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INFLUENCE OF SEVERAL METHODS OF FLOWER AND FRUITLET THINNING ON THE YIELD AND QUALITY OF GALA MUST APPLES

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ABSTRACT

Apple trees of the Gala Must, grafted onto the dwarfing M.9 rootstock, planted in 2014 at a spacing of 3.5×1.8 m, were subjected to flower and fruitlet thinning in 2022–2024. Seven thinning combinations were used: 1 – (M) Mechanical thinning of flowers at the stage when the petals had emerged in 2 or 3 flowers in the inflorescence, using the German BAUM device; 2 – (C) Chemical thinning of fruitlets with Globaryll 100 SL containing cytokinin; 3 – (H) Hand thinning of fruitlets after June drop; 4 – (M+C) Mechanical thinning of flowers with the BAUM device supplemented by chemical thinning of fruitlets as in pt. 2; 5 – (M+H) Mechanical thinning of flowers with the BAUM device supplemented by hand thinning of fruitlets after June drop; 6 – (C+H) Chemical thinning of fruitlets with Globaryll 100 SL supplemented by hand thinning after June drop; 7 – (Control) Trees in which neither flowers nor fruitlets were thinned out.

In most treatments, the thinning of flowers or fruitlets caused a significant decrease in fruit yield but improved fruit quality, compared with the control. The thinning treatments increased the weight and size of apples, as well as their soluble solids content. Most apples were of a favourable marketable size in the range of 7.0–7.5 cm. The combined thinning treatments (M+H, M+C, C+H) resulted in the production of too many overgrown apples, which are known to be more susceptible to bitter pit, which in turn may reduce their storage life. Most of the thinning treatments resulted in a higher soluble solids content in the fruit without a significant effect on their firmness.

Keywords: apple tree, BAUM device, mechanical thinning, yielding, fruit quality

INTRODUCTION

The thinning of flowers or fruitlets is commonly used in fruit growing. In the case of apple trees, regulating fruiting is a very important treatment in commercial orchards. Many apple cultivars tend to produce an excessive number of flower buds, very abundant flowering and fruit setting. The fruitlets compete with one another for the limited range of assimilates supplied by the tree. Removing unnecessary flowers or fruitlets improves the leaf-to-fruit ratio. This allows a better supply of assimilates to the remaining fruitlets on the tree. In order to obtain good quality apples, 20–30 leaves per fruit are necessary [Seehuber et al. 2014]. If fruiting is too abundant, the apples produced are small and of low commercial value [Solomakhin and Blanke 2010].

When apple trees blossom very abundantly, it is enough for about 7% of the flowers to set fruit to obtain a profitable marketable yield of good quality [Untiedt and Blanke 2001]. Mechanical or chemical thinning of flowers or fruitlets is therefore necessary to obtain high-quality fruit [Blanke 2008], to reduce the labour consumption of subsequent hand thinning of fruitlets

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and, consequently, to prevent trees from switching into biennial bearing [McArtney et al. 1996].

Fruit growers need to remove excess amounts of flowers or fruitlets from apple trees annually [Peifer et al. 2018]. Looney [1993] stated that activities aimed at obtaining the optimal number of fruitlets on the tree are the most important agrotechnical treatments in apple cultivation, influencing the high quality of apples (mainly increasing their size, improving the economic efficiency of the orchard, and ensuring appropriate flowering in the following year, which ensures regular fruiting) [Greene and Costa 2013, Solomakhin et al. 2012]. In addition, thinning out flowers helps maintain a balance between vegetative growth and fruiting in apple trees [Dennis 2000].

In general, the aim of thinning is to produce fewer fruits [Link and Blanke 1998], but of better quality. Thinning flowers or fruitlets is time-consuming and expensive, therefore experiments are conducted to improve it. Thinning can be performed at various phenological stages of tree development, from flowering to when the fruitlets are as large as 18 mm in diameter [Greene and Costa 2013].

In practice, three main methods are used for thinning fruitlets or flowers of fruit trees: by hand [Embree et al. 2007, Hampson and Bedford 2011], by chemical means [Basak 2000, Dennis 2000, Wertheim 2000, Dorigoni and Lezzer 2007, McArtney and Obermiller 2010], and by mechanical means [Bertschinger et al. 1998, Schupp et al. 2008, Solomakhin and Blanke 2010, Seehuber et al. 2014, Lordan et al. 2018].

Hand thinning of apple fruitlets is most often done after the period of the natural drop of fruitlets, which usually occurs about 6 weeks after the trees have reached the full-bloom stage [McArtney et al. 1996]. This method of fruit thinning is the most reliable, most accurate and most effective, but also the most expensive and very time-consuming [Menzies 1980, Costa et al. 2013], and performing it after the natural drop of fruitlets may negatively affect fruit size in a given year and flowering in the following year [Dennis 2000, Fallahi and Greene 2010].

During hand thinning of fruitlets, the smallest, russeted, pest-damaged and deformed fruits are removed, and ‘fruit clusters’ are thinned out. Even if hand thinning of fruitlets does not result in the required improvement in fruit size, it does have an impact on the more abundant setting of flower buds for the following year.

Thinning of fruitlets by hand is now performed less and less frequently due to the high labour consumption and high costs [Schupp et al. 2008, Martin-Gorriz et al. 2012]. It is becoming increasingly difficult to carry out hand thinning from year to year due to decreasing labour availability [Strijker 2005, Greene and Costa 2013]. Hand thinning of fruitlets is therefore a supplementary treatment that follows chemical thinning, which is not always fully sufficient [Menzies 1980].

In apple and pear cultivation, chemical thinning of fruitlets is commonly used to improve fruit quality and prevent biennial bearing [Tromp 2000, Whiting and Ophardt 2005]. When chemically thinning flowers or fruitlets, the final effect depends largely on the weather conditions during the treatment [Robinson and Lakso 2011, Costa et al. 2013, Lordan et al. 2018], the age of the trees, the intensity of flowering, and the apple cultivar [Wertheim 2000, Greene and Costa, 2013], as well as the active substance of the preparation used, its dose and the date of the treatment.

Fruit growers are reluctant to use chemicals for thinning during or just after flowering because of the risk of late spring frosts, which can significantly reduce the yielding of trees. The optimal solution seems to be the use of preparations containing the growth regulator benzyladenine (BA) for the late thinning of apple fruitlets. This treatment is performed when apple fruitlets are 10–12 mm in diameter, or even 15–18 mm in the case of some cultivars. This stage usually occurs 2–4 weeks after flowering [Basak et al. 2013]. At that time, the percentage of fruit-setting can already be reliably estimated.

In order to obtain positive results when thinning fruitlets with preparations containing benzyladenine, warm and humid weather is necessary during the treatment and preferably for the next few days. The minimum temperature should be around 18°C, and preferably 20–25°C. For the effectiveness of the treatment, the optimal temperature is more important than the stage of fruitlet development [Buban 2000].

When planning a thinning strategy, on the one hand it would be good to perform the treatment relatively early – then it has the greatest impact on the formation of flower buds for the following year [Wertheim 2000], but on the other hand, with late thinning, when it is already obvious how many fruitlets will remain on the tree, it is easier to decide which chemicals and in what doses should be used for thinning.

Great concern for food safety together with environmental awareness have limited the availability of chemical thinning agents. Due to the effectiveness of chemical thinning, which depends mainly on weather conditions, as well as the impossibility of using it in organic farming, and in the case of hand thinning also due to the lack of workers and high labour costs, attempts are being made to introduce treatments using various types of devices for mechanical thinning of flowers [Damerow et al. 2007, Solomakhin and Blanke 2010, Basak et al. 2013, Kon et al. 2013, Seehuber et al. 2014, McClure and Cline 2015, Theron et al. 2016].

The mechanical thinning of flowers is a more environmentally friendly technology, an alternative to traditional, standard chemical and hand thinning of fruitlets and is another method that improves the regularity of fruiting. The effectiveness of mechanical flower thinning, unlike chemical thinning, is less dependent on weather conditions, the cultivar, or the age of trees [Dorigoni et al. 2010]; it also requires less time and is cheaper than thinning by hand. Mechanical thinning allows complete elimination or very significant reduction in the doses of the chemical preparations used for thinning, which is very beneficial when introducing eco-friendly or integrated production methods.

Most studies have shown that mechanical thinning of flowers reduces their numbers on the tree and improves the quality of fruit at harvest [Solomakhin et al. 2012, Lordan et al. 2018]. The way tree crowns are trained, and also the growth vigour of a given apple cultivar, is crucial to achieving the expected results when using devices for mechanical flower thinning [Bertschinger et al. 1998, Schupp et al. 2008, Pflanz et al. 2016]. In most commercial orchards, trees are nowadays trained in the form of a spindle-shaped (conical) leader crown. In this form, the lateral shoots extending from the leader in the lower part are the longest, and those at the top the shortest. Densely planted orchard trees trained in the form of a slender spindle crown are suitable for mechanical flower thinning [Schupp et al. 2008, Hampson and Bedford 2011].

During mechanical thinning, flowers are knocked to the ground or damaged together with young leaves. This stimulates the release of ethylene in the shoots, which also additionally promotes the subsequent drop of fruitlets after the treatment. Mechanical flower thinning is most effective when performed from the time of the full opening of 2–3 flowers in the inflorescence, but it can also be performed over a longer time, from the pink bud stage until the end of flowering [Veal et al. 2011, Hehnen et al. 2012, Solomakhin et al. 2012, Kon et al. 2013].

The effects of mechanical flower thinning are visible soon after the treatment, so they can be corrected if necessary after the trees have flowered by spraying them, for example, with agents containing benzyladenine, or by thinning the fruitlets manually [Schupp et al. 2008, Basak et al. 2013, Kon et al. 2013]. Hehnen et al. [2012] showed that combining mechanical thinning of flowers with hand or chemical thinning of fruitlets helped to obtain optimal results in terms of flower thinning and fruit quality in some apple cultivars.

The mechanical thinning of flowers with the BAUM device manufactured in Germany, which was designed for trees trained in the form of a spindle crown, allows a significant reduction in the labour costs needed to perform hand thinning of fruitlets. Using this method allows the grower to become largely independent from the traditional thinning methods, i.e. chemical and by hand. It is a simple, cheap, and effective procedure. Mechanical thinning, although not as popular as chemical or hand thinning, is certainly a real alternative to the other methods used.

Fruit growers are reluctant to conduct early thinning of flowers with mechanical devices due to the risk of late spring frosts, which can significantly reduce the yielding of trees [Hampson and Bedford 2011], and also due to the increased risk of fire blight on such trees, caused by the possible penetration of the pathogen into the plant through damaged bark after the mechanical thinning of flowers [Ngugi and Schupp 2009]. In addition, mechanical flower thinning can damage young leaves on the spurs (less intense photosynthesis), which play an important role at the beginning of fruit growth [Bertschinger et al. 1998, Ngugi and Schupp 2009, Solomakhin and Blanke 2010, Greene and Costa 2013, Basak et al. 2013, McClure and Cline 2015, Win et al. 2023]. Flowers that have been injured during mechanical thinning and have not fallen from the trees may develop misshapen, uneven fruit, but this is rare.

The aim of this study was to develop a mechanical method of flower thinning and to compare this approach to chemical and manual thinning of fruitlets.

MATERIAL AND METHODS

The experiment was conducted in 2022–2024 and assessed the effectiveness of mechanical thinning of apple blossoms in comparison with hand thinning of fruitlets and chemical thinning of fruitlets with a preparation containing cytokinin. The study on the thinning of flowers and fruitlets of apple trees was conducted in the Experimental Orchard of the Institute of Horticulture – State Research Institute in Dąbrowice, on apple trees of the cultivar Gala Must, grafted onto the M.9 rootstock and planted in 2014 at a spacing of 3.8×1.5 m. The trees were trained in the form of a conical spindle crown. The experiment was established on a podsolic soil, with a mechanical composition defined as slightly loamy sand, soil quality class IVb.

In 2022–2024, spring temperatures were exceptionally moderate, with many sunny days and not much rainfall. The trees blossomed and bore fruit quite abundantly every year. The earliest flowering of the trees was recorded in 2024, around the 10th of April. At the time of spraying the trees with Globaryll 100 SL, intended for thinning fruitlets, the air temperature was 20°C, and in the following days above 20°C, and there was no wind. Average air temperatures and precipitation totals from April to September in 2022–2024 are shown in Table 1. Globaryll 100 SL is a plant growth regulators containing the natural hormone benzyladenine (BA), which belongs to the cytokinin group.

During the growing season, the experimental plot was subjected to the necessary orchard maintenance work consisting of standard treatments: fertilization, irrigation, weeding, and spraying the trees against diseases and pests.

The experiment was set up in a block design, with four replications. Each experimental plot consisted of five consecutive trees in a row.

Mean fruit weight was calculated from the weight of a fruit sample divided by the number of apples in that sample.

Fruit size measurements were performed by calibrating according to the diameter, with division into size grades every 0.5 cm. The size grades ranged from 6.0 cm to 8.5 cm.

Measurements of fruit colour (red blush coverage) were based on a 1–4 scale: 1 – fruits with blush covering up to 25% of the surface, 2 – blush covering 25% to 50% of the surface, 3 – blush covering 50% to 75% of the surface, 4 – fruits with blush covering more than 75% of the surface.

Mean fruit weight, size and colour development were determined on samples of 4 standard 20 kg crates of apples from the evaluated combinations.

Table 1. Average air temperature and total precipitation from April to September in 2022–2024

Parameter	April	May	June	July	August	September
			2022			
Average air temperature (°C)	5.3	13.2	18.3	18.3	19.9	11.0
Total precipitation (mm)	24.4	36.8	68.4	116.6	82.0	39.4
			2023			
Average air temperature (°C)	7.6	11.4	17.1	19.4	20.2	16.3
Total precipitation (mm)	49.4	41.6	30.2	61.6	95.0	12.8
			2024			
Average air temperature (°C)	10.5	16.3	18.7	20.6	19.4	16.2
Total precipitation (mm)	23.8	39.8	48.6	23.2	30.6	33.2

Measurements of fruit firmness and refraction were taken immediately after harvest on 10 representative apples from each replication, using a hand-held Effegi firmness meter (Fruit Pressure Tester, FT 327, T.R. Turoni Srl, Italy). The measurements were taken twice on each fruit, on the blush side and on the opposite side.

Refraction (soluble solids content) was determined on the same fruit used to measure fruit firmness. The measurements were performed using an electronic refractometer (Pocket Refractometer PAL-1, ATAGO, Japan).

For the mechanical thinning of flowers, a BAUM-type device was used, developed in Germany in 2007 [Damerow et al. 2007], which was adapted to trees trained in the form of a spindle crown. The BAUM device has the ability to remove flowers located in the crown close to the tree leader, and not only in its peripheral zones [Veal et al. 2011]. Removing flowers from the depths of the crown is a desirable procedure because those flowers produce fruits of lower quality [Kong et al. 2009]. The BAUM flower thinner is a small device, easy to transport, working with a tractor equipped with a hydraulic lift. It is equipped with an arm from which 3 horizontally positioned rotors extend, which can be set in any position (changing both the height and the angle of inclination). During thinning, they enter between the tree branches. The rotors rotate around their own axis and have thin plastic cords installed on them that knock down the flowers [Basak et al. 2013].

The following combinations of flower and fruit thinning were used annually:

1. Mechanical thinning of flowers at the end of April, at the stage of open flower petals in two or three flowers in the inflorescence. The procedure was performed with the BAUM device, at a tractor working speed of 5 $km \cdot h^{-1}$ and a rotation speed of the flower knocking rotors of 300 rpm (M).
2. Chemical thinning of fruitlets in the last ten days of May, when fruitlets had reached a size of about 10–12 mm. The treatment was performed with Globaryll 100 SL containing cytokinin, at a dose of 1.5 $l \cdot ha^{-1}$ (C).
3. Hand thinning of fruitlets in mid-June, after the June drop. One fruitlet was left in the cluster, at intervals of approx. 10–15 cm (H).
4. Mechanical thinning of flowers with the BAUM device supplemented by chemical thinning of fruitlets with Globaryll 100 SL on the dates as above (M+C).
5. Mechanical thinning of flowers with the BAUM device supplemented by hand thinning of fruitlets after the June drop (M+H).
6. Chemical thinning of fruitlets with Globaryll 100 SL supplemented by hand thinning of fruitlets after the June drop (C+H).
7. The control consisted of trees in which neither flowers nor fruitlets were thinned out (Control).

The obtained results were statistically processed using the variance analysis method. Duncan's test was used to assess the significance of differences between means at a significance level of 5%.

RESULTS AND DISCUSSION

In most treatments performed in our study, the thinning of flowers or fruitlets caused a significant decrease in fruit yield and improvement in fruit quality in comparison with the control. In some combinations, there were no significant differences in fruit yield and quality between the mechanical flower thinning and chemical fruitlet thinning when compared with the control trees. The thinning treatments of flowers and fruitlets of the Gala Must apple trees reduced the yield of apples, depending on the year and combination, in relation to the control trees within the range of 7.2 to 57.0% and caused an increase in mean apple weight from 3.8% to as much as 63.5% (Tables 2–4).

The greatest reduction in the percentage of fruit set (by approx. 48.0%) in 2023–2024 was caused by mechanical flower thinning supplemented by hand thinning of fruitlets, and the smallest (7.0 to 17.0%) in 2022–2024 in the combinations where only chemical or mechanical thinning was performed. Similar results of mechanical flower thinning had been obtained by Solomakhin and Blanke [2010], Basak et al. [2013], Schupp and Kon [2014], McClure and Cline [2015], and Lordan et al. [2018].The cumulative fruit yield for the three-year study period was significantly lower for the trees in the M+H and C+H combinations (Table 4).

Each method of flower and/or fruitlet thinning, except the chemical thinning of fruitlets alone, caused a significant increase in mean fruit weight (Tables 2–4). The lowest increase in mean fruit weight in the Gala Must was recorded in the combinations where only the chemical thinning of fruitlets was performed (3.8 to 4.9%) and also where only mechanical flower thinning was applied (22.0 to 32.3%).

Table 2. Effects of flower/fruitlet thinning of Gala Must/M.9 trees on the yield and mean weight of apples in 2022

Treatments	Yield (kg·tree^{-1})	Yield (t·ha^{-1})	Yield reduction (%)	Mean weight of apple (g)	Increase in mean weight of apple (%)
Control	36.7 ±0.58 b*	64.4	–	123 ±1.73 a	–
M	30.3 ±0.88 b	53.1	17.5	150 ±4.62 b	22.0
M+H	19.2 ±1.73 a	33.7	47.7	174 ±2.60 cd	41.5
M+C	15.8 ±0.33 a	27.7	57.0	161 ±0.33 bc	30.9
C	34.0 ±2.60 b	59.6	7.5	129 ±4.91 a	4.9
C+H	16.2 ±1.15 a	28.4	55.9	178 ±2.31 d	44.7
H	20.7 ±0.88 a	36.3	43.6	157 ±3.76 b	27.6

* M – mechanical thinning of flowers, C – chemical thinning of fruitlets, H – hand thinning of fruitlets.
Means in columns followed by the same letter are not significantly different at the $p = 0.05$ level of significance.

Table 3. Effects of flower/fruitlet thinning of Gala Must/M.9 trees on the yield and mean weight of apples in 2023

Treatments	Yield (kg·tree^{-1})	Yield (t·ha^{-1})	Yield reduction (%)	Mean weight of apple (g)	Increase in mean weight of apple (%)
Control	51.4 ±0.88 c*	90.2	–	96 ±2.60 a	–
M	47.7 ±2.89 c	83.7	7.2	127 ±3.76 b	32.3
M+H	27.0 ±2.03 a	47.4	47.5	149 ±4.91 c	55.2
M+C	35.8 ±0.88 b	62.8	30.4	133 ±3.76 b	38.5
C	45.1 ±2.31 c	79.1	12.3	100 ±0.00 a	4.2
C+H	33.0 ±2.03 ab	57.9	35.8	157 ±3.46 c	63.5
H	34.0 ±0.88 ab	59.6	33.9	157 ±2.60 c	63.5

* For explanations, see Table 2.

Table 4. Effects of flower/fruitlet thinning of Gala Must/M.9 trees on the yield and mean weight of apples in 2024, and the cumulative fruit yield for 2022–2024

Treatments	Yield (kg·tree^{-1})	Yield (t·ha^{-1})	Total yield for years 2022–2024 (kg·tree^{-1})	Yield reduction (%)	Mean weight of apple (g)	Increase in mean weight of apple (%)
Control	44.5 ±1.15 c*	78.1	132.6 ±12.71 c	–	106 ±1.15 a	–
M	38.8 ±2.02 b	68.1	116.8 ±15.30 bc	12.8	132 ±2.60 b	24.5
M+H	22.8 ±0.58 a	40.0	69.0 ±6.94 a	48.8	156 ±2.89 c	47.2
M+C	26.0 ±0.88 a	45.6	77.6 ±17.32 ab	41.6	137 ±4.91 b	29.2
C	40.4 ±2.31 bc	70.9	119.5 ±9.87 bc	9.2	110 ±1.73 a	3.8
C+H	25.1 ±0.58 a	44.0	74.3 ±14.45 a	43.7	163 ±4.33 c	53.8
H	26.8 ±0.88 a	47.0	81.5 ±11.27 ab	39.8	160 ±1.45 c	50.9

* For explanations, see Table 2.

Kon et al. [2013] noted a decrease in apple yield by over 50% and an increase in mean fruit weight by 28 g as a result of mechanical flower thinning, compared with fruit from control trees. Kong et al. [2009], Veal et al. [2011], and McClure and Cline [2015] demonstrated in their experiments that mechanical flower thinning with the BAUM device of several apple cultivars limited excessive yielding of trees, improved fruit quality, and prevented biennial bearing.

In 2023 and 2024, in the control combination and where the fruitlets on the trees were thinned out only chemically, there was as much as 34.2 to 60.2% of small fruits (up to 6.5 cm in diameter), depending on the combination. In all the other combinations of flower and/or fruitlet thinning, no more than 12.6% of apples were in this size range (Tables 6–7). In the same years, in the control combination and where only chemical thinning of fruitlets was performed, the percentage of fruits with a diameter above 6.5 cm ranged from 39.8 to 65.8%, whereas in all the other combinations, after the thinning of flowers and fruitlets, at least 87.4% of such apples was recorded, and even close to 100.0% in some combinations (Tables 6–7).

Similar results with mechanical flower thinning and fruitlet thinning by hand, and also with the combined use of these two methods of regulating the fruiting of the Gala Mondial apple had been obtained by Peifer et al. [2018]. In their study, these authors obtained a similar percentage of yield reduction, and also an increase in fruit size. Beber et al. [2016] had found in their study that mechanical thinning of apple blossoms with additional hand thinning of fruitlets could be an effective method of ensuring optimal annual fruiting of apple trees.

Some of the thinning treatments in our experiment gave an undesirable result due to the development of exceptionally large apples. This was particularly evident in the combinations where one method of thinning was later supplemented by another. In the combinations M+H, M+C, C+H, and also H, the percentage of apples with a diameter of at least 8.0 cm and larger was from 12.4% to as high as 41.9%. In most of these combinations, the percentage of such large fruits was about 30.0% (Tables 5–7).Very large apples are more susceptible to bitter pit and a number of other diseases that are promoted by the low calcium content in the fruit, which may also reduce their storage life [Wójcik et al. 2009].

In the control combination (52.4 to 53.7%) and where only chemical thinning of fruitlets was performed, as much as 45.3 to 58.2% of the fruit developed colour on only up to 50% of the surface, whereas in the combination where hand thinning was the only treatment, the percentage of such fruit was only from 5.5 to 9.2%. A relatively small percentage (7.0 to 20.4%) of fruits with poorly developed colour on up to 50% of the surface was also obtained in the M+H combination (Tables 8–10).The highest number of well-coloured apples, with red blush coverage exceeding 75% of the skin surface, was obtained in the H and M+H combinations. In these combinations, the percentage of the most extensively coloured fruit ranged from 42.6 to 68.5% (Tables 8–10).

For comparison, in the experiment by Seehuber et al. [2014], the mechanical thinning with the BAUM device resulted in the knocking down of 25–33% of flowers from the trees. The mechanical thinning of apple blossoms was then supplemented by chemical or hand thinning of fruitlets, and the combined treatments contributed to improving the quality of the fruit. Apples from the trees subjected to thinning were larger, better coloured, and had a higher soluble solids content. The results obtained in our experiment are consistent with those of Seehuber et al. [2014].

In another study, Solomakhin and Blanke [2010] had mechanically thinned out flowers of the apple cultivars Golden Delicious Reinders and Gala Mondial with the aim of improving fruit quality and reducing the labour input for subsequent chemical and hand thinning of fruitlets. The control consisted of unthinned trees or trees thinned only by hand. The mechanical thinning of flowers had a positive effect on fruit size, firmness and soluble solids content compared with the fruit from the control trees.

In our experiment, results similar to those of Solomakhin and Blanke [2010] were obtained only in the improvement of fruit size. We found no significant differences in the firmness or the soluble solids content of the fruits from mechanically thinned trees in comparison with the control ones. In our study, apples from the trees subjected to any method of flower and/or fruit thinning, except for mechanical flower thinning alone and chemical of fruitlets in year 2022, had a significantly higher soluble solids content than those from the control trees (Tables 11–13).

Results similar to those of our experiment had been obtained in studies by other authors, such as Solomakhin et al. [2012] and Pflanz et al. [2016]. They found an improvement in fruit size, better colour development, and

Table 5. Effects of flower/fruitlet thinning of Gala Must/M.9 trees on the percentage of apples in different size grades in 2022

Treatments	Percentage of apples in size grades					
	6.0 cm	6.5 cm	7.0 cm	7.5 cm	8.0 cm	8.5 cm
Control	8.1 ±3.01 b*	20.4 ±1.58 d	34.7 ±2.87 cd	34.7 ±4.37 a	1.9 ±1.32 a	0.2 ±0.75 ab
M	0.0 ±0.00 a	1.2 ±0.65 b	20.2 ±3.24 bc	56.2 ±1.47 c	20.4 ±2.69 c	2.0 ±1.11 bc
M+H	0.0 ±0.00 a	0.1 ±0.50 ab	8.5 ±1.35 a	49.0 ±3.92 bc	37.5 ±3.68 de	4.9 ±0.87 cd
M+C	0.0 ±0.00 a	0.1 ±0.50 ab	15.1 ±2.48 ab	41.2 ±1.97 ab	32.2 ±1.44 cde	11.4 ±0.63 d
C	0.0 ±0.00 a	7.9 ±1.26 c	38.3 ±3.67 d	46.1 ±2.74 abc	7.7 ±1.32 b	0.0 ±0.00 a
C+H	0.0 ±0.00 a	0.2 ±0.75 ab	8.1 ±2.90 a	37.1 ±4.56 ab	45.8 ±3.11 e	8.8 ±3.84 d
H	0.0 ±0.00 a	0.0 ±0.00 a	24.2 ±4.17 bcd	46.3 ±3.49 abc	27.0 ±2.47 cd	2.5 ±1.08 bc

* For explanations, see Table 2.

Table 6. Effects of flower/fruitlet thinning of Gala Must/M.9 trees on the percentage of apples in different size grades in 2023

Treatments	Percentage of apples in size grades					
	6.0 cm	6.5 cm	7.0 cm	7.5 cm	8.0 cm	8.5 cm
Control	15.9 ±3.71 b*	43.9 ±3.38 c	34.9 ±4.39 bc	5.2 ±1.29 a	0.1 ±0.25 a	0.0 ±0.00 a
M	0.4 ±0.29 a	12.2 ±3.34 b	52.3 ±4.79 c	32.5 ±4.14 b	2.5 ±2.25 ab	0.1 ±0.25 ab
M+H	0.0 ±0.00 a	0.9 ±0.87 a	19.6 ±3.94 ab	47.9 ±2.25 bcd	26.7 ±3.16 c	4.9 ±2.17 c
M+C	0.0 ±0.00 a	6.9 ±3.22 b	39.0 ±2.72 bc	41.7 ±4.23 bc	11.7 ±3.33 bc	0.7 ±0.71 ab
C	14.1 ±1.35 b	46.1 ±3.33 c	33.4 ±3.90 bc	6.4 ±1.55 a	0.0 ±0.00 a	0.0 ±0.00 a
C+H	0.0 ±0.00 a	0.7 ±0.75 a	12.1 ±4.03 a	54.7 ±4.07 cd	30.8 ±2.71 c	1.7 ±0.71 bc
H	0.0 ±0.00 a	0.1 ±0.50 a	9.1 ±1.87 a	57.6 ±3.42 d	29.5 ±3.57 c	3.7 ±1.03 c

* For explanations, see Table 2.

Table 7. Effects of flower/fruitlet thinning of 'Gala Must'/M.9 trees on the percentage of apples in different size grades in 2024

Treatments	Percentage of apples in size grades					
	6.0 cm	6.5 cm	7.0 cm	7.5 cm	8.0 cm	8.5 cm
Control	11.6 ±2.97 b*	33.2 ±1.70 d	34.0 ±3.15 c	20.0 ±2.50 a	1.1 ±0.71 a	0.1 ±0.25 ab
M	0.2 ±0.00 a	7.2 ±2.96 c	33.7 ±1.44 c	45.5 ±2.02 b	12.2 ±0.85 b	1.2 ±0.63 bc
M+H	0.0 ±0.00 a	0.6 ±0.48 a	14.7 ±4.06 a	49.8 ±3.33 b	29.9 ±2.61 cd	5.0 ±1.18 d
M+C	0.0 ±0.00 a	3.8 ±1.38 bc	25.6 ±3.12 bc	41.3 ±3.04 b	22.9 ±3.52 c	6.4 ±0.48 d
C	7.4 ±0.65 b	26.8 ±2.25 d	36.0 ±2.17 c	26.1 ±0.50 a	3.7 ±0.65 a	0.0 ±0.00 a
C+H	0.0 ±0.00 a	0.9 ±0.25 ab	11.1 ±2.06 a	46.1 ±4.03 b	36.3 ±3.81 d	5.6 ±2.29 d
H	0.0 ±0.00 a	0.1 ±0.25 a	17.1 ±3.81 ab	49.7 ±2.33 b	29.7 ±2.17 cd	3.4 ±1.03 cd

* For explanations, see Table 2.

Table 8. Effects of flower/fruitlet thinning of Gala Must/M.9 trees on the percentage of apples in different blush coverage ranges in 2022

Treatments	Percentage of apples in blush coverage ranges			
	>25%	25–50%	50–75%	<75%
Control	10.8 ±1.55 c*	41.8 ±6.89 b	32.4 ±3.09 abc	15.0 ±6.30 a
M	3.9 ±1.26 b	24.6 ±6.29 b	41.9 ±3.30 bc	29.6 ±4.29 ab
M+H	0.0 ±0.00 a	7.0 ±2.90 a	24.5 ±2.47 a	68.5 ±3.20 c
M+C	1.1 ±1.15 ab	24.6 ±4.48 b	46.4 ±3.71 c	27.9 ±3.12 ab
C	2.3 ±1.25 b	43.0 ±3.38 b	38.4 ±5.06 bc	16.3 ±3.64 a
C+H	0.9 ±1.44 ab	25.0 ±3.57 b	34.0 ±5.89 abc	40.1 ±3.28 b
H	0.0 ±0.00 a	5.5 ±2.81 a	30.0 ±3.49 ab	64.5 ±5.85 c

* For explanations, see Table 2.

Table 9. Effects of flower/fruitlet thinning of Gala Must/M.9 trees on the percentage of apples in different blush coverage ranges in 2023

Treatments	Percentage of apples in blush coverage ranges			
	>25%	25–50%	50–75%	<75%
Control	7.4 ±1.47 b*	46.3 ±4.77 d	38.4 ±2.06 bc	7.9 ±2.50 a
M	0.4 ±0.29 a	24.1 ±5.20 bc	41.8 ±2.75 c	33.7 ±2.74 cd
M+H	1.1 ±0.41 a	19.3 ±4.01 ab	37.0 ±3.77 bc	42.6 ±3.94 de
M+C	2.9 ±1.75 ab	38.0 ±2.40 cd	37.1 ±1.60 bc	22.0 ±4.11 bc
C	6.4 ±1.70 b	51.8 ±4.66 d	28.7 ±2.53 a	13.1 ±3.51 ab
C+H	2.5 ±1.08 ab	27.2 ±3.04 bc	37.7 ±3.25 bc	32.6 ±4.44 cd
H	0.5 ±0.58 a	8.7 ±4.09 a	31.8 ±2.33 ab	59.0 ±5.76 e

* For explanations, see Table 2.

Table 10. Effects of flower/fruitlet thinning of Gala Must/M.9 trees on the percentage of apples in different blush coverage ranges in 2024

Treatments	Percentage of apples in blush coverage ranges			
	>25%	25–50%	50–75%	<75%
Control	9.2 ±1.03 c*	43.2 ±2.78 c	35.4 ±1.63 ab	12.2 ±2.72 a
M	2.4 ±0.48 b	24.9 ±2.32 b	40.9 ±1.55 b	31.8 ±1.19 b
M+H	0.5 ±0,25 a	13.5 ±2.72 a	31.4 ±1.04 a	54.6 ±4.03 c
M+C	2.6 ±0.85 b	31.0 ±2.25 b	41.3 ±2.17 b	25.1 ±3.25 b
C	4.7 ±1.55 b	46.5 ±2.59 c	33.6 ±2.25 a	15.2 ±1.08 a
C+H	2.4 ±1.08 b	26.4 ±3.75 b	35.9 ±4.03 ab	35.3 ±3.99 b
H	0.3 ±0.29 a	8.0 ±1.26 a	31.1 ±0.75 a	60.6 ±1.03 c

* For explanations, see Table 2.

Table 11. Effects of flower/fruitlet thinning of Gala Must/M.9 trees on fruit firmness and soluble solids content immediately after harvest, and the mean number of apples per tree in 2022

Treatments	Firmness (kG)	Soluble solids (%)	Mean number of apples (per tree)
Control	7.9 ±0.11 a*	13.0 ±0.34 a	298 ±0.33 c
M	8.0 ±0.11 a	13.3 ±0.31 a	204 ±6.64 b
M+H	8.7 ±0.18 c	14.4 ±0.33 bc	110 ±4.62 a
M+C	8.8 ±0.20 c	14.8 ±0.40 c	98 ±1.15 a
C	8.5 ±0.11 bc	13.7 ±0.30 ab	276 ±8.95 c
C+H	9.4 ±0.17 d	15.7 ±0.37 d	92 ±3.76 a
H	8.2 ±0.24 ab	15.0 ±0.26 cd	131 ±4.00 a

* For explanations, see Table 2.

Table 12. Effects of flower/fruitlet thinning of Gala Must/M.9 trees on fruit firmness and soluble solids content immediately after harvest, and the mean number of apples per tree in 2023

Treatments	Firmness (kG)	Soluble solids (%)	Mean number of apples (per tree)
Control	6.5 ±0.12 ab*	12.5 ±0.28 a	537 ±5.20 d
M	6.3 ±0.15 a	12.6 ±0.30 a	383 ±10.11 c
M+H	6.7 ±0.11 abc	15.3 ±0.21 d	181 ±8.66 a
M+C	6.5 ±0.18 ab	14.5 ±0.20 c	273 ±10.39 b
C	6.4 ±0.15 a	13.4 ±0.30 b	452 ±7.80 c
C+H	6.9 ±0.11 bc	14.8 ±0.16 cd	210 ±4.62 ab
H	7.0 ±0.15 c	14.4 ±0.26 c	217 ±3.46 ab

* For explanations, see Table 2.

Table 13. Effects of flower/fruitlet thinning of Gala Must/M.9 trees on fruit firmness and soluble solids content immediately after harvest, and the mean number of apples per tree in 2024

Treatments	Firmness (kG)	Soluble solids (%)	Mean number of apples (per tree)
Control	7.2 ±0.08 bc*	12.7 ±0.21 a	418 ±6.93 e
M	7.1 ±0.11 b	12.9 ±0.22 a	294 ±8.66 c
M+H	6.7 ±0.10 a	15.3 ±0.21 d	146 ±6.93 a
M+C	7.6 ±0.12 d	14.7 ±0.13 c	190 ±6.93 b
C	7.4 ±0.10 cd	13.5 ±0.23 b	366 ±8.08 d
C+H	7.1 ±0.11 b	15.3 ±0.23 d	154 ±8.08 ab
H	7.0 ±0.13 ab	14.7 ±0.15 c	168 ±4.04 ab

* For explanations, see Table 2.

higher soluble solids content in apples collected from the trees on which mechanical flower thinning had been performed with the BAUM device, compared with unthinned trees. Schupp and Kon [2014], in turn, reported that in their experiment they found no differences in soluble solids content in the fruits harvested from those trees on which flowers had been mechanically thinned out, compared with the fruits from only hand-thinned trees.

In another study, Win et al. [2023] subjected Fuji apple trees to mechanical thinning of flowers with the Darwin device and to chemical thinning of fruitlets, and also to the combined use of these two thinning methods, and compared the results with hand thinning as the control. The authors found that none of the thinning methods had a significant effect on fruit size, weight, or colour. However, the treatments improved fruit firmness and soluble solids content immediately after harvest.

In a study by Misimović et al. [2012], apple fruitlets were thinned out by means of the natural foliar fertilizers Goëmar BM 86 E (a product from algae GA14 Ascophyllum nodosum + N, MG and Mo) and Goëmar Folical (GA14 + Ca and B). The authors found that after spraying apple trees with these fertilizers, the shedding of fruitlets increased, compared with the control trees. The harvested fruits had a greater weight and contained more soluble solids as a result of foliar fertilization, but were less firm than apples from the control combination.

Schupp and Kon [2014] found that mechanical flower thinning increased apple firmness, relative to the control. Unlike the results obtained by Solomakhin and Blanke [2010] and Schupp and Kon [2014], the results for fruit firmness in our study were not unambiguous. In one year, some flower and/or fruit thinning treatments significantly increased the firmness of apples compared with those harvested from the control trees, while in another year the firmness of such fruit was lower or no significant differences were found (Tables 11–13).

All of the flower and/or fruit thinning methods used, except for the chemical thinning of fruitlets with the preparation Globaryll in 2022, significantly reduced the number of fruits per tree compared with the control (Tables 11–13). It seems that the flowers/fruitlets were thinned out too much, especially in the M+H and C+H combinations, and where the fruitlets were only thinned out by hand. As a result, a large percentage of the fruit harvested from the trees in these combinations, in the size range of 8.0 cm and larger, were apples that were evidently too large. Such large apples are susceptible to many diseases and may not keep well.

Lordan et al. [2018] in their study report that reducing the rotational speed of the rotor that removes flower buds in the Darwin machine from 270 to 230 rpm, at a tractor speed of 5 km·h^{-1}, helped to obtain the optimal number of fruits per tree. Using these parameters of the tractor and the mechanical flower thinning machine, the authors did not achieve significant differences in the yield and size of apples of the Gala in comparison with hand or chemical thinning. The results obtained by Lordan et al. [2018] were consistent with those of Seehuber et al. [2014], who also found that reducing the speed of the rotors reduced the thinning effect.

In our study, significant differences in fruit yield and size were noted mainly where fruitlets had been thinned out by hand, compared with the chemical and mechanical thinning of flower buds. In another study by Solomakhin et al. [2012] conducted on Golden Reinders® apple trees, it was concluded that no significant differences in fruit yield were observed when comparing hand thinning of fruitlets with mechanical thinning of flower buds at a tractor speed of 5–7.5 km·h^{-1} and 300–480 rpm of the rotors. The study conducted by Veal et al. [2011] had suggested that to obtain the best effectiveness of mechanical flower thinning in the cultivars Golden Delicious, Gala, Elstar and Braeburn, a tractor speed of 5–7.5 km·h^{-1} and rotor speed of 300–420 rpm were needed.

CONCLUSIONS

1. With the exception of the mechanical thinning of flowers and chemical thinning of fruitlets, all other methods of thinning caused a significant reduction in apple yield, and only with the exception of the chemical thinning of fruitlets did they significantly increase mean fruit weight.
2. The best results of the thinning were found as a result of mechanical thinning of flowers with the BAUM device, reducing fruit yield by 7.2 to 17.5%, depending on the year and caused increase of the number of fruits within the desired marketable size range of 7.0–7.5 cm in diameter.
3. Apples from trees mechanically thinned using the BAUM device had a higher average fruit weight than those from chemically thinned trees, but lower

than those from manually thinned trees, and also had a lower soluble solids concentration than fruit from both of these treatments.
4. Chemical thinning of fruitlets reduced fruit yield by 7.5 to 12.3%, depending on the year, and resulted in the production of a large number of undesirably small apples.
5. Combining the different methods of flower and fruitlet thinning, as well as thinning by hand only, resulted in excessive growth of apples to a diameter of 8.0 cm and above.
6. Most of the flower and/or fruitlet thinning treatments increased the soluble solids content relative to its level in the control fruit.

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