FLOWER INDUCTION AND FLOWER BUD DEVELOPMENT IN APPLE AND SWEET CHERRY

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ABSTRACT

As a result of studies conducted in the last 20-30 years, new information has been obtained about the flower bud formation in apple and cherry, including some data about the presence of genes determining the reproductive organs of the apple. Some issues about the flower induction, histological transformation of the apical meristem, morphological differentiation of the flower buds, factors and conditions influencing the flower bud formation and the quality of the reproductive organs are discussed in this survey. Some attention has been paid to the tree pruning, summer pruning in particular, the fertilization, irrigation and treatment with growth regulators, by means of which processes of flower bud formation can be regulated.

Keywords: apple, cherry, flower induction, histological transformation, morphological differentiation, agricultural practices

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Introduction

Numerous studies on flower bud formation of temperate fruit plants have been conducted in many countries (16, 17, 64, 67). In spite of that, a great part of the most important characteristics of flower bud formation remains insufficiently clarified both by theoretical biology and applied horticulture (16). Special attention deserves the clarification of the morphogenetic changes that occur between the vegetative state of the buds and the initiation of flower organs (39).

The presence of relative dormancy between the initiation of the flowers and anthesis is characteristic of most fruit plants (64). In apple, for example, the cycle of flower development often lasts from 9 to 10 months, but only a short lapse of time is due to an active passing of this process, namely at the appearance and formation of the floral primordia in summer and at the final formation of flower parts in spring (67). The period of relative dormancy permits the buds to pass a complete cycle of their development in two successive calendar years. This provides an opportunity of decreasing the competition for nutrients between the developing flowers and vegetative parts, thus presenting a great advantage for the perennial fruit tree species, including apple and sweet cherry, in comparison with annual plants (64). The ability for a change in the predetermination of the buds, in the case when conditions for the transition from the vegetative into the reproductive state become unfavorable, may be considered another advantage.

According to Zimmerman (132), duration of the juvenile period, characteristic of the tree plants propagated by seeds, is genetically controlled. The time of appearance of the first flowers in given genotypes can be accelerated by application of different methods. It seems that the most effective is stimulation of the vegetative growth, so that the seedlings can reach a large size as soon as possible. The onset of the flower bud formation in the seedlings of the apple can be accelerated by means of grafting on the dwarfing rootstock M 9; the growing conditions are of decisive importance, however (116). The more vigorous the growth, the smaller the difference is, in flowering between the grafted seedlings, and those grown on their own roots. The transition from the juvenile into that of maturity phase may be due to various mechanisms, including the hormonal control over the distribution of assimilates in the zone of the apical meristems (52).

In order to reduce the duration of the unproductive period in the grafted young trees grafting on dwarfing or semi-dwarfing rootstocks is applied on a mass scale in apple and pear growing in particularly. However, the weakening of growth is not always desirable, particularly in the first one and second year after planting (25). In this respect, the characteristic of the cultivars to form feathers and the conditions created for a vigorous growth, are of special importance. As considerably more fruit buds are initiated for the third year in pear cultivars that form more feathers in the first than in second year, the authors considered that the best prediction for the duration of the unproductive period can be done on the basis of the difference in the number of feathers per tree in the first two years. The formation of feathers is usually described as a type of branching due to the decreased apical dominance (22).

The flower bud formation in the mature trees is fundamentally determined by the presence of hormones (16). The lack of initiation of flower buds in the cultivars with alternate bearing, was related in the past directly to the effect of exhausting assimilates and the reserve substances by the fruits. Now it has been attributed to the action of hormones and particularly to gibberellins, produced in the young fruitlets in the so called 'on year' (80).

Sites of flower bud formation

Most of the commercially significant apple cultivars bear fruit mainly on spurs (37). The main leaf area of the trees from the 'green apex' phase to the complete bloom is formed on these spurs. Some of the leaves also develop on them later; the total spur leaf area is formed up to one month after flowering (38). By and large, during this period the preliminary induction of the flower bud formation on the spurs occurs (17). Leaves on the spurs in the spur-type apple cultivars constitute more than 60% of the total leaf area of the tree; hence they are essential for the fruit-bearing (104). In the spur cultivars of 'Delicious' the leaf number and leaf area per spur are larger in the spur type strains of 'Delicious' than in the standard strains (119). The presence of a sufficiently large leaf area per spur in pear is a significant factor favoring flower bud initiation (63). In apple, every vegetative spur needs 100 to 150 cm^2 leaf area in the last 90 days of the growing season in order to initiate a 'vigorous' flower bud. Therefore, proper agricultural measures are necessary to ensure development of such area (104). At a young age and under special conditions, trees of some apple cultivars initiate flower buds on the tops of the long shoots and laterally in the axils of their leaves (37). The flower buds in apple, apical or lateral, are mixed and they contain primordia of vegetative and reproductive organs. Flower buds of sweet cherry are initiated laterally, in fascicles and are unmixed (simple) (124). They are disposed laterally on short spurs or near to the base of longer shoots.

Development of the flower buds

Flower bud formation is a complex phenomenon. Considering the flower bud formation genes to be a basic factor in its occurrence, and formation of gametes in the time of meiosis as a final event, Wellensiek (121) formulated the statement that the initial reasons for formation of flowers can be defined as 'something happening between the flower forming genes and the meiosis'. This statement is still valid (16). For the flower initiation it is necessary to stop the retaining of the genes responsible for the flower bud formation and in this sense the induction of flower bud formation can mean something similar to de-blocking.

The identification and characterization of a number of homeotic genes connected with the flower bud formation in some model angiosperm species, such as *Antirrhinum majus* L. and *Arabidopsis thaliana* (L) Heynh., have allowed, in the last ten-year period, to seek their homologues in the fruit species, and more specific in the apple, which is the most important representative of the species from the temperate climatic zone (39). Such genes are isolated from flower buds in the still initial phases of their development, from flower organs and fruits of some apple cultivars (68, 110, 111, 118, 129).

The flower bud formation in the apple passes in the following succession: induction of flower bud formation, histological transformation and morphological differentiation (17).

Flower bud induction

According to Dolega et al. (32), induction gives an impulse to the sufficiently developed and 'susceptible' buds to transition from vegetative to generative phase. It is still not clear which are the fundamental reasons for induction (16, 76). It could be said that this is a qualitative change, the final result of which can be programming of the strategically disposed parts from the meristem to forming flowers (17). The induction can also be viewed as a process during which previously repressed information is being transformed to form a new structure, namely the flower bud. The genes of the type of AFL (Apple Floricaula/Leafy) are supposed to be included in the induction (68). According to Luckwill (78) the induction is connected with changes in the hormonal balance, and according to Sachs (106) with changes in the distribution of the assimilates in the apical meristem. Link (76) shares the point of view that the flower bud induction, as well as the fruit set and the fall of fruits or of primordia of different organs of the plant, depend on the interaction in space and time of its own growth substances and those retaining growth. Together with the well-known method of defoliation for determining the critical period of the flower bud induction in apple, it is possible to use spraying by GA_3 within the supposed time of the induction (75).

Histological transformation

When the apex of the still vegetative bud receives a signal for differentiating as a flower bud, a sequence of events takes place (17). The mitotic activity becomes total for the whole apex changing its histological structure. The central meristem is more unfolded and is now under the subdermatogen. By this rearranging, but without any morphological changes in the apex, the histological transformation is carried out, and from that moment on the initiation of the flowers is irreversible.

Morphological differentiation

Apple is a fruit-tree species of the temperate climatic zone, on which the greatest number of studies is conducted, referring to the initiation of flower buds. The studies on the sweet cherry are limited.

The apple flower bud is a shortened axis, usually carrying 21 formations, inserted in the spiral sequence (1). It consists of bud scales, transitional leaves, true leaves and bracts (a leaf form, lamina and stipules of which are totally depressed). The axis ends in primordium of the 'king flower' and the primordia of the lateral flowers are formed in the axils of the three bracts and the three upper leaves. Under the whorl of the flowers in the axils of one or two of leaves, a primordium of a vegetative bud is located. Out of this bud, during the vegetation, a bourse shoot is formed which can, in its turn, form a new flower bud.

The morphological differentiation occurs only if the structure of a vegetative bud is complete (16). The differentiation of flower primordia in apple can start when the primordia of the appendages described above have already been initiated.

The total appendages formed before the appearance of the first indication for the transition of the buds from vegetative into reproductive state represents a 'critical number of nodes'. This number is varying depending on cultivar, from 16 to 20 (55, 57, 62, 80). The total number of appendages formed by the appearance of the sepals of the apical flower in the cluster is also specific for the cultivars and can be influenced by the ecological conditions and the ways of growing (83).

For the formation of bracts and the initiation of flowers in their bases, it is necessary for the plastochrone (the time between the forming of the primordia of two neighboring organs) to be shortened to 7 days (42). In a series of publications (40, 41, 42) raised an idea of a system of development based on the inhibition of given organs by the neighboring ones.

The widening and slight swelling of the bud apices, when they become dome-like in shape, is usually accepted as the first visible indication of the transition from vegetative to reproductive state (1, 50, 57, 61, 62, 67, 81, 130). For a greater precision in determining the moment of transition to a reproductive state in the apple, the onset of the bract initiation could be taken into consideration (42, 70). However, when observed under a stereoscopic microscope, the bracts are not visible at the moment of their appearance but a little later. It would be better to use an electronic microscope enabling the observation of the separate parts of the developing flower buds at their mere initiation, as it can be concluded from the results of some studies on apple and sweet cherry (1, 13, 14, 30, 39, 50). In connection with the clarification of the morphogenetic events between the vegetative development and the onset of the floral organ initiation, Foster et al. (39) suggested the concept, according to which the widening of the bud apex preceding the doming could be accepted as the first visible sign of the transition to floral development in the apple.

There is a certain order in the onset and the rate of morphological differentiation in some fruit tree species, which can be put in the following order of succession: sweet cherry, apple, pear, peach, quince (131). Our studies (unpublished data) reveal the same order as far as sweet cherry and apple are concerned.

According to Kolomiets (67), Bergh (13), Huang (62) and Foster et al. (39) the morphological differentiation in apple is expressed in the following order. After induction of the flower bud formation and the histological transformation of the apical meristem, laterally to the growing apex a swelling is formed and this is a primordium of a bract. In the axil of the bract a lateral flower is initiated. Simultaneously the primordium of the following bract is formed and in its axil the next lateral flower is formed, etc. It is followed by the primordium of the apical flower, which overtakes in its development the lateral flowers. The five sepals on the apical flower do not appear simultaneously and at the beginning they are not of the same size. Later on, on the inner side of the sepals, at the point of their juncture, petal primordia appear. After that, the stamen primordia are formed, in shape of a ring, under the petals, with a second ring of stamens below the first one. Finally the center of the bottom of the cave sinks and five swellings of the carpels appear. The lateral flowers are formed like the apical one.

The appearance of the primordia of the separate flowers in sweet cherry, within the framework of the same bud, is nearly simultaneous (131). Certain differences in the phases of development of flowers in a given bud of sour cherry can be observed up to the initiation of the anthers and carpels; after that, all flowers look similar (30).

With the onset of the morphological differentiation in the month of July (6, 31, 66, 67, 86) carpel primordia in the apple appear in September to October. The further formation of flower parts occurs till the transition of plants into a state of winter dormancy (67). Toward the end of autumn all flower primordia, except those of the sepals, are found in an undifferentiated state. The carpels usually form seed cases but are not yet present in form of a pistil.

The microsporogenesis and the macrosporogenesis in the apple occur in the following calendar year (71, 89). From the initiation of the anthers in the autumn till the full formation of pollen in spring more than half a year passes under the condition of Moldova (71).

The rate of development of flower buds during the different phases is not constant, particularly under unfavorable meteorological conditions (62). The development can be retarded for a certain period of time. Consequently, it is difficult to establish how long a given phase lasts.

In sweet cherry the rate of development of buds is accelerated. The pistil primordia can be observed at the beginning of September under the conditions of Bulgaria (45) and toward the end of the same month in Germany (32) or Switzerland (14). Under identical conditions of the environment for growing, pistil stigmas can be observed in December in sweet cherry and in March of the following year in apple (131).

Factors and conditions for flower bud formation

The development of flower buds, from induction to the anthesis, is subjected to the influence of different factors and conditions, which at a certain moment are responsible for flower bud formation.

Cultivar

The onset of the histological (15) and morphological (20, 61, 66, 95, 130) differentiation in apple may depend on the characteristics of a cultivar. The cultivars can exert an influence also with respect to the further development of flower buds (89).

Rootstock

Rootstocks, as components of the grafted fruit trees, may influence the time of initiation of flower buds. According to Buban (15) some apple rootstocks exert this influence only on specific cultivars. The same was noted by Elek (33) in sour cherry. Apparently an interaction between the two components of a tree takes place, leading to a change in the time of onset of the morphological differentiation. In some studies (66, 69, 102) the differences between the observed rootstocks were not significant. Studies of Hirst and Ferree (55, 56, 57, 59) are indicative in that respect. The authors found that rootstocks do not influence the time of terminal growth of shoots, although their length depends on the rootstock vigor. They also do not influence the 'critical number' of appendages in the transition of buds from vegetative to generative state or the time of flower initiation. The 'critical number' of appendages was about 20 throughout all years of study, irrespective of the differences in climatic conditions. However, the share of spurs with initiated flower buds increased under the influence of dwarfing rootstocks. The rootstocks showing different vigor did not significantly influence the initial development of flower buds of the 'Stevnsbaer' sour cherry cultivar (72).

Fruit-bearing branches

Differences in the time of initiation of flower buds on different types of fruit bearing branches have been commonly noted. Bud differentiation usually starts at the earliest on the perennial spurs, somewhat later on the younger and more vigorous ones, and at the latest, on the shoots (6, 67).

Sometimes the onset of flower formation on branches with identical position (of the same age) can occur suddenly and almost simultaneously in all of them (80), and in other cases within a much longer time (66, 81).

Shoot growth

Differentiation of flower buds is often associated with the growth of the shoots. Termination of growth is considered as a prerequisite for flower initiation (6, 57). The spurs stop their growth 2-4 weeks after the bloom (16, 63, 98), whereas the shoots may continue their growth. According to Luckwill and Silva (80) flower initiation in spur and axillary buds of 'Golden Delicious' apple, occurs about two weeks after growth cessation of long shoots, but it is one month later in the terminal buds of the shoots.

Vegetative growth and flower bud formation are considered as antagonistic processes (26, 113). The antagonism, however, is not characteristic of all apple cultivars. In those prone to initiate axillary flower buds on long shoots, as is the case 'Melba', this phenomenon may not be manifested (87).

Depressing influence of the fruit

The depressing influence of the fruit on flower bud formation is a common phenomenon in the fruit tree species with alternately bearing cultivars, such as apple (26, 65, 92). The direction of this influence within the system of the spur is basipetal (76). A great part of the fruit-bearing wood in apple and pear is formed on old spurs and is located lower than fruits, so it is exposed to their inhibiting influence. The flower initiation on spurs is controlled mainly by factors active within the system of every separate spur (63, 79). In the pear cultivar 'Williams', which under certain conditions forms fruits without seeds, a high degree of correlation between the leaf area and the number of the initiated flower buds was noted. When in the system of a spur there are fruits with developing seeds, the buds present on it remain in a vegetative state. The slowing down influence on the flower bud formation according to Luckwill (78, 79) is hormonally based. Depression of flower bud formation by a part of fruits in the alternately bearing apple cultivars can be manifested by the prolonged plastochrone (43). In these cultivars it continues up to 18 days and this is not favorable for flower initiation, whereas in the regularly bearing cultivars the plastochrone is 7 days.

In apple trees with a high load of fruit, the onset of the flower initiation can be slowed down (5, 66). Differences between the cultivars have been noted in this respect. In 'Jonathan' and 'Starking' there is a tendency for slowing down the onset of the histological differentiation but in the 'Parker Pippin' there is no such tendency (17).

Cytochemical changes

The cytochemical changes occurring in the buds and their neighboring organs and tissues, influence in some way their transition from vegetative to generative state. The increased content of nucleic acids (18, 19, 107) and the decreased content of IAA (123) favor the flower bud formation. The presence of fruit on spurs results in a decrease of the nucleic acid content and increase of the nucleohistone and this has a negative effect on the flower bud differentiation (18, 19). Fruits reduce also the starch content in the fifth to sixth week after full bloom (48). According to this author the high starch content in the spurs cannot be regarded as a direct cause for flower bud initiation, but only as an excellent and rapid indicator of the direction of metabolic processes resulting from the low amounts of auxin and gibberellins in the surrounding tissues.

The Sachs' hypothesis (106) for diverting assimilates, referring to the interrelation between the vegetative and the reproductive development deserves attention. According to this hypothesis the induction of flower bud formation provokes the activation of the central zone of the apical meristem of the bud, which is a necessary condition for initiating flowers and their early development, in the presence of a big quantity of assimilates.

Hormones

Five clearly defined types of plant hormones (gibberellins, auxins, cytokinins, ethylene and growth inhibitors) have been recognized. Each of them performs numerous functions, which act simultaneously to regulate the behavior of fruit plants (79). Particular attention in the studies related to the flower bud formation in these plants has been paid to the gibberellins, which are determined as the fundamental factor for the lack of flower bud formation in the alternately bearing apple and pear cultivars (78, 79). Depression of the flower bud formation with the purpose of overcoming the alternate bearing is also observed in the application of the exogenous gibberellins up to the fourth week after flowering (17, 114). Summarizing the opinions of different authors about the way the endogenous auxins and gibberellins act on flower bud formation, point out that auxins have an indirect, but favorable effect on the initiation of fruit buds at the beginning of the growing season. Auxins located in seeds, younger than four weeks, attract more nutrients to the spurs. This is important, as the early, fast development of the leaf primordia and of young leaves early in the season, is a prerequisite for the flower bud initiation. The gibberellins, translocated from the seeds starting in the third to fourth week after full bloom, counteract the favorable auxin effect and decrease flower bud formation. By means of enhancement of growth of shoots, they indirectly decrease flower bud formation. In the period before the flower initiation, seeds of the alternately bearing apple cultivars diffuse considerably more gibberellins than seeds of those with regular bearing (49, 60).

Ecological conditions

The initiation and development of flower buds can be influenced by the ecological conditions. High temperatures can indirectly inhibit the bud formation in some apple cultivars by means of a change in the length of the plastochrone under the influence of the gibberellins produced in the apices of the growing long shoots (113). Variations of temperature with great day and night amplitudes, has also a depressing influence on flower bud formation (4). The cool weather before the onset of the morphological differentiation, as observed in some years, can lead to the slowing down of its onset (1, 88). Heat accumulation between full bloom and the onset of floral initiation however is not accounted for variations in onset among seasons (81). The favorable climatic conditions for the photosynthesis with a longer period after fruit harvesting, even in late ripening cultivars, in countries such as New Zealand, can lead to formation of more 'vigorous flowers' and this has a favorable effect on the productivity of cultivars (35).

Under conditions of the subtropical climate, where the low positive temperatures necessary for satisfying the chilling requirements, are insufficient, part of the flower buds, which have started their development in some apple cultivars, are transformed into vegetative ones. The flower parts do not develop, but the buds do not fall off, as it is in the stone fruit species, as bourse shoots develop from them (96).

Quality of the reproductive organs

The ability of apple flowers to set fruit as well as the form and size of resulting fruits are related to the morphology of the blossom cluster, which in turn depends on the phase of development, reached by the flower buds at the time of flowering (2, 104). With a lack of vigor in the apple trees, formation of flower buds on vegetative spurs starts early in summer. As a result, in next spring the already flowering spurs appear 'old', have small primary leaves and initiate small fruits. The primary leaves are those grown first from the dormant buds of the bearing apple trees. In the exceptionally vigorous trees or in those having a lot of fruit, the flower bud formation is late and in spring the flowering spurs are 'young', they have very large primary leaves, but they do not set enough fruit. In the well-maintained trees the vegetative spurs form 'vigorous' flower buds within a normal time and in the next spring well-formed flower clusters with 5-6 flowers, with leaves of average size, develop from them. These flower clusters set many fruits, a great part of which fall off during the June drop, but the yield is normal, regarding both quantity and quality.

The age of the fruit-bearing wood influences the quality characteristics of flower clusters in apple (24, 74, 103, 117). The clusters with an axillary position on one-year-old wood differ in quality from those disposed terminally on a 2-3-year-old wood. The former usually have smaller size, their primary leaves are smaller and lighter in color, their flowers are less numerous or smaller. They also have a shorter bloom time and this reduces the chances for effective pollination. The fruit set of that kind of flowers is weaker and they develop in smaller fruits (74, 117). The flower clusters of 2-year-old trees differ in quality from the clusters in the older trees (103). The fruit set, however, increases only until the trees reach 6 years of age.

The apical flower in the cluster dominates over the lateral flowers but this domination varies between the cultivars and can be modified by ecological conditions and by the characteristics of different years (35). The apical flowers set more fruit, compared to the lateral flowers, and in presence of lateral fruits, the apical fruit keeps its priority concerning the size until ripening (46).

The fruit yield and the harvest date influence the development of flower organs in the autumn and in early spring (21, 108, 126). The heavy fruit load in the previous year can cause deformation of the papillas of the stigmas, and late picking of fruits slows down the development of flower clusters, which in turn leads to the decreased fruit set.

Primary leaves in the clusters are of particular importance for the fruit set and for the further fruit development (14, 36, 73). Cumulated yields of diverse apple cultivars depend to a great extend on these leaves (105). The 'vigorous' and 'weak' spurs can be determined by the number and area of primary leaves; however, these characteristics are not sufficient for predicting the fruit traits (8). In this respect more valuable are the mean dry matter of one primary leaf, the total weight of the leaves per spur and the specific dry matter of the primary leaves ($mg.cm^{-2}$), which in turn depend on the intensity of insolation. In the zones of tree crowns well exposed to light the values of these characteristics are higher (8, 9).

At the beginning of the season the area of the primary leaves increases rapidly (73) and at full bloom it represents around two-thirds of the total leaf area of the spurs (99). Early development of the fruit is connected, to a great extent, with assimilates derived from the primary leaves (53). Two weeks after full bloom assimilates derived from the primary leaves are distributed more or less evenly among the fruitlets, leaves themselves and bourse shoots (115). In the next two weeks the share of assimilates sent to the fruitlets increases considerably. Up to three weeks after bloom, the vigorous, fruiting spurs with 9-10 primary leaves and no more than one fruit, can satisfy or get close to satisfying their needs of own assimilates, whereas the weak spurs, the overshadowed ones and those with more fruit need to import assimilates from other branches (23). The distribution of assimilates during these three weeks seems to be very important for the final fruit set and also for their growth potential.

Assimilates derived from the bourse shoots are initially spent for the needs of the shoots themselves; after that the share of assimilates sent to the fruitlets successively increases and by the eighth week after bloom the two attracting centers have almost the same shares in uptake of these assimilates (115). The overshadowing, both in the year preceding flower bud formation and in the current year, decreases the photosynthetic potential of the spurs by means of decreasing the specific weight of the primary leaves, the leaf area of the bourse shoots and the specific weight of these leaves. The bourse shoots arising from the dormant flower buds initially restrict the fruit setting and early fruit development within the system of the bearing spur, but later favor retaining of fruits, particularly at the June drop of fruitlets (100).

The flower quality in the cherry can be connected with the time of anthesis, and this in turn depends on the position of flowers on a fruit-bearing wood (97). The later the bloom, the smaller the fresh weight of the flowers, pistils, ovaries, fruits and soluble solids content in fruits. The flower buds disposed on spurs have, in general, a later bloom than the buds disposed at the base of longer shots. The formation of a double fruit of cherry as a result of the formation of double pistils in the time of differentiation of the flower buds in the previous year represents a big problem for some regions with warmer summers (85). A critical factor for the formation of flowers with double pistils in the cherry cultivar 'Satohnishiki' is the daily air temperature above 30^{0}C (11). Buds are most sensitive to high temperatures when they are in the transitional phase from differentiation of sepals to differentiation of petals (10). It is possible, by means of artificial shading, particularly during unusually warm summers, in order to lower the air temperature, to reduce the formation of double pistils (12). Forcing of sweet cherry trees applied to accelerate the fruit ripening can decrease the formation of double pistils through accelerating the rate of bud differentiation and avoiding their exposure to high temperatures when they are still sensitive to them (10). Quality of the flower buds and flowers of sour cherry determines their sensitivity to frost at the end of winter and at the beginning of spring (72). Under the influence of the rootstock Colt, the quality of flower buds and flowers of the 'Stevnsbaer' sour cherry was significantly lowered, as shown by a high percentage of damaged or dead buds and flowers, and dramatically low percentage of fruit set.

Practical considerations

By means of monitoring the development and quality of the flower buds, it is possible to predict the potential yield (3) and provide necessary agro-technical measures in the year preceding flowering (14, 32).

Pruning

Dormant pruning and its influence on the growth and fruiting of the apple trees have been an objective of numerous studies (37, 86). The studies of the summer pruning are more limited.

Summer pruning, applied to young, vigorously growing apple trees, can be favorable for flower bud formation (90). It is desirable for this type of pruning to be applied in the first half of the summer (77). In some cases the summer pruning does not have any positive influence on the initiation of flower buds (47). Its effect depends on the characteristics of cultivars (120). Summer pruning can reduce the total number of flower buds per tree, but it can increase the number of flowers per inflorescence, so the total number of flowers per tree may not be finally changed (93). For training tree crowns, the summer pruning is preferred over the dormant one, but it does not always result in an increase of yield (87). As far as dormant pruning is concerned, shortening of one-year-old shoots can be employed in the cultivars inclined to initiate flower buds on long shoots, with no negative effect on flower bud formation. Various responses of trees to summer pruning, reported in the different studies may be also due to the differences in date, method of pruning and its severity.

In sweet cherry, shortening of current season shoots till the forty-fifth day after full bloom increases the number of flower meristems in the nodes, disposed at the bases of these long shoots, accelerates the flower initiation and favors formation of larger flower buds by the end of August (50, 51). The authors recommend summer pruning for young sweet cherry trees densely planted. Tipping of extension shoots in the third year after planting leads to an increase of the number of flower buds in the basis of the shoots; however, the total number of flower buds per tree can be decreased (120).

Use of fertilizers

Fertilization of fruit plants is a treatment that may considerably affect both the flower bud formation and fruit set. It must be done according to soil fertility, characteristics of the cultivars and rootstocks, climatic conditions, fruit load and desired fruit quality (65). Application of high dozes of phosphorus at tree planting can increase the number of the initiated flower buds (94, 128). Phosphorus is supposed to influence indirectly flower bud formation by means of changing the level of the cytokinins synthesized in the roots (58). The nitrogen fertilization after conclusion of terminal growth of extension shoots may stimulate flower bud formation (127). The earlier application stimulates growth and this is undesirable for the potential flower bud formation. Summer fertilization with nitrogen, as an addition to that applied in spring, increases the vitality of ovules and stigmas in some apple cultivars (125). In the alternately bearing cultivars nitrogen fertilization in spring of the 'off' year must be limited, whereas the fertilization in autumn, as well as in spring of the following, 'on' year should be abundant (122).

The growth and initiation of flower buds in young apple trees of the cultivar 'Fuji', fertilized by ammonia or nitrate form of nitrogen grown in sand culture, depended on the rootstock on which the trees have been grafted (44). Trees on dwarfing or semi-dwarfing clonal rootstocks, fertilized with the ammonium nitrogen, formed a greater number of shoots and flower buds, compared with those fertilized with the nitrate form. At the same time, growth and flowering of trees on vigorous rootstocks, was not influenced by the forms of nitrogen.

Irrigation

Irrigation influences favorably the flower bud formation in apple (66). Particular attention deserves fertigation, which has been lately applied in intensive orchards. With an optimum supply of water and nutrients, by means of fertigation, young apple trees initiate more flower buds, irrespective of the acceleration of growth (27, 28, 29). Competition between growth and fruiting can be aggravated as a result of the unbalanced influence, by a specific rootstock, irrigation or other factors. The situation may be changed, however, when growth is stimulated by simultaneous water and nutrient supply, which may affect metabolism in a more balanced manner, possibly avoiding the lack of specific metabolites important for flower initiation in critical stages. Through fertigation, root activity, extension shoots growth and the development of the nodes in the axillary buds may be improved to a degree at which a greater part of these buds become flower buds.

Pollination

In sweet cherry, special attention deserves providing proper pollination in a due time, taking into consideration the short vitality of the ovules and of the embryo sacs (109).

Growth Regulators

Some of the changes occurring in processes of flower bud formation of fruit plants, as a result of the application of growth regulators were discussed in detail by Mitov et al. (91). Here, some viewpoints, expressed in the last 3 decades, will be presented. In apple, the changes are oriented mainly in two directions: induction of flower bud formation by suppression of growth by means of treatment with retardants (substances suppressing growth) (54, 78, 79) or cytokinins (101) and inhibition of flower bud formation by applying gibberellic acids (54, 84, 112). According to Luckwill and Silva (80) treatments with retardants may weaken the competitive vigor of the long shoots, thus resulting in directing assimilates to the initiating flower buds. This causes the sudden shortening of the plastochrone, and it is a prerequisite for flower initiation. In case of the gibberellic acids an opposite mechanism can be expected. Sometimes retardants reduce the growth of extension shoots without influencing the flower initiation (47). A similar phenomenon is observed in the sweet cherry (34). In this species the treatment with paclobutrazol usually increases the number of flower buds, but a part of leaves may fall off earlier, resulting in a decrease of fruit number and yield (7).

It is assumed that spraying with the gibberellic acid GA_3 blocks the first steps in the process of flower bud formation before the growth of the shoots has stopped (112). This growth regulator can suppress the flower bud formation without visible influence on growth (54). The treatment with GA_{4+7}, up to the 22[nd] day after full bloom, reduces the number of flowers for the next year more than the same treatment applied later (84). Spraying of alternately bearing apple cultivars with gibberellic acids in the 'off' year may be helpful in overcoming alternate bearing (82). However, with varying time of initiation of flower buds, it is difficult to determine the exact date of treatment in the different years (81). Diverse effects obtained with growth regulators in different studies indicate that special care is necessary at their application. Growth regulators should be employed as additional means to the traditional agricultural practices. Their restricted application is necessary also in connection with the preservation of the natural environment.

Conclusions

The flower bud formation in fruit plants of the temperate climatic zone, including apple and sweet cherry, is a complicated biological phenomenon, which was the objective of many studies, lately including explanation of its genetic essence. However, some of the most characteristic moments of the bud transition from the vegetative into the reproductive state and their further development, have still not been sufficiently clarified. The existence of versatile relations is presumed, between the genetic control, the hormonal balance and the presence of sufficient amount assimilates in the plant as a whole and more precisely in the forming flower buds. The development of flower buds is related to the characteristics of the fruit tree species and cultivars, ecological conditions and agricultural practices. Quality of the reproductive organs depends on the factors and conditions for flower bud formation, which in turn influences the quantity and quality of fruit production.

The initiation and development of flower buds in apple and sweet cherry can be successfully regulated by means of scientifically well-founded agro-technical practices such as pruning, fertilization, irrigation and treatment with growth regulators.

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