INDIAN JOURNAL OF
ARID HORTICULTURE
2017, Vol. 12 (1-2):1-9

Pollination and pollenization in fruit crops

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(Received: 30.01.2018; Accepted: 6.03.2018)

Abstract

Some fruit crops are monoecious in nature, while many others possess hermaphrodite flowers. On the contrary, there are fruit crops which are dioecious in nature. There may be various kinds of situations which mar effective pollination. Diploid plants produce abundant pollen, however triploid plants fail to do so. The flowers some time bloom earlier to critical period of receptivity of stigma and some time it may flower beyond the receptivity of stigma. All these contraventions distract the process of pollination and consequently, pollenization becomes inevitable. In present article attempt has been made to cover all such related aspects of pollination and pollenization so as to have better understanding of these phenomena towards better fruit set.

Key words: *Pollination, pollenization, pollenizers, pollinator effective pollination period, transference of pollen, and pollinator effectivity.*

Introduction

Pollination is the act of transferring of pollen grains from anther to the stigma of the flowers. It is one of the first and most important steps in successful fruit production, and for almost 90 per cent of angiosperms (Ollerton *et al.* 2011) this vital ecological service is facilitated through insect vectors, mainly bees (Kevan and Baker 1983; Michener 2007). When the pollen grains of anther is transferred to the stigma of same flower, or different flowers on the same plant, the process is referred to as self pollination or autogamy, e.g. citrus, guava, grape, etc. Autogamy occures within hermaphrodite flowers or perfect flowers. However, transfer of pollen grains from anther of one flower to the stigma of the another flower located on different plant of the different cultivar of same/related species, is referred to as cross pollination or allogamy, e.g. apple, pear, mango, walnut, aonla, etc. The mode of pollination is influenced by several factors cleistogamy, homogamy and geitonogamy are notable factors in self pollination. In cleistogamy condition the pollination and fertilization occur within the closed flower, e.g. grape. The plants expressing homogamy have male and female gametes matured at same time which favours self pollination, e.g. citrus, peach, apricot, etc. Plants follow geitonogamy mode of pollination. Actually, geitonogamy is a greek word derived from *geiton* which means neighbour and *gamein* which means to marry. Thus, it is the process of pollination of flower by another flower of same flowering plant. This process leads to reduce outcrossing, e.g. orchids. Chasmogamy, self incompatibility, male sterility, dichogamy are important determinant of cross pollination. Some plants produce flower which possess either of male or female sexes. It is also known as dicliny. This is of two types a) monoecy- in this condition the male and female flowers are produced on the same plant at different locations, e.g. walnut, jackfruit, aonla, pecannut, hazelnut, chestnut etc. b) dioecy- in this condition the male and female flowers are produced on different plants, e.g. date palm, papaya, kiwifruit, persimmon, pistachio nut, etc. In case of chasmogagamy, the flowers open and their reproductive organs are exposed to external environment and subsequently they are cross pollinated (Simpson, 2006). These flowers are attractive so, they attract insects (like- bees, butterflies, moths etc.), birds, bats, squirrels and animals for pollination. In some cases self incompatibility is encountered. In this situation pollens are unable to fertilize the ovule upon self pollination. It is found in important fruits such as apple, pear, apricot, almond, cherry, mango, pineapple, etc. It is mainly classified as sporophytic self incompatibility- a kind in which the incompatibility reaction of the pollen is determined by the genotype of the plant on which it is produced, e.g. mango; and gametophytic self incompatibility- a mechanism in which incompatibility reaction of the pollen is determined by its own genotype rather than the plant on which it is produced, e.g. apple, pear, almond, cherry, loquat, pumelo, etc. Male sterility makes the plant inclined to cross pollination. The plant expresses failureness to produce functional anthers/pollens, e.g. triploid banana, triploid apple varieties such as King of Topkins, Blenheim Orange, etc. In some instance dichogamy leads to cross pollination. The plants have differential in time of maturity of male or female gamete. It is of two types a) protoandry- in which anthers mature before the pistil, e.g. walnut, coconut, etc., and b) protogymy- in which pistils mature before the anthers, e.g. banana, annona, pomegranate, plum, avocado, fig, sapota etc.

In control of these set of mechanism plants undergo self and cross pollination. The uncertainty of no fruitfulness/poor fruit set is more in case of cross pollination which is very often susceptible to failure. But, it can be arrested falling preservation of pollen. Pollen storage is a useful technique to establish a pollen bank which can be used to store genetic diversity and it can be used by plant breeders for plant improvement. This technique may be very helpful for monoecious plants to avoid hybridization barriers. Pollen bank can provide the viable pollen to commercial growers of fruits.

Pollen storage can be considered as a new emerging technology for genetic conservation (Roberts. 1975; Omura and Akihama. 1980; Akihama and Omura. 1986). Also since pollen is available easily in large quantity on most of the fruits trees and is a compact gene material. variable gene pool representing species and location can be stored. especially in cryogenic containers. occupying a relatively smaller space. The National Seed Storage Laboratory at Frot Collins. Kolorado. USA. has started pollen storage as one of the components of germplasm preservation (Standwood *et al.*, 1986). Cryogenic storage of pollen is easy and has been considered of great value in supplementing the usual germplasm preservation techniques by seed and clonal storage. and for enriching haploid gene pool.

Effective pollination period (EPP)

During every time and also at the very movement of receptivity of stigma. availability of viable pollen is not always assured. In order to help facilitate the pollination especially during lean period of availability of pollen grains. preservation is inevitable. The concept of effective pollination period (EPP) was developed by Williams in 1965 to asses flower receptivity. Effective pollination period is defined as the number of days during which pollination is effective in producing a fruit and is determined by the longevity of the ovules minus the time lag between pollination and fertilization. If effective pollination period is longer. chances of fertilization and seed development are greater. Pollination must occur within 2 to 4 days after anthesis otherwise the embryo sac will degenerate before fertilization. EPP plays a very important role in fruit set especially in temperate fruits and can be as short as 3 days and as long as 12 days. Williams developed a temperature response index for the estimation of time required for a pollen tube to grow and reach to the embryo sac. The index is based on the daily mean temperature over a period of time and when the pollen tube growth index reach to 100 per cent or above. the pollen tube should have reached the embryo sac and fertilized the ovule.

Transference of pollen/techniques of pollination

A pollen grain produced by the anther of the male flower. must be transferred to a stigma of the female flower. is very essential for successful pollination. In cross pollinated plant species it requires some transference agencies. It is affected by many of agencies like insects. birds. animals. wind. water etc. Transference of pollen by insects is also known as entomophily mode of pollination. In *Prunus*, pollen is transferred by insects. mainly of the *Apis genus*. belonging to the family Apidae (Griggs. 1953).

It mainly includes bees pollination (melittophily or hymenopterophily). butterflies pollination (psychophily). moth pollination (phalaenophily). housefly pollination (sapromyiophily). wasps etc. as principal agents of transference of pollen grains. e.g. mango. guava. ber. litchi. citrus. custard apple. apple. peach. plum. almond, walnut. Goodman. (1994) observed the efficiency of honeybees in influencing pollination in stone fruits and in pome fruits (Table 1). Sharmah *et al.*. (2015) also reported the impact of honeybee (*Apis cerana*) pollination on productivity of different fruit crops (Table 2). Pollination by is also known as ornithophily mode of pollination. It include parrots. bats (cheiropterophily) etc. as agents of transference of pollen grains. It commonly occurs in red. large and tubular flowers which secrete nectar. e.g. banana. pineapple. Pollination by mammals/animals is treated as zoophily mode of pollination. Elephant. monkey. squirrels etc. are very potent agents of pollen transference. Wind represents anemophily mode of pollination. e.g. date palm. coconut. cashewnut, papaya, jackfruit, sapota. pomegranate etc. are pollinated by wind. Wind pollinated plants produce pollen grains in abundance. These plants devoid of showy flowers and they don't produce scent or nectar. Water is potent way of transference of pollen. It is also known as hydrophily mode of pollination. Large flowers and leaves of these plants are floating on the surface of water which favours water pollination, e. g. lily. gaint water lily.

Pollinator effectiveness and efficiency

It is defined as the pollinator efficacy in relation to floral resource consumption and pollen wastage. More will be the pollinator effectiveness and efficiency more will be the fruit set. For Successful pollination pollinators effectiveness and its efficiency are utmost important. Pollinator effectiveness is the total contribution to plant reproductive success. and thus. it reflects pollinator efficacy and intensity of visitation in a simple conceptual model. It may refer to the contribution of an individual or population of a species of pollinator or a functional group of pollinators (Fishbein and Venable. 1996; Avila and Freitas. 2011). It can be estimated directly from the seed set. Pollinator efficiency is closely linked to pollinator foraging strategies. and there is a clear dichotomy between animal and plant expectations (Borrell. 2007; Fishbein and Venable. 1996).

Pollenization

Pollenization is a process of planting the variety which provides sufficient pollen for pollination. The plants which provides pollen grains for pollination are termed as pollenizer. Some plants are capable of self pollenization. but not all plants. For such plants which are incapable in self pollenization. pollenizers are required for good production of fruits. Many plants are dioecious. e.g. kiwi. papaya. date palm etc. This situation necessitates pollenization (Singh. 2017).

Pollenization depends upon various ability of pollinizer. such as regular its in its blooming habit. flowering early. overlapping flowering with the main

variety, viability of pollen, compatibility of pollen, winter hardiness in case of temperate pollenizers and pollen production at relatively low temperature etc.
Warmund obeserved different crab apple varieties as a pollenizer according to their blooming period and also found that the pollenizers often planted in between the rows or within the rows in commercial orchards had better production

Very often pollinizers are used in pollination management such plants provide abundant, compatible and viable pollen at the same flowering time as the pollinated plant. In apple, diploid varieties produce abundant viable pollen. Triploid varieties are generally fail to produce viable pollen. It is caused due to abnormal cell division in triploid plants (e.g. Baldwin, Rhode Island Greening, Tomkins King, Jonagold etc.). The pollenizer variety should have regularity in bearing in order to have continuity in fruit production. The main variety fail to receive sufficient pollen if there is off year on the pollenizing variety. Precocity in bearing is worth consideration while selecting pollenizer as it influences age at which plant is likely to come into bearing. The very non precocious variety of apple Northern Spy on non-precocious sededling root may require 12 years to produce the first bushel of fruit on a tree. Although, Northern Spy is a good source of pollen but it should not be planted as a pollinizer variety for precocious varieties such as Golden Delicious, Wayne and Yellow Newtown (Roger 1978). Early bloomer pollenizing varieties are better sources of pollen. This early type of bloomer has further advantage of the fact that the flowers that are pollinated earlier get more available time to be fertilized due to available suitable temperature (Singh, 2017) and thus fruit set hastens. The pollenizer variety may be planted in complete block or interplanted within row (Warmund,2002). With successful pollenization and pollination in plum yield has been increased to the tune of 23 per cent when Kala Amritsary has been pollinated with Titron and in Kataru Chak plum variety 13 per cent when pollinated with Kala Amritsari (Bal, 2010)

Warmund (2002) reported that some reliable pollenizer varieties (Fig. 2) planted in apple orchard for better production Pollination has been found to enhance fruit set, fruit weight and fruit size. Pollination ultimately leads to fertilization and seed development, and influences the number and distribution of seeds within the fruit, which has long been known to influence fruit quality (Brault and de Oliveira, 1995; Ward *et al.*, 2001; Dražeta, 2002) and quantity (Brain and Landsberg, 1981; Garratt *et al.*, 2014).

Table 1: Role of honeybees in the pollination of stone fruits and in pome fruits

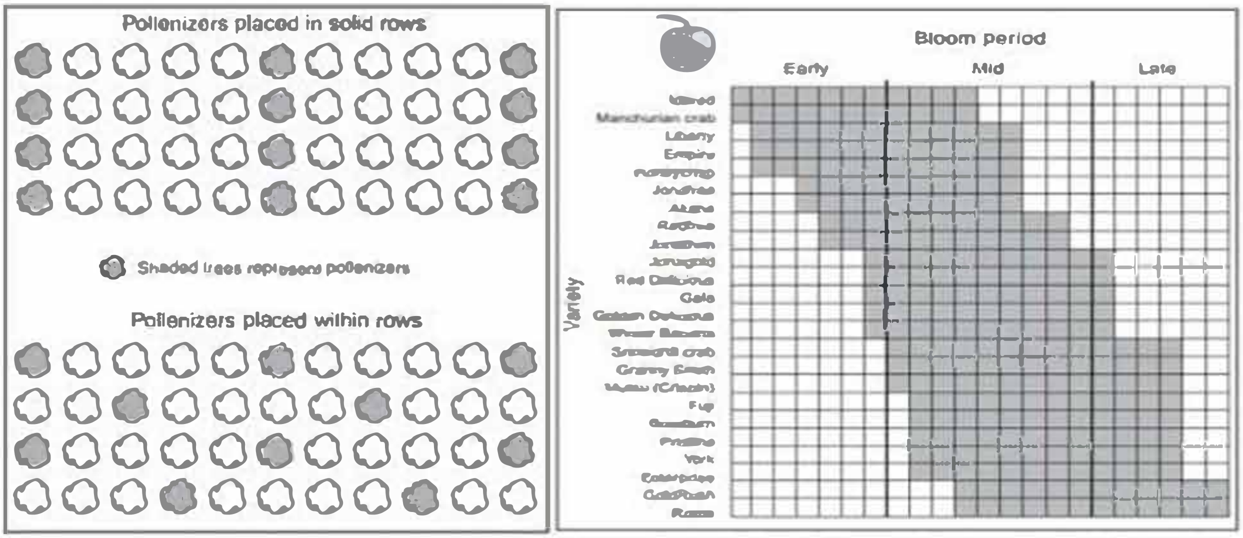
Fruit	**Variety**		**Fruit set (per cent)**	**Yield/tree (kg)**
Stone fruits				
Apricot	Trevatt	Open*	19	99
		Enclosed**	11	67
Cherry	Moss Early	Open	36	35
		Enclosed	2	2
Peach	Golden Queen	Open	26	216
		Enclosed	22	155++
Peach	Crawford	Open	28	47
		Enclosed	10	18
Plum	Satsuma	Open	6	38
		Enclosed	2	15
Pome fruit				
Apples	Yates	Open*	240	125
		Enclosed**	8	9
Pears	Winter Nelis	Open	53	88
		Enclosed	5	12

* Open trees: trees to which bees and other insects have access
** Enclosed trees: trees enclosed during flowering in bee-proof cages to prevent bee pollination
++ Weight of fruit harvested not significantly different

Table 2: Impact of honeybee (*Apis cerana*) pollination on fruit productivity

Crop	Increase in fruit set (per cent)	Increase in fruit weight (per cent)	Increase in fruit size (length, diameter in per cent)	References
Apple	10	33	15, 10	Verma and Dutta, (1986)
Peach	22	44	29, 23	Partap *et al.*, (2000)
Plum	13	39	11, 14	Partap *et al.*, (2000)
Citrus	24	35	9, 35	Partap, (2000a)
Strawberry	112	48	Misshapen fruits decreased by 50 percent	Partap, (2000b)

Source: Sharmah *et al.*, (2015)



(a) (b)

Fig. I a) Planting of pollenizer in compact as well as inter-row. b) Bloom period of different variety of crab apple

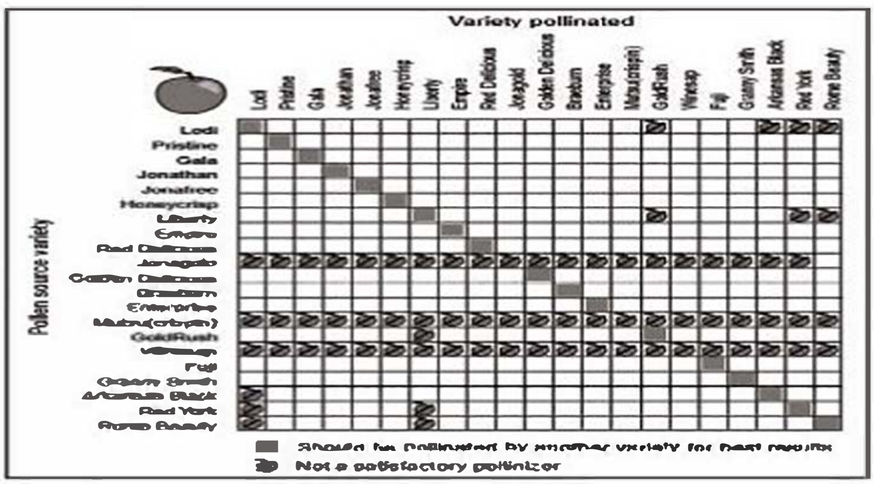


Fig. 2 Pollenizer variety for apple

Use of pollinator safe pesticides

Use of pesticides for crop protection is harmful for pollinators (bees). It is very important to understand that what type of pesticide is to spray, when to spray to assure good pollination and fruit set in the fruit trees. Generally pesticides which have warning labels on it are very harmful for bees. To protect the pollinators some safety measures like use of pesticide which have a low extended residual toxicity, the use of pesticides that come in the form of wettable powder, use of pesticide with very low concentration which have low toxicity to bees etc. can be taken.

Some systemic insecticides which have low toxicity for the mammals can be used. Neonicotinyl systemic insecticides like imidacloroprid, dinotefuran, thiamethoxam and clothianidin etc., are least toxic to bees. Its toxicity for bees also depends upon the type of application and time of application of that insecticide. It is advised to avoid the use of these neonicotinyl insecticides at the time of flowering (Vera Krischik, 2014).

Pollination in different fruit crops

Most of the fruit crops require pollination to ensure proper fruit set and consequently better production. In apple best fruit set is attained if it is largest or king blossom is pollinated. Some apple varieties may be self pollinated like Golden Delicious, Liberty, Loda, Empire, Jonathan, Jonagold, Rome and Granny Smith. Crab apple is widely used as a pollenizer when it is planted at similar distance to early to mid blooming apple variety (Warmund). The delicious apple shows cross compatibility with Winesap, while a different variety is required to pollinate it (Chadda and Pareek, 1993).

In case of japanese plum, it requires cross pollination to ensure fruit set because of selfincompatiblity and unable to bear fruit parthenocarpically (Hartmann and Neumuller, 2009). Some pollenizer varieties are recommended for Japanese plum in different areas according to their fruit set recorded under orchard. Fortune acts as a pollenizer for Black Gold, likewise Black Diamond and Larry Ann for Black Star, Black Diamond for Black Amber, and Ambra, Black Diamond for Fortune and Angeleno, and Fortune for Golden Globe (Guerra, 2011). Cultivar Santa Rosa is a good pollenizer for Oishiwase, Soldam and White plum, while Beniryozen is most suitable pollinizer for Formosa (Chung *et al.*, 1998).

The pear cultivars grown in plains of northern India are partially self fruitful or partially fruitful but the cultivars which are grown in the temperate regions are self-incompatible or self unfruitful so they need cross-pollination. Fitzgerald (2005) reported some compatible pollenizer varieties in European and Asian pears (Table 3). High bee populations in the crop will not only ensure good fruit set, but will increase seed numbers in each fruit in pear. The majority of pollinators of pear tre eeare honey bees. Three colonies of bees per hectare may be sufficient.

Most peaches and nectarine are self fruitful. In these crops, single variety can be planted in compact block. There is no need of pollenizer variety. However, some variety like J.H. Hale is self unfruitful. It requires another variety for pollination.

Most sour cherry varieties are self fruitful. Varieties like Montmorency, English Morello, Meteor and Northstar are self fruitful.

Sweet cherry varieties like Stella, Lapins, and Sunbrust are self fruitful as well cross compatible with other varieties. Most other varieties are self unfruitful and requires pollenization. Many are cross incompatible. Incompatibility wise, grouping of sweet cherry varieties are as under:

I. Black Tartarian, Early Rivers

II. Venus, Windsor, Van, MERTON Bigarrean

III. Emperor Francis, Napolean, Bing, Lambert, Compact Lambert, Vernon

IV. Viva, Victor, Vogue

V. Gold

VI. Hedelfinger

VII. Schmidt

VIII. Rainier, Hudson, Giant, Chinook

X. Ulster, Vic

Hence, these groups should not be planted. One group of variety is pollenized by another group of variety.

In loquat many varieties are self incompatible. These require pollenization. Incompatible varieties are as under:

Self incompatible varieties: Golden Yellow, Improved Golden Yellow, Pale Yellow, Large Agra.
Partially self in compatible varieties: Large Round, Fire Bll, Thames Pride, California Paride, Tanaka.

Variety California Advance is pollenizer for Improved Golden Yellow, California Advance and Tanaka have been found pollenizers for many cultivars in loquat (Pathak, 1999).

In almond most varieties are self fruitful. It necessitates cross- pollination. The varieties like Non-pareil and I.X.L., California Paper Shell and I.X.L., Jordanalo and Harpareil are intersterile. They require pollenization with some other varieties (Bal, 2010).

Many citrus cultivars are seedless and produced parthenocarpically without pollination. Some cultivars may produce fruit either way. If pollinated, there may have seeds in the segments and no seeds if not (Vardi *et al.*, 2008). Citrus that requires pollination may be self-compatible, thus pollen must be moved only a short distance from the anther to the stigma by a pollinator. Some citrus, such as Meyer Lemons, are popular container plants. When these bloom indoors, they often suffer from blossom drop because of no access pollinators. Hand pollination is a solution. A few citrus, including some tangelos and tangerines, are self-incompatible, and require cross pollination. Pollenizers must be planned when groves are planted. Managed honeybee hives at bloom time are often used to ensure adequate pollination.

In date palm which is a dioecious fruit plant pollination depends upon the pollenizer cultivars. Pollen from different male pollenizer affect the fruit set, weight, pulp, and time of maturity of the fruit, as well as seed characteristics such as weight (Iqbal *et al.*, 2012; Shafique *et al.*, 2011). When the trees are pollinated with Madjool and Barakah pollen there is highest fruit set and yield. Whereas, when the trees are pollinated with Jarvis, pollen it gives early maturity (Muhtased and Ghnaim 2007). Pollenization with Zahidi cultivar had the highest fruit set per cent 50.30, while bunches pollinized with the Khadrawy cultivar had fruit set per cent 13.25 (Ricardo *et al.*, 2017).

Pollination is useful in mango. It produces thousands of small flowers in single panicle which may be male and harmaphrodite. The percentage of perfact flowers may be 5 to 50 per cent depending upon cultivars (Chadda and Pareek, 1993). The pollination in mango is mainly entomophilous (by house flies and hover fly), (Randhawa and Damodaran, 1961). Honey bee plays an important role in its pollination. The cultivar Dasehari was recommended as pollenizer for Langra (Ram and Sirohi, 1994). Ber is also cross pollinated fruit crop, it does not set any fruit by self pollination (Bal, 2010). In aonla the fruiting depends upon the sufficient pollenizers. Provision of 10 per cent pollenizers has been found optimum in aonla. It has been observed that NA7 is a good pollenizer for NA6. Planting of 2-3 varieties in an orchard solved the problem of pollenizer. In fig, the Smyrna type develops fruit only when receives pollen from Capri fig, also known as caprification (Radha and Mathew, 2007).

In majority of temperate and stone fruits, nuts, tropical and subtropical fruits honeybee is dominating pollination agent. In most fruit crops pollenizer varieties have been found useful (Table 4). Hence, while planning orchard both the processes of pollination and pollenization deserve to be taken into account. This is in the way of successful orcharding

Table 3: Some compatible pollenizer varieties in European and Asian pears

European Pears	**Compatible Pollenizers**
Bartlett	d'Anjou, Bosc, Comice
Bosc	Bartlett, Comice, d'Anjou, Seckel
Comice	Bartlett, Bosc, d'Anjou, Seckel
d'Anjou	Bartlett, Bosc, Comice, Seckel
Seckel	Bosc, Comice, (Bartlett is not compatible)
Asian Pears	**Compatible Pollenizers**
Chojuro	Shinseike, Bartlett
Nijisseiki (Twentieth Century)	Chojuro, Shinseike, Bartlett
Hosui	Partially self-fruitful
Shinseike	Chojuro

Table 4: Account of pollinators and pollenizers in fruit crops

Fruit crops	Pollination type	Major pollinator	No. of bee hives/ha for effective pollination	Ratio of pollenizers to main variety in the orchard
A. Temperate and stone fruits, nuts				
Apple	Largely cross-pollinated	Honeybees and bumble bees	4-5	33 per cent
Pear	Partly or entirely self-sterile, requiring cross-pollination	Honeybees and bumble bees	3-4	Inter-planting of 3-4 varieties in a block is recommended
Apricot	Cross-pollination essential	Honeybees	2-3	33 per cent
Peach	Mostly self-fruitful, some varieties require cross-pollination	Honeybees, rarely other insects and wind	2-3	1:2
Plum	Self fruitful to self-incompatible	Honeybees, bumble bees and blow flies	2-3	Every 4th tree in every 4th row
Almond	Cross-pollination essential	Honeybees	6-8	One row of pollenizer for every two rows of main cultivar
Cherry	Cross-pollination essential	Honeybees	2-3	10 per cent pollenizers
Persimmon	A very unusual sex distribution. Some varieties are self-pollinated and others require cross-pollination	Honeybees, Bumble bees and wind	2-3	A special plan is required to plant A type and B type varieties
Walnut	Cross-pollination essential	Wind	-	-
Pecan nut	Cross-pollination essential	Wind	-	-
Pistachio nut	Cross-pollination essential	Wind, Honeybees	-	1:8 (male: female)
Chestnut	Self-sterile	Wind, Honeybees, chafer beetles	-	1:1 or 1:2 (male: female)
Hazelnut	Self-sterile	Wind	-	15-20 per cent inter-planting of two cultivars is recommended
Blueberry	Self-sterile to cross-sterile	Honeybees	2-3	10 per cent
Olive	Self-sterile to self fertile	Wind, Honeybees	-	11 per cent. Sometimes inter-planting of two cultivars is recommended
Strawberry	Self-pollinated, cross-pollination beneficial	Honeybees, wild bees	10-25	No specific recommendation

B. Tropical and sub-tropical fruits				
Mango	Self to cross-pollination	Houseflies, honeybees, hover flies	5-7	Inter-planting of 3-4 varieties in a block is useful
Citrus	Self-sterile to self fertile	Honeybees	1-2	10-15 per cent in self incompatible forms
Grapes	Self-sterile to self fertile	Honeybees and other hymenopterous insect	1	No specific recommendation
Banana	No need of pollination. However, sometimes, cross-pollination takes place	Bats and birds	-	-
Papaya	Self to cross-pollinated	Sphinx moth, sun bird, humming bird, butterflies and honeybees	-	About 10 per cent male plants should be there in an orchard in dioecious varieties, but no need for gynoedioecious varieties
Coconut	Self to cross-pollinated	Wind	-	Inter-planting of dwarf and tall cultivars is useful
Litchi	Self-fruitful, but cross-pollination is beneficial	Honeybees, hover flies, wasp and houseflies	4-5	No specific recommendation
Guava	Self to cross-pollinated	Honeybees and hover flies	-	No specific recommendation
Loquat	Self to cross-pollinated	Honeybees and hover flies	-	Inter-planting of 2-3 varieties in a block in recommended
Ber	Self-incompatible	Yellow wasp, houseflies and *Trigona sp.*	-	Inter-planting of 2-3 varieties in a block in recommended
Aonla	Both self and cross-incompatible	Wind, wasp and houseflies	-	Inter-planting of 2-3 varieties in a block in recommended
Fig	Both self to cross-pollinated	Wasp (*Blastophaga psens)*	-	In some forms, planting of Capri figs is essential
Pomegranate	Self to cross-pollinated	Honeybees, beetles and wind	-	No specific recommendation
Sapota	Self-sterile	Wind, honeybees	-	No specific recommendation

Source: Sharma, 2006.

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