either non-functional or incapable of fertilizing the female reproductive organs (stigma) of the same or another flower. This sterility can hinder successful fertilization and seed production.

Topic 5 | The role of insects in transporting pollen

Objectives and key messages

Topic objectives	• Appreciate the importance of insects in pollination.
Key messages to bring out	The animals known for effective flower pollination primarily include honeybees, followed by wild bees, butterflies, hummingbirds, moths, certain flies and wasps, and nectar-feeding bats. The honeybee stands out as the key pollinator. For optimal pollination, orchards should ideally have 2 to 4 bee colonies per hectare of fruit. Insecticide application during blossoming or even post-blossoming should be avoided to safeguard bees and other beneficial insects. Insect hotels can support the population of wild bees.

The apple tree relies on insects for pollinating its flowers, a pivotal process in fruit production. Wind alone doesn't suffice for pollination. Apple blossoms produce limited pollen amounts, and these grains are often clumped together, making them less airborne due to their weight. Hence, it's crucial to maintain a robust insect population during the flowering period.

The animals known for effective flower pollination primarily include honeybees, followed by wild bees, butterflies, hummingbirds, moths, certain flies and wasps, and nectar-feeding bats. Among these, the honeybee stands out as the key pollinator. Its significance arises from overwintering as a colony, enabling a large workforce to be active during spring flowering. Given the early profusion of apple flowers, honeybees typically account for the bulk of pollination.

For optimal pollination, orchards should ideally have 2 to 4 bee colonies per hectare of fruit. Orchard owners can ensure adequate honeybee presence by either keeping their colonies or collaborating with specialised beekeepers, who may provide colonies for hire based on honeybee availability.

Timing is crucial. Honeybees should be in the orchards as soon as flowering begins, around when 5-10% of the flowers have bloomed. Beekeepers must establish favourable conditions: strategically placing beehives in sheltered areas to shield the bees from harsh weather and potential threats. Protecting bees from insecticides is necessary. Insecticide application during blossoming or even post-blossoming should be avoided to safeguard bees and other beneficial insects. Adhering strictly to bee protection regulations when using plant protection products is essential. Regular checks of beehives for deceased insects are also crucial for their well-being.

Fig. 5: Wild bee hotel.

Naturally occurring wild bees, bumblebees, and other insects play a significant role in pollination, especially because they sometimes forage at lower temperatures, unlike honeybees that tend to stay in the hive below 12 degrees Celsius. Ideally, these different species complement each other. Fruit producers actively protect and support the various insect species found in nature. In cases where temperatures remain consistently cold during the flowering season, bumblebee colonies can also be procured.

Both bees and bumblebees could distinguish between beneficial and less favourable plants for nectar collection. One criterion for these insects is the sugar content in the nectar. Apples typically have a nectar sugar concentration of 21%, while pears contain significantly less sugar. Bees naturally prefer flowers with higher sugar content, sometimes leading to lower fruit set. During the flowering period, it’s advisable to avoid nearby competing crops that have attractive flowers for insects, such as rapeseed, mustard, or radishes.

If natural habitats are lacking, insect hotels can support the population of wild bees. Wild bees fly even at low temperatures. However, due to the small number of individuals, they do not have the efficiency of honeybee colonies.

Topic 6 | Optimising fertilisation outcomes

Objectives and key messages

Topic objectives	• Identify effective orchard layouts to achieve the ideal ratio of pollinizing varieties for maximum fruit production. • Evaluate grafting and pollen dispensers as innovative alternatives to dedicated pollinator trees. • Examine the role of water sources in enhancing bee activity and pollination success. • Identify best practices for safely and efficiently transporting bees to optimize pollination. • Recognize the importance of maintaining a balanced fruit set for quality and yield. • Identify the eight key factors contributing to low fruit sets in orchards.
Key messages to bring out	It is essential to have an adequate number of trees of a pollinator variety within the flight range of pollinators like bees, bumblebees, and other insects. There are various land layouts that can be used. Alternatives to dedicated pollinator trees or mixed variety plantings are a) grafting where a branch of a pollinator variety onto the main tree, and b) Hive pollen dispensers are devices placed at the hive's entrance and are constructed so that outgoing foragers are forced to walk through the pollen. If the water source is available within 100 meters of the orchard, bees will spend less time searching for water, and more time is available for pollination. When transporting bees, several important aspects must be considered to ensure the health and safety of the bees. Aim to achieve a balanced fruit set (percentage of flowers that develop into fruit), ensuring that 10–30% of flowers develop into fruit. Avoid higher fruit sets to prevent alternate bearing and to produce larger, higher-quality fruit. There are eight possible causes of a low fruit set despite abundant flowering.

Pollinizing Varieties (Pollinisers)

Since pollen from flowers of the same variety does not ensure successful fertilisation, care must be taken to ensure that the flowers are pollinated by pollen of a different variety. Studies by the Central Institute for Subtropical Horticulture have shown that the compatibility of the varieties planted in India varies greatly based on the fruit set after pollination. Royal Delicious as a pollen source resulted in a very low fruit set. The pollen leads to low fertilisation of various other varieties.

In traditional orchards of Himachal Pradesh, there is a very low ratio of pollinizing varieties, due to which there is a considerable lack of abundant pollens during the blossom period. According to UHF, the ratio of pollinizing varieties in apple orchards should be 33%. There are various ways to increase the pollinizing varieties ratio in orchards to handle this situation. This can be done through multiple methods.

It is essential to have an adequate number of trees of a pollinator variety within the flight range of pollinators like bees, bumblebees, and other insects. Pollinator varieties encompass those without identical incompatibility genes to the primary variety. Achieving this involves planting orchards with diverse varieties. If multiple financially viable varieties exist, intermixing rows or trees is preferred. The timing of flowering among these varieties is crucial. The greater the variety of cultivars within an area, the wider the pollen diversity. Royal Delicious with the entire pollen source resulted in a very poor fruit set.

There is very little relationship with the cultivars for fruits and therefore high compatibility in pollination.

Fig. 6: Ornamental apple "Manchurian".

Fig. 7: Various ornamental apple varieties.

Land layouts

Therefore, when planning to establish new orchards, the land layout should ensure an optimum ratio of pollinizing varieties in the orchard. There are different ways of laying out orchards. In regions where cultivating a single highly productive or profitable variety is more economically advantageous, using isolated trees with specific pollinator varieties is plausible. These trees, often ornamental apples with low relatedness but 100% compatibility and ample pollen production, should constitute roughly 5% of evenly dispersed trees among the productive varieties. Although these ornamental apples themselves lack commercial viability, they're usually planted in less preferred locations to free up prime spots. They can also be placed in traditional beehive spots.

The flowers of ornamental apples often have more stamens than conventional apple varieties (up to 40) and, in normal years with moderate temperatures, produce a large amount of pollen with a high germination capacity during flowering. It is not uncommon for the fruits of ornamental apples to be attacked by pathogenic fungi or become a welcoming food source for mice. Both are unwanted by farmers because they can spread in the main crop.

Compared to conventional cultivars, ornamental apple trees do not produce a countable yield, apart from their fertilisation performance, despite being comparable in costs and taking up space. For low-growing ornamental apples (Evereste, Red Sentinel, Golden. Gem), the planting distance in the row can be reduced to 0.75 to 0.8 metres. But, for normal to robust growing varieties (M. Hopa, Hillieri, Prof. Sprenger), a planting distance of 1.0 metres should be maintained.

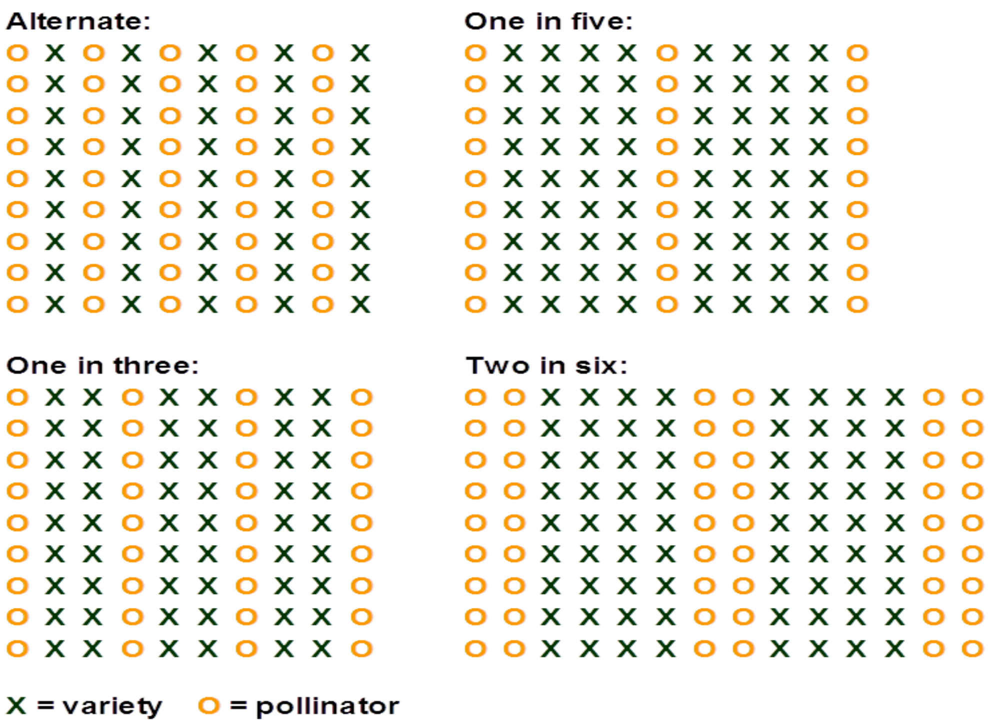


Fig. 8: The one in nine method (pollinators interspersed with the main variety).

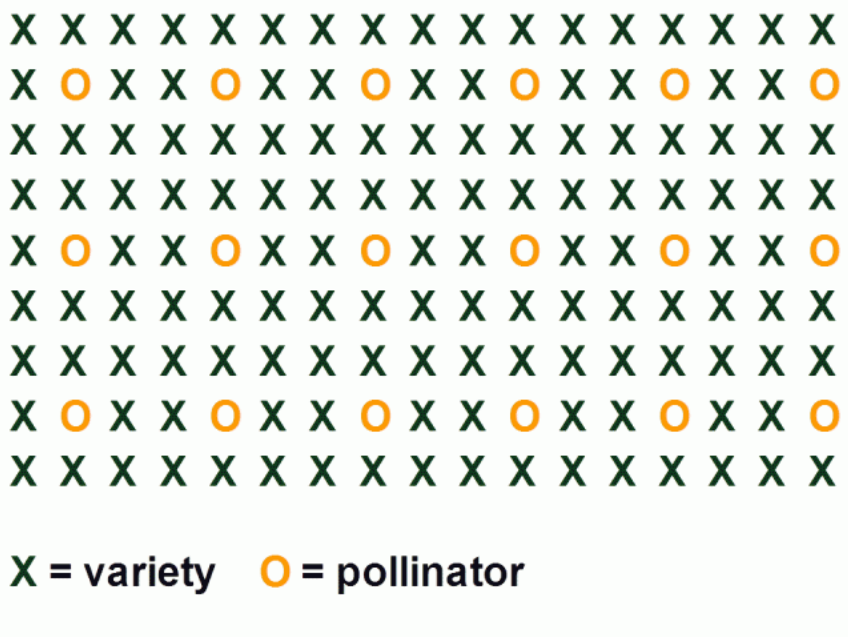


Fig. 9: The full row method (pollinator varieties are planted in full rows).

Grafting

An alternative to dedicated pollinator trees or mixed variety plantings involves grafting a branch of a pollinator variety onto the main tree. Each tree then possesses its own pollinator within its domain, but this method also occupies productive space.

One of them is grafting top-working trees where required with suitable pollinizer cultivars throughout the orchards. For this method, choose appropriate pollinizer varieties according to your orchards' conditions and then graft these varieties' scions on side branches of trees so that after two to three years, they start blooming and help in pollination by increasing pollen numbers in orchards.

Fig. 10: Grafting pollinizer varieties.

Fig. 11: Grafted pollinizer variety in bloom.

Fig. 12: Cut branch of a pollinator variety in a plastic bucket filled with water.

Instead of utilising a live tree or grafted branch of a pollinator variety, another approach is to place a cut branch of a pollinator variety in a bottle or plastic bag filled with water and tied within the tree in orchards wherever required. This method will also help with better pollination. But of course, it is additional work to cut branches several times. Their efficiency is very uncertain because, depending on the weather, the flowers age very quickly, and their attractiveness for pollinating insects rapidly diminishes. It is also uncertain where the branches with the flowers should come from.

Fig. 13: A plastic bag with branch of a pollinising variety tied to an apple tree.

Pollen Dispensers

Another option is using pollen dispensers. Hive pollen dispensers are devices placed at the hive's entrance and are constructed so that outgoing foragers are forced to walk through the pollen. This facilitates the pollen adhering to the body of foragers and is effective in pollinizer-deficient orchards and conditions when flowering does not synchronize.

Fig. 14: Types of pollen dispensers.

Fixation and use of pollen dispenser

The pollen dispenser is fixed at the hive entrance of an Apis mellifera strong colony. Two grams of dehisced pollen should be mixed with powdered and dried anther husk in a 1:1 ratio.
The mixture should be kept in a pollen dispenser daily from 09:00 to 11:00 A.M. continuously for five days.

All of the latter methods are mainly used where one variety dominates in cultivation, and therefore, there is no financial interest in another variety as a pollinator. They are compromises that also require effort and attention. The decisive factor in all cases is that a sufficient amount of foreign pollen can be taken up by the pollinating insects and transported to the flowers.

Management of honeybee population in orchard

Honeybees are the most dominant pollinators in apple orchards. Interestingly, these can be easily managed, and depending upon the required concentration, they can be placed strategically in an orchard. Three strong honeybee colonies per hectare are recommended for orchards having a 25-33% polliniser population. Place honeybee colonies in apple orchards at 5-10% bloom. The colonies should have a strength of 6-8 bee frames, with 3-4 frames of broods and a prolific queen. Beekeepers must establish favourable conditions: strategically placing beehives in sheltered areas to shield the bees from harsh weather and potential threats.

Bees work best when temperatures are above 18oC. A guideline states that on a hot day, at least 75 bees should leave the entrance every minute from the hive having 20,000 or more adult bees.

However, honeybee activity is affected by environmental factors such as airflow, clouds, the temperature of the previous night, and how long the hive has been in its present location. Cool weather, rain, or winds may prevent bees from leaving their hives.

Fig. 15 & 16: Bees pollinating apple flowers.

Water Requirements

Bees can generally fly considerable distances in need of water. If there is no source of water near orchards, then it will fly to great distances to find it. They use water to dilute the collected nectar and feed it to the larvae in the hives. If the water source is available within 100 meters of the orchard, bees will spend less time searching for water, and more time is available for pollination. So, creating favourable conditions for bees is sensible and beneficial. Bees require access to water, and fruit growers must consider this need by providing clean and fresh water sources near the apiary.

Fig. 17: An apple orchard with beehives.

Fig. 18: A standard beebox.

Movement of Honeybee Colonies

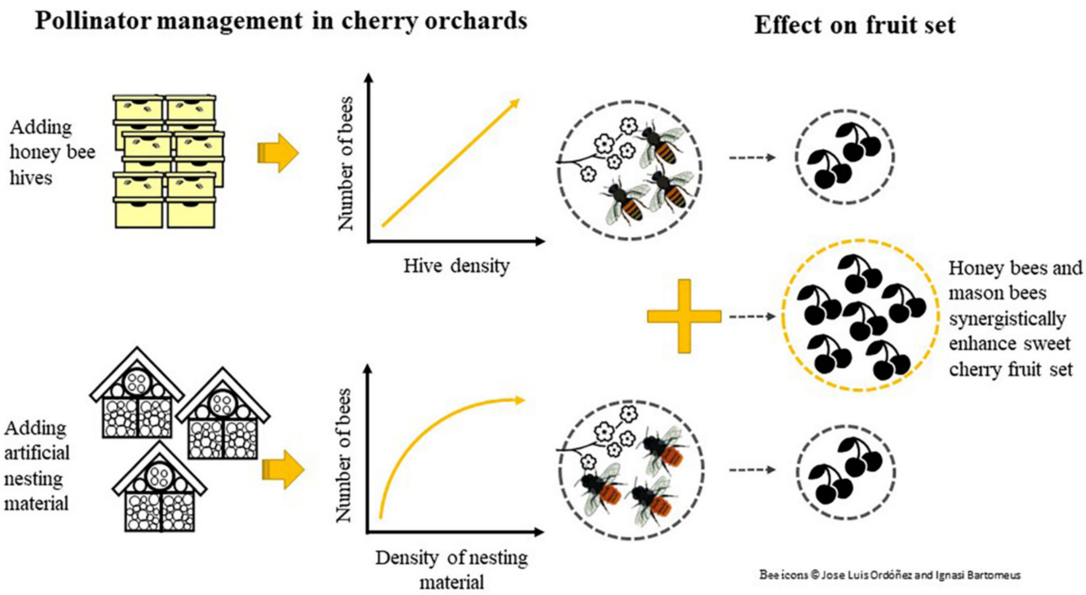


Fig. 19: Effect on fruit set by adding honeybee hives and artificial nesting material.

Every bee transport is a stressful situation for the colony. It would be ideal to transport the colony at night, as this is when all the bees are in the hive. When transporting bees, several important aspects must be considered to ensure the health and safety of the bees:

- Ventilation and temperature: bees need sufficient ventilation during transport to ensure good air circulation. Care must be taken to ensure that the grid floor is open and the entrance hole is only closed with a grid and not a wedge. Temperature control is also important, as too high or too low temperatures can harm the bees.
- Securing the hives: Hives must be stable and securely fastened during transport to prevent them from shifting or being damaged during the journey.
- Avoidance of stress and vibrations: Smooth transport without strong vibrations is essential to minimise stress for the bees. Strong vibrations or shocks can make the bees restless and lead to injuries. Bees tend to become fuzzy under stress. This causes the temperature to rise, and the bees die when they become sticky with wax and honey that is becoming liquid.
- Protection from foreign substances: To maintain the well-being of the bees, hives should be protected from the entry of foreign bodies, dust, or other potentially harmful substances.
- Transport time: The transport time should be kept as short as possible to minimise stress for the bees. Long transport times can lead to exhaustion and an increased mortality rate.

Use of Pheromones in Pollination

Pheromones are a mixture of chemical substances released by bees into their hives or environment that cause changes in the behaviour of other bees. Honeybees produce a number of pheromones in different situations. For pollination purposes, Brood pheromones are used. These pheromones are produced by honeybee larvae. These pheromones tell bees that larvae are present and require more pollen.

These pheromones encourage worker bees to collect more pollen and visit more flowers. By visiting more flowers, there are better chances of cross-pollination in apple orchards, which results in a better fruit set. It may also benefit the colony, including the production of more brood and honey and increased potential for colony splitting. Some pheromones are sprayed at the time of bloom to attract pollinator insects and improve their movement within the orchards to ensure better pollination.

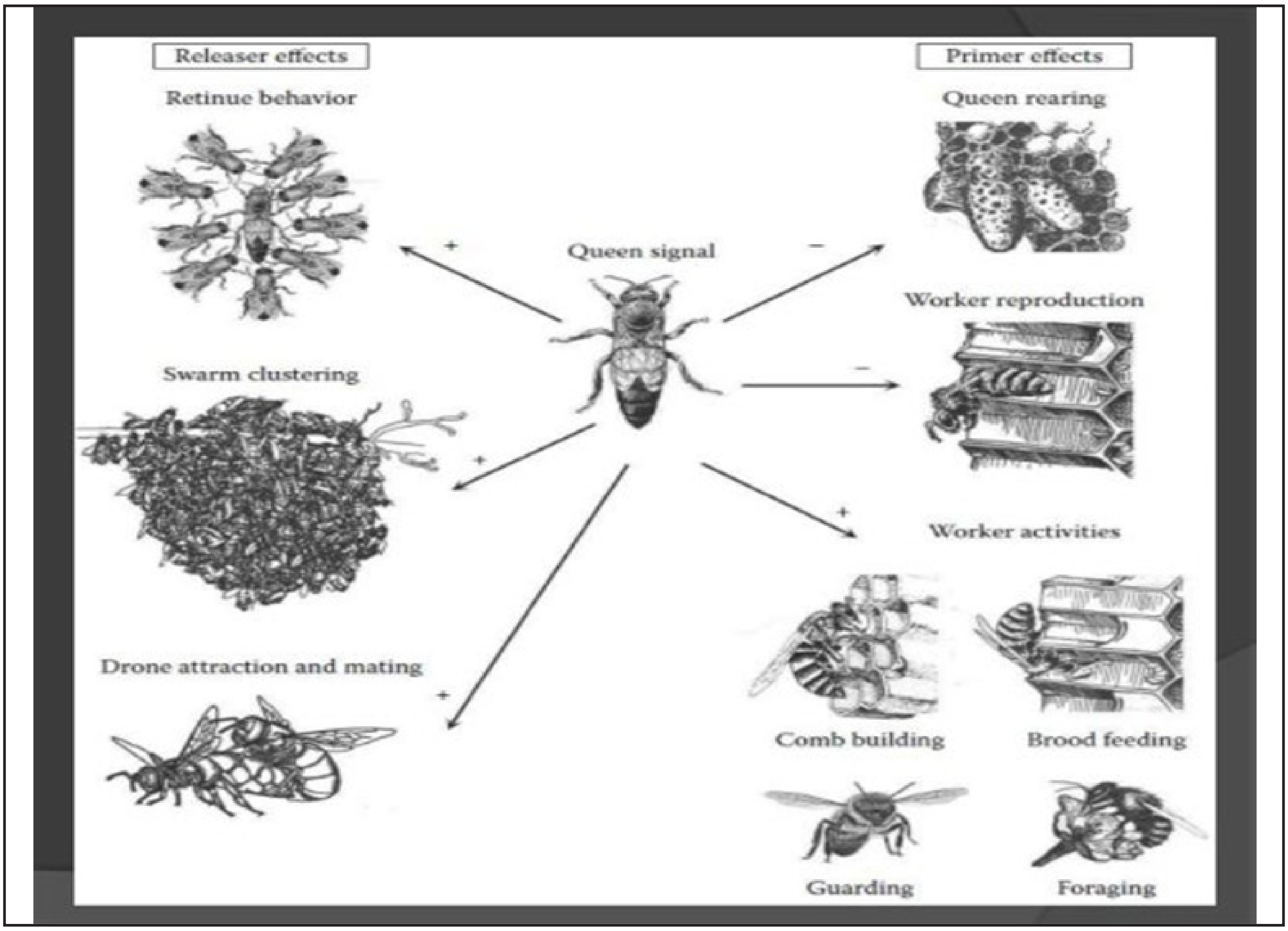


Fig. 20: Effect of different types of pheromones on behavioural changes of honeybees.

Fertilisation success and further development of the fruit set

Fruit set is the percentage of flowers that develop into fruit. This percentage is usually between 10 and 30 %, depending on the year, variety, flowering density and weather conditions. In principle, fruit growers aim for an average annual yield. Excessive fruit sets are negative because trees go into alternation and do not produce fruit of sufficient size.

The quality of the flower buds exerts the first influence on fruit set and fruit development. High-quality flowers preferentially set fruit, and the quality is reflected in the bud and flower size. Urea spraying in the period between harvest and leaf fall before winter delays leaf fall and improves the nitrogen status of the trees, as a large proportion of the nitrogen goes into the tree's reserves.

After generally successful fertilisation, the ultimate aim is to achieve a good but not excessive fruit yield. The fruit grower can hardly positively influence the further development of the fruit set after fertilisation. Hormones can be used in the early stages of development to reduce harmful excessive fruit set.

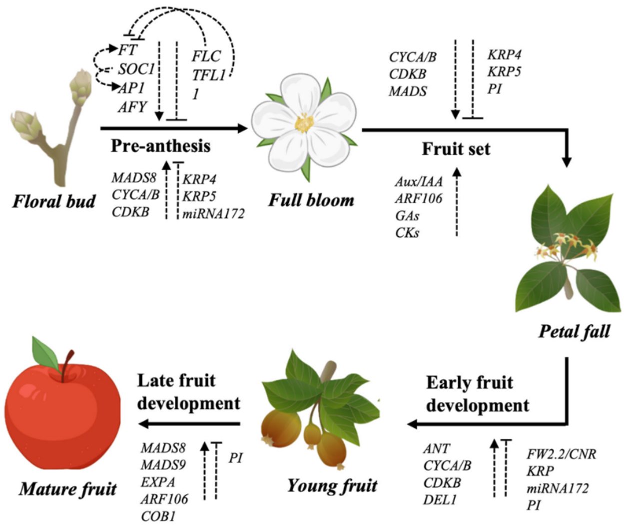


Fig. 21: Development of fruit set.

__Some scientific background:__ After fertilisation, the ovules develop and influence further development through phytohormone production.

- Formation of separating tissue at the base of the stalk is prevented, and the tendency to June fall is reduced
- Cell division and cell elongation are stimulated, the apples grow evenly,
- Transport of nutrients into the fruit is initiated, and the apples become sweeter
- This clear relationship between fruit development and phytohormone content only exists at the beginning of fruit development. In the later stages of fruit growth, the phytohormone content drops sharply, but the fruit still shows intensive growth. The seeds no longer have any significant influence on fruit development after June. As the ovules show increased phytohormone production at the beginning of fruit development, this hormone surge is sufficient to initiate fruit development.

Possible causes for lack of fertilisation

If no or only a few fruits are formed despite abundant flowering, this can have various causes:

1. The planted variety is self-infertile, and the tree is very far away from the tree with the pollinator variety, or there is no suitable variety for fertilisation at all.
2. The planted variety is self-infertile, and the second tree, which is suitable as a pollinator variety, blooms with a time delay so that one variety is no longer ready for fertilisation when the other blooms.
3. There are too few bee colonies in the crops.
4. There are no natural insects, such as wild bees, bumblebees, etc., in the neighbourhood.
5. There is no bee flight when the fruit tree is in bloom because it is too wet and/or too cold.
6. A cold snap or night frost causes the blossoms to freeze.
7. Although all the conditions for a bee flight are present, the bees find a more attractive food supply (e.g. in a nearby mustard field) and avoid the fruit blossoms.
8. The flowers produce little nectar, or the nectar production only lasts a few days, so that the flowers are not attractive enough for insects. This is particularly the case with pears and sour cherries.

Topic 7 | Wild insect pollinators

Objectives and key messages

Topic objectives	• Understand the crucial role of wild insect pollinators in enhancing apple production.
Key messages to bring out	Apple production in Himachal Pradesh is severely impacted by inadequate pollination. Bee pollination is critical for improving apple quality and yield. Preference for the European honeybee in India have contributed to the declining populations of the Indian honeybee. Indian honeybees are more suited to local climatic conditions and are more likely to survive in extreme weather conditions. Wild bees, flies, bats, wasps, beetles, moths, and butterflies are other beneficial insects that provide the rest of the pollination. Pollination services are more effective and stable when there is high pollinator diversity and abundance, which leads to higher crop production.

Pollinators and pollination are crucial in the functioning of terrestrial ecosystems, including those dominated by agriculture. Most plants need animals, especially insects, to move their pollen from the male to the female parts of the flower and allow seed production. The productivity of many crops is dependent on optimum pollination, so a decline in pollinator abundance will compromise global agricultural production. Approximately 70% of the tropical crop species are dependent on pollinators for pollination and optimum yields, such as fruits and vegetables. Since India is the world's second-largest producer of fruits and vegetables, the economic value of pollination's contribution in the country is estimated at $726 million. In Himachal Pradesh, it is estimated at $365 million.

In agriculture, artificial methods of pollination have only partially reduced plants' dependence on pollinators. Pollination by insects, primarily bees, remains an essential step in the production of many crops, including melons, squash, apples, berries, and almonds.

The decline of pollinating insects has serious socioeconomic consequences for the large population of small and marginal farmers. For them, a fall in yield level would be detrimental to subsistence. Possible drivers for the decline of insect pollinators include habitat loss, intensive land use, the introduction of foreign species, pollution from chemical inputs such as pesticides, the introduction and spread of parasites, detrimental beekeeping practices, and climate change. This demands a response from farmers, land managers, conservationists, and political decision-makers to the impending 'global pollinator crisis'.

Understanding the causes of pollination failure in plants can aid effective pollinator conservation strategies, such as protecting and restoring plant resources and bee flora, habitat management and creation of protected natural areas, and reduction of chemical inputs on farms. These will ensure food provision, mating, and nesting sites for pollinators.

Pollination Deficit in Apple Orchards

Pollination is crucial to growing quality apples, and surveys in Himachal Pradesh have revealed that inadequate pollination has severely affected apple production. Pollination by bees enhances fruit set, overall fruit yield, weight, shape, and colour of apple fruit and reduces premature fruit drop. This inadequate pollination in apples is largely attributed to declining populations of natural pollinators. Two major factors contributing to pollinator decline include an increase in monoculture-dominated agriculture and the negative impacts of modern agricultural interventions such as the use of pesticides.

The Honeybee

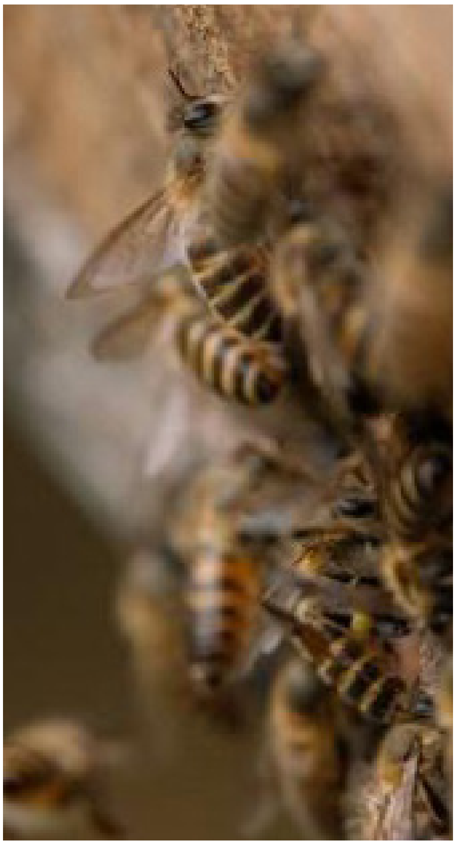


Fig. 22: The honeybee.

The leading insect group involved in managed pollination are the bees, particularly the honeybee *(genus Apis)*. Despite their importance as honey producers, their role as a pollinator remains the most important economic contribution. Honeybees can be easily kept and can pollinate a wide spectrum of plants. Both wild and managed bee species make an important contribution to crop pollination. The European honeybee *(Apis mellifera)* is a widespread domesticated bee worldwide.

Preference for the European honeybee in India and the decline of traditional methods of beekeeping have contributed to the declining populations of the Indian honeybee. Indian honeybees are a native species of efficient pollinators that can easily be managed and placed in orchards when the trees bloom. They have been used in India in traditional beekeeping and are a crucial cultural and natural asset. Habitat loss also primarily affects Indian honeybees since they depend on natural rather than managed nesting sites. Indian honeybees are more suited to local climatic conditions and are more likely to survive in extreme weather conditions.

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Wild Insect Pollinators

Honeybees are not the only insects that pollinate the crops. Wild bees, flies, bats, wasps, beetles, moths, and butterflies are other beneficial insects that provide the rest of the pollination. Pollination services are more effective and stable when there is high pollinator diversity and abundance, which leads to higher crop production.

There are more than 20,000 bee species on Earth, including 199 species found in Himachal Pradesh alone. Important wild bees for pollination in apple orchards include bumblebees (Bombus spp.), leafcutter bees (Megachile spp.), mining bees (Andrena spp.), and mason bees (Osmia spp.).

For some crops, wild pollinators contribute more to global crop production than honeybees. Managed honeybees cannot fully compensate for the loss of wild pollinators. This means that actions must be taken to protect the natural areas surrounding the orchards where wild pollinators live and reduce pesticide use in orchards. In-farm bee habitats should also be promoted to ensure that wild pollinators continue to visit.

Fig. 23: Wild insect pollinators.

A reduction in wild pollinator diversity is harmful not only to cultivated crops but can also be disastrous for wild plants. Farms close to forest areas have a higher number of wild pollinators. Therefore, it is important to conserve forest areas.

Topic 8 | Protecting bees and wild insects

Objectives and key messages

Topic objectives	• Identify 11 measures to protect bees when planting trees. • Identify active substances in plant protection products that are hazardous to bees.
Key messages to bring out	There are 11 simple and cheap measures to protect bees on apple orchards. There are certain substances/chemicals in plant protection products that are harmful to bees.

The simplest and cheapest pollination measure is the protection of bees and other pollinators in orchards, as these insects play an essential role in pollinating fruit trees. Here are some measures to protect bees when protecting plants in orchards:

- Choosing bee-friendly pesticides: Fruit growers must select pesticides that are less harmful to bees. This includes using pesticides with low toxicity to bees and avoiding applications during the flowering period.
- Avoidance of overdosing: Fruit growers dose their pesticides according to specified instructions. Excessive doses are not effective, damage bees and are expensive.
- Timed applications: Since bees are most active during the flowering period, fruit growers must apply plant protection products outside the fruit trees' flowering periods. This reduces the risk of direct exposure. Bees are not active at night.
- Avoid unintentional treatments of other flowering plants in the crops under or between the trees or in neighbouring areas. Insecticides harmful to bees applied to these flowers will damage wild insect populations. Beekeepers will avoid the places where their honeybees will be harmed.
- Remove the flowers in the endangered areas. Fruit growers mow the flowers in the crops to be treated before applying toxic pesticides.
- Optimisation of plant protection application techniques: Fruit growers must use plant protection techniques to apply plant protection products only to fruit trees and not to areas that do not require plant protection. For this purpose, the technology must be set for low drift and targeted application. The blower must not be set too high. This saves money and protects

beneficial insects.

- Respect for the beehive of the bee colony: Fruit growers do not use products that are harmful to bees within a radius of at least 20 metres around a beehive.
- Monitoring and control: Fruit growers monitor the occurrence of pests and diseases in orchards. Plant protection applications are used not according to the routine but according to actual needs. This saves money, avoids residues on the fruit and protects the environment.
- Communication and cooperation: Fruit growers should communicate with beekeepers and local beekeeping associations to coordinate the flowering phases of the fruit trees and the planned pesticide applications. Beekeepers can remove the bee colonies from the crops in good time during treatments or close the flight holes.
- Training and education: Fruit growers and workers in orchards are regularly informed about the correct handling of plant protection products and the protection of pollinators.
- Prohibition of particularly hazardous pesticides: Fruit growers must comply with legal regulations and refrain from using pesticides that are particularly hazardous to bees.

In addition to carefully using pesticides, fruit growers can also actively ensure better living conditions. They may create bee protection strips near orchards. Alternative sources of food and habitat, even outside of the fruit blossom, can be offered, and habitats for insects on unused land can be maintained.

All preparations containing one of the following active substances fall into the category of plant protection products that are hazardous to bees:

- Abamectin
- a-Cypermethrin
- Bifenthrin
- Carbaryl
- Chlorpyriphos (Dursban)
- Chlorpyriphos-methyl
- Chlothiadin
- Cyfluthrin
- Cypermethrin
- Deltamethrin
- Diazinon
- Dichlobenil
- Dichlorphos
- Dimethoate
- Diqua,
- Esfenvalerat
- Etofenprox
- Fenoxycarb
- Flufenoxuron
- Imidacloprid
- Indoxycarb
- Lambda cyhalothrin
- Malathion
- Methiocarb
- Methomyl
- Milbemectin
- Oxydemeton-methyl
- Parathion
- Phosmet
- Pyridaben
- Pyrimiphos-methyl
- Spinosad
- Spirodiclofen
- Teflubenzuron
- Thiamethoxam
- Triflumuron

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