Agricultural Research & Technology
Open Access Journal
ISSN: 2471-6774

Juniper Publishers
key to the Researchers

Research Article
Volume 22 Issue 3 - August 2019
DOI: 10.19080/ARTOAJ.2019.22.556197

Agri Res & Tech: Open Access J

Different Methods of Thinning Influenced by Variety and Hail Nets in Apple Orchards

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Submission: July 23, 2019; **Published:** August 20, 2019

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Abstract

Looking at the effects of thinning on apple quality, the purpose of this study was to investigate the fallouts of thinning methods in different varieties and under hail nets. The experiment was developed in Bavendorf, South Germany. The 'Pinova'and 'Braeburn' apple trees were covered with two types of hail net: white, black and without nets. The following thinners were tested: Mechanical thinning (MT) with the 'Darwin machine'; chemical thinning with Metamitron (CT-Metamitron) or 6-benzyladenine (CT-BA) and hand thinning (HT). The evaluations were: fruit set, time taken for HT, photosynthesis measurements, fruit retention, yield, fruit quality, and thinning efficacy value. The CT-BA treatment required the highest number of hours to perform HT for both varieties and hail nets. Comparing the varieties, the Pinova demonstrated less efficiency for thinning treatments, hence more hours were needed to thin by hand. Photosynthesis measurements were clearly different between CT-Metamitron versus CT-BA and MT curves, where CT-Metamitron remained in effect for 11 days after the treatment. The HT treatment had the highest value for thinning efficacy with 93% and the MT treatment achieved 74% followed by CT-Metamitron with 64% and CT-BA with 54%. Overall the Braeburn variety is easier to thin than the Pinova variety and the black hail nets showed negative effects on color value.

Keywords: Malus domestica; Thinning efficacy value; Crop load; Apple trees; Broken limbs; Chemical thinning; Apple production; Photosynthesis measurements; Fruit retention; Yield; Fruit quality

Introduction

Apple trees (Malus domestica) naturally produce an excess of fruitlets that negatively affect the commercial value of the fruit. A prerequisite for an annual crop is an adequate number of flowers per tree, thus enough flower-bud formation in the preceding year. This can only be achieved when there is not too much fruit per tree [1]. Only 7% of flowers per tree are necessary to achieve a satisfactory yield [2]. Fruit thinning has been practiced for many years and serves a variety of purposes. An excess of fruit per tree can result in small fruit size and poor quality, broken limbs, exhaustion of tree reserves, and reduced alternate fruit-bearing [3]. Nevertheless, uncertainties regarding the cost and availability of agricultural labor for hand-thinning in the future have provided a focus for renewed efforts to find alternative thinning materials for apples [4]. Chemical thinning is one of the most important cultural practices in apple production. Thinners are applied during flowering and or during the early post-bloom periods [5]. The chemical thinners used for apples are NAA (Naphthaleneacetic Acid), Ammoniumthiosulfate (ATS), Carbaryl, Benzyladenine (BA), Ethephon (Ethrel) and more recently, Metamitron.

Young apple fruit generally becomes insensitive to thinning chemicals after they reach a diameter of around 16mm, coinciding with increasing carbohydrate reserves within the tree. Studies observed the effects of shade treatments on fruit set in apples, which should alter the gene expression after the imposition of abscission stimuli including shade and naphathaleneacetic acid [6] and benzyladenine [7]. This provides the hypothesis that a carbohydrate deficit in the fruit is one of the earliest responses to chemical or environmental stimuli that trigger abscission in apple fruit [8]. Benzyladenine is a chemical belonging to the cytokinin group that, when applied to thinning in apple, increases fruit size by acting on cell division and the effect is proportional to application time and concentration used [9]. According to Greene [10] BA can increase fruit size even without the thinning effect. It has been considered a good thinner because it shows low toxicity and low residual plant growth and has been shown to imitate the biological action of plant-synthetized cytokinin [11].

The inhibitor metamitron exhibited thinning activity when applied to apple fruitlets from 10 to 12mm diameter stage [12].

Metamitron disrupts the photosynthesis apparatus for 7 to 10 days post-application, reducing electron transport rates by as much as 60% [4]. This chemical act similarly to shading. By doing this it strengthens the competition between different sinks and induces abscission in weaker fruit [13]. The carbohydrate deficit in the fruit cortex provides the primary stimulus for fruit abscission and increased ethylene levels cause the stimulus that ultimately triggers the abscission zone in the fruit pedicel [8]. The availability and efficiency of chemical thinning depend on crop, orchard, weather conditions, phenological stage, variety, flowering dynamics, and tree age. This means that hand thinning is often required to adapt crop load for expected fruit size and quality [14]. Lately, chemical thinning has been adversely affected by legislation and the limited number of registered compounds. An alternative is the usage of a mechanical flower thinning. Numerous mechanical approaches have been attempted including limb and trunk shakers, rotating arms in the canopy and manually hitting libs. The Darwin machine appears to show real promise for more widespread commercial use [15,16].

Mechanical thinning offers a lengthy period for application during flowering. It provides a 2-3week temporal lapse of time without limitations due to cold weather as with chemical thinning. A disadvantage is that the training system must be tailored to the machine [17]. The increased occurrence of hailstorms during the growing period, likely due to global climate change, resulted in the installation of either black or white protective hail nets in many fruit growing regions of the world used to protect apple fruit against hail storms and hail damage [18]. It is known that a close relationship exists between apple orchard light interception and productivity. Intercepted light is the light that is taken in by plants, mainly by leaves, and provides the energy to drive the process of photosynthesis, which is fundamental to the growth and fruiting of all plants, including apple trees. In recent years colored hail nets have become available with their possible positive effects on phytochrome, photosynthesis, yield and fruit quality [19]. The aim of the present study was to evaluate the effects and properties of different thinning techniques on the quality and production of apple fruit (Braeburn and Pinova varieties) in South Germany. And the effect of the hail net on mechanical and chemical thinning as new.

Materials and Methods

Field conditions

The experiment was carried out in an experimental orchard in Bavendorf, South Germany. The twelve-year-old 'Pinova' and 'Braeburn' apple trees (*Malus domestica* L. Borck) were grafted on M.9, spaced in 3.0 x 0.8 m and conducted in a spindle system, covered with two types of hail net: white/transparent net, black net and without net (uncovered). The hail net mesh size was "3x7" mm. The shading effect of the white hail net was up to 15% and of the black net up to 25%.

Treatments

The following thinners were tested: hand thinning, mechanical thinning with the 'Darwin machine' (Fruit Tec®, Germany); Chemical thinning with: 6-benzyladenine (BA) (19g/L - Maxcel® - Valent BioSciences) and Metamitron (15g/L - Brevis® - Adama), all sprayed with 1000 liters of water per hectare applied with a turbo atomizer.

A complete randomized block design was used, with four replications (four trees per replication), the treatments (Hand thinning (HT), mechanical thinning (MT) and two chemical thinners (CT)), three different hail nets (without, white and black), and two apple varieties (Braeburn and Pinova) organized as triple factorial (4x3x2). The treatments were applied as follows:

a. Mechanical thinning;

b. Hand thinning;

c. Chemical treatment with 6-BA (Maxcel®) at 7,5 $L.ha^{-1}$ ($150mg.L^{-1}$);

d. Chemical treatment with Metamitron (Brevis®) at $2,2kg.ha^{-1}$ ($333mg.L^{-1}$); Mechanical thinning was performed with a tractor at a 9 $km.h^{-1}$ speed and 270 rpm with fifty percent strings, a total of 216 strings (meaning strong) [20] were used in full bloom (FB) (BBCH scale 65) [21]on April 23, 2014. HT was performed when the fruit had reached around 25mm. When the fruit had reached around of 12mm diameter the chemical products were sprayed with a tractor machine/turbo atomizer on May 17, 2014.

Evaluations

i. **Fruit set (%):** all flower clusters were counted per tree. In the end total numbers of fruit per tree were counted, and the percentage of fruit set was estimated.

ii. **Time taken for HT:** measured and calculated as average per tree, then calculated as hours per hectare. The aim of HT was to keep around 75 fruits per tree with an average 150g per fruit, yielding 40 to 50 tons per hectare.

iii. **Production per Trunk Cross Sectional Area (TCSA):** Tree trunk diameter was measured twenty centimeters above graft point and the number and weight of fruit per trunk cross sectional area was calculated.

iv. **Photosynthesis measurements (loss of fluorescence):** It was estimated one day before chemical thinning was applied to get the information for zero day and during the 27 following days. It was measured with the Agrofirm – Chlrophyll Fluorometer. Metamitron is an herbicide, which is used in sugar beet. The PSI-meter machine has been used for the MLHD method (minimum lethal herbicide dose) which is a new concept for optimizing chemical weed control in the herbicide strategy. Using a PSI-meter, it is possible to observe whether there is an effect on plants through the use of herbicides. The effect of inhibiting photosynthesis can be accurately observed 2-3 days after the treatment. For the measurement, the leaf is placed between a clip and the measuring window. The abaxial side of the leaf is measured but the device is not able

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to save values. The PSI-meter shows the measured data on a display. The scale goes from 0 (no damage to photosystem I, completely healthy) to 100 (all photosystems I are blocked, no photosynthesis at all) [22]. The data is expressed in percentage of damage. A large value means that the herbicide has had a large effect.

v. **Fruit retention:** All fruit on the trees were harvested in Autumn – harvest dates had been: Pinova: first picking - September 24 and second picking October 6. Braerburn: first picking – October 9 and second picking October 30, 2014.

vi. **Yield :** Each plant was totally harvested and all the fruit was weighed and counted.

vii. **Fruit quality:** average fresh mass weight (FMW), diameter and color were measured. The GREEFA MSE 2000 grading machine was used. FFW was measured by weighing each fruit. The diameter was taken with an optical camera system while turning every single fruit. The maximum and minimum diameter was measured next to the height of each fruit while turning the fruit round and using ´fixpoints` set by the camera software. Next, to this surface, the fruit can be measured where the green/yellow ground-color can be separated from the red/reddish skin parts. Then the surface is calculated as red colored in (%) and ground colored in (%).

viii. **Thinning efficacy value (TEV):** The formula was adapted for thinning calculation and based on the different numbers of flower clusters/blossoms per used tree.

TARGET = (FL – X);

FL = Total flowers per tree.

X= Desired number of fruit per tree.

REAL = (FL – Y);

Y= Actual number of fruits per tree.

GAP = REAL X 100

TARGET

TEV = (GAP – NF) * 100

100 – NF

NF - Natural fruit set

The TCSA was calculated, flower clusters/blossoms were counted and the number of fruits that were necessary per tree to have the expected yield was estimated. After the harvest it was possible to know the number of fruit and weight that there were in the tree and it is possible to correlate with expected yield. Then it was possible to calculate 100% thinning efficacy value when the optimal number of wanted fruit per tree is reached and sometimes a value of over 100% can mean overthinning. The natural fruit fall of the Braeburn variety was then subtracted – without net (100-90); white net (100-80) and black net (100-70); and Pinova variety – without and white net (100-70) and black net (100-80). This natural fruit fall was calculated in recent years (This data is not shown). Results were statistically processed using analysis of variance, t test and factorial analysis methods in the Sisvar 5.6 statistical package [23]. Meaningful comparisons were generated using Tukey's test at the (5% level).

Results

Fruit set

In fruit set, there was an interaction between thinning methods and different hail nets (Table 1). For the thinning treatment with CT–Metamitron, the white and black hail nets reduced as much as 28-15% of fruit set, respectively, when compared to the treatment without the hail net. No interactions were verified for other treatments. As to the effects of hail nets in the thinning methods, it was noticed that in the treatment without a hail net the HT and MT were the most effective treatments with a reduction in fruit set of around 50% and 25%, respectively, compared to treatments with chemicals thinning (Table 1).

Table 1: Benzyladenine (BA), Metamitron Chemical thinning (CT), Mechanical (MT), Hand thinning (HT)) and different hail nets (without, white and black) on fruit (%) set in apple trees (Bavendorf, Germany, 2014).

	Hail Nets		
Thinners	Without	White	Black
CT–BA	62.8 Ca	59.8 Ba	58.9 Ca[1]
CT – Metamitron	67.7 Ca	56.8 Bb	48.4 Bb
MT - Darwin®	47.1 Ba	50.9 Ba	46.9 Ba
HT – Hand	30.1 Aa	32.6 Aa	29.9 Aa
LSD	9,49[x]	10,41[y]	
F – p-value	0.01**		

[1]Measurements followed by lower-case[x] letters in the same row and measurements followed by upper-casey
letters in the column do not differ at the 5% level by Tukey's test. **Significant at 0.05, *Significant at 0.1, ns = not statistically significant.

Table 2: (Benzyladenine (BA), Metamitron Chemical thinning (CT), Mechanical (MT), Hand thinning (HT)) and two varieties (Braeburn and Pinova) on fruit set (%) in apple trees (Bavendorf, Germany, 2014).

	Varieties	
Thinners	Braeburn	Pinova
CT–BA	47.6 Cb	73.5 Ca[1]
CT – Metamitron	45.8 Cb	69.5 BCa
MT - Darwin®	34.7 Bb	61.9 Ba
HT – Hand	24.7 Ab	37.1 Aa
LSD	6,47[x]	8,50[y]
F - p-value	0.006**	

1Measurements followed by lower-casex letters in the same row and measurements followed by upper-casey letters in the column do not differ at the 5% level by Tukey's test. **Significant at 0.05, *Significant at 0.1, ns = not statistically significant.

For white hail nets, the treatments with CT and MT showed higher numbers of fruit set, statistically differing from HT, which had a smaller fruit set. The HT showed a fruit set of 32.6%, re-

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ducing around 45% comparing to the other treatments. For black nets, the HT treatment presented the smallest fruit set, followed by MT and CT-Metamitron which did not differ statistically. The CT-BA showed the highest fruit set. The HT treatment significantly decreased fruit set by 50% compared with CT-BA and 37% compared with CT–Metramitron and MT (Table 1). An interaction has been observed between thinning methods and the different varieties for the fruit set variable. For the Braeburn variety, HT obtained the smallest fruit set number reducing 50% compared to the CT-BA, followed by MT reducing by 27% and lastly CT-Metamitron reducing by 4%. For the Pinova variety, HT obtained the smallest fruit set number reducing 50% compared to the CT-BA, followed by MT reducing by 16% and lastly CT-Metamitron reducing by 5% (Table 2).

There was no interaction between the hail nets and the varieties for variable fruit set as shown by F test.

Hand Thinning

The CT-BA treatment required the highest number of hours to perform HT for both varieties and hail nets. For the Braeburn variety, the treatment without hail nets with CT-BA showed 40% and 55% higher numbers of hours to perform HT than with white and black hail nets, respectively. For the treatments with white and black hail nets the number of hours required to thin by hand was not very different. For treatment without hail nets, the number of hours to perform HT treatments was greater. The CT-Metamitron treatments in the Braeburn variety under black hail nets showed 62% and white hail nets 36% fewer hours to perform HT than without any hail nets. It was noted that with the MT, the number of hours to thin by hand was similarly independent of which hail net was used. For the Pinova variety, the CT-BA treatment with white net showed the highest number of hours to perform HT 25% and 10% fewer hours were required to thin by hand for black nets and without nets, respectively, compared to thinning with white nets.

For the Pinova variety with CT-Metamitron, the number of hours to perform HT was similar for all hail nets. For MT treatment, the black nets showed 30% fewer hours and without nets 15% fewer hours to thin by hand than white nets. Comparing the varieties, the Pinova demonstrated less efficiency for thinning treatments, hence more hours were needed to thin by hand than the Braeburn variety. It could be seen that Braeburn with white and black hail nets showed to be more sensitive to the CT-Metamitron and CT-BA treatments than the Pinova variety, where fewer hours were required to perform HT for the Braeburn variety. For the treatments without hail nets, for both varieties, the number of hours to thin by hand was nearly the same.

Number of fruit per TCSA

Regarding the number of fruit per TCSA, there was an interaction between thinning methods and different hail nets (Table 3). For the CT treatments, the black hail nets reduced around 18% of the number of fruits per TCSA, when compared to without and white hail nets. No interactions were verified for MT and HT. Looking at the effects of hail nets in the thinning methods, without the hail net, the HT reached the lowest number of fruits per TCSA, reducing by 63% when compared with CT-BA. The HT statistically differed from MT reduction by 27%, compared with CT-BA, followed per CT-Metamitron and CT-BA with the highest number of fruits per TCSA (Table 3). For the treatment with white hail nets, the HT reached the lowest number of fruits per TCSA reducing around 54% compared with CT-BA. This was followed by MT reduction of 25% and CT-Metamitron reduction of 2.5%, compared with CT-BA. The MT statistically differed from CT-BA and CT-Metamitron. For the black hail nets, the HT showed the lowest number of fruits per TCSA reducing around 48% compared to CT-Metamitron. The HT statistically differed from MT reduction by 21% and CT-BA reduction by 6%. The MT statistically differed from CT-Metamitron, however, it did not differ from CT-BA (Table 3).

Table 3: (Benzyladenine (BA), Metamitron Chemical thinning (CT), Mechanical (MT), Hand thinning (HT)) and different hail nets (without, white and black) on number of fruit per TCSA in apple trees (Bavendorf, Germany, 2014).

	Hail Nets		
Thinners	Without	White	Black
CT–BA	8.4 Ca	7.6 C a	6.3 BCb[1]
CT – Metamitron	8.3 Ca	7.4 C ab	6.7 Cb
MT - Darwin®	6.1 Ba	5.7 Ba	5.3 Ba
HT – Hand	3.1 Aa	3.5 Aa	3.5 Aa
LSD	1.13[x]	0.65[y]	
F - p-value	0.003**		

Measurements followed by lower-casex letters in the same row and measurements followed by upper-casey letters in the column do not differ at the 5% level by Tukey's test. **Significant at 0.05, *Significant at 0.1, ns = not statistically significant.

Table 4: (Benzyladenine (BA), Metamitron Chemical thinning (CT), Mechanical (MT), Hand thinning (HT)) and two varieties (Braeburn and Pinova) on number of fruit per TCSA in apple trees (Bavendorf, Germany, 2014).

	Varieties	
Thinners	Braeburn	Pinova
CT–BA	6.4 Bb	8.9 Ca[1]
CT – Metamitron	6.1 Bb	8.4 Ca
MT - Darwin®	5.5 Ba	5.9 Ba
HT – Hand	3.2 Aa	3.5 Aa
LSD	0.70[x]	0.92[y]
F - p-value	0.000**	

1Measurements followed by lower-casex letters in the same row and measurements followed by upper-casey letters in the column do not differ at the 5% level by Tukey's test. **Significant at 0.05, *Significant at 0.1, ns = not statistically significant.

There was an interaction between thinning methods and the different tree varieties on the variable number of fruits per TCSA (Table 4). For CT-thinners, the Braeburn variety showed a smaller number of fruits per TCSA, reducing around 26% compared to

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the Pinova variety. No interactions were verified for MT and HT. For the Braeburn variety, the lowest number of fruits per tree was for HT, reducing 50% compared to CT-BA. This was followed by MT, which showed a reduction of 14% and CT-Metamitron reduction of 5%, which did not statistically differ from each other. The CT-BA treatment had the highest number of fruits per TCSA with 6.4 apples (Table 4). For the Pinova variety, the lowest number of fruits per tree was noticed for HT, reducing 60% compared to CT-BA. The MT showed a reduction of 33% and CT-Metamitron a reduction of 7%, therefore CT-Metamitron did not statistically differ from CT-BA, which had the highest number of fruits per TCSA, with 8.9 apples (Table 4).

There was no interaction between the hail nets and the varieties for variable number of fruits per TCSA as shown by F test.

Chlorophyll Fluorescence analysis

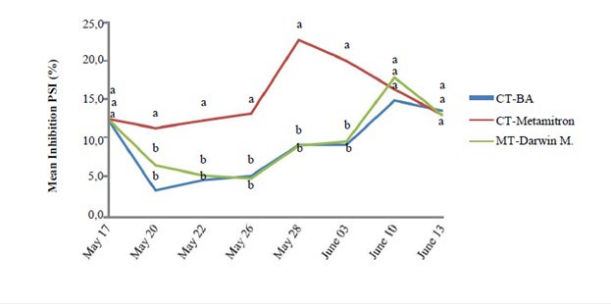

Figure 1: Inhibition of photosystem I (PSI) (%) of each thinning treatment, measured May 17-June 13, 2014. On May 17 photosynthesis was measured before treatment was applied. Measurements marked with the same letter on the same day do not differ at the 5% level by Tukey's test.

From May 20 until June 03 statistical differences were observed between CT-Metamitron and other treatments (Figure 01). There were clear differences between CT-Metamitron versus CT-BA and MT curves. The following development of the values is mostly dependent on the Metamitron application. The CT-Metamitron started high but had a great increase on May 28, eleven days after spraying. The CT-BA and MT treatments showed constant values throughout. At the end of the measurement, the curves of all treatments joined at the same level.

Yield per tree

On the yield per tree, there was an interaction between thinning methods and different hail nets (Table 5). For the CT treatments, the black hail nets reduced around 22% of yield per tree, when compared to without and white hail nets. No interactions were verified for MT and HT. When it comes to the effects of hail nets in the thinning methods, the HT reached the lowest yield per tree reducing 40%, compared with CT-BA, which did not statistically differ from MT reduction by 30%, followed per CT-Metamitron and CT-BA with the biggest yield per tree (Table 5). For the treatment with white hail nets, HT reached the lowest yield per tree reducing around 40% compared with CT-BA. Followed by MT and both chemicals thinners, respectively. MT differed statistically from CT-BA, however, it did not differ from the CT-Metamitron (Table 5). For the black hail nets, the HT showed the lowest yield per tree reducing around 23% compared to CT-BA. The HT did not statically differ from MT and CT-Metamitron (Table 5).

Table 5: (Benzyladenine (BA), Metamitron Chemical thinning (CT), Mechanical (MT), Hand thinning (HT)) and different hail nets (Without, white and black) on apple tree yield (kg/tree) (Bavendorf, Germany, 2014).

	Hail nets		
Thinners	Without	White	Black
CT–BA	30.7 B a	29.5 Ca	23.8 Bb[1]
CT – Metamitron	28.4 B a	26.9 BCa	20.7 ABb
MT - Darwin®	21.3 A a	23.5 Ba	21.5 ABa
HT – Hand	17.9 A a	17.5 Aa	18.3 Aa
LSD	3.44[x]	3.78[y]	
F - p-value	0.0001**		

1Measurements followed by lower-casex letters in the same row and measurements followed by upper-casey letters in the column do not differ at the 5% level by Tukey's test. **Significant at 0.05, *Significant at 0.1, ns = not statistically significant.

There was no interaction between thinning methods and the different tree varieties on variable yield per tree as shown by F test.

Fruit Number

Table 6: (Benzyladenine (BA), Metamitron Chemical thinning (CT), Mechanical (MT), Hand thinning (HT)) and different hail nets (without, white and black) on number of fruit in apple tree (Bavendorf, Germany, 2014).

	Hail nets		
Thinners	Without	White	Black
CT–BA	219.0 Da	209.4 Ca	156.4 Bb
CT – Metamitron	189.2 Ca	187.8 Ca	143.9 Bb
MT - Darwin®	138.7 Ba	152.2 Ba	137.7 Ba
HT – Hand	87.7 Aa	91.8 Aa	95.8 Aa
LSD	27.01[x]	29,63[y]	
F - p-value	0.000**		

1Measurements followed by lower-case lettersx in the same row and measurements followed by upper-casey letters in the column do not differ at the 5% level by Tukey's test. **Significant at 0.05, *Significant at 0.1, ns = not statistically significant.

As regards the number of fruits per tree, some interactions between thinning methods and different hail nets were observed (Table 6). For the CT treatments, the black hail nets reduced around 26% of the number of fruits per tree, when compared to without and white hail nets. No interactions were verified for MT and HT. Without hail nets, the HT reached the lowest number of fruits per tree reducing by 60%, when compared with CT-BA. The HT statistically differed from MT reduction by 37%, compared with CT-BA, followed by CT-Metamitron and CT-BA with the highest number of fruits per tree (Table 6). For the treatment with white hail nets, the HT reached the lowest number of fruits per tree, reducing around

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56% compared with CT-BA. This was followed by MT reduction by 28% and CT-Metamitron reduction by 11%, compared with CT-BA (Table 6). For the black hail nets, the HT showed the lowest number of fruits per tree reducing around 39% compared to CT-BA. The HT statistically differed from MT reduction by 12% and CT-Metamitron reduction by 9%, compared with CT-BA (Table 6). Some influence regarding thinning methods and the different tree varieties was noticed on the variable number of fruit (Table 7). For thinners, the Braeburn variety showed a smaller number of fruits per tree, reducing around 25% compared to the Pinova variety, with the exception of HT, which did not differ statistically.

Table 7: (Benzyladenine (BA), Metamitron Chemical thinning (CT), Mechanical (MT), Hand thinning (HT)) and two varieties (Braeburn an Pinova) on number of fruit in apple tree (Bavendorf, Germany, 2014).

	Varieties	
Thinners	Braeburn	Pinova
CT–BA	167.0 Cb	222.9 Ca[1]
CT – Metamitron	147.1 BCb	200.2 Ca
MT - Darwin®	127.8 Bb	158.0 Ba
HT – Hand	86.3 Aa	97.3 Aa
LSD	18.42[x]	24,19[y]
F - p-value	0.001**	

1Measurements followed by lower-casex letters in the same row and measurements followed by upper-casey letters in the column do not differ at the 5% level by Tukey's test. **Significant at 0.05, *Significant at 0.1, ns = not statistically significant.

Table 8: Effects of different hail nets (without, white and black) and two varieties (Braeburn and Pinova) on number of fruit in apple trees (Bavendorf, Germany, 2014).

	Varieties	
Hail Nets	Braeburn	Pinova
Without	151.2 Aa	166.1 B a[1]
White	124.7 Bb	195.8 Aa
Black	120.1 Bb	146.7 Ca
LSD	24.91[x]	19,10[y]
F - p-value	0.004**	

1Measurements followed by lower-case lettersx in the same row and measurements followed by upper-casey letters in the column do not differ at the 5% level by Tukey's test. **Significant at 0.05, *Significant at 0.1, ns = not statistically significant.

It was found that in the Braeburn variety the lowest number of fruit per tree was for HT, reducing by 48% compared to CT-BA. This was followed by MT, which should a reduction of 23% and CT-Metamitron reduction of 12%, compared with CT-BA. The CT-Metamitron did not statistically differ from CT-BA which had the highest number of fruits per tree with 167 apples (Table 7). For Pinova variety, the lowest number of fruits per tree was for HT, reducing by 56% compared to CT-BA. Followed by MT reduction by 29% and CT-Metamitron reduction by 10% compared to CT-BA, however, CT-Metamitron did not statistically differ from CT-BA which had the highest number of fruits per tree with 222 apples (Table 7). There were significant effects between the hail nets and the varieties on the variable number of fruits (Table 8). For the white and black hail net treatments, the number of fruits was 36% and 18% less, respectively, for Braeburn variety, than for Pinova variety. Upon verifying the interaction of hail nets on the different varieties. For the Braeburn variety, the number of fruits was inferior with the white and black hail nets compared to without hail nets. However, it was found that without hail nets, the number of fruits was 20% higher. For Pinova variety, the number of fruits was 25% and 15% inferior with the black and without hail nets, respectively, compared to white hail nets (Table 8).

Fresh Mass Weight

Table 9: Effects of different types of thinning (Benzyladenine (BA), Metamitron Chemical thinning (CT), Mechanical (MT), Hand thinning (HT)) and different hail nets (without, white and black) on weight (g) in apple trees (Bavendorf, Germany, 2014).

	Hail Nets		
Thinners	Without	White	Black
CT-BA	141.5 Cb	149.0 B ab	155.1 BC a[1]
CT - Metamitron	152.1 BCa	150.8 Ba	147.3 Ca
MT - Darwin®	159.2 Ba	157.2 Ba	159.3 Ba
HT - Hand	204.4 Aa	197.3 Aab	191.7 Ab
LSD	10.7[x]	11.8[y]	
F - p-value	0.007**		

1Measurements followed by lower-casex letters in the same row and measurements followed by upper-casey letters in the column do not differ at the 5% level by Tukey's test. **Significant at 0.05, *Significant at 0.1, ns = not statistically significant.

As for FMW, there was an interaction between thinning methods and the different hail nets (Table 9). For the CT-BA, it was observed that the black hail nets increased around 9% of and decreased 6% for HT when compared to without hail nets. No interactions were verified for MT and CT-Metamitron. Looking at the effects of hail nets in the thinning methods, without hail nets, the HT reached the highest FMW, which increased 31%, when compared with CT-BA. The HT statistically differed from MT reduction by 11%, followed by CT-Metamitron reduction by 7%, compared with CT-BA. The CT-BA had the lowest average, with 141.5 grams per fruit (Table 9). For the treatment with white hail nets, the HT reached the highest FMW, increasing around 24% compared with CT-BA. The HT statistically differed from MT reduction by 5% and CT-Metamitron reduction by 1%, compared to CT-BA, with 149.0 grams per fruit (Table 9). For the black hail nets, the HT showed the highest FMW, increasing 23% compared to CT-Metamitron. The HT statistically differed from MT reduction by 7.5% and CT-BA reduction by 5%, compared with CT-Metamitron. The MT statistically differed from CT-Metamitron; however, it did not differ from CT-BA (Table 9).

There was a noticeable interaction between thinning methods and the different tree varieties on variable FMW (Table 10). For

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thinners, it was observed that the Braeburn variety showed the highest fruit weight, increasing around 12% compared to the Pinova variety. No interactions were verified for HT. Observing the effects of different varieties on thinning methods, for the Braeburn variety the highest FMW was achieved with HT, which increased by around 20% compared to other treatments. The HT treatment had the highest FMW with 201.3 grams per fruit. The other treatments did not show statistical differences from each other (Table 10). For the Pinova variety, the highest FMW was for HT, which was around 28% higher than with CT-BA and CT-Metamitron and 22% greater compared to MT. The HT treatment had the highest FMW with 194.3 grams per fruit (Table 10). Differences were obbserved between the hail nets and the varieties for variable fruit weight (Table 11). For the white and black hail net treatments, fruit weights were 17% and 9% higher, respectively, for the Braeburn variety compared to the Pinova variety. The effects of hail nets on the different varieties, on the Braeburn variety, the FMW were 4% and 8% higher with black and white nets, respectively, compared to without hail nets (Table 11). On the contrary to the Braeburn variety, the Pinova variety, showed 10% and 5% lower FMW with the white and black nets, respectively, compared to without hail nets (Table 11).

Table 10: (Benzyladenine (BA), Metamitron Chemical thinning (CT), Mechanical (MT), Hand thinning (HT)) and two varieties (Braeburn and Pinova) on FMW (g) in apple trees (Bavendorf, Germany, 2014).

	Varieties	
Thinners	Braeburn	Pinova
CT–BA	156.8 Ba	140.4 Cb[1]
CT – Metamitron	163.9 Ba	136.1 Cb
MT - Darwin®	165.7 Ba	151.4 Bb
HT – Hand	201.3 Aa	194.3 Aa
LSD	7.33[x]	9,63[y]
F - p-value	0.001**	

1Measurements followed by lower-casex letters in the same row and measurements followed by upper-casey letters in the column do not differ at the 5% level by Tukey's test. ** Significant at 0.01, ns = not statistically significant.

Table 11: Effects of different types of hail nets (Without, white and black) and two varieties (Braeburn and Pinova) on fruit weight (g) in apple trees (Bavendorf, Germany, 2014).

	Varieties	
Hail Nets	Braeburn	Pinova
Without	165.1 Ba	163.5 Aa[1]
White	179.2 Aa	147.9 Bb
Black	171.5 Ba	155.1 Bb
LSD	10.92[x]	7.60[y]
F - p-value	0.000**	

1Measurements followed by lower-case letters in the same row and measurements followed by upper-case letters in the column do not differ at the 5% level by Tukey's test. **Significant at 0.05, *Significant at 0.1, ns = not statistically significant.

Diameter

Table 12: (Benzyladenine (BA), Metamitron Chemical thinning (CT), Mechanical (MT), Hand thinning (HT)) and different hail nets (without, white and black) on diameter (mm) in apple trees (Bavendorf, Germany, 2014).

	Hail Nets		
Thinners	Without	White	Black
CT–BA	70.2 Cb	71.6 Cab	72.6 Ba[1]
CT – Metamitron	72.1 BCa	70.3 BCa	71.6 Ba
MT - Darwin®	73.5 Ba	72.8 Ba	73.5 Ba
HT – Hand	79.6 Aa	79.1 Aa	78.2 Aa
LSD	2.30[x]	2.53[y]	
F - p-value	0.09*		

1Measurements followed by lower-casex letters in the same row and measurements followed by upper-casey letters in the column do not differ at the 5% level by Tukey's test. **Significant at 0.05, *Significant at 0.1, ns = not statistically significant.

On of fruit, between thinning methods and the different hail nets some changes were noticed (Table 12). For the CT-BA, the black hail nets increased the diameter of fruits by 3.3%, when compared to without hail nets. No interactions were verified for CT-Metamitron, MT and HT. Without hail nets, HT reached the highest diameter per fruit, which increased by 12%, when compared with CT-BA. The HT statistically differed from MT, decreasing by 5%, compared with CT-BA, followed by CT-Metamitron and CT-BA with the lowest diameter per fruit (Table 12). For the treatment with white hail nets, the HT reached the highest diameter per fruit, increasing 11% compared with CT-Metamitron. Followed by MT and CT-BA, increasing around 9% compared with CT-Metamitron (Table 12). Under black hail nets, the HT showed the highest diameter per fruit, increasing around 8% compared to other treatments. The HT statistically differed from other treatments and these did not differ between each other (Table 12).

Table 13: (Benzyladenine (BA), Metamitron Chemical thinning (CT), Mechanical (MT), Hand thinning (HT)) and two varieties (Braeburn and Pinova) on diameter (mm) in apple trees (Bavendorf, Germany, 2014).

	Varieties	
Thinners	Braeburn	Pinova
CT–BA	72.1 Ba	70.1 Ca[1]
CT – Metamitron	73.3 Ba	69.3 Cb
MT - Darwin®	73.5 Ba	73.1 Ba
HT – Hand	79.4 Aa	78.6 Aa
LSD	1.57[x]	1.63[y]
F - p-value	0.008**	

1Measurements followed by lower-casex letters in the same row and measurements followed by upper-casey letters in the column do not differ at the 5% level by Tukey's test. **Significant at 0.05, *Significant at 0.1, ns = not statistically significant.

Thinning methods affected the different tree varieties on the variable diameter of fruit (Table 13). For CT-Metamitron, it was observed that the Braeburn variety showed the highest diameter,

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increasing 5.5% compared to the Pinova variety. No interactions were verified for other treatments. The Braeburn variety the highest diameter was achieved with HT, increasing around 8% compared to other treatments. The HT treatment had the highest diameter with 79.4mm per fruit. The other treatments were not statistically different from each other (Table 13). For the Pinova variety, the highest diameter was for HT, increasing around 11% compared to CT-BA and CT-Metamitron and 7% compared to MT. The HT treatment had the highest diameter with 78.6mm per fruit (Table 13). There was an interaction between the hail nets and the varieties for variable diameter of fruit (Table 14). For the white hail net treatment, the effects of hail nets in fruit diameter were 6.5% less for the Pinova variety compared to the Braeburn variety. For the effects of hail nets on the different varieties, it was found that for the Braeburn variety, the diameter of fruit was 3.3% less without nets, compared to white hail nets, however these did not statistically differ from black hail nets (Table 14).

Table 14: Effects of different types of hail net (without, white and black) and two varieties (Braeburn and Pinova) on diameter (mm) in apple trees (Bavendorf, Germany, 2014).

	Varieties	
Hail Nets	Braeburn	Pinova
Without	73.5 Ba	74.2 Aa[1]
White	76.0 Aa	71.0 Bb
Black	74.3 ABa	73.5 Aa
LSD	1.90[x]	1.63[y]
F - p-value	0.000**	

1Measurements followed by lower-casex letters in the same row and measurements followed by upper-casey letters in the column do not differ at the 5% level by Tukey's test. **Significant at 0.05, *Significant at 0.1, ns = not statistically significant.

Color value

Table 15: (Benzyladenine (BA), Metamitron Chemical thinning (CT), Mechanical (MT), Hand thinning (HT)) and different hail nets (without, white and black) on color value in apple trees (Bavendorf, Germany, 2014).

	Hail Nets		
Thinners	Without	White	Black
CT–BA	55.6 Ca	59.8 Ba	55.6 Ba[1]
CT – Metamitron	65.3 Ba	57.0 Bb	46.2 Cc
MT - Darwin®	67.1 Ba	59.8 Bb	49.5 BCb
HT – Hand	86.0 Aa	75.5 Ab	69.7 Ab
LSD	7.43[x]	8.15[y]	
F - p-value	0.000**		

1Measurements followed by lower-casex letters in the same row and measurements followed by upper-casey letters in the column do not differ at the 5% level by Tukey's test. **Significant at 0.05, *Significant at 0.1, ns = not statistically significant.

About to the color value, there was an interaction between thinning methods and the different hail nets (Table 15). For the CT-Metamitron and MT-Darwin, utilizing black hail nets, around 19% less color value was observed, when compared to white hail nets and 30% compared to without hail nets. For the HT, for black hail nets, 19% and 7.6% less color value was observed, compared to white and without hail nets, respectively. No interactions were verified for CT-BA. When the effects of hail nets on the thinning methods are considered, the HT achieved the highest color value, which increased by 36%, when compared with CT-BA. The HT statistically differed from MT, decreasing by 17%, comparing with CT-BA, followed by CT-Metamitron and CT-BA with the lowest color value (Table 15). For the treatment with white hail nets, the HT reached the highest diameter per fruit, increasing around 23% compared to other treatments. For the black hail nets, the HT showed the highest color value, increasing around 30% compared to CT-Metamitron and MT and 20% compared to CT-BA (Table 15).

Table 16: Effects of different types of thinning (Benzyladenine (BA), Metamitron Chemical thinning (CT), Mechanical (MT), Hand thinning (HT) and two varieties (Braeburn and Pinova) on color value in apple trees (Bavendorf, Germany, 2014).

	Varieties	
Thinners	Braeburn	Pinova
CT–BA	60.0 Ba	49.6 Bb[1]
CT – Metamitron	62.9 Ba	54.1 Bb
MT - Darwin®	58.6 Ba	56.1 Ba
HT – Hand	75.3 Aa	78.9 Aa
LSD	5.06[x]	6.65[y]
F - p-value	0.000**	

1Measurements followed by lower-casex letters in the same row and measurements followed by upper-casey letters in the column do not differ at the 5% level by Tukey's test. **Significant at 0.05, *Significant at 0.1, ns = not statistically significant.

Table 17: Effects of different types of hail nets (without, white and black) and two varieties (Braeburn and Pinova) on color value in apple trees (Bavendorf, Germany, 2014).

	Varieties	
Hail Nets	Braeburn	Pinova
Without	67.1 Aa	70.0 Aa[1]
White	67.6 Aa	56.3 Bb
Black	57.8 Ba	52.8 Ba
LSD	6.33[x]	5.25[y]
F - p-value	0.000**	

1Measurements followed by lower-case letters in the same row and measurements followed by upper-case letters in the column do not differ at the 5% level by Tukey's test. **Significant at 0.05, *Significant at 0.1, ns = not statistically significant.

There was an interaction between thinning methods and the different tree varieties on the variable colour value (Table 16). For CT-thinners, the Pinova variety showed smaller numbers for colour value, reducing around 15% compared to the Braeburn variety. No interactions were verified for MT and HT. Consider-

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ing the varieties under the different thinning methods, Braeburn presented the highest colour value was for HT, increasing around 20% compared to other treatments (Table 16). For the Pinova variety, the results were similar to the Braeburn variety. The highest colour value was observed for HT, increasing 32% compared to other treatments (Table 16). The hail nets and the varieties showed some differences for variable colour value (Table 17). For the white hail net treatment, the colour value was 17% less for the Pinova variety compared to the Braeburn variety. For the Braeburn variety, the color value was around 13% less with black nets, compared to without and white hail nets (Table 17). For the Pinova variety, the color value was 24.5% less with the black nets, compared to without hail nets. The white hail nets did not statistically differ from black hail nets (Table 17).

Thinning efficacy value (TEV)

The HT treatment had the highest TEV for both varieties (Figure 2). The MT treatment had 22% less thinning efficacy than HT and 15% more thinning efficacy than CT-Metamitron. Comparing the CT-Metamitron and CT-BA, the difference observed was 12%. It could be seen that MT was closer to HT. What is important to consider is that in 2014 there was a very high natural fruit set compared to other years. It was noted that both varieties showed similar TEV for the same treatment.

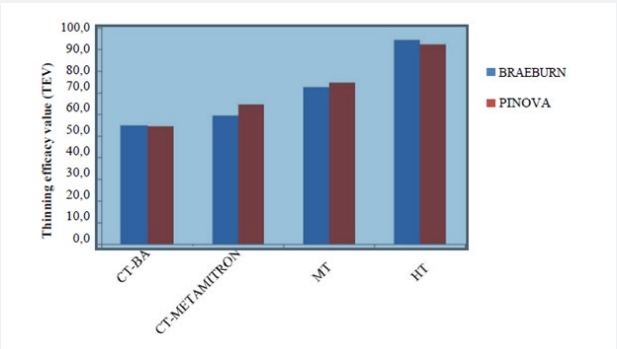

Figure 2: TEV for Braeburn and Pinova apple varieties once thinning treatments (Benzyladenine (BA), Metamitron Chemical thinning (CT) and Mechanical (MT) were performed (Bavendorf, Germany, 2014).

Discussion

In general, MT was the most efficient treatment, followed by CT-Metamitron and the CT-BA showed the mildest thinning results. According to Solomakhin and Blanke [19], the percentage of removed flowers increased linearly proportional to the MT intensity in apple trees removing 57-85% of flowers relative to 93% in the control indicates effective MT as a prerequisite for sufficient fruit size, coloration and fruit quality at harvest. This was achieved with 420 rpm at both 5.0km.h^{-1} and 7.5km.h^{-1} in 'Gala' apple trees using MT equipment called the 'Bonner machine'. Kon et al. [24], determined that fruit set decreased linearly proportional to the MT intensity in Buckeye Gala apple trees using a 'Darwin machine'. It was observed that the fruit weight did not have statistical differences between the six spindle speeds tested. The explanation was that high spindle speed removed fruiting spurs in the middle and encouraged development of fruit on the periphery of the canopy, which often produces inferior fruit, remained after thinning treatment. In relation to HT, as it was expected, positive effects were found for most characteristics tested, confirming the findings reported in the literature that HT is labor intensive, it takes a long time and it requires expensive management. It was observed that some treatments like CT-BA required around 300 hours or more per hectare of hand thinning to achieve satisfactory thinning efficacy. The thinning efficacy value for HT was 93%.

In previous string studies, treatment generally removed less than one blossom on average from each of the blossom clusters in the recommended range of treatments [19] was observed by Kon et al., [24] that using spindle speeds of 180 and 210 rpm provided the best overall thinning response and minimized injury to spur leaves, but crop load reduction was insufficient in years of heavy fruit set. In the present study, 210 rpm with 9km.h^{-1} was used and Kon et al. [24] used 4.8km.h^{-1}, meaning heavy thinning. In the present study, the majority of the results showed that MT did not differ from CT-Metamitron, but differed from CT-BA. In a trial with CT in 'SunCrisp' apple trees, McArtney and Obermiller [4], reported reduction in fruit set and of total yield with the application of Metamitron 300 mg.L^{-1}, where fruit diameter was 18.8mm. Similar results were observed in 'Gala' apple trees by the application of Metamitron 350 mg.L^{-1} where fruit diameter was 18mm [6]. Similarly to the present results, McArtney and Obermiller [4] observed declined photosynthesis measurements 2 days after the foliar application of metamitron to 'SunCrisp' apple trees and the values on sprayed trees remained suppressed 11 days after treatment when applied at 300mg.L^{-1}. Schuller [25] (2014) demonstrated a significant effect of Metamitron on photosynthesis measurements in comparison to the control, lasting from 10 days in the lowest concentration to 17 days in the highest concentration after the application.

In trials with CT in 'Galaxy' and 'Braeburn' apple trees, Schuller [25] noted that Metamitron was an effective apple fruit thinner, which had advantages in comparison to the BA, like high thinning efficacy and less weather dependency. In years with low temperatures, the Metamitron showed a big advantage over BA. The rate of the first application at the 8-10mm diameter stage was related to variety, vitality and blooming of the trees. Metamitron had an advantage over BA in that it was possible to take fluorescence measurements and if necessary, perform a second application at the 12-14mm diameter stage. The remaining Metamitron stress for fruit abscission depends on the concentration and weather conditions. The second application rate can be decided depending on photosynthesis measurements and tree conditions. Thinning efficacy of Metamitron depended upon the time of application and the year of trials [12] 'Elstar' apple trees were used with early applications of Metamitron 350mg.L^{-1} at the fruitlet 6-8mm diameter stage, which caused a strong overthinning in 2006 while no thinning effect was observed in 2007. Metamitron 350mg.L^{-1} was not

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effective when applied at 12-14 mm diameter in 2006 and 2008, however, it was very effective in 2007. The conclusion was an adaptation of dosage on the fruitlet diameter and/or light intensity seems to be necessary for optimizing the thinning efficacy of Metamitron.

In a trial with CT in 'Fuji', 'Maxi Gala' and 'Fred Hough' apple trees using Metamitron isolated or in combination with BA showed great efficacy in reducing fruit production to an optimal level when performed at 5-15mm fruit size for the three varieties tested. Metamitron 768 $mg.L^{-1}$, Metamitron 384 $mg.L^{-1}$ + BA 40 $mg.L^{-1}$ and Metamitron 768$mg.L^{-1}$ + BA 40 $mg.L^{-1}$ were used. The effect of reducing fruit production provided a great increase in fruit size and all chemical thinners significantly increased fruit weight from 26.2% to 40.3% compared to HT. There was an overthinning plus leaf phytotoxicity in the 'MaxiGala' variety with 768 $mg.L^{-1}$ of Metamitron. Results prove that Metamitron might be an important alternative among chemical thinners for apples. One application of Metamitron plus BA would be sufficient for thinning, even in hard thinning varieties. In this present result, Metamitron 333 $mg.L^{-1}$ and BA 150 $mg.L^{-1}$ were used and performed at the 12mm stage, where the fruit size and weight significantly decreased compared to HT. The MT was an effective apple fruit thinner. It could be possible to use HT or MT with any type of hail nets without differences in crop load, however some differences in colour value should occur with white and black nets. The use of MT with black and without hail nets did not give differing variable yields when compared to HT. The thinning efficacy value for MT was 74%.

Similar to the present results, the use of black hail nets reduced the potential photosynthesis, leading to a reduction in yield and red color of the fruit. These authors concluded that the white hail net is recommended to protect against hail in 'Fuji' apple trees, because it permitted better quality and intensity light for photosynthesis than black hail nets [26]. The use of CT with black hail nets showed statistical differences for some variables measured, when it was compared with white and without hail nets. The CT-Metamitron with black nets showed lower fruit set and color value. The CT-BA with black nets showed an increase of fruit weight and diameter. However, if compared to the CT-Metamitron and CT-BA for each type of hail net, the efficacy observed for CT-BA were lower than CT-Metamitron, where the thinning efficacy value of CT-Metamitron was 62% and 54% for CT-BA. According to Solomakhin and Blanke [27], the fruit growth was greater with colored hail nets, without effect on yield, however, fruit coloration was hampered under the hail nets depending on net color. Similarly, to the present results, they observed differences in results, likely influenced by different varieties. Overall, tree growth under colored hail nets was genetically influenced, with the 'Fuji' variety being more prone and sensitive to the adverse effects of colored hail nets than 'Pinova' variety, but was also influenced by the environment.

For the thinning treatments for Braeburn variety, most variables measured did not have statistical differences among MT, CT-Metamitron, and CT-BA. However, it was observed in trials without nets that the number of hours to thin was different among the treatments. On the other hand, for Pinova variety the majority of the results showed that MT differed from CT-Metamitron and CT-BA. Overall the Braeburn variety is easier to thin than Pinova variety. The Braeburn variety showed lower fruit set than the Pinova variety in all hail net experiments. For the Braeburn, variety lower values were observed for most variables measured for white and black hail nets. In contrast, the Pinova variety was only influenced when black hail nets were used. In 2014, a very high natural fruit set was noted. Despite this, the trials performed showed effective thinning efficacy. It appears that it is necessary to continue the development of optimal values for chemical concentrations and application times for CT-Metamitron and CT-BA, as well as for MT intensity. For fruit growers, a good thinning strategy must be developed.

Conclusion

For the chlorophyll fluorescence measurements, there significant differences among CT-Metamitron versus CT-BA and MT curves, where CT-Metamitron remained in effect for 11 days after the treatment. The HT treatment had the highest value for thinning efficacy with 93% and the MT treatment achieved 74% followed by CT-Metamitron with 64% and CT-BA with 54%. Overall the Braeburn variety is easier to thin than the Pinova variety and the black hail nets showed negative effects on color value. It seems that it is necessary to continue the development of optimal values for chemical concentrations and application, as well as for MT intensity. Overall further study should be carried out on different varieties, types of hail net and weather conditions.

Acknowledgements

CAPES, CNPq and the Araucaria Foundation for the financial support of the research and the doctoral scholarship.

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DOI: 10.19080/ARTOAJ.2019.22.556197

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