Thinning Methods to Regulate Sweet Cherry Crops

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Contributor: Grzegorz Łysiak

In perennial fruit crops, bearing can be influenced by various factors, including environmental conditions, germplasm, rootstocks, and cultivation methods. Cherries, one of the most important and popular fruit species from the temperate climate zone, achieve high prices on the market. New agricultural technologies and environmental factors force a change in the approach to cherry cultivation. Old-type cherry orchards, with their high demand for water, nutrients, and manual work, are replaced by orchards of self-pollinating cherry cultivars grown on dwarf rootstocks. These changes make it necessary to search for ways to regulate fruiting, in particular to thin buds, flower, and fruit. In light of environmental regulations and consumer pressure, thinning methods are being sought that either do not involve the use of chemicals or that use eco-friendly chemical agents.

fruit quality pruning growth regulation fruit set crop value

1. Introduction

Thinning is carried out regularly on stone fruit species such as peach and nectarine, but rarely on apricots, plums, sweet cherries, or sour cherries. The response to and effectiveness of thinning depend not only on the species and cultivar, but also on climatic and soil conditions and agricultural treatments, especially pruning. Yield as well as vegetative growth are related to the intensity and timing of thinning [1]. In recent times, interest in the use of thinning has increased due to increased market requirements regarding the size and quality of fruit [1].

Fruit trees produce numerous flowers that they cannot turn into fruit and maintain until harvest. The number of flowers on a tree is very large and, depending on the species and size of tree, there may be up to 50,000 flowers per sweet cherry tree and up to 20,000 flowers per peach tree [2]. In pome species, in order to obtain a good quality marketable crop, it is sufficient if only a few to about a dozen percent of flowers set fruit. For this reason, apple trees yield well when 7% of flowers have set fruit. Stone fruit species require a higher level of pollination. In peach, sufficient yield is obtained when 25% of flowers set fruit [2], whereas sweet cherries yield well with a fruit setting ratio of 25–40% [3][4].

Rootstock strongly affects the number of flowers. Fruit trees grown on dwarf and semi-dwarf rootstocks set more flower buds [5]. However, cherry trees on dwarf rootstocks often bear an excessive number of small fruit with low sugar content [6]. Therefore, flower thinning is necessary to prevent over-yielding and provide high-quality fruit [6][7] in terms of the basic fruit quality parameters, such as size, colour, total soluble solids, and firmness [2].

The fruiting of trees is affected by a number of factors, which include environmental factors, such as tree nutrition, light, and temperature. Often, however, endogenous factors are crucial, such as processes that regulate the initiation of flower buds; they take place during the summer and depend on the number of fruit on the tree. Fruit and developing seeds can, through the production of gibberellins, inhibit the initiation of flower buds and thus reduce the number of flowers in the next season [1].

Thinning is most often conducted with the use of chemicals. Chemical thinning reduces the workload compared to manual thinning and weakens the tendency to biannual bearing [2], a frequent feature of cross-pollinated cultivars. However, the number of chemical compounds approved for thinning and the protection of fruit plants is being constantly reduced in the EU. In addition, due to consumer pressure, retail chains are forcing the limitation of the number of permissible chemical treatments or the exclusion of certain active substances [8]. As manual thinning of cherries is very expensive due to the size of tree and number of fruit, it is necessary to develop a chemical thinning technology that would be especially suitable for the treatment of abundantly fruiting self-pollinating cultivars [9].

The need for thinning sweet cherries is driven by the market—a higher market price is paid for larger fruit. The size of fruit is primarily a cultivar-specific feature, but is largely influenced by the number of fruit on the tree, and this depends, among other things, on the level of pollination resulting from weather conditions prevailing in the period of pollination and fertilisation [1]. Cherry trees produce a very large number of fruit per shoot compared to peaches or apples, but as the weight of the fruit/cm^2 of the cross-sectional area of the trunk is low, thinning is not physiologically justified. Although cherry is a cross-pollinated species, which can sometimes cause poor pollination, the more commonly cultivated self-pollinating cultivars set much more fruit than the cross-pollinated ones and thus require thinning for the fruit to meet the quality requirements [9]. Thinning improves crop quality in that it reduces fruit set in self-pollinating cherry cultivars, which set 10–15% more fruit than cross-pollinated cultivars [10][11].

Therefore, when fruit or flower bud set is high, early thinning can significantly increase the crop value. However, thinning of flowers or fruit of cherries [12], apricot, European plum, or Japanese plum [9][13][14] to regulate the size and to increase the crop value is only relevant in years of high yield, that is, when the number of buds or fruit set is very high. With a low yield, the fruit is naturally larger and of better quality. In addition, for stone fruit species, it is advisable to use thinning of buds at a later stage so as to prevent excessively loaded branches from breaking [9][13][14].

2. The Effect of the Rootstock on Thinning

The use of dwarf rootstocks such as ‘Gisela 5’ and Tabel® Edabriz in the production of commodity sweet cherries in the United States increased yield despite induced precocity and reduced tree vigour compared to the use of standard Mazzard rootstock. The increase in yield, however, resulted in smaller fruit, which was explained as due to indequate crop load management [15][16]. This effect was particularly acute in the cultivation of self-fertile cultivars such as ‘Lapins’, ‘Sweethart’, and ‘Summit’ [17][18]. The best solution used to improve the fruit size on trees growing on dwarf rootstocks was to remove of 30 to 50% of fruiting spurs [19]. Thinning can also be optimised by measuring the number of fruit to the branch cross-sectional area ratio. The best fruit quality was obtained with 10 sweet cherries per cm^2 of branch cross-sectional area [20][21]. The selection of the rootstock and thinning have a positive effect on many fruit quality parameters [22][23].

Rootstock can affect the yield regardless of vigour [24], but the rule according to which higher yield is associated with smaller fruit is rootstock-independent [10][25][26][27][28]. In a situation where the effectiveness of chemical thinning varies from year to year, a rational solution, especially for self-fertile cultivars, is the use of an appropriate rootstock that allows achieving acceptable yields of good quality cherries [15]. Comparative studies carried out on self-fertile ‘Lapins’ sweet cherry trees showed that the highest yield per tree and yield efficiency with relatively large fruit (~7 g) were obtained on trees grown on Gi 154/7 and Gisela 4 rootstocks. Large cherries were harvested from trees growing on P-HL-A and Gi 523/02 rootstocks—7.7 and 7.6 g, respectively, but the total yield for the research period was significantly lower. Small fruit (6.1 g) and low yield were obtained on trees growing on the popular Gisela 5 dwarf rootstock [29]. Other studies show that the size of fruit from trees grafted on Gisela 5 depends on crop size and weather conditions [30][31]. In addition, subsequent experiments with the use of various rootstocks indicate that in addition to the rootstock and cultivar, soil, and climatic conditions are very important factors shaping the fruit quality [32][33]. Rootstock affects the number of bouquet buds and the number of flowers in the inflorescence [34]. The use of Gisela 5 dwarf rootstock significantly increased the number of flower buds compared to the more strongly growing Colt rootstock [35]. In addition, a comparison of the Edabriz and F12/1 rootstocks indicated that the number of flowers and spurs on branches of trees grown on Edabriz was larger, whereas the size of fruit was smaller than on trees grown on the strongly growing F12/1 [36].

3. The Impact of Thinning on Fruit Quality

Size is one of the most important fruit characteristics that consumers pay attention to and that affects the fruit's market value [37][38]. Fruit quality is directly related to the intensity of flower and fruit thinning. Studies show that an increase in yield is often accompanied by a smaller fruit size [15][39][23][37]. The response to thinning depends on the age of the tree, the quality of flower buds, the competition between flowers in the inflorescence and the tree crown, and the timing of the procedure. In addition, the order in which flower buds open on shoots can indirectly affect protection against frost and, at the same time, the effectiveness of thinning. Buds on short shoots generally develop faster than those on long shoots, and therefore it is advisable to thin short shoots if there is a risk of frost. On the other hand, delayed thinning may cause that mainly buds on weak long shoots, which flower latest, will be removed. In addition, treatment delay affects vegetative growth and differentiation of flower buds for the next year [40]. Fruit on short shoots (less than 25 cm) reach smaller sizes, because those shoots have too many flower buds and too few leaves to produce fruit of the right size. Therefore, in order to improve the fruit size in cultivars that produce a large number of short shoots, shoots should be headed back so as to leave only one bud [21][24][17][41]. Such thinning intensity improves the fruit size, coloration, firmness, and content of sugars and acids [12][41].

The effect of thinning on quality parameters also depends on the cultivar. A high crop load and a thinning treatment carried out 6–8 weeks after flowering caused a significant decrease in fruit size of 'Sweetheart' sweet cherries, but there was no decrease in fruit diameter when thinning was conducted earlier. The date of thinning also affected firmness and TSS (Total Soluble Solids) concentration, for example, no reduction in fruit acidity was observed in fruit from trees thinned immediately after flowering [21]. The size of fruit is also associated with greater availability of assimilates during the period of cell division, which occurs up to 11 days after flowering. Later, the fruit grows only as a result of an increase in the volume of cells [42][43]. Thinning after flowering increases the susceptibility of fruit to cracking at lower crop load levels [44].

As consumers prefer large cherries, new sweet cherry cultivars should be able to bear fruit with a minimum diameter of 25 mm. According to consumer expectations, new cherry cultivars introduced to the market should have a weight of 11–13g, a diameter of 29–30 mm, TSS of 17–19%, firmness of 70–75 UF, and juice pH of 3.8 [45].

Thinning of flowers and spurs increases the share of fruit with a diameter over 25.5 mm [23]. Fruit from two-year-old spurs has been found to have higher TSS compared to fruit from other tree fruiting parts [46].

Thinning significantly increases not only the fruit size, but also the level of TSS and anthocyanins, and the total antioxidant capacity of seeds. Therefore, the opinion that thinning can increase the organoleptic and nutraceutical properties of cherries has gained acceptance [22]. A higher leaf area-to-fruit ratio results in a higher fruit mass, a darker fruit colour, a higher TSS, a higher ratio of sugars to acids, and earlier fruit ripening [47]. In addition, the content of glucose, fructose, and sorbitol; the sum of individual sugars; and the content of malic acid differed significantly depending on the thinning treatment. By contrast, a low leaf area-to-fruit ratio may prolong the ripening process [47].

Years with high rainfall are associated with the problem of fruit cracking, which is cultivar-specific. Studies of the relationship between crop load and the incidence of cracking have shown a negative correlation. The cracking tendency can be determined, but only after the end of cell division. Fruit width has been observed to be positively correlated with cuticular cracking, but contrary to what has been maintained in literature, the relationship between the concentration of soluble sugars or firmness and the incidence of cracking is low and debatable. It seems that the decisive factors, in addition to the genetic propensity of the cultivar, are crop load and fruit size [44].

As discussed above, flower bud thinning can regulate the fruit-to-leaf area ratio on trees grown on dwarf rootstocks. This ratio influences the yield, fruit quality, and vigour of trees, but it has no effect on the whole canopy net CO_2 exchange rate (NCER canopy), which indicates that it does not affect the intensity of photosynthesis. According to the results obtained at Michigan

State University, NCER canopy and net assimilation are more strongly determined by weather and sun altitude. Trees thinned to 20 fruit/m^2 of leaf area had yield reduced by 68%, but higher fruit weight (+25%), higher firmness (+25%), higher soluble solids (+20%), and fruit diameter (+14%) compared to unthinned (control) trees (84 fruit/m^2). In the same study, the flower-to-leaf ratio did not affect the subsequent induction of flower buds, although the fruit-to-leaf area ratio influenced the growth in the second part of summer [48].

Studies assessing the effects of thinning with ATS on the fruit quality of three self-sterile or partially self-sterile cultivars (‘Blaze Star’, ‘Samba’, ‘Techlovan’) were conducted in Germany. Thinning efficiency was not dependent on the ATS concentration used. The treatments had no effect on fruit weight and anthocyanin content, but resulted in an increase in total soluble solids and pH value of the juice [49].

Thinning tests were also carried out with limestone sulphur and the fungicide Netzschwefel Stulln (in which the active substance is soluble sulphur in the form of micro granules), but no visible results were achieved. The only positive outcome of the application was lower flower infestation by *Monilinia laxa* [50][51].

4. The Effect of Thinning on Yield

Thinning may affect the yield [21][52][53][54]. The use of sulphur lime (FOLS) as a thinning agent on the self-fertile ‘Bing’/Gisela®5 cultivar reduced the yield by up to 40% [55][56][48]. The application of ATS to thin flowers of the cross-pollinated ‘Regina’ sweet cherry on the ‘Gisela 5’ rootstock resulted in a yield decrease by 29.4% at 20 g ATS L^{-1}, 43.0% at 30 g ATS L^{-1}, and 48.9% at 40 g ATS L^{-1} [20]. In another study, manual thinning of the spurs, flower buds or flowers of the self-fertile ‘Lapins’ sweet cherry trees improved the fruit quality without reducing the yield [39]. Another parameter evaluated by researchers is crop value, which varies depending on fruit quality. Crop value increased after ATS and FOLS chemical thinning of ‘Bing’ sweet cherries [15] and after thinning of flowers of ‘Bing’ cherry trees grown on the Gisela 5 rootstock. The same was observed for ‘Sweetheart’ sweet cherries grafted on the ‘Mazzard’ rootstock, where the removal of 50% of flower buds increased the crop value [12]. By contrast, thinning of flowers and spurs of Gisela 6-rooted trees caused a decrease in crop value [23].

5. The Effect of Thinning on Vegetative Growth

The indicators most commonly used to measure vegetative growth are the trunk cross-sectional area, the average and total shoot length, and indicators based on leaf surface. In cherries, shoot length is positively correlated with leaf surface [46], whereas shoot growth is negatively correlated with crop size [12].

The vigour of cherry trees decreases with increasing yield [57]. High cropping trees have reduced shoot growth and leaf area compared to non-blooming trees [45]. In a study on ‘Lapins’ sweet cherries grafted on the rootstock ‘Mazzard F-12/L, spur thinning reduced leaf area, but only if the percentage of removed fruiting spurs was above 50%. Removing 50% of spurs or less did not affect the overall leaf area on the tree. This is probably due to a larger leaf area in combinations where thinning was used. By contrast, the removal of 75% of spurs resulted in leaf area reduction, whereas it did not affect shoot length [25]. A high fruit-to-leaf area ratio reduces shoot length but does not affect leaf surface. The shoot growth rate in the initial 40–50 days of the growing season depends on the reserves stored in the lignified organs of the tree. The shoot growth rates are highest near the onset of phase III of fruit development, i.e., 49–60 days after flowering, and decrease later. In the post-harvest period, shoot length increase by only 15% [48].

6. The Effect of Thinning on Physiological Processes

Thinning, especially chemical thinning, is a serious interference with plant physiological processes. The use of chemicals, especially desiccants, may lead to leaf damage [51], which forces the plant to regenerate and repair injuries, causing the consumption of stored reserves.

However, at the initial stage of fruit growth, assimilates are supplied from reserves accumulated in wood, and not from developing leaves. Therefore, it is assumed that the use of desiccant agents, also those damaging the leaves, will not have a significant impact on fruit set [51][15]. Later, however, fruit is nurtured by compounds produced by photosynthesis in leaves, which is reflected in the level of carbohydrates—leaves of non-fruiting cherry trees were found to have a higher concentration of carbohydrates compared to fruit-bearing ones [58]. The distribution of assimilates is also affected by the removal of a part of spurs in the dormancy period. Such pruning improves the distribution of assimilates among a smaller number of fruit and, thus, can ensure a better balance between growth and fruiting [59].

Thinning has been found to influence the mineral composition of leaves. Hand thinning of flowers improves the absorption and content of nutrients. Thinning of sweet cherry flowers affects the seasonal changes in the absorption of micro- and macroelements in cherries. The content of nutrients in leaves differed significantly between treatments carried out before, during and after fruit ripening [60].

Photosynthetic activity can be monitored by measuring leaf gas exchange. It has been observed that leaf gas exchange is reduced after thinning. This is because it takes some time for leaves to regenerate after treatment. Among trees thinned with desiccant agents, the leaves of trees thinned with ATS regenerated the fastest, and ATS reduced gas exchange only slightly [55]. However, note that phytotoxicity of desiccant agents, such as ATS, depends on the course of weather conditions during treatment [51].

Oil-based preparations used for thinning may also have negative side effects, such as choking of stomata, which limits leaf gas exchange and increases intercellular carbon dioxide concentration thus resulting in plant stress [61]. Phytotoxic activity manifest in leaf burn was observed on trees treated with ATS, tergitol, and fish oil mixed with California liquid. Those substances probably damage the structure of photosystem 2 and the thylakoid membrane [62][63], and consequently reduce fluorescence (Fv), gas exchange (NCER), and stomatal conductance (gs) [62]. Young, developing leaves are more vulnerable to damage, so thinning agents hinder photosynthesis in those leaves to a larger extent than in mature leaves. This is likely due to the yet unfully developed ability to photosynthesize, unripe stomata [64], and higher absorption of thinning preparation by the tender epidermis [55].

Some thinners damage the photosynthetic complex absorbing light and increase energy dispersion through non-photochemical processes [65][66]. A similar fluorescence reduction was observed in several tree species in response to foliar application of salt [65]. Treatments with fish oil combined with California liquid (FOLS) after flowering did not affect fluorescence but significantly lowered the efficiency of photosystem 2 (ΦPSII) [62].

Thinners may also slow down the formation of chlorophyll in leaf tissues. Chemical thinning was observed to reduce chlorophyll content by 6–19%. The increase in SPAD values (chlorophyll content) after chemical thinning is positively related with the increase in leaf NCER (CO_2 exchange rate) [55], which proves that lower chlorophyll content is a factor limiting photosynthesis in young leaves [67].

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