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Chemical thinning programs for 'Fuji Mishima' apple trees under black anti-hail net

Abstract – The objective of this work was to evaluate chemical thinning programs containing mixtures of different plant growth regulators, at low concentrations, applied to 'Fuji Mishima' apple trees at post-blossom, as well as to identify the most effective in reducing fruit set, decreasing the need of manual thinning, and improving fruit quality. Under a black anti-hail net, the apple trees were sprayed with the six following chemical thinning protocols (treatments): benzyladenine (BA) + gibberellin$_{4+7}$ (GA) at full bloom (FB) and BA + carbaryl (CB) on fruitlets with a 15 mm diameter; BA + GA at FB and naphthaleneacetic acid (NAA) + CB on fruitlets with a 7 mm diameter; BA + GA at FB and BA + CB on fruitlets with a 15 mm diameter; ethephon (ETH) + CB on fruitlets with a 15 mm diameter and metamitron (MM) + ETH on fruitlets with a 20 mm diameter; and MM on fruitlets with a 7 mm diameter and MM on fruitlets with a 20 mm diameter. The treatments were compared with an untreated and a manual thinning control. The black net reduced photosynthetically active radiation in 22%. For 'Fuji Mishima' apples under a black anti-hail net, the chemical thinning program consisting of BA + GA (47 + 47 g a.i. ha^{-1}) at FB, followed by BA + CB (80 + 288 g a.i. ha^{-1}) on fruitlets with a 15 mm diameter, consistently reduces fruit set, requires less manual thinning, and improves fruit weight and size.

Index terms: *Malus domestica*, photosynthetically active radiation, plant growth regulators, semi-vigorous rootstock.

Programas de raleio químico para macieira 'Fuji Mishima' sob tela antigranizo preta

Resumo – O objetivo deste trabalho foi avaliar programas de raleio químico contendo misturas de diferentes reguladores de crescimento de plantas, em baixas concentrações, aplicados em macieiras 'Fuji Mishima' pós-floração, bem como identificar os mais eficazes em reduzir a frutificação efetiva, diminuir a necessidade de raleio manual e melhorar a qualidade dos frutos. Sob tela antigranizo preta, as macieiras foram pulverizadas com os seis seguintes protocolos de raleio químico (tratamentos): benziladenina (BA) + giberelina$_{4+7}$ (GA) em plena floração (PF) e BA + carbaril (CB) em frutos com 15 mm de diâmetro; BA + GA em PF e ácido naftalenoacético (ANA) + CB em frutos com 7 mm de diâmetro; BA + GA em PF e BA + CB em frutos com 15 mm de diâmetro; ethephon (ETH) + CB em frutos com 15 mm de diâmetro e metamitron (MM) + ETH em frutos com 20 mm de diâmetro; e MM em frutos com 7 mm de diâmetro e MM em frutos com 20 mm de diâmetro. Os tratamentos foram comparados com um controle não tratado e um de raleio manual. A tela preta reduziu a radiação fotossinteticamente ativa em 22%. Para maçãs 'Fuji Mishima' sob tela preta antigranizo, o programa de raleio químico BA + GA (47 + 47 g i.a. ha^{-1}) em PF, seguido de BA + CA (80 + 288 g i.a. ha^{-1}) em frutos com 15 mm de diâmetro, reduz consistentemente a

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frutificação efetiva, requer menos raleio manual e melhora a massa e o tamanho dos frutos.

Termos para indexação: *Malus domestica*, radiação fotossinteticamente ativa, reguladores de crescimento de planta, porta-enxerto semivigoroso.

Introduction

Fruitlet thinning is a way of adjusting crop load, consequently altering the leaf:fruit ratio, to improve fruit size and quality (Musacchi & Serra, 2018). In the apple (*Malus domestica* Borkh.) crop, manual thinning is one of the most common techniques used to reduce crop load; however, it is limited by the low number of people available for the activity, which causes a significant increase in production costs (Petri et al., 2017; Lazzarotto, 2018). An alternative to minimize the requirement for manual thinning are chemical thinners, such as plant growth regulators (PGRs), which play an important role in improving fruit quality by directly affecting fruit growth (Wismer et al., 1995; Gabardo et al., 2019) or leading to crop load reduction to occur earlier in the season (Greene, 2017).

In Southern Brazil, anti-hail nets have been widely used to assure apple fruit yield and quality (Lazzarotto & Fioravanço, 2020) by protecting the orchards from the hailstorms that occur in the region (Martins et al., 2017). However, the shaded environment promoted by the nets hinders crop load adjustments by increasing natural fruitlet drop (Brglez Sever et al., 2021) and causing sap to flow towards leaves and branches rather than to the growing fruitlets, i.e., plant growing organs to compete (Boini et al., 2019). In this scenario, the thinning effects of the PGRs used as chemical thinners are eventually potentialized due to a possible synergistic effect caused by the combinations of their different mechanisms of action (Stover et al., 2001; Cline et al., 2019; Clever, 2022). Benzyladenine, for example, increases the competition among growing fruitlets, leaves, and branches, whereas metamitron, naphthaleneacetic acid, and carbaryl reduce the availability of assimilates for growing organs, and ethephon enhances the threshold of ethylene, triggering fruitlet abscission (Eccher et al., 2013; Rademacher, 2015).

For these reasons, in Southern Brazil, chemical thinning is avoided in orchards covered with anti-hail nets or carried out using conservative concentrations combined with manual thinning. Therefore, alternatives are sought to minimize the risk of overthinning without requiring manual thinning.

The objective of this work was to evaluate chemical thinning programs containing mixtures of different plant growth regulators, at low concentrations, applied to 'Fuji Mishima' apple trees at post-blossom, as well as to identify the most effective in reducing fruit set, decreasing the need of manual thinning, and improving fruit quality.

Materials and Methods

The experiment was carried out over two crop seasons, in 2020/2021 and 2021/2022, in a commercial orchard implemented in 2011, under a central leader system, in the municipality of Bom Jesus, in the state of Rio Grande do Sul, Brazil (28°38'46.25"S, 50°36'57.85"W, at 1,026 m above sea level). The climate of the region is Cfb, subtropical with a mild summer, according to Köppen-Geiger’s classification, with an annual precipitation above 1,600 mm and mean annual temperatures between 12 and 14°C (Alvares et al., 2013).

Meteorological data from full bloom until December drop were recorded for both seasons (Figure 1). In the first, total precipitation was 809.4 mm, total solar radiation was 3,565 Mj m^{-2} (average of 21 Mj m^{-2} per day), and mean temperature was 19.21°C. For the period from full bloom until the fruitlets reached a 7, 15, and 20 mm diameter, the accumulated degrees-day (DD, base 4.4°C) was 209.2, 318.7, 434.2, respectively, whereas mean temperature and mean solar radiation were 16.71°C and 13 Mj m^{-2}, 17.05°C and 19 Mj m^{-2}, and 17.92°C and 14 Mj m^{-2} (Inmet, 2022).

In the second season, total precipitation was 686.4 mm, total solar radiation was 3,815 Mj m^{-2} (average of 22 Mj m^{-2} per day), and mean temperature was 19.59°C. In addition, for the period from full bloom until the fruitlets reached a 7, 15, and 20 mm diameter, DD was 159.8, 304.8, and 377.8, respectively, whereas mean temperature and mean solar radiation were 14.52°C and 12 Mj m^{-2}, 14.65°C and 11 Mj m^{-2}, and 14.00°C and 17 Mj m^{-2} (Inmet, 2022).

The evaluated apple cultivar was Fuji Mishima, and Maxi Gala was used as the pollinizer cultivar. The apple trees were grafted on the 'Marubakaido' semi-vigorous rootstock with an M9 interstem that induced them to be vigorous and tall (~5.5 m). To increase light interception in the inner canopy, the trees were green pruned after the fruit set period. Tree density was 1,883 plants per hectare (4.25x1.25 m).

The orchard was covered with a black anti-hail net with a 4.0x7.0 mm mesh and 18% shading, installed on a flat-shaped frame. For evaluation, the trees were selected at the pink bud stage, aiming for bloom uniformity.

The experiment was set as a randomized complete block design with three blocks (rows). The following eight treatments (T1–T8) were carried out (Table 1): T1, untreated control; T2, control with manual thinning only; T3, benzyladenine (BA) + gibberellin (GA) at full bloom, followed by BA + ethephon (ETH) on fruitlets with a 15 mm diameter; T4, BA + GA at full bloom, followed by naphthaleneacetic acid (NAA) + carbaryl (CB) on fruitlets with a 7 mm diameter; T5, BA + GA at full bloom, followed by BA + CB on fruitlets with a 15 mm diameter; T6, ETH + CB on fruitlets with a 15 mm diameter, followed by metamitron (MM) + ETH on fruitlets with a 20 mm diameter; T7, BA + GA at full bloom, followed by BA on fruitlets with a 7 mm diameter and by MM on fruitlets with a 20 mm diameter; and T8, MM on fruitlets with a 7 mm diameter, followed by MM on fruitlets with a 20 mm diameter. Using a motorized backpack sprayer calibrated to deliver 1,000 L ha^{-1} of water, each treatment was sprayed on five trees in each row. However, only the three central trees were evaluated and one in each end of the experimental unit was left as a guard tree, totalizing nine replicates per treatment. In T3, T4, T5, and T7, spraying at full bloom aimed to enhance fruit quality as both of the PGR hormone classes increase fruit size when applied early in the season during intense fruitlet cell division, potentially increasing cell number and size (Rademacher, 2015).

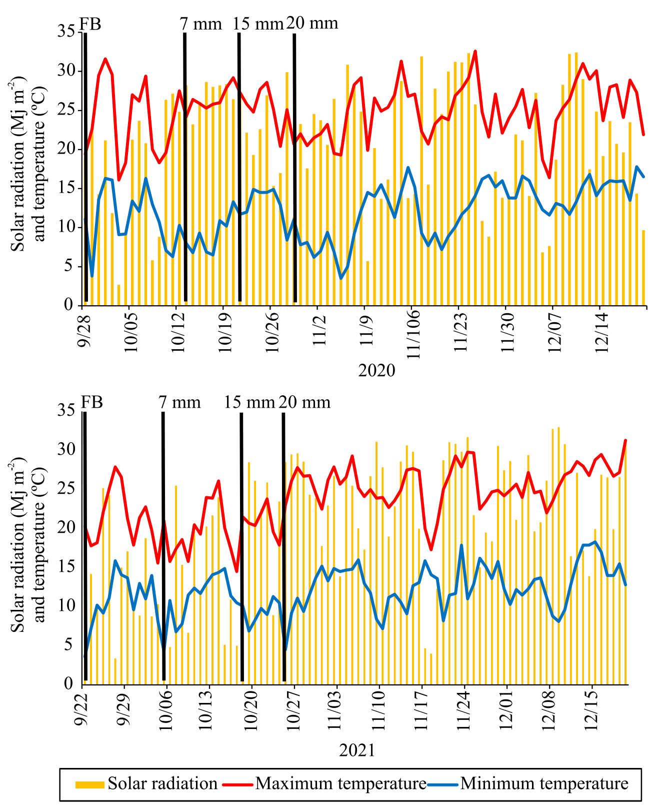

Figure 1. Meteorological conditions throughout the period of natural fruitlet drop (from full bloom until December) of 'Fuji Mishima' apple (*Malus domestica*) trees, in 2022, in the municipality of Bom Jesus, in the state of Rio Grande do Sul, Brazil. FB, full bloom; 7 mm, fruitlets with a 7 mm diameter; 15 mm, fruitlets with a 15 mm diameter; and 20 mm, fruitlets with a 20 mm diameter.

Before full bloom, three branches on opposite sides of the canopy (one in the upper, middle, and lower scaffold) were tagged with the count of flower clusters. For T6 and T8, the flower clusters were evaluated when the fruitlets reached 15 and 7 mm of diameter, respectively. Fruit set was determined on 11/16/2020 and 11/22/2021 by counting clusters and measuring cluster size. Afterwards, manual thinning was performed by two people per tree in all treatments, except in T1 (untreated control), leaving one fruit per leafless spur, two fruits in leafed spurs, and three fruits per brindle; the number of removed fruitlets was counted.

On 12/24/2021, on a clear-sky day, the incident photosynthetically active radiation (PAR) was determined in the environments with and without the black anti-hail net. For this, every 2 s, a total of 435 measurements of sunlight were carried out each hour from 9 a.m. to 3 p.m. using the BH1750FVI luminance sensor (ROHM Co., Ltd., Ukyo-ku, Kyoto, Japan) positioned in the middle of a row, at 2.0 m above soil level, coupled to the Arduino UNO board (RoboCore Tecnologia LTDA, Santana de Parnaíba, SP, Brazil) equipped with the Adafruit datalogger v1.0 (Adafruit Industries, New York City, NY, USA). The output measurements in Lumens per square meter were converted to Watts per square meter according to Michael et al. (2020).

On 3/16/2021 and 3/17/2022, harvesting was performed in all treatments and all fruits of each tree

Table 1. Description of the treatments with the corresponding growth stages, active ingredients, and concentrations of the plant growth regulators used as chemical thinners for 'Fuji Mishima' apple (*Malus domestica*) trees grown under a black anti-hail net, in 2022, in the municipality of Bom Jesus, in the state of Rio Grande do Sul, Brazil.

Treatment[(1)]	Growth stage (fruitlet diameter)			
	Full bloom	7 mm	15 mm	20 mm
T1	Untreated control			
T2	Manual thinning only			
T3	Benzyladenine + gibberellin$_{4+7}$ (47+47 g a.i. ha^{-1})	-	Benzyladenine (80 g a.i. ha^{-1}) + ethephon (1,440 g a.i. ha^{-1})	-
T4	Benzyladenine + gibberellin$_{4+7}$ (47+47 g a.i. ha^{-1})	Naphthaleneacetic acid (19 g a.i. ha^{-1}) + carbaryl (288 g a.i. ha^{-1})	-	-
T5	Benzyladenine + gibberellin$_{4+7}$ (47+47 g a.i. ha^{-1})	-	Benzyladenine (80 g a.i. ha^{-1}) + carbaryl (288 g a.i. ha^{-1})	-
T6	-	-	Ethephon (1,440 g a.i. ha^{-1}) + carbaryl (288 g a.i. ha^{-1})	Metamitron (238 g a.i. ha^{-1}) + ethephon (1,440 g a.i. ha^{-1})
T7	Benzyladenine + gibberellin$_{4+7}$ (47+47 g a.i. ha^{-1})	Benzyladenine (80 g a.i. ha^{-1})	-	Metamitron (238 g a.i. ha^{-1})
T8	-	Metamitron (154 g a.i. ha^{-1})	-	Metamitron (238 g a.i. ha^{-1})

[(1)]From treatments 3 to 8, a surfactant adjuvant was added at a concentration of 0.015% v/v. a.i., active ingredient.

were counted and weighed. For each tree, a sample of 20 fruits was collected to evaluate fruit size (length and diameter) and seed number. Fruit weight was the product of the division between yield and number of fruits per each tree, which was multiplied by 1,000 to be transformed into grams.

The data were subjected to the Shapiro-Wilk and Levene tests to check the assumptions of normality and homoscedasticity, respectively, of the analysis of variance (ANOVA), as well as to QQ-plots, histograms, and boxplots to check distribution and outliers. In case of violation, data were transformed by √y or Asin(√y/100) for percentage data. All data were subjected to mixed-effects ANOVA, where the factors years and treatments were fixed, and year:block and block:tree were random. When significant, means were separated through the least significant difference test, at 5% probability. Fruit set data were analyzed though linear contrasts, also at 5% probability. All statistical analyses were performed using the R software, v.4.2.1, with packages nlme v.3.1-160, emmeans v.1.8.4-1, and car v.3.1-1 (R Core Team, 2013).

Results and Discussion

PAR showed an overall reduction of 22% under the black anti-hail net, with slight variations throughout the day, i.e., 23, 23, 22, 21, 22, 22, and 22% at 9 a.m., 10 a.m., 11:00 a.m., noon, 1 p.m., 2 p.m., and 3 p.m., respectively (Figure 2). When the sun angle was

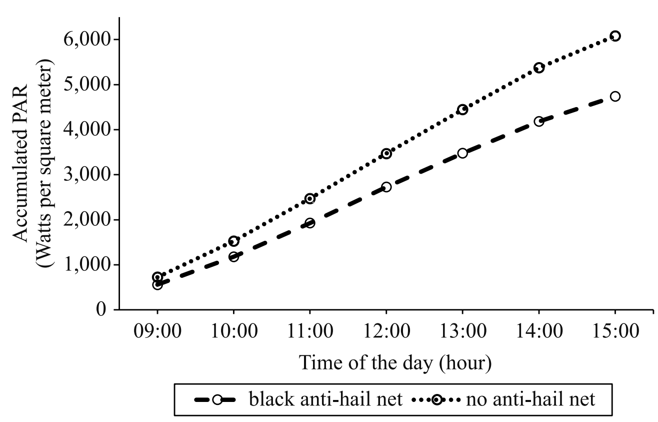

Figure 2. Accumulated photosynthetically active radiation (PAR), at 400–700 nm, between rows of 'Fuji Mishima' apple (*Malus domestica*) trees at a height of 2.0 m in an area uncovered and covered with a black anti-hail net. n=435 measurements. Data obtained on 12/24/2021 in the municipality of Bom Jesus, in the state of Rio Grande do Sul, Brazil.

closer to 90°, at noon, PAR was slightly lower than when the inclination was greater, which is likely due to the triangle-shaped frame of the structure covering the orchard. Bosco et al. (2018) also observed that the black anti-hail net reduced PAR, as well as wind speed; however, the authors found a higher reduction of 32.8%, which could be attributed to the fact that they summed up the shading caused by the net and canopies, measured by installed sensors. In other experiments using sensors installed above the canopies and black anti-hail nets, reductions of 21 and 19 to 21% were reported by Amarante et al. (2018) and Gonzalez et al. (2020), respectively, which are values similar to those of the present study.

The estimated initial flower bud load of the trees was 845.26 and 406.21 in the first and second seasons, respectively. Based on these values, the first season was the "on year" and, the second, the "off year" due to bearing alternance. When the treatments were compared with the untreated control, fruit set was significantly reduced in T4, T5, T7, and T8 in the first crop season, but only in T4 and T5 in the second, when it increased due to a lower initial flower bud load that resulted in a lower competition (Table 2). Relative fruit set was equivalent in all treatments, except in T6, for which no treatment effect was observed in the first season. In the second season, the strongest thinning effect of treatment was found for T5, followed by T4 and T3.

When the initial flower bud load is high, thinning intensity also tends to be high, and vice-versa, as the high abundance of flowers leads to an enhanced demand for assimilates and an increased competition between plant growing organs (Greene, 2017; Lordan et al., 2019, 2020). This pattern was observed in the present study since more treatments promoted fruitlet thinning in the first season, but only T4 and T5, in the second. For 'Empire' apples, considered hard to thin, Stover et al. (2001) concluded that NAA and BA showed a stronger thinning effect when associated with CB, specifically in the periods from petal fall to fruitlets with 5 mm in diameter and when fruitlets were around 10 mm in diameter, respectively, as noted from full bloom to fruitlets with a 20 mm diameter in the second season, whose temperature of 14.46°C was cooler than that of 17.09°C in the first (Figure 1). Moreover, the synergy between NAA and BA with CB may be involved in their effect on the source-sink relationship, as NAA and CB temporarily reduce the availability of assimilates for the fruitlets, whereas BA increases their demand, meaning that a combination of both could enhance the stress that triggers abscission (Eccher et al., 2013; Rademacher, 2015).

Byers et al. (1990) added that the thinning effect of CB was intensified by four-days of 92% shading, overthinning 'Delicious' apple trees, which was not observed in the present study since T6 did not reduce fruit set, probably because late chemical thinning is ineffective in 'Fuji Mishima' apples. However, for 'Empire' apples, Elfving & Cline (1993) concluded that BA + ETH had the same effect as BA alone, differently from the mild effect of this combination found here.

In addition to the chemical thinner per se, spray timing is also important, as the peak of susceptibility to fruitlet drop generally occurs between 200 and 250 DD, with no visible effect after 300 DD (Lordan et al.,

Table 2. Fruit set (fruits/flower clusters) of 'Fuji Mishima' apple (*Malus domestica*) trees grown under a black anti-hail net as a function of different fruitlet thinning programs carried out in 2022 in the municipality of Bom Jesus, in the state of Rio Grande do Sul, Brazil[1].

Treatment	Plant growth regulators	Fruit set (fruits per cluster)	
		2020/2021	2021/2022
UTC (T3, T4, T5, T7)	-	0.95	1.47
UTC T6	-	1.07	1.69
UTC T8	-	1.07	1.60
T3	BA+GA_{4+7}, FB / BA+ETH,15	0.81	1.31
T4	BA+GA_{4+7}, FB / NAA+CB,7	0.70	1.07
T5	BA+GA_{4+7}, FB / BA+CB,15	0.70	0.85
T6	ETH+CB, 15 / MM+ETH,20	1.24	1.76
T7	BA+GA_{4+7}, FB / BA, 7 / MM,20	0.71	1.57
T8	MM,7 / MM,20	0.80	1.64
Contrasts			
T3 vs UTC		ns	ns
T4 vs UTC		*	**
T5 vs UTC		*	**
T6 vs UTC		ns	ns
T7 vs UTC		*	ns
T8 vs UTC		*	ns
CV (%)		31.02	

[1]Data transformed by √y. UTC, untreated control; BA, benzyladenine; GA_{4+7}, gibberellic $acid_{4+7}$; FB, full bloom; ETH, ethephon; NAA, naphthaleneacetic acid; CB, carbaryl; MM, metamitron; 15, fruitlets with a 15 mm diameter; 7, fruitlets with a 7 mm diameter; 20, fruitlets with a 20 mm diameter; and CV, coefficient of variation. * and**Significant at 5 and 1% probability, respectively. [ns]Nonsignificant.

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2020). When sunlight is less available and a threshold that is not appropriate for a surplus of assimilates is reached (i.e., shading), the sink of assimilates is shifted from the growth of fruits towards that of extension shoots and leaf area (Boini et al., 2019).

Lakso et al. (2007) and Robinson & Lakso (2011) concluded that, in apple trees, the reserves stored from the previous fall are used for bud break and blooming, lasting until petal fall, when the expanding leaf area is the source of assimilates. Therefore, according to these authors, when the sky is cloudy and temperatures are high after bloom, the peak of susceptibility is sharp as the lack of sunlight impairs photosynthesis and high temperatures stimulate intense cell division and dark respiration in plant growing organs. Contrastingly, in cool and sunny springs, this process takes longer and postpones the peak of susceptibility since the competition between organs is less intense, allowing of more fruitlets to sustain a constant growth. Gonzalez et al. (2020) found that higher temperatures increased the thinning effect of the second application of MM on 'Gala' apples, but that netting did not affect fruitlet thinning. In the present work, the applied thinners performed poorly in the second season due to the cooler spring and lower accumulation of DD, as well as to the lower flower bud load, compared with the previous season. However, in the first season, the conditions for fruitlet drop were more favorable, i.e., higher initial flower bud load and warmer temperature, which explains why fruit set was affected by T7 and T8 (Figure 1).

Therefore, in the first season, a high natural fruitlet drop (81% of abscission) was observed due to the high initial flower bud load (higher competition), shaded environment (anti-hail net), and warmer temperatures. In the second season, thinning (71% of abscission) and, consequently, fruit quality, was reduced since the initial bud load was lower (lower competition) and temperatures were cooler.

Although in the first season T4, T5, T7, and T8 reduced fruit set, the latter two required less manual thinning, whereas T4 was equivalent to manual thinning only (Table 3). In the second season, as T4 and T5 reduced fruit set, they also induced the highest proportion of single-fruited clusters, which led to a lower manual fruit removal. At harvest, the targeted fruit load (chemical + manual thinning) was 280 fruits per tree and yield was 58 Mg ha^{-1}. The treatments that reached values close to these were T5 and T8, despite their extremely high initial flower bud load, in the first season, and all treatments, except the controls, in the second.

The reduction in fruit set was linked to the increase in fruit weight, diameter, and length in T4, T5, T7, T8, and T2 in the first season (Table 4). However, in the second, due to a cooler spring, larger and heavier fruits were obtained in T3, T5, and T7. Moreover, none of

Table 3. Fruit number at harvest, yield, clusters with a single fruitlet, and number of fruitlets removed by manual thinning (NFRMT) of 'Fuji Mishima' apple (*Malus domestica*) trees grown under a black anti-hail net as a function of different fruitlet thinning programs carried out in the 2020/2021 and 2021/2022 crop seasons, in the municipality of Bom Jesus, in the state of Rio Grande do Sul, Brazil[(1)].

Treatment	Active ingredients	Fruit number at harvest		Yield (Mg ha^{-1})		Clusters with a single fruitlet (%)		NFRMT	
		2020/2021	2021/2022	2020/2021	2021/2022	2020/2021	2021/2022	2020/2021	2021/2022
T1	Untreated control	803a	589a	136a	84a	47ab	24bc	-	-
T2	Manual thinning only	498bc	446ab	102bc	70ab	-	-	143a	104a
T3	BA+GA_{4+7}, FB / BA+ETH,15	495bc	298c	99bc	58bc	46ab	36ab	93bc	58bc
T4	BA+GA_{4+7}, FB / NAA+CB,7	481bc	271c	105abc	46c	42b	39a	125ab	40c
T5	BA+GA_{4+7}, FB / BA+CB,15	398c	315bc	92c	55bc	46ab	47a	93bc	38c
T6	ETH+CB, 15 / MM+ETH,20	652ab	279c	123ab	49bc	40b	23bc	125ab	63abc
T7	BA+GA_{4+7}, FB / BA, 7 / MM,20	465bc	320bc	108abc	63abc	56a	22bc	76c	79ab
T8	MM,7 / MM,20	443c	367bc	99bc	55bc	56a	13c	67c	89ab
CV (%)	-	25.43		23.69		28.21		33.83	

[(1)]Means followed by equal letters, in the columns, do not differ by the least significant difference test, at 5% probability. Data transformed by √y. BA, benzyladenine; GA_{4+7}, gibberellic $acid_{4+7}$; FB, full bloom; ETH, ethephon; NAA, naphthaleneacetic acid; CB, carbaryl; MM, metamitron; 15, fruitlets with a 15 mm diameter; 7, fruitlets with a 7 mm diameter; 20, fruitlets with a 20 mm diameter; and CV, coefficient of variation.

Table 4. Fruit weight, diameter, length, and length:diameter ratio of 'Fuji Mishima' apple (*Malus domestica*) trees grown under a black anti-hail net as a function of different fruitlet thinning programs carried out in 2022 in the municipality of Bom Jesus, in the state of Rio Grande do Sul, Brazil.

Treatment	Active ingredient	Fruit weight (g)		Fruit diameter (cm)		Fruit length (cm)		Length:diameter ratio	
		2020/2021	2021/2022	2020/2021	2021/2022	2020/2021	2021/2022	2020/2021	2021/2022
T1	Untreated control	90.6d	80.8b	6.38c	5.85d	5.23d	5.03c	0.82ab	0.86bc
T2	Manual thinning only	114.1abc	87.6b	6.61bc	6.03cd	5.41bcd	5.10c	0.82ab	0.85c
T3	BA+GA_{4+7}, FB / BA+ETH,15	110.3bc	107.5a	6.59bc	6.42a	5.41bcd	5.48ab	0.82ab	0.85bc
T4	BA+GA_{4+7}, FB / NAA+CB,7	117.0abc	91.8b	6.90a	6.11c	5.67a	5.25bc	0.82ab	0.86bc
T5	BA+GA_{4+7}, FB / BA+CB,15	125.1a	94.9ab	6.79ab	6.15bc	5.63ab	5.54a	0.83a	0.90a
T6	ETH+CB, 15 / MM+ETH,20	107.7c	92.9b	6.61bc	6.17bc	5.37cd	5.20c	0.81ab	0.84c
T7	BA+GA_{4+7}, FB / BA, 7 / MM,20	123.6ab	108.5a	6.76ab	6.37ab	5.60abc	5.53a	0.83a	0.87b
T8	MM,7 / MM,20	120.1abc	84.1b	6.90a	5.94cd	5.59abc	5.06c	0.81b	0.85bc
CV (%)	-	19.65		6.43		5.92		3.53	

(1)Means followed by equal letters, in the columns, do not differ by the least significant difference test, at 5% probability. BA, benzyladenine; GA_{4+7}, gibberellic $acid_{4+7}$; FB, full bloom; ETH, ethephon; NAA, naphthaleneacetic acid; CB, carbaryl; MM, metamitron; 15, fruitlets with a 15 mm in diameter; 7, fruitlets with a 7 mm in diameter; 20, fruitlet with 20 mm in diameter; and CV, coefficient of variation.

the treatments had an effect on seed number in both seasons.

All treatments that reduced fruit set improved fruit size/weight, except in the off year (2021/2022), when only the treatments containing BA sprayed on fruitlets with a 7 or 15 mm diameter did. According to Wismer et al. (1995) and Gabardo et al. (2019), this PGR is known to promote fruit growth at some extent due to fruitlet cell division, independently of the crop load. In addition to being directly affected by fruit set reduction, fruit size/weight is also affected by early season temperatures, which, if cooler, may compromise fruit size due to a lower cell division rate (Musacchi & Serra, 2018). In the present study, in general, the fruits had a globose shape in both seasons, especially in the first when the temperatures were higher, being slightly more oblong in the second, particularly in T5 (Table 4 and Figure 1). This finding is important since fruit shape influences consumer preferences, i.e., flattened apple fruits are perceived as misshaped and unappealing (Musacchi & Serra, 2018).

Conclusion

For 'Fuji Mishima' apples (*Malus domestica*) grown under a black anti-hail net, the chemical thinning program consisting of benzyladenine + gibberellic $acid_{4+7}$ (47 + 47 g a.i. ha^{-1}) sprayed at full bloom, followed by benzyladenine + carbaryl (80 + 288 g a.i. ha^{-1}) on fruitlets with a 15 mm diameter, consistently reduces fruit set, requires less manual thinning, and improves fruit weight and size.

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