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Floral biology, pollination and fertilisation of temperate zone fruit trees

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Summary: The knowledge of blooming, pollination and fertilisation and its use are indispensable in maximizing of cropping potential of fruits in economical fruit production. In attaining maximum yield a greater attention has to be focused on choosing cultivar combinations, and results of experiments on blooming, pollination and fertilisation must be applied carefully.

To have efficient bee pollination requires attention at the time of designing an orchard. It requires furter attention at the time of bloom of any of the fruit-bearing species. Markets demand new types of fruit which forces constant changes in the cultivar composition of orchard. The blooming, pollinating and fertilisation characteristics of cultivars chosen have to be known before an orchard is set up. Apart from the general knowledge of trees considered to be planted, there is a great need to know the flowering, pollinating and fertilisationcharacteristics of each cultivar in detail.

Key words: flowering phenology, pollination, fertilisation, honey-bee, temperate zone tree fruit species.

Flowering phenology and fertilisation

Questions of fertilisation-biology

The success of fruit growing depends largely on the fruit set as the result of an effective fertilisation, finally on the viability of the pollen being compatible in a genetically determined sense; and agents as vehicles of pollination carry this pollen from the anthers to the stigmata. Meanwhile, in fruit growing countries all over the world, and in most fruit species, difficulties related to insufficiencies of fertility appeared.

The list of main fruit tree species and varieties as well as varieties, the ratio of auto-incompatible varieties grown in Hungary, moreover, the results and conditions of fertilisation are summarised in *Table 1*. In spite of the considerable number of varieties grown, the choice from the point of view of the practice is insufficient, all the same. The choice of competitive varieties grown successfully and sold favourably on the markets still ought to be increased.

The Hungarian assortment of fruit varieties has been developed by a permanent effort of clone selection started about 60 years ago. Those varieties are still precious components of our orchards: sweet and sour cherries, apricots, walnuts and chestnuts. Cross breeding was also effective in releasing varieties of sweet and sour cherry, apricot and almond.

Apple

Apple varieties to be pollinated efficiently, need an overlap of blooming periods of the respective varieties at least of 50%, moreover for some varieties (e.g. the Red Delicious types) a 70% synchrony is advised. Varieties assigned to the same group of blooming period are guaranteed to pollinate each other. In commercial plantations, those varieties ought to be associated, which belong to the same group of blooming period. A reliable combination of three varieties (with at least 50–70% coincidence of bloom) is recommended. Three varieties are obligatory, when one of them is a triploid (e.g. Jonagold, Mutsu) or diploid but its pollen is partially defective (e.g. Staymared, Red Winesap), or its effective pollination period is very short (e.g. Red Delicious and its types, Gloster). Three varieties are also recommended if one of them belong to another (neighbouring) blooming time group.

The majority of apple varieties are entirely auto-incompatible, just a few are slightly self-fertile (*Soltész,* 1997), cross-pollination is indispensable. Natural parthenocarpy is a rare phenomenon.

Triploid varieties (e.g. Mutsu, Jonagold) are not worth of being used as pollinisers because their pollen is largely sterile. Partial pollen sterility – even less fertile than of the triploids – is found in some diploid varieties (e.g. Staymared, Melba, McIntosh) too (*Soltész,* 1997). Those varieties deserve the same planting design as the triploids.

The blooming time of mutants is largely similar to that of their original variety – except some rare cases – therefore they may substitute each other in planning the association, but their type of auto-incompatibility being maintained excludes their association with each other.

Table 1. The number of authorised varieties of fruit species and the ratio of auto-incompatible varieties in Hungary

Species	Number of varieties*	The ratio of Hungarian varieties (%)	Ratio of auto-incompatible varieties (%)	Remark
Apple	114	18	100	Alternate bearing
European pear	39	15	100	Parthenocarpy is happening
Asian pear	4	0	100	Over-pollination is frequent
Quince	6	50	100	Tendency to self-fertility, but its expression is variable
Sweet cherry	31	52	74	Frequently poor fruit set, cross-incompatibility occurs
Sour cherry	25	95	24	Frequently poor fruit set
European plum	29	24	45	Male sterile varieties occur
Japanese plum	4	0	100	Inter-incompatibility
Apricot	28	71	39	Early bloom, spring frost damage is frequent
Peach	49	16	0	Over-setting, yield fluctuation is important
Almond	9	100	100	Early bloom
Walnut	10	80	0	Apomictic tendency, dichogamy
Chestnut	6	100	100	Low rates of self-fertilisation

*Harsányi and Mády, 2004

Pear

The triploid pear varieties (e.g. Diel Butter) are not suitable to be pollinisers; their pollen is highly sterile. Alexander, Clapp's Favourite and Williams are good for that purpose because their pollen is viable and grows a tube. The large majority of pear varieties is auto-incompatible, or in some seasons at very low rates self-fertile.

Among pear varieties grown in Hungary, one single summer ripe variety, 'Arabitka' is an exception in producing natural parthenocarpy in pure stands. All the rest of pears are to be associated with other polliniser varieties – though some of them may produce seedless fruits at low frequencies.

As good polliniser varieties are considered those, which induce 10% fruit set, at least, by their pollen on other varieties.

Sweet cherry

Sweet cherry varieties grown earlier in Hungary were all entirely auto-incompatible. In the recent assortment, some self-fertile varieties are still considered to be exceptions (Stella, Sunburst, Lapins, Sweet Heart, Celeste, Canada Giant, and the Hungarian bred Alex). The spread of further self-fertile varieties is expected.

Among stone fruits, the highest frequency of mutually cross-incompatible varieties is found in sweet cherries. Many of the varieties are very similar to each other, most of the varieties are closely related and some of them are simple mutations of other varieties.

Varieties are raised from spontaneous seedling with unknown parentage. Old varieties used to be a mixture of biotypes. Several pairs of sweet cherry varieties were described, which were cross compatible in one country but cross-incompatible in another country; therefore the references in the international literature are to be used with care or after having checked the identity of the respective varieties. Moreover, the host of local varieties are rarely represented in other countries.

Sour cherry

Blooming periods of sour cherry varieties are very variable. In the case of auto-incompatible and partially self-fertile varieties, this moment has far reaching practical consequences. Sour cherries have a very short period of effective pollination. Pollination ought to ensue within one or at least two days after the opening of the flower. In recent Hungary, the majority of commercially grown sour cherry varieties are self-fertile, whereas the types of 'Pándy meggy' are auto-incompatible. Auto-incompatible and insufficiently self-fertile varieties yield irregularly, in most seasons small quantities. The tendency of self-fertility varies according to season and growing site.

In the future, the assortment of sour cherries ought to be composed of varieties, which are at a high degree self-fertile, and the auto-incompatible ones have to be cancelled from the list.

The variety 'Pándy meggy' is entirely auto-incompatible regarding its genotype. Low and irregular yields are expected in most seasons. In spite of the presence of efficient polliniser varieties (close synchrony of bloom, favourable weather conditions, optimal placement and rate of associated varieties) the yields are often unsatisfactory. The late blooming period and irregularities in the process of macro- and micro-sporogenesis causing low quality of pollen are the reasons of the bad fame of Pándy meggy as a source of pollen too.

Within the assortment of sour cherry varieties, all intermediate scales between total auto-incompatibility and complete self-fertility occur. The partially self-fertile varieties perform their yielding ability according to the ecological conditions in a sensitively variable way. At best, those varieties ought to be considered as they were auto-incompatible in planning of association of varieties, and adequate pollinisers should be provided for them.

For dependable yields in sour cherries, we need fruit set rates around 25–30%.

Plum

The majority of plum varieties grown worldwide is auto-incompatible or partially self-fertile at a very low rate. The yields of those varieties are variable yearly.

All intermediate degrees between auto-incompatibility and self-fertility are present in the species. The Japanese plums bloom very early, most of them are auto-incompatible, only some of them are partially self-fertile.

The partially self-fertile varieties are considered auto-incompatible, which polliniser varieties. Among the European plums are also male sterile varieties.

Apricot

The species is blooming at very early dates; therefore late spring frosts are threatening the flowers. European and North American varieties are mostly self-fertile, but there are also auto-incompatible ones.

Also male sterile varieties are known. The insufficient development of the pistils is a frequently met trait and cause of flower sterility in many varieties.

Auto-incompatible apricot varieties need polliniser varieties; but for that purpose, self-fertile varieties are recommended as being more reliable. In some cases, mutually cross-incompatible varieties are also found (*Szabó & Nyéki,* 1991).

Peach

Hungary is on the northern border of peach growing, therefore, yields are relatively low and the yearly variation is high, the security of production with the present assortment is unsatisfactory. The grown peach varieties are all self-fertile. In China, male sterile varieties are also known. The extent of self-fertility changes yearly. Cross-pollination is not desirable because the highly self-fertile varieties are inclined to set more fruit than usual.

Almond

It is the fruit, which starts blooming the earliest. The occurrence of auto-incompatibility is generally present. There are only a few self-fertile varieties (e.g. Truoito, Le Grand). The criterion of self-fertility is a regular yield with a fruit set of 25–30% at least, and also the self-pollinated flowers develop viable embryos.

Fruit set rates are rather low in most of the seasons, because the early bloom is endangered by the late frosts, moreover, insect activity is then insufficient.

A frequent cause of moderate fertility is the underdevelopment of pistils. Summer drought is often blamed for the occurrence of defective female organs in the flowers of the next spring. In almond plantations, associations of more than two (3–4) varieties are recommended. The varieties are preferably placed into alternate rows near each other. Honeybees perform the pollination. The nectar secretion as well as pollen production of flowers is lower than of other fruit species, but during the early spring, no alternative attractive sources of food are available for the insects. For the sake of efficacy, the use of 7–10 beehives per hectare is recommended.

Walnut

Varieties belonging to the European walnut (*Juglans regia*) species are more or less self-fertile. Auto-incompatible varieties are really very rare. The occurrence of apomixis, i.e. development of embryo without fertilisation, was also stated in walnuts. The possibility to obtain acceptable yield in seasons of unfavourable weather conditions is attributed to this faculty.

In Hungary, selected local varieties may produce high rates of fruit set of 60–98%. Yielding potential of traditional varieties is calculated by the% frequency of mixed buds bearing female flowers, and the number of fruits developed per fruiting shoots.

With the appearance of varieties developing female flowers also on lateral buds, the potential yields are increased, as a rate of fruit set around 50–80% and the rate of more than 60% of fruit bearing shoots may result shoots bearing more than 2.5–3.0 fruits. At those conditions fruit set around 50–60% would be sufficient for an abundant harvest.

In spite of the fact that walnuts are self-fertile, the possibility of cross pollination should be maintained because the time of pollen release used not coincide with the receptivity of stigmata on the same variety, thus other pollen sources should be available. Practically, dichogamy or the divergent time of bloom in the sexes, the short life-expectance of the pollen grains and the short period of functionality of stigmata are excluding self-fertilisation of walnuts.

An important requirement of walnut yields is the optimal pollen supply of the stigmata.

It is a special point of interest in walnuts that an overdosing of viable pollen on the stigmata causes the abscission of female flowers, i.e. decline of fruit set. Optimal doses of pollen supply cannot be influenced except in plantations of grafted trees to well known varieties (genotypes) (*Soltész,* 1997).

Chestnut

Self-pollination has little chances on chestnut trees because of the dichogamy of male and female flowers. Moreover, also a true, genetically founded auto-incompatibility is stated.

The European chestnut varieties grown in Hungary set fruit with self-pollination at a very low rate, i.e. 7–50 nuts per 100 cupules (inflorescences), which means really auto-incompatibility.

In order to secure a safe cross-pollination, the associated varieties ought to be planted as near as to a 30–40 meter distance.

Problems of fertilisation and yield show up at growing sites far from being considered as optimal for the species. Near to the northern border of the chestnut-growing zone, winter- and spring-frosts, moreover, cool and rainy weather around the blooming period diminish the chances of fruiting considerably.

The strong tendency of flower initiation (flower bud density) and subsequently, flower density in the spring allow a reasonable fruit set even after frost damages occurring throughout the cold season. Fruit load and a desired rate of fruit set necessary to obtain economically significant yields are approached by applying different norms depending on the fruit species. The parameters of the individual fruit species are highly variable (*Table 2*). The higher rate of fruit set is aimed for, the more important is the protection against adverse weather conditions during the blooming period.

Table 2 Flower density and fruit set of fruit species (*Soltész et al., 2004*)

Fruit species	Relative flower density (1–5)*	Fruit set (%) needed to obtain dependable yields	Average yield necessary to be satisfactory economically (t/ha)
Apple	3	5–10	40
Pear	3	5–10	30
Quince	2	5–10	30
Sweet cherry	5	30–40	15
Sour cherry	5	30–40	15
European plum	3	20–30	25
Japanese plum	5	5–10	25
Apricoti	3	10–20	15
Peach	2	10–20	25
Currants	3	60–70	6
Gooseberry	2	60–70	8
Raspberry*	2	60–70	10
Blackberry*	3	60–70	20
Strawberry*	2	60–80	10
Walnut	2	60–80	3
Chestnut	2	60–80	3
Hazelnut	2	60–80	2
Almond	3	30–50	2

* the number of fruitlets of the polycarpium, or of the achenes of strawberry should develop at a rate of 60–70%

** 1 – very low flower density, 5 – maximal flower density

The field of applying results obtained in floral biology is the planning of association of varieties in the planting design

The purpose of associating varieties is to facilitate regular, dependable and high quality yields over successive years. One of the main components of safe yield, prone to be influenced by thoughtful planning is to provide conditions favourable for efficacious pollination and fertilisation of flowers.

A rather large variability of fruit yields in individual orchards over the same region is mainly due to the hazard of insufficient pollination. A somewhat higher and more regular fruit set would result in substantially more dependable yield than experienced during the last years.

For the low and irregular yields a couple of possible causes could be blamed:

- auto-incompatibility of the varieties,
- non-overlapping blooming periods of otherwise cross-compatible varieties,
- cross-incompatible combination of varieties,
- inadequate supply of pollen sources, or polliniser plants,
- deleterious weather conditions during the blooming period,
- lack of honeybees or other insects.

All items of the list of causes above are related to the fact that an efficacious pollination is an important limiting factor of fruit yields in most plantations.

The choice among the possible planting designs should be led by the primary endeavour of optimal conditions for pollination of fruit trees in the future plantation.

The importance of a successful pollination will increase with progressing intensification of technologies and practices of integrated as well as biological growing methods too, because a few varieties promising the best qualities and competitive commodities tend to become prevailing on huge areas:

- single or few varieties will occupy large plantations,
- blocks or even pure (monovarietal) planting designs will be preferred,
- new varieties (and clones) will appear as the best alternatives.

At planning of the association of varieties, which are characterised by different dates of bloom and inter-fertility relations, adequate planting designs are to be found. Varieties to be pollinated should be cross compatible mutually or at least unilaterally if one of them is self-fertile. The relative rate of varieties either in alternate rows or within the rows, and the distance between the trees are the criteria of the design to be realised.

Varieties, which are highly self-fertile (e.g. sour cherry, peach, plum) are ideal for the purpose to form mono-varietal blocks with many advantages in technology and phytosanitary measures.

Auto-incompatible varieties (e.g. apple, pear, quince, sweet cherry, Japanese plum) being obligate cross-pollinated crops and need mixed plantations with selected polliniser varieties that are possibly mutually cross-fertile and their blooming periods overlap each other to a sufficient extent. Maximal yields are possibly achieved with „good" polliniser combinations.

How many varieties are recommended for a mixed block?

The first question is whether the respective varieties are self-fertile or auto-incompatible, moreover, partially self-fertile. The yielding potential of the whole plantation depends largely on the number of varieties and their spatial distance to each other. The security of a perfect mutual fertilisation is the best guarantee of safe yields.

The varieties associated contribute to that aim through two independent criteria: cross-compatibility relations and the main blooming periods, the extent they overlap each other (*Table 3*). As the blooming period of varieties (their assignment to blooming time groups) may change yearly as a consequence of diverse physiological sensitivity of varieties (e.g. the varieties of unstable blooming period), the most deleterious meteorological adversities ought to be considered by planting more than one (2–4) polliniser variety. Three varieties guarantee a really safe mutual cross-pollination. Postulating a main variety to be pollinated, one of its pollinisers should anticipate, the other should follow the main bloom of the main variety for the sake of safety.

Table 3. The minimal overlap of blooming periods necessary to obtain the desired fruit set (*Soltész, 1997*)

Fruit species	Fertility characteristics of the varieties to be pollinated	The minimal overlap of blooming periods (%)	Fruit species	Fertility characteristics of the varieties to be pollinated	The minimal overlap of blooming periods (%)
Apple	A, diploid	50	Walnut	A	60
	A, triploid	60	Chestnut	A	80
Pear	A, diploid	60	Hazel	A	80
	A, triploid	70	Sand thorn	A	90
Quince	A	70	Gooseberry	B-2	40
Medlar	C	50	Red currant	A	90
Sweet cherry	A	70	Black currant	A	90
	B-2	40		C	80
Sour cherry	A	70	Josta	C	70
	B-2	40	Raspberry	C	50
Plum	A	70	Blackberry	A	80
	B-1	40		C	60
	B-2	40	Loganberry	A	70
Apricot	A	70	Strawberry	C	60
	B-1	40	Black elder	C	80
Peach	A	70	Aronia	C	80
	B-1	40	Blueberry	C	80
Almond	A	80			

Explanation:

- A cross-pollination is indispensable
- B-1 varieties of large fruit are duly self-fertile, therefore, additional cross-pollination may cause oversetting, and consequently, thinning is indispensable.
- B-2 varieties of small fruit are duly self-fertile, therefore, additional cross-pollination may cause oversetting, and consequently, without thinning fruit size declines below acceptability
- C yields are satisfactory with pure self-fertilisation; however, a complementary cross-pollination improves yields as well as the market quality of fruit

If the main variety is auto-incompatible, the ensemble of three varieties should be mutually cross-compatible. A third variety may increase the safety by diminishing the risk, which ensues with the fall out of one of the pollinisers (by lack or delayed bloom). Three varieties are recommended if one of them is a poor pollen-producer (e.g. triploid or male sterile).

The relative presence of the polliniser variety within the plantation

The planning of a plantation determines the varieties to be planted as well as their relations. One of the varieties, which is considered as the most important, the main variety, if it cannot be left alone without any cross-compatible polliniser, it should be represented by the highest frequency, whereas the rest of varieties may serve as pollinisers – complementary or auxiliary – varieties. The planting rates of the latter depend on the commercial value of their fruit, let alone their necessity as a source of pollen. A good pollen producer, may bear fruit of minor quality, therefore its presence should be minimised.

The distinction of main and polliniser varieties is justified as long as the ratio within the plantation is essentially different (e.g.: 95–5%, 90–10%, 85–15%). For wind-pollinated species (e.g. chesnut, walnut) 5–10%, for insect-pollinated species at least 15–20% polliniser varieties are recommended.

The distance between trees of the main variety to be pollinated and those of the pollinisers

The yield (i.e. fruit set) of the auto-incompatible trees declines with the increasing distance to the source of pollen, i.e. polliniser trees. Figures typical to individual fruit species are shown in *Table 4*. The radius of efficacy of polliniser trees is 10–15 m especially under adverse weather conditions, but increases up to 20–30 m under favourable conditions.

The placement of varieties within the plantation

A safe and efficacious fertilisation supposes principally a higher ratio of polliniser trees either in the neighbouring rows or alternating within the rows of the plantation. The requirements of integrated growing technologies as well as the variety-specific processes and timing of interventions would prefer the opposite, i.e. a possibly maximal uniformity from the point of view of technical reasons.

The following planting designs considering the fruit growers have developed the association of varieties:

Table 4 The distance suggested between the main variety and the polliniser in the planting system *(Soltész, 1997)*

Fruit species	Maximal distance recommended between the trees and the pollen source (m)
Apple diploid	25
triploid	10
Pear diploid	20
triploid	8
Quince and medlar	7–10
Sweet and sour cherry (auto-incompatible)	6–8
Sweet cherry (self-fertile)	12–16
Sour cherry (self-fertile)	20–30
Plum (auto-incompatible)	15–20
(small fruit, self-fertile)	20–30
(large fruit, self-fertile)	30–40
Apricot and peach (auto-incompatible)	20–25
(self-fertile)	30–40
Almond	6–8
Walnut, chestnut	50–100
Hazelnut	50
Gooseberry, red currant, raspberry	30
Black currant (auto-incompatible)	3–4
(self-fertile)	6–8
Josta	20
Blackberry (auto-incompatible)	6–10
(self-fertile)	12–20
Strawberry	25–30
Black elder	10
Aronia, blueberry	15–20
Sand thorn	8–10

(1) Polleniser varieties are scattered within the rows of the plantation

The „scattered“ arrangement facilitates a reduction of the presence of polliniser varieties to 5–10%, which means about e.g. 20 m distance between the polliniser trees, depending on the intensity of the orchard (the smaller trees the lower is the ratio of pollinisers). The efficacy of bee pollination is better in the scattered distribution, but the performance of training, plant protection procedures and harvest is negatively influenced. It is an important requirement that the harvest (ripening) time and/or the appearance of the polliniser varieties should clearly differ from those of the main variety.

(2) Pollinisers are assigned to „pure" rows:

In spite of the advantages of the former (scattered placement of the trees of polliniser varieties) system, the separation of varieties in pure (mono-varietal) rows has given priority. The advantages of that system are beyond doubt in the practice of growing technology especially harvesting operations. Its disadvantage is clearly the higher (more than 20%) rate of the polliniser variety as an obligate consequence.

Auto-incompatible varieties need to be near to the polliniser, being possibly neighbours. Main varieties may occupy 2 rows between 1 row of pollinisers on both sides. The sequence of varieties should reflect the timetable of their harvests.

In up to date fruit production cannot exist without the use of beehives, which guarantee the safe transfer of pollen to its destination.

Table 5 presents the numerical data of beehives required in commercial fruit plantations. There are some experiences accumulated, which may become useful in practical fruit growing. Nevertheless, a host of conditions could modify the suggested parameters. Self-fertile varieties (e.g. sour cherries, plums) need bee pollination as well.

Table 5 How many beehives are necessary to pollinate fruit trees *(Kozma et al., 2003)*

Fruit species	Number of beehives per hectare
Apple in traditional	1–3
in high density plantations	3–6
Pear	2.5–3
Quince	1
Sweet cherry	3–5
Sour cherry	5–8
Plum	2.5–5
Apricot	3–5
Peach	0.5–1
Almond	7–10
Strawberry	10–25
Raspberry	5–6
Gooseberry	5–6
Black currant	3–5

Remark: a strong beehive means about 20.000 honeybees

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