Impact Of Post-Flowering Chemical Thinning On The Fruit Yield And Quality Metrics In 'Fuji Suprema' Apple Trees

Abstract

Under the climate variability conditions of southern Brazil, post-flowering thinning is a safer practice than thinning during flowering. This study aimed to evaluate the effect of the application of post-flowering thinning agent on 'Fuji Suprema' apple when used in combinations. The experiment was carried out in an experimental orchard located in the municipality of Caçador, Santa Catarina, Brazil during the2017 to 2020 harvest seasons. We tested treatments combining Benzyladenine (BA) with Ethephon (ET) or Metamitron (MM), as well as individual applications of each product at different concentrations on apple fruits. Applications were made individually or in tank mixes during post-flowering periods, with manual thinning when fruits were 8 to 12 mm in diameter and chemical thinning at 15 to 20 mm in diameter. Treatments were as follows: 1. Control (manual thinning); 2. BA(400 ml/100 L) + ET (200 ml/100 L); 3. BA(400 ml/100 L) + MM (100 g/100 L); 4. BA(600 ml/100 L); 5. ET(240 - 200 ml/100 L); MM(150 ml/100 L); MM(150 ml/100 L) + ET (200 ml/100 L).The results showed that the combination of Metamitron with Benzyladenine or Ethephon effectively regulated fruit set and enhanced fruit quality, making these combinations suitable for thinning under southern Brazil conditions.

Keywords:*Malus domestica* Borkh.; effective fruiting; fruit quality; production.

Introduction

Apple (*Malus domestica* Borkh.) is one of the most important fruit crops of temperate climate in Brazil, with a planted area of approximately 33,000 ha and production above 1.0 million tons in years without climatic adversities (FAOSTAT, 2024). When the apple tree is grown under conditions where its chilling requirement is not satisfied, an irregular flowering that extends over a long period occurs, causing a heterogeneous effective fruiting (Sezerino, 2018). Under these conditions, post-flowering thinning is more efficient than thinning during flowering (Fernades, 2013). The efficiency of chemical thinning agents depends on some environmental factors such as temperature, humidity and the amount of light, which may be the reason for the variability in the results. Knowledge of the temperature and light incidence three to four days after the application of the thinning agents has made the thinning process more predictable and reliable (Byers; Coast; Vizzotto, 2003; Greene, 2016).

Reducing effective fruiting, particularly in years when climatic conditions favor excessive fruiting, is necessary to regulate production and increase fruit size and quality (Salvador *et al.*, 2006). Thinning is an important technique, as it allows reducing the number of fruits per plant, significantly improving the quality of the remaining fruits (Bound, 2015), and can be done manually, chemically or mechanically (Ilie *et al.*, 2016; Lanar, 2024).

Chemical thinning can be adopted as a substitute for manual thinning to reduce labor costs, since this practice allows removing excess fruits, adjusting the production capacity of the plants and, consequently, avoiding the alternation of production, since the floral induction for the next year's production occurs concomitantly with the phase of intense cell division and initial growth of the fruits of the current crop season (Dennis, 2002; Greene, 2016; Petri *et al.*, 2013). In addition, the setting of four or more fruits per inflorescence makes manual thinning difficult (Costa; Dal Cin; Ramina, 2006).

Although chemical thinning does not fully replace manual thinning, it provides growers with greater timing flexibility to make final adjustments, as well as minimizing production alternation and reducing the labor needed for manual thinning (Epagri, 2017).

The ideal timing for thinning is defined by the development stage of the fruits, with recommended diameter ranges between 8-12 mm and 15-20 mm. In the initial stage, fruits intensely compete for resources, and strategic removal ensures the best development of the remaining fruits. At the 15-20 mm range, thinning allows for adjustment of the plant's load, preventing overload and ensuring that the fruits reach desirable size and quality. These practices optimize plant performance, resulting in more uniform and economically viable harvests (Epagri, 2017).

The products used for chemical thinning of fruits can be applied before flowering, during flowering or in the post-flowering period (Petri *et al.*, 2016). Due to the climatic conditions of the southern region of Brazil, the effective fruiting from year to year is very variable. Under these conditions, the adoption of thinning during flowering becomes a practice of greater risk for the producer, since it is only possible to evaluate the need and intensity of thinning after fertilization of fruits (Petri *et al.*, 2016).

Among the chemical thinning agents available for the apple crop, Naphthalene Acetic Acid (NAA), Benzyladenine (BA), Ethephon (Ethrel®) and, more recently, Metamitron, a product that inhibits photosynthetic activity (Basak, 2011), stand out.

The effect of BA on apple thinning is proportional to the time of application and concentration used (Greene *et al.*, 1990). BA is a compound of the cytokinin group that acts in cell division and, therefore, has been shown to be effective in increasing fruit diameter (McLaughlin; Greene, 1984; Greene *et al.*, 1992; Byers; Carbaugh, 1991; Wismer *et al.*, 1995). According to Greene (2005), BA can increase fruit diameterin the absence of thinning, by increasing cell division. BA has been considered a good thinning agent because it has a low toxicological profile and mimics the biological action of cytokinin, which is synthesized in plants (Yuan; Greene, 2000a; 200b). However, the combination of BA and Carbaryl is more effective than itssingle application, being considered one of the most effective combinations for chemical thinning of apple (Byers; Carbaugh, 1991). The objective of this study to evaluate the response of 'Fuji Suprema' apple to the application of post-flowering thinning agent combinations.

Methodology

Apple trees of the 'Fuji Suprema' cultivar, trained in the central leader system, according to the technical recommendations for the crop(Epagri, 2006), were used in the study. The study was carried out during four vegetative cycles in an orchard located in Caçador, Santa Catarina, Brazil (latitude 26º46'S, longitude 51º W, altitude 960 m), with "Cfb" climate and soil classified as *Nitossolo Bruno distrófico* (Ultisol). The experimental design was randomized blocks, with five replicates, each consisting of one plant. Treatments consisted of post-flowering chemical thinning agents, arranged as follows: 1. Control (manual thinning); 2. Benzyladenine (BA) 400 ml/100 L + Ethephon 200 ml/100 L; 3. Benzyladenine 400 ml/100 L + Metamitron 100 g/100 L; 4. Benzyladenine 600 ml/100 L; 5. Ethephon 240 - 200 ml/100 L; Metamitron 150 ml/100 L; Metamitron 150 ml/100 L + Ethephon 200 ml/100 L.

For the experiments, the commercial product Maxcel® with 2% Gibberellic Acid(GA) was used as a source of BA; the commercial product Promalin® with 1.8% GA4+7 and 1.8% BAwas used as source of GA4+7+ BA; and the commercial product Ethrel® with 24% Ethephon was used as a source of Ethephon. The products were applied using a motorized knapsack sprayer (20L) with a tip containing three D-S fan-type nozzles.

Manual thinning was performed when the fruits were 8 to 12 mm in diameter, and chemical thinning was performed when the fruits were 15 to 20 mm in diameter, adopting as a criterion the maintenance of two fruits ontwigs and one fruit on spur.In each plant, two branches were marked for the evaluations of effective fruiting, fruit drop and number of fruits per inflorescence. Effective fruiting was evaluated by the ratio between the number of fruits and the number of flower clusters observed during full flowering, multiplied by 100 to obtain the fruiting percentage (*[number of fruits/flower clusters] x 100*). Total fruit production per plant was determined by weighing the fruits at harvest in kg plant^{-1}, and the average fruit mass was calculated by dividing the total mass by the total number of fruits harvested, with the fruits being classified by size. The data collected were analyzed using ANOVA, with the means of significant variables ($p<0.05$) compared by the Scott-Knott test at a significance level of 5%.Analysis procedures were performed using SISVAR software, version 5.8 (Ferreira, 2019).

Results and Discussion

The control treatment showed the highest average values of production per plant (28.7 kg plant^{-1}), similar to the treatments with BA + Metamitron (25.2 kg), Ethephon (25.3 kg) and Metamitron alone (26.6 kg). The combined use of Metamitron + Ethephonled to the lowest average production (17.5 kg), indicating a greater drop or reduction in the number of fruits (Table 1). There were significant differences between treatments and between years (2017 and 2018), but not in all years. This may be related to climatic variations or response of the plants. The variation in responses between years demonstrates the importance of considering climatic conditions and the management of post-flowering thinning agents. High concentrations of Metamitron can cause excessive thinning, and it should be considered that high temperatures (29 to 31°C) during the application or up to 4 days after intensify the thinning action (Greene, 2014).

Table 1 – Effect of chemical thinning agents on production per plant (kg plant^{-1}) of ‘Fuji Suprema’ apple trees.

Treatments	2017	2018	2019	2020	Mean
1. Control (manual thinning)– Fruits 8-12 mm	53.5 a	25.2 a	18.3 ^{ns}	15.3 ^{ns}	28.7a
2. Benzyladenine(400 ml/100 L) +	39.8 a	24.9 a	14.0	15.7	23.6b

Ethephon(200 ml/100 L)– Fruits 15-20 mm					
3. Benzyladenine(400 ml/100 L) + Metamitron(100 g/100 L)– Fruits 15-20 mm	44.0 a	22.6 a	23.5	10.7	25.2a
4. Benzyladenine(600 ml/100 L)– Fruits 15-20 mm	46.1 a	15.2 b	19.8	14.2	23.8b
5. Ethephon(240 - 200 ml/100 L)– Fruits 15-20 mm	44.3 a	20.2 a	20.1	16.5	25.3a
6. Metamitron(150 ml/100 L)– Fruits 15-20 mm	51.5 a	20.5 a	19.6	14.7	26.6a
7. Metamitron(150 ml/100 L) + Ethephon(200 ml/100 L)– Fruits 15-20 mm	28.6 b	9.8 b	16.8	14.7	17.5b

Means followed by the same letter are not significantly different, as determined by the Scott-Knott test at 5% probability level. ns: not significant (p>0.05).

The treatments with Benzyladenine alone and combinedwith Ethephon maintained the highest number of fruits per inflorescence after thinning (4.6 and 4.2 fruits, respectively). This indicates lower efficiency of chemical thinning in reducing the number of fruits per inflorescence (Table 2). Regarding fruit drop, the treatments Metamitron alone and combined with Ethephon induced a higher percentage of drop of fruits larger than 15 mm (18.1% and 24.9%, respectively). This may include the reduced production observed in treatments that combine these products.

Table 2 – Effect of chemical thinning agents on the number of fruits per inflorescence and percentage of fruit drop of 'Fuji Suprema' apple trees.

Treatments	**Before thinning**	**After thinning**	**Drop of fruits larger than15mm (%)**
1. Control (manual thinning) – Fruits 8-12 mm	4.2 b	3.5 b	8.7 b
2. Benzyladenine (400 ml/100 L) + Ethephon (200 ml/100 L) – Fruits 15-20 mm	4.7 a	4.6 a	8.5 b
3. Benzyladenine (400 ml/100 L) + Metamitron (100 g/100 L) – Fruits 15-20 mm	4.2 b	3.6 b	19.4 a
4. Benzyladenine (600 ml/100 L) – Fruits 15-20 mm	5.1 a	4.2 a	5.9 b
5. Ethephon (240 - 200 ml/100 L) – Fruits 15-20 mm	4.9 a	4.3 a	10.2 b
6. Metamitron (150 ml/100 L) – Fruits 15-20 mm	4.1 b	3.9 b	18.1 a
7. Metamitron (150 ml/100 L) + Ethephon (200 ml/100 L) – Fruits 15-20 mm	3.9 b	3.5 b	24.9 a

Means followed by the same letter do not differ from each other by the Scott-Knott test at 5% probability level. ns: not significant (p>0.05).

Treatments with Metamitron alone and combined with Ethephon showed fruits with higher average weights (112.0 and 117.5 g, respectively), indicating that the reduction in the number of fruits favors individual growth. The control treatment had a lower average weight compared to these treatments, probably due to the greater competition between fruits for the assimilation of resources (Table 3). Manual thinning maintains the highest average production per plant, but with fruits of lower weight.

Table 3 – Effect of chemical thinning agents on the average fruit weight (g $fruit^{-1}$) of 'Fuji Suprema' apple trees.

Treatments	2017	2018	2019	2020	Mean
1. Control (manual thinning) – Fruits 8-12 mm	125.2 b	96.3 a	122.8 ^{ns}	113.8 ^{ns}	115.0 a
2. Benzyladenine (400 ml/100 L) + Ethephon (200 ml/100 L) – Fruits 15-20 mm	127.6 b	88.0 b	111.6	104.7	108.0 b
3. Benzyladenine (400 ml/100 L) + Metamitron (100 g/100 L) – Fruits 15-20 mm	146.2 a	82.1 b	125.6	94.1	112.0 a
4. Benzyladenine (600 ml/100 L) – Fruits 15-20 mm	120.6 b	85.8 b	112.1	92.1	102.6 b
5. Ethephon (240 - 200 ml/100 L) – Fruits 15-20 mm	125.2 b	82.4 b	110.5	102.8	105.2 b
6. Metamitron (150 ml/100 L) – Fruits 15-20 mm	138.2 a	83.1 b	122.6	104.0	112.0 a
7. Metamitron (150 ml/100 L) + Ethephon (200 ml/100 L) – Fruits 15-20 mm	145.9 a	91.1 a	131.2	102.0	117.5 a

Means followed by the same letter are not significantly different, as determined by the Scott-Knott test at 5% probability level. ns: not significant (p>0.05).

The control treatment showed higher effective fruiting (108.7%) over the years. Benzyladenine combined with Metamitron and Metamitron alone led to the lowest levels of effective fruiting (67.2% and 102.9%, respectively), which may be a consequence of the higher percentage of fruit drop induced by these treatments (Table 4). Significant differences in effective fruiting were observed only in the first year of evaluation, when the treatment Benzyladenine + Ethephon did not differ from the control. This demonstrates that the efficiency of chemical thinning agents depends on factors such as application stage, climatic conditions and formulation.

Table 4 – Effect of chemical thinning agents on the effective fruiting (%) of 'Fuji Suprema' apple trees.

Treatments	2017	2018	2019	Mean
1. Control (manual thinning) – Fruits 8-12 mm	109.0 a	142.2 ^{ns}	75.0 ^{ns}	108.7 ^{ns}
2. Benzyladenine (400 ml/100 L) + Ethephon (200 ml/100 L) – Fruits 15-20 mm	119.9 a	112.8	71.5	101.4
3. Benzyladenine (400 ml/100 L) + Metamitron (100 g/100 L) – Fruits 15-20 mm	59.5 b	135.8	73.9	89.7
4. Benzyladenine (600 ml/100 L) – Fruits 15-20 mm	58.3 b	80.0	63.3	67.2
5. Ethephon (240 - 200 ml/100 L) – Fruits 15-20 mm	76.0 b	235.5	80.6	130.7
6. Metamitron (150 ml/100 L) – Fruits 15-20 mm	66.6 b	181.8	60.3	102.9
7. Metamitron (150 ml/100 L) + Ethephon (200 ml/100 L) – Fruits 15-20 mm	25.9 b	207.5	52.5	95.3

Means followed by the same letter are not significantly different, as determined by the Scott-Knott test at 5% probability level. ns: not significant (p>0.05).

The results show that manual thinning maintains a higher number of fruits and, consequently, higher production per plant, but with lower average fruit weight. In turn, chemical treatments, Metamitron (alone and combined), reduce the number of fruits and increase their average weight. Similar results were reported by Greene (2014), who indicated that high concentrations of Metamitron (>300 mg/L) and high temperature conditions (29–31 °C) intensify the thinning effect, so care should be taken in the application to avoid excessive fruit drop. These results reinforce that chemical thinning is a viable alternative to manual thinning, especially when optimizing fruit size and quality. Proper management, adjusted to climatic conditions, is essential to maximize the benefits of these technologies.

The incidence of russeting did not show significant differences, indicating that Benzyladenine, Ethephon and Metamitron do not cause russetingwhen applied to fruits with 15 mm diameter. The results showed that Metamitron or Metamitron plus Ethephon or BA can be effective for fruit drop when applied to fruits of 15 mm or more in the cv. ‘Fuji Suprema’, so they can be used as a chemical thinning supplement in the whole plant or in the upper part of the crown. The results confirm those reported by Brunner (2014), who obtained maximum reduction of effective fruiting in the cv. ‘Fuji’ when applyingMetamitron to fruits up to 12 mm in diameter.

The efficacy of combinations of Benzyladenine, Ethephon, and Metamitron for post-blossom chemical thinning in 'Fuji Suprema' apple trees aligns with previous studies that also highlight the importance of chemical thinning in optimizing fruit production and quality. For instance, Byers and Carbaugh (1991) had already identified the effectiveness of chemical thinning in apples, suggesting that these practices can reduce competition for resources among fruits and improve their development.

Furthermore, Brunner's (2014) research on the impact of Metamitron as a thinning compound in apple plants also supports the idea that the use of chemical agents can be beneficial for fruit quality. Therefore, the results reinforce the existing literature, showing that the combination of different thinning agents can be an effective strategy under the variable climatic conditions of southern Brazil.

The use of chemical thinning can help producers more precisely adjust the fruit load, resulting in a more uniform and higher-quality harvest. This can lead to an increase in the market value of the fruits, especially in markets that prioritize larger and higher-quality apples.

Chemical thinning can reduce the need for manual thinning, which is a labor-intensive practice. This can result in significant savings in production costs, allowing producers to use resources more efficiently.

The application of chemical thinning offers greater flexibility in terms of timing and management strategy, allowing producers to make adjustments based on weather conditions and fruit development. This can be especially important in years with climatic variations that affect blooming and fruit development

Conclusions

Treatments with chemical thinning agents were effective in fruit drop, number of fruits and average fruit weight. Benzyladenine (Maxcel®) and Ethephon (Ethrel®) alone or in combination maintained production at competitive levels, with moderate effects on fruit reduction.

Metamitron (Goltix®), alone or in combination with Ethephon (Ethrel®), promoted greater fruit drop, favoring fruits of higher weight and quality, which is relevant for markets that prioritize large fruits (>70 mm).

Disclaimer (Artificial intelligence)

Author(s) hereby declare that generative AI technologies such as Large Language Models (ChatGPT-4), have been used during the writing or editing of manuscripts.

Details of the AI usage are given below:

1. Review of grammar and syntax for clarity and technical accuracy;
2. Improvement of the manuscript in the description of treatments and methodology;
3. Translation of specific excerpts between Portuguese and English, ensuring accuracy in scientific terminology.

The author(s) reviewed and validated all AI-generated suggestions to ensure they were aligned with the context and objectives of the study.

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