UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
FACULDADE DE AGRONOMIA
PROGRAMA DE PÓS-GRADUAÇÃO EM FITOTECNIA

RALEIO QUÍMICO EM MACIEIRAS ‘GALAXY’ E ‘FUJI SUPREMA’ COM E SEM TELA ANTIGRANIZO

Lucas De Ross Marchioretto
Engenheiro Agrônomo/UCS
Mestre em Produção Vegetal/UDESC

Tese apresentada como um dos requisitos
à obtenção do Grau de Doutor em Fitotecnia
Área de concentração Sistemas de Produção Vegetal

Porto Alegre (RS), Brasil
Julho de 2023

CIP - Catalogação na Publicação

Marchioretto, Lucas De Ross
Raleio químico em macieiras 'Galaxy' e 'Fuji Suprema' com e sem tela antigranizo / Lucas De Ross Marchioretto. -- 2023.
140 f.
Orientador: Gilmar Arduino Bettio Marodin.

Coorientadora: Andrea De Rossi.

Tese (Doutorado) -- Universidade Federal do Rio Grande do Sul, Faculdade de Agronomia, Programa de Pós-Graduação em Fitotecnia, Porto Alegre, BR-RS, 2023.

1. reguladores de crescimento. 2. ajuste de carga de frutos. 3. queda natural de frutos. 4. microclima. 5. Malus domestica Borkh.. I. Marodin, Gilmar Arduino Bettio, orient. II. De Rossi, Andrea, coorient. III. Título.

Elaborada pelo Sistema de Geração Automática de Ficha Catalográfica da UFRGS com os dados fornecidos pelo(a) autor(a).

LUCAS DE ROSS MARCHIORETTO
Engenheiro Agrônomo - UCS
Mestre em Produção Vegetal - UDESC

TESE

Submetida como parte dos requisitos
para obtenção do Grau de

DOUTOR EM FITOTECNIA

Programa de Pós-Graduação em Fitotecnia
Faculdade de Agronomia
Universidade Federal do Rio Grande do Sul
Porto Alegre (RS), Brasil

Aprovado em:14/07/2023
Pela Banca Examinadora

GILMAR ARDUINO BETTIO MARODIN
Orientador
PPG Fitotecnia/UFRGS

ANDREA DE ROSSI
Coorientadora
EMBRAPA UVA E VINHO

AIKE ANNELIESE KRETZSCHMAR
UDESC/Lages

GILMAR RIBEIRO NACHTIGALL
EMBRAPA UVA E VINHO

RENAR JOÃO BENDER
PPG Fitotecnia/UFRGS

SIMONE MUNDSTOCK JAHNKE
Coordenadora do Programa de
Pós-Graduação em Fitotecnia

CARLOS ALBERTO BISSANI
Diretor da Faculdade de
Agronomia

AGRADECIMENTOS

A Deus por ter me abençoado e ter me dado forças para vencer os desafios, e pela graça de ter concluído essa etapa mesmo diante dos desafios da pandemia de COVID-19 e do falecimento de meu Pai ocorrido ao final do doutorado.

A meus pais queridos Nazareno Marchioretto (*in memoriam*) e Dilce Maria De Ross Marchioretto pelo apoio e incentivo aos estudos, por sempre terem me incentivado a estudar e me aperfeiçoar.

A minha coorientadora Dra. Andrea De Rossi, pelo voto de confiança desde o meu mestrado passando por todo o doutorado, por toda a força e apoio para a realização dos experimentos, e os conhecimentos passados. Foi uma parceria bastante frutífera e com muito aprendizado. Foi um privilégio meu.

Ao meu orientador professor Gilmar Arduino Bettio Marodin, pela parceria e amizade, pelos conhecimentos passados e por todo o apoio que contribuiu bastante para o meu desenvolvimento pessoal.

A EMBRAPA Uva e Vinho de Vacaria-RS e todos os seus colaboradores pela ajuda imprescindível à realização dos experimentos, além da amizade e dos momentos de descontração.

A UFRGS pelo ensino de qualidade e aos professores que tive ao longo do doutorado, que contribuíram para o meu desenvolvimento profissional.

Ao CNPQ pelo suporte financeiro e pela bolsa de estudos.

A todos aqueles que participaram da minha vida acadêmica.

Muito Obrigado!

MANEJO DO RALEIO QUÍMICO EM POMARES DE MACIEIRA DAS CULTIVARES GALAXY E FUJI SUPREMA EM FUNÇÃO DA PRESENÇA DE TELA ANTIGRANIZO[1]

Autor: MSc. Lucas De Ross Marchioretto
Orientador: Prof. Dr. Gilmar Arduino Bettio Marodin
Coorientadora: Dra. Andrea De Rossi

RESUMO

Devido à grande ocorrência de granizo na região Sul do Brasil, a utilização de telas antigranizo para a cobertura do pomar tem sido amplamente adotado por produtores, uma vez que isso permite maior segurança e sustentabilidade na produção. Entretanto, as telas antigranizo apresentam alguns efeitos indesejados em relação à produção uma vez que muitos produtores têm receio de utilizar raleantes químicos, uma vez que a queda natural dos frutos é acentuada nesse ambiente. Com isso, o objetivo desse trabalho foi avaliar o impacto da tela antigranizo sobre o efeito de programas de raleio químico com reguladores de crescimento. Para isso, foi conduzido em pomar comercial localizado no município de Bom Jesus-RS, Brasil, durante as safras de 2019/20, 2020/21, e 2021/22 um experimento com as cultivares Galaxy e Fuji Suprema cultivadas em ambiente com e sem a presença de tela antigranizo de cor branca. Para cada um dos ambientes houve nove tratamentos, sendo: um controle não tratado, um controle com somente raleio manual, ácido naftaleno acético (ANA) aplicado em plena floração, benziladenina (BA) aplicado em frutos com 8 mm, metamitron (MM) aplicado em frutos com 15 mm, e as aplicações sequenciais destes: ANA+BA; ANA+MM, BA+MM, e ANA+BA+MM. As variáveis analisadas foram: padrão de abscisão de frutos em função de raleantes e presença ou ausência de tela, frutificação efetiva, carga de frutos, eficiência produtiva, recobrimento de cor vermelha e russeting, peso médio de frutos, diâmetro e altura de frutos, número de sementes por fruto, firmeza de polpa, e sólidos solúveis totais. Além disso, parâmetros meteorológicos dos ambientes com e sem tela antigranizo como radiação fotossintéticamente ativa, temperatura, e umidade relativa foram analisadas. A tela antigranizo reduziu a radiação fotossintéticamente ativa em 16% ao longo da safra, diminuiu a temperatura máxima e aumentou a mínima, assim diminuindo a amplitude térmica. Com isso, o padrão de abscisão de frutos foi afetado, sendo mais prolongado que nas plantas a pleno sol. Entretanto, não houve interferência do efeito de tela no efeito dos raleantes químicos, sendo que estes tiveram a mesma eficácia em ambos os ambientes. Para ‘Galaxy’, o tratamento ANA+BA e para ‘Fuji Suprema’ os tratamentos ANA+BA, ANA+MM, ou ANA+BA+MM reduziram a carga de frutos adequadamente, além de melhorar a qualidade dos frutos.

---

[1] Tese de Doutorado em Fitotecnia, Faculdade de Agronomia,
Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brasil. (139f). Julho, 2023.

MANAGEMENT OF THE CHEMICAL THINNING IN APPLE ORCHARDS OF THE CULTIVARS GALAXY AND FUJI SUPREMA AS A FUNCTION OF ANTI-HAIL NET COVERING[1]

Author: MSc. Lucas De Ross Marchioretto
Advisor: Prof. Dr. Gilmar Arduino Bettio Marodin
Co-Advisor: Dr. Andrea De Rossi

ABSTRACT

Due to the occurrence of hail in southern Brazil, the use of anti-hail nets to cover orchards has been widely adopted by producers, as this allows for greater safety and sustainability in production. However, anti-hail nets have some undesirable effects in relation to production, since many producers have concerns on using chemical thinners on covered orchards, since the natural fruitlet drop is accentuated in this environment. Thus, the objective of this work was to evaluate the impact of hail net on the effect of chemical thinning programs with growth regulators. For this, an experiment was carried out in a commercial orchard located in the municipality of Bom Jesus-RS, Brazil, during the 2019/20, 2020/21, and 2021/22 seasons, with the cultivars Galaxy and Fuji Suprema grown in an environment with and without the presence of a white anti-hail net. For each environment there were nine treatments, as follows: an untreated control, a control with manual thinning only, naphthalene acetic acid (NAA) applied in full bloom, benzyladenine (BA) applied to 8 mm fruits, metamitron (MM) applied in fruits with 15 mm, and their sequential applications: ANA+BA; ANA+MM, BA+MM, and ANA+BA+MM. The variables were: fruit abscission pattern as a function of thinning and presence or absence of screen, fruit set, crop load, yield efficiency, red color coverage and russeting, mean fruit weight, diameter and length of fruits, number of seeds per fruit, flesh firmness, and total soluble solids. In addition, meteorological parameters of the environments with and without anti-hail net such as photosynthetically active radiation, temperature, and relative humidity were evaluated. The anti-hail net decreased the photosynthetically active radiation by 16% throughout the season, decreased the maximum temperature and increased the minimum temperature, thus reducing the thermal amplitude. With this, the dynamics of fruit abscission was altered, being longer under netting than in plants without net covering. However, there was no influence to the effect of chemical thinners, and these had the same effectiveness in both environments. For 'Galaxy', ANA+BA treatment, and for 'Fuji Suprema', ANA+BA, ANA+MM, or ANA+BA+MM treatments reduced crop load adequately, in addition to improving fruit quality.

---

[1] Doctoral Thesis in Plant Science, Faculdade de Agronomia,
Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil. (139p) July, 2023.

SUMÁRIO

RELAÇÃO DE TABELAS

Página

ARTIGO 1

ARTIGO 2

ARTIGO 3

Página

RELAÇÃO DE FIGURAS

Página

REVISÃO BIBLIOGRÁFICA

ARTIGO 1

Página

ARTIGO 2

ARTIGO 3

Página

1 INTRODUÇÃO

A cultura da macieira começou a apresentar proeminência comercial no Brasil durante a década de 70, quando eram dados incentivos fiscais às empresas via dedução de imposto de renda àquelas que reflorestassem áreas, sendo que à época os plantios de macieira eram considerados como reflorestamento (Petri *et al.*, 2011). Ainda segundo os autores, o ministério da agricultura na época fez um mapeamento climático adequado à cultura e definiu as regiões de altitude do Sul do Brasil como propícias ao cultivo, onde até hoje se concentra a produção de maçã no Brasil.

A área cultivada com macieira sobre o território brasileiro tem se mantido estagnada nas últimas décadas, porém com modestos aumentos de produtividade ao longo dos anos. Além disso, no ano de 2021 a cultura ocupou uma área de 32.897 ha, sendo colhido um montante de quase 1,3 milhões de toneladas da fruta, o que colocou o Brasil como o 11° maior produtor de maçã do mundo (FAO, 2022).

A região Sul do Brasil, apesar de possuir clima favorável à cultura da macieira, é a região mais acometida por granizo, especialmente o Estado do Rio Grande do Sul (Nedel; Sausen; Saito, 2012). A região subtropical do continente sul-americano é o local onde se formam grandes complexos convectivos de mesoescala durante a primavera-verão, caracterizado como o encontro das frentes quentes que transportam as nuvens trazendo umidade da região amazônica para a região sul do continente (devido à barreira física imposta pela cordilheira dos Andes) com as frentes frias do Sul, levando à formação de tempestades, ventania e granizo (Durkee; Mote; Shepherd, 2009).

Para evitar prejuízos com queda de granizo, uma solução bastante efetiva é a utilização de telas antigranizo sobre o dossel das árvores. Entretanto, a presença de tela antigranizo promove algumas alterações no microclima, como redução da radiação fotossintéticamente ativa (RFA) (Bosco *et al.*, 2015), redução de temperatura, e aumento da umidade relativa (Solomakhin; Blanke, 2010), que causam alterações na planta e nos frutos, como redução da coloração vermelha (Leite; Petri; Mondardo, 2002), e até mesmo estímulo ao vigor vegetativo em árvores enxertadas sobre porta-enxertos vigorosos, redução da frutificação efetiva e redução do retorno de florada (Leite; Petri; Mondardo, 2002; Middleton; Mcwaters, 2002).

O crescimento vegetativo está diretamente relacionado com a quantidade de radiação solar interceptada pelo dossel e a temperatura, especialmente durante a primavera, tendo em vista que em uma primavera com mais períodos nublados e baixas temperaturas há potencial de se reduzir em até 31% da produção de frutos em relação a uma primavera ensolarada e com temperaturas mais altas, já que aproximadamente 64% da fotossíntese global da árvore de macieira é direcionada para os frutos (Wagenmakers, 1996).

A temperatura elevada e a alta incidência luminosa na primavera estimulam a rápida expansão da área foliar na macieira, e isso garante a fotossíntese necessária ao bom desenvolvimento inicial dos frutos (Wagenmakers, 1996). Em condições encontradas no sul do Brasil, a presença de tela antigranizo não causou impacto significativo na temperatura, mas reduziu a Radiação Fotossintéticamente Ativa (RFA) do dossel em torno de 34% (Bosco *et al.*, 2017). A menor RFA incidente faz com que a planta procure outros meios para compensar as condições desfavoráveis, como aumentar a área foliar, a síntese de clorofila b (aumentar o complexo antena para captação de luz no fotossistema II), tendo menor ponto de compensação luminosa, que evita perda de carbono e compensa a menor taxa de assimilação (Amarante *et al.*, 2007).

Como os reguladores de crescimento agem na dinâmica da relação fonte-dreno dos assimilados, as condições climáticas têm efeito direto sobre a fotossíntese líquida e a capacidade da planta de fornecer assimilados aos frutos em desenvolvimento (Lakso; Robinson; Greene, 2006), e isso tem efeito direto sobre a efetividade dos raleantes químicos, tendo em vista que sob condições favoráveis à fotossíntese líquida como primavera com alta radiação solar incidente, temperaturas diurnas mais altas e noturnas baixas, o efeito sobre a indução da abscisão de frutos é menor que em uma condição climática de temperaturas noturnas elevadas e dias nublados (Robinson; Lakso, 2004).

Nesse contexto de condições menos favoráveis à produção de frutos, empiricamente muitos produtores notam maior queda natural de frutos em macieiras cultivadas sob tela antigranizo, criando-se grande receio quanto ao uso de reguladores de crescimento utilizados como raleantes químicos. Estudos envolvendo a dinâmica da queda natural de frutos em pomares cobertos com tela antigranizo, bem como a interação disso com os raleantes químicos são bastante incipientes. Diante destas considerações, o objetivo do presente estudo foi avaliar a dinâmica de abscisão de frutos em fase inicial de desenvolvimento e o efeito de aplicações de reguladores de crescimento utilizados como raleantes químicos em clones de macieira das cultivares Gala e Fuji enxertados sobre porta-enxerto M9, cultivados em ambiente com e sem a presença de tela antigranizo.

2 REVISÃO BIBLIOGRÁFICA

2.1 Dinâmica da abscisão natural de frutos de macieira

No ovário de flor de macieira que originará um fruto, há aproximadamente 10 óvulos, divididos em cinco lóbulos cada qual com aproximadamente dois óvulos. Quando ocorre a germinação dos grãos de pólen no estigma de uma cultivar compatível, o tubo polínico se desenvolve até atingir a base do ovário. Na base do ovário o tubo polínico atravessa a micrópila para fecundar os óvulos. No tubo polínico, há o núcleo do tubo polínico, além de dois núcleos generativos. Já dentro do saco embrionário, um dos dois núcleos generativos se une a célula ovo formando o zigoto diploide. O núcleo generativo se une aos dois núcleos polares produzindo um núcleo triploide. O zigoto formará o embrião, e o núcleo triploide formará o endosperma (Ramírez; Davenport, 2013).

Entretanto, a macieira, quando não apresenta alternância produz muito mais flores, que são fecundadas, do que ela vai conseguir suportar o crescimento, sendo que, para os frutos de macieira atingirem padrão comercial, aproximadamente 90% dessas flores e frutos devem sofrer abscisão (Lakso; Goffinet, 2013).

Logo após a polinização, em cada óvulo fecundado (aproximadamente 10 óvulos por fruto), há intensa divisão celular, e o crescimento do fruto acontece somente por esse meio até pelo menos 5 semanas após a fecundação; além disso, durante essa fase de intensa multiplicação celular também a planta como um todo apresenta alta taxa respiratória, que vai diminuindo ao longo da safra, uma vez que após o período de queda natural dos frutos até a queda das folhas, o crescimento ocorre somente por expansão celular (Lakso; Goffinet, 2013).

Até a antese o suprimento de assimilados ocorre através da hidrólise do amido armazenado no outono anterior (ou seja, da colheita até a queda das folhas) para os órgãos em crescimento, e logo após a antese, o suprimento de assimilados é fornecido através da fotossíntese das folhas ainda em crescimento (Breen *et al.*, 2020). Portanto, durante essa fase, que começa na antese e se estende até "December drop, (June drop no hemisfério norte)" as condições meteorológicas exercem muita influência na taxa de abscisão dos frutos, uma vez que afetam a taxa de fotossíntese e respiração, e consequentemente o balanço de carbono disponível para o crescimento dos frutos (Lakso; Robinson, 2015).

A abertura das flores na inflorescência da macieira segue uma ordem, onde a primeira flor a abrir é a flor central (rainha), que é polinizada primeiro, e em seguida, a flor dois logo ao lado da rainha, que abre e é polinizada, e assim segue até a abertura da quinta flor, que é a última a abrir, localizada na base da inflorescência (Figura 1) (Jakopic *et al.*, 2015).

FIGURA 1. Posição da flor rainha, lateral 2, lateral 3, lateral 4, lateral 5, e lateral 6 na base da inflorescência.

A flor central sendo a primeira a ser polinizada, é a primeira a iniciar a multiplicação celular, e consequentemente a primeira a estabelecer o dreno; assim, há formação de mais vasos do floema, que aumentam a capacidade de fornecer assimilados, e assim, aumentar a taxa de multiplicação celular do fruto central (Celton *et al.*, 2014). Quando um fruto se desenvolve de forma mais rápida, por ter embriões mais desenvolvidos, provoca aumento da capacidade de dreno, em uma situação de competição por assimilados com outros frutos e órgãos em crescimento, fazendo com que os frutos menos desenvolvidos e com menor número de embriões diminuam a sua taxa de exportação de auxina pelo pedicelo; além disso, essa alteração na taxa de exportação de auxina pode ser promovida também por crescimento vegetativo vigoroso. Este fenômeno se chama dominância correlativa. Com a diminuição do transporte polar de auxina dos frutos laterais da inflorescência, há aumento da síntese de etileno na base do pedicelo, levando à formação da zona de abscisão e queda do fruto (Bangerth, 2000).

2.2 Mecanismo de ação do sombreamento e dos reguladores de crescimento ácido naftaleno acético, benziladenina e metamitron utilizados como raleantes químicos sobre a abscisão dos frutos

O sombreamento sobre as macieiras promove redução das taxas de fotossíntese e redução da transpiração dos frutos (Amarante *et al.*, 2007, 2009; Zibordi; Domingos; Corelli-Grappadelli, 2009); além disso, reguladores de crescimento como ácido naftaleno acético e benziladenina, diminuem a condutância estomática, também diminuindo a taxa transpiratória dos frutos. A redução da taxa transpiratória provoca menor fluxo via floema aos frutos, que associado a menor taxa de produção de assimilados, causa decréscimo no gradiente de concentração osmótico das folhas até os frutos, reduzindo o descarregamento via floema, diminuindo assim a força de dreno dos frutos, e paralisando o crescimento por estes não terem pressão de turgor para o crescimento durante a noite (Morandi *et al.*, 2011; Zibordi; Domingos; Corelli-Grappadelli, 2009).

Tanto o sombreamento (92%) quanto o ácido naftaleno acético têm ação direta no desacoplamento do fotossistema II, levando à fotoinibição temporária, e diminuição da fotossíntese; isso leva à menor produção de assimilados, que leva à diminuição do transporte de sorbitol aos frutos. Além disso, há inibição do transporte de auxina nas folhas e frutos, e elevação da biossíntese de etileno e ácido abscísico, que estão relacionados à ativação de enzimas degradadoras da lamela média, levando ao aumento da sensibilidade desse tecido ao etileno, devido ao menor efluxo de auxina dos frutos, levando à formação da zona de abscisão no pedicelo dos frutos. Tanto a auxina quanto o sombreamento paralisam a taxa de multiplicação celular dos frutos, e isso leva a diminuição da força de dreno, o que leva ao acúmulo de sorbitol nas folhas, e à diminuição da fotossíntese, desencadeando o processo de abscisão, pela evolução do etileno (Bangerth, 2000; Milić *et al.*, 2017; Zhu *et al.*, 2011). O efeito do ácido naftaleno acético em promover aumento do tamanho de frutos ocorre devido ao aumento da expansão celular dos frutos remanescentes, mas para isto, deve ser acompanhado de redução da carga de frutos (Milić *et al.*, 2017).

Após a aplicação de ácido naftaleno acético, nos três dias seguintes, ocorre diminuição crescente dos níveis de assimilação de CO_2, chegando a até 34% de redução (Untiedt; Blanke, 2001). Além disso, esse regulador de crescimento não age somente na diminuição da produção de assimilados, como também aumenta a taxa respiratória em até 46%, o que contribui para tornar o balanço de carbono negativo, intensificando o estresse nutricional aos frutos. Ainda, sua aplicação é indicada logo após a antese, pois é o momento de intensa multiplicação celular e respiração mitocondrial, fazendo com que a taxa de multiplicação diminua e torne os frutos drenos mais fracos, levando mais facilmente ao estresse nutricional (Untiedt; Blanke, 2001). Além disso, quando a aplicação do Ácido Naftaleno Acético é mais precoce, entre a antese e frutos com diâmetro de 11 mm, há menor chance de desenvolvimento de frutos pigmeus (Black; Bukovac; Hull, 1995). O ácido naftaleno acético é 50% absorvido pelas folhas durante a primeira hora após a aplicação, e situações que favoreçam a permanência das gotículas por mais tempo sobre as folhas favorecem sua absorção; entretanto, após seis horas, mesmo que as gotículas sequem, ainda há absorção, porém em menor velocidade. Além disso, temperaturas altas, de 25 para 35 °C, aumentam em até 140% a absorção do fitorregulador, e temperaturas mais amenas, de 16 para 26 °C aumentam a absorção em até 37%, podendo causar excesso de raleio (Black; Petracek; Bukovac, 1995).

A benziladenina é um regulador de crescimento que após aplicado sobre a planta, é absorvido durante um período de 24 horas. Este fitormônio promove multiplicação celular onde é aplicado; dessa maneira, ele tem efeito raleante quando aplicado nas folhas isoladas ou com frutos, pois quando aplicado somente nos frutos, não há raleio (Greene *et al.*, 1992). Quando há intensa competição por assimilados devido ao efeito do fitorregulador, e consequente redução na disponibilidade de assimilados aos frutos, o déficit nutricional provoca estresse no córtex, levando ao aumento da síntese de espécies reativas de oxigênio, e para contornar esse aumento, há síntese do antioxidante isopreno. Quando os níveis deste atingem um certo limiar, há aumento da síntese de etileno e ácido abscísico (Eccher *et al.*, 2013). Pode-se especular que o aumento dos níveis de ácido abscísico e etileno no córtex dos frutos, leve a diminuição da síntese ou do transporte (efluxo) de auxina nos frutos, pois Schröder; Link e Bangerth (2013) relataram aumento do transporte de auxina de ramos presentes nos esporões, juntamente com diminuição do efluxo de auxina vinda dos frutos laterais da inflorescência de macieira, juntamente com a paralização do crescimento destes, o que levou à abscisão. A diminuição do efluxo de auxina na base do pedicelo dos frutos leva à síntese de etileno, e à criação da zona de abscisão (Bangerth, 2000). Além disso, quando a benziladenina é aplicada em temperaturas acima de 30 °C, há diminuição da fotossíntese, e aumento da taxa de respiração mitocondrial, o que aumenta ainda mais o déficit nutricional nos frutos (Yuan; Greene, 2000). Por isso, este regulador de crescimento é aplicado quando os frutos estão com 8 a 10 mm de diâmetro, pois é o período de maior competição por assimilados nas plantas, uma vez que há intensa multiplicação celular, e a área foliar ainda está se desenvolvendo (Lordan *et al.*, 2020; Yuan; Greene, 2000).

O metamitron é um inibidor do fotossistema II, que provoca fotoinibição por um período considerável de pelo menos 20 dias (Gonzalez *et al.*, 2019), sendo que até cinco dias após a aplicação, não há melhora no quadro de fotoinibição (Mcartney; Obermiller; Arellano, 2012). Além disso, temperaturas noturnas acima de 14 °C, por pelo menos quatro dias após a aplicação, aumentam o efeito raleante do metamitron, por aumentar a taxa respiratória e afetar negativamente o balanço de carbono (Gonzalez *et al.*, 2020). O metamitron é mais efetivo em promover raleio de frutos quando aplicado em frutos com mais de 12 mm de diâmetro em relação a aplicações mais precoces (Cline; Bakker; Beneff, 2022; Francescatto; Lordan; Robinson, 2020; Mcartney; Obermiller, 2014).

2.3 Os efeitos da tela antigranizo sobre o microclima e as plantas

Na presença de tela antigranizo, dependendo da região onde o pomar é localizado, por exemplo, em regiões com alta radiação solar e temperatura, e baixa umidade relativa do ar (regiões temperadas semiáridas), a cobertura do pomar com tela apresenta efeito benéfico, pois ajuda a diminuir a radiação solar excessiva, diminui a temperatura máxima e aumenta a humidade relativa do ar, diminui a velocidade do vento, melhorando o estado hídrico da planta, diminuindo assim os estresses abióticos (Aoun; Manja, 2020; Dussi *et* *al.*, 2005; Salazar-Canales *et al.*, 2021; Serra *et al.*, 2020). Por exemplo, Solomakhin e Blanke (2008), a presença de tela antigranizo diminuiu a temperatura do ar em 1,3 °C, e apresentou umidade relativa 5% mais alta em relação ao pomar sem tela; McCaskill et al. (2016) relataram além de diminuição de 15% na radiação solar global abaixo da tela, como também redução de 13% na evapotranspiração de referência, velocidade do vento e maior humidade relativa 13% maior, o que leva a melhora da condição hídrica e menor requerimento de irrigação. Além disso, as condições de menor velocidade do vento, maior umidade relativa, e menor evapotranspiração de referência levam a menor perda de água do solo, podendo ser até 20% maior (vol/vol) que um pomar descoberto por tela antigranizo (Kalcsits *et al.*, 2018), sendo essas características mais desejáveis em regiões semiáridas.

Entretanto, em regiões onde não há restrição hídrica e ocorre precipitação constante, e consequentemente há muitos dias nublados, a radiação solar pode ser menos de 50% de um dia de céu claro, e o sombreamento das telas, associado ao aumento das temperaturas mínimas (noturnas), e diminuição das temperaturas máximas (diurnas), podem ter efeito deletério no balanço de carbono da planta e aumentar a abscisão natural de frutos (Brglez-Sever *et al.*, 2021; Salazar-Canales *et al.*, 2021; Solomakhin; Blanke, 2010), além de diminuir a coloração e a concentração de sólidos solúveis (Dussi *et al.*, 2005; Iglesias; Alegre, 2006).

Na condição em que o efeito da tela afeta negativamente, devido à maior queda de frutos a planta direciona a produção de assimilados para o crescimento vegetativo (Solomakhin; Blanke, 2010, 2008), que por sua vez, faz com que a interceptação luminosa não difira das plantas não cobertas (Bosco *et al.*, 2017), porém, possivelmente leve a maior sombreamento do interior do dossel, com a diminuição da fotossíntese (Amarante *et al.*, 2007, 2009). Porém, os efeitos negativos relacionados à diminuição da radiação podem ser minimizados ao se utilizar telas de cor clara, pois estas possuem o efeito de aumentar a quantidade de radiação difusa, facilitando a entrada de luz no dossel fechado (Abdel-Ghany; Al-Helal, 2010; Basile *et al.*, 2012; Salazar-Canales *et al.*, 2021).

Diversos fatores das telas antigranizo afetam o microclima dos pomares, sendo o tipo de trama e a espessura dos fios os que influenciam principalmente a quantidade de radiação solar que estará disponível às plantas; no caso de telas de cores neutras como preta, branca, cinza ou pérola, não há interferência nas características espectrais da luz; além disso, outra gama de telas disponíveis são as fotosseletivas, que contém pigmentos coloridos dispersores e refletores de luz misturados à composição dos fios, que alteram além da quantidade, a distribuição espectral da luz solar (luz violeta e azul, relação vermelho: vermelho extremo, radiação fotossintéticamente ativa), e aumentam a difusão da luz para o interior das copas, como no caso das telas vermelhas, amarelas, azuis, etc (Vuković *et al.*, 2022). As telas antigranizo de modo geral, também afetam outros parâmetros no microclima do pomar como a redução da velocidade do vento (Bosco *et al.*, 2017) e aumento da umidade relativa e das temperaturas mínimas (Solomakhin; Blanke, 2010).

Entre as telas neutras, as de cores mais escuras como preta e cinza são as que mais reduzem a quantidade de radiação fotossintéticamente ativa para as plantas, em relação às de cores claras como branca ou perolada, porém, estas apresentam a vantagem de compensarem o sombreamento com maior quantidade de radiação solar difusa, que é capaz de penetrar no interior do dossel vegetativo e fornecer radiação solar às partes sombreadas da copa (Bastías; Corelli-Grappadelli, 2012; Salazar-Canales *et al.*, 2021; Vuković *et al.*, 2022). Por outro lado, as telas fotosseletivas possuem a capacidade de alterar espectralmente uma pequena parte da radiação absorvida pelos fios da tela, e via o amento da radiação difusa, oferecer às plantas radiação com características diferentes à radiação solar natural (Vuković *et al.*, 2022).

A tela azul possui pico de transmissão de luz na banda entre 400-540 nm, e absorção na faixa do UV (ultravioleta) e vermelho. As telas verdes possuem pico de transmitância em 520 nm, e na faixa do vermelho-extremo. As telas de cor vermelha possuem pico de transmitância em todos os comprimentos de onda acima de 590 nm, e muito pouca luz azul e UV é transmitida. Telas amarelas aumentam a transmitância de luz acima do comprimento de onda de 515 nm, aumentando também a transmitância de luz verde, vermelha e vermelho-extremo (Vuković *et al.*, 2022). Dentre as telas das cores: azul, vermelha, branca, e preta, a de cor branca possui a característica de refletir a luz no mesmo espectro que em condição a céu aberto, porém, refletindo maior quantidade de UV que numa condição sem tela, enquanto que as outras cores modificam o espectro da luz (Zoratti *et al.*, 2015).

As diferentes telas fotosseletivas também alteram a relação da luz nos espectros do azul, vermelho, e vermelho-extremo, sendo que a maior predominância de luz azul está relacionada com menor crescimento vegetativo e encurtamento de entrenós, enquanto que menor relação vermelho: vermelho-extremo induz a maior crescimento vegetativo devido à síndrome do escape da sombra (Bastías; Corelli-Grappadelli, 2012). Além disso, as telas de cores vermelha e azul, reduzem a radiação fotossintéticamente ativa em aproximadamente 27%, enquanto que as de cores escuras (cinza), reduzem em até 37%, segundo os autores. Em um experimento com 'Imperial Gala' sob telas das cores preta, branca, perolada, vermelho, e azul, conduzido no Planalto Catarinense, a tela de cor preta foi a única que teve efeito deletério sobre a produção e a qualidade dos frutos, porém a perolada foi a mais benéfica por aumentar a produção (Amarante *et al.*, 2018). Em um trabalho comparando a influência espectral das telas: branca, preta, azul, amarela, e vermelha, sobre o crescimento de frutos e ramos, a tela branca foi a que menos reduziu a radiação no espectro do azul e do verde, e a que mais transmitiu radiação fotossintéticamente ativa, e isso se refletiu em maior taxa de crescimento dos frutos, e crescimento vegetativo baixo (Boini *et al.*, 2022). Assim, as telas claras e de cor neutra como a branca, são as que menos interferem negativamente na cultura da macieira.

As diferentes telas fotosseletivas também alteram as características microclimáticas dos pomares. Em relação a uma área sem tela (descoberta), a tela branca tem a propriedade de aumentar em 0,7 °C a temperatura noturna, e diminuir em 1 °C a temperatura diurna. A temperatura com a tela vermelha, durante a noite, segue o mesmo padrão que a área descoberta, mas durante o dia, diminui a temperatura máxima em 0,5 °C. E as telas azul e preta diminuem a temperatura noturna em 1 °C, e aumentam a temperatura diurna em 1,5 °C em relação a área descoberta (Zoratti *et al.*, 2015). Além disso, segundo os mesmos autores, a humidade relativa também foi alterada pelas telas fotosseletivas, sendo que nas áreas cobertas com as telas azul e branca, a humidade relativa foi 10% menor que as áreas cobertas com as telas preta e vermelha, e estas não diferiram da área descoberta.

As telas fotosseletivas, são benéficas principalmente em regiões áridas ou semiáridas, onde são utilizadas principalmente para o sombreamento (Kalcsits *et al.*, 2017; Olivares-Soto; Bastías, 2018; Serra *et al.*, 2020), onde essas telas diminuem a radiação fotossintéticamente ativa e radiação ultravioleta, e assim, diminuem muito a incidência de queimadura da epiderme dos frutos (escaldadura) e o estresse ambiental devido a altas temperaturas e radiação solar. Esse melhor conforto térmico diminui extremos de déficit de pressão de vapor, e evita o encolhimento dos frutos nas horas mais quentes e secas do dia, evitando o retardamento do crescimento (Boini *et al.*, 2022). A maior transmitância de radiação solar difusa pelas telas brancas ou peroladas também induzem a uma correlação positiva entre condutância estomática e fotossíntese líquida, o que não ocorre com as telas azuis, cinzas ou pretas (Salazar-Canales *et al.*, 2021). Diante da discussão até aqui, o uso de telas neutras de cores claras como branca ou perolada são as que possuem menor interferência negativa sobre a macieira, e portanto, a de cor branca será a utilizada nesse projeto de pesquisa.

2.4 Referências

ABDEL-GHANY, A. M.; AL-HELAL, I. M. Characterization of solar radiation transmission through plastic shading nets. **Solar Energy Materials and Solar Cells**, Amsterdam, v. 94, n. 8, p. 1371–1378, 2010.

AMARANTE, C. V. T. *et al.* Disponibilidade de luz em macieiras “Fuji” cobertas com telas antigranizo e seus efeitos sobre a fotossíntese, o rendimento e a qualidade dos frutos. **Revista Brasileira de Fruticultura**, Jaboticabal, v. 31, n. 3, p. 664–670, 2009.

AMARANTE, C. V. T. *et al.* Radiação, fotossíntese, rendimento e qualidade de frutos em macieiras “Royal Gala” cobertas com telas antigranizo. **Pesquisa Agropecuária Brasileira**, Brasília, DF, v. 42, n. 7, p. 925–931, 2007.

AOUN, M.; MANJA, K. Effects of a photoselective netting system on Fuji and Jonagold apples in a Mediterranean orchard. **Scientia Horticulturae**, Amsterdam, v. 263, [art.] 109104, 2020.

BANGERTH, F. Abscission and thinning of young fruit and their regulation by plant hormones and bioregulators. **Plant Growth Regulation**, Dordrecht, v. 31, p. 43–59, 2000.

BASILE, B. *et al.* Photo-selective hail nets affect fruit size and quality in Hayward kiwifruit. **Scientia Horticulturae**, Amsterdam, v. 141, p. 91–97, 2012.

BASTÍAS, R. M.; CORELLI-GRAPPADELLI, L. Light quality management in fruit orchards: Physiological and technological aspects. **Chilean Journal of Agricultural Research**, Chillán, v. 72, n. 4, p. 574–581, 2012.

BLACK, B. L.; BUKOVAC, M. J.; HULL, J. Effect of spray volume and time of NAA application on fruit size and cropping of Redchief ‘Delicious’ apple. **Scientia Horticulturae**, Amsterdam, v. 64, n. 4, p. 253–264, 1995.

BLACK, B. L.; PETRACEK, P. D.; BUKOVAC, M. J. The effect of temperature on uptake of NAA by Redchief `Delicious’ apple leaves. **Journal of the American Society for Horticultural Science**, Alexandria, VA, v. 120, n. 3, p. 441–445, 1995.

BOINI, A. *et al.* Early apple fruit development under photoselective nets. **Scientia Horticulturae**, Amsterdam, v. 292, [art.] 110619, 2022.

BOSCO, L. C. *et al.* Apple production and quality when cultivated under anti-hail cover in Southern Brazil. **International Journal of Biometeorology**, New York, v. 59, n. 7, p. 773–782, 2015.

BOSCO, L. C. *et al*. Microclimate alterations caused by agricultural hail net coverage and effects on apple tree yield in subtropical climate of Southern Brazil. **Bragantia**, Campinas, v. 77, n. 1, p. 181–192, 2017.

BREEN, K. *et al.* Revisiting the role of carbohydrate reserves in fruit set and early-season growth of apple. **Scientia Horticulturae**, Amsterdam, v. 261, [art.] 109034, 2020.

BRGLEZ SEVER, M. *et al*. Natural June thinning of fruitlets and yield characteristics of apple trees growing under coloured anti-hail netting. **European Journal of Horticultural Science**,
Stuttgart, v. 86, n. 2, p. 136–145, 2021.

CELTON, J.-M. *et al.* Additional amphivasal bundles in pedicel pith exacerbate central fruit dominance and induce self-thinning of lateral fruitlets in apple. **Plant Physiology**, Rockville, v. 164, n. 4, p. 1930–1951, 2014.

CLINE, J. A.; BAKKER, C. J.; BENEFF, A. Multi-year investigation on the rate, timing, and use of surfactant for thinning apples with post-bloom applications of metamitron. **Canadian Journal of Plant Science**, Ottawa, v. 102, n. 3, p. 628–655, 2022.

AMARANTE, C. V. T. *et al.* Fruit quality and yield of ‘Imperial Gala’ apple trees protected by anti-hail nets of different colorations in southern Brazil. **Acta Horticulturae**, The Hague, v. 1205, n. 1205, p. 897–904, 2018.

DURKEE, J. D.; MOTE, T. L.; SHEPHERD, J. M. The Contribution of mesoscale convective complexes to rainfall across subtropical South America. **Journal of Climate**, Boston, v. 22, n. 17, p. 4590–4605, 2009.

DUSSI, M. C. *et al.* Shade nets effect on canopy light distribution and quality of fruit and spur leaf on apple cv. Fuji. **Spanish Journal of Agricultural Research**, Madrid, v. 3, n. 2, p. 253-260, 2005.

ECCHER, G. *et al.* Early induction of apple fruitlet abscission is characterized by an increase of both isoprene emission and abscisic acid content. **Plant Physiology**, Rockville, v. 161, n. 4, p. 1952–1969, 2013.

FAO - FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. [**Base de dados FAOSTAT**]. Rome: FAO, 2022. Disponível em: https://www.fao.org/faostat/en/#data/QCL. Acesso em: 25 jun. 2022.

FRANCESCATTO, P.; LORDAN, J.; ROBINSON, T. L. Efficacy of metamitron as a postbloom thinner – the American Northeast experience. **Acta Horticulturae**, The Hague, v. 1281, n. 1281, p. 413–420, 2020.

GONZALEZ, L. *et al.* Effect of different application rates of metamitron as fruitlet chemical thinner on thinning efficacy and fluorescence inhibition in Gala and Fuji apple. **Plant Growth Regulation**, Dordrecht, v. 89, n. 3, p. 259–271, 2019.

GONZALEZ, L. *et al.* Evaluation of chemical fruit thinning efficiency using Brevis® (Metamitron) on apple trees (‘Gala’) under Spanish conditions. **Scientia Horticulturae**, Amsterdam, v. 261, [art.] 109003, 2020.

GREENE, D. W. *et al.* Mode of action of benzyladenine when used as a chemical thinner on apples. **Journal of the American Society for Horticultural Science**, Alexandria, VA, v. 117, n. 5, p. 775–779, 1992.

IGLESIAS, I.; ALEGRE, S. The effect of anti-hail nets on fruit protection, radiation, temperature, quality and probability of Mondial Gala apples. **Journal of Applied Horticulture**, Lucknow, v. 8, n. 2, p. 91–100, 2006.

JAKOPIC, J. *et al*. It’s great to be the King: apple fruit development affected by the position in the cluster. **Scientia Horticulturae**, Amsterdam, v. 194, p. 18–25, 2015.

KALCSITS, L. *et al.* Above and below-ground environmental changes associated with the use of photoselective protective netting to reduce sunburn in apple. **Agricultural and Forest Meteorology**, Amsterdam, v. 237–238, p. 9–17, 2017.

KALCSITS, L. *et al.* Shade netting reduces sunburn damage and soil moisture depletion in'Granny Smith'apples. **Acta Horticulturae**, The Hague, n. 1228, p. 85-90, 2018.

LAKSO, A. N.; GOFFINET, M. C. Apple fruit growth. **The New York Quarterly**, New York, v. 21, n. 1, p. 11–14, 2013.

LAKSO, A. N.; ROBINSON, T. L. Decision support for apple thinning based on carbon balance modeling. **Acta Horticulturae**, The Hague, v. 1068, , p. 235–242, 2015.

LAKSO, A. N.; ROBINSON, T. L.; GREENE, D. W. Integration of environment, physiology and fruit abscission via carbon balance modeling-implications for understanding growth regulator responses. **Acta Horticulturae**, The Hague, v. 727, p. 321–326, 2006.

LEITE, G. B.; PETRI, J. L.; MONDARDO, M. Effects of net shield against hailstorm on feature of apples production and fruit quality. **Revista Brasileira de Fruticultura**, Jaboticabal, v. 24, n. 3, p. 714–716, 2002.

LORDAN, J. *et al.* Modelling physiological and environmental factors regulating relative fruit set and final fruit numbers in apple trees. **Journal of Horticultural Science and Biotechnology**, Ashford, v. 95, n. 5, p. 600–616, 2020.

MCARTNEY, S. J.; OBERMILLER, J. D. Use of shading and the PSII inhibitor metamitron to investigate the relationship between carbohydrate balance and chemical thinner activity in apples. **Acta Horticulturae**, The Hague, n. 1042, p. 27–31, 2014.

MCARTNEY, S. J.; OBERMILLER, J. D.; ARELLANO, C. Comparison of the effects of metamitron on chlorophyll fluorescence and fruit set in apple and peach. **HortScience**, Alexandria, VA, v. 47, n. 4, p. 509–514, 2012.

MCCASKILL, M. R. *et al.* How hail netting reduces apple fruit surface temperature: a microclimate and modelling study. **Agricultural and Forest Meteorology**, Amsterdam, v. 226, p. 148-160, 2016.

MIDDLETON, S.; MCWATERS, A. Hail netting of apple orchards— australian experience. **The Compact Fruit Tree**, East Lansing, v. 35, n. 2, p. 51–55, 2002.

MILIĆ, B. *et al*. The growth of apple central fruits as affected by thinning with NAA, BA and naphthenic acids. **Erwerbs-Obstbau**, Berlin, v. 59, n. 3, p. 185–193, 2017.

MORANDI, B. *et al.* Shading decreases the growth rate of young apple fruit by reducing their phloem import. **Scientia Horticulturae**, Amsterdam, v. 127, n. 3, p. 347–352, 2011.

NEDEL, A.; SAUSEN, T. M.; SAITO, S. M. Zoneamento dos desastres naturais ocorridos no estado do Rio Grande do Sul no período 1989 - 2009: granizo e vendaval. **Revista Brasileira de Meteorologia**, Rio de Janeiro, v. 27, n. 2, p. 119–126, 2012.

OLIVARES-SOTO, H.; BASTÍAS, R. M. Photosynthetic efficiency of apples under protected shade nets. **Chilean Journal of Agricultural Research**, Chillán, v. 78, n. 1, p. 126–138, 2018.

PETRI, J. L. *et al*. Avanços na cultura da macieira no Brasil. **Revista Brasileira de Fruticultura**, Jaboticabal, v. 33, p. 48–56, 2011. Número especial.

RAMÍREZ, F.; DAVENPORT, T. L. Apple pollination: a review. **Scientia Horticulturae**, Amsterdam, v. 162, p. 188–203, 2013.

SALAZAR-CANALES, F. *et al.* Photo-selective nets differentially affect microclimatic conditions, leaf physiological characteristics, and yield in hazelnut (*Corylus avellana* L.). **Horticulture Environment and Biotechnology**, New York, v. 62, n. 6, p. 845–858, 2021.

SCHRÖDER, M.; LINK, H.; BANGERTH, K. F. Correlative polar auxin transport to explain the thinning mode of action of benzyladenine on apple. **Scientia Horticulturae**, Amsterdam, v. 153, p. 84–92, 2013.

SERRA, S. *et al*. Photoselective protective netting improves ‘Honeycrisp’ fruit quality. **Plants**, Basel, v. 9, n. 12, [art.] 1708, [p. 1–20], 2020.

SOLOMAKHIN, A.; BLANKE, M. M. Coloured hailnets alter light transmission, spectra and phytochrome, as well as vegetative growth, leaf chlorophyll and photosynthesis and reduce flower induction of apple. **Plant Growth Regulation**, Dordrecht, v. 56, n. 3, p. 211–218, 2008.

SOLOMAKHIN, A.; BLANKE, M. The microclimate under coloured hailnets affects leaf and fruit temperature, leaf anatomy, vegetative and reproductive growth as well as fruit colouration in apple. **Annals of Applied Biology**, Warwickshire, v. 156, n. 1, p. 121–136, 2010.

UNTIEDT, R.; BLANKE, M. Effects of fruit thinning agents on apple tree canopy photosynthesis and dark respiration. **Plant Growth Regulation**, Dordrecht, v. 35, p. 1–9, 2001.

VUKOVIĆ, M. et al. Sustainable food production: innovative netting concepts and their mode of action on fruit crops. **Sustainability**, Basel, v. 14, n. 15, [art.] 9264, 2022.

WAGENMAKERS, P. S. Effects of light and temperature on potential apple production. **Acta Horticulturae**, The Hague, n. 416, p. 191–198, 1996.

YUAN, R.; GREENE, D. W. Benzyladenine as a chemical thinner for `McIntosh' Apples. I. Fruit thinning effect1s and associated relationships with photosynthesis, assimilate translocation, and nonstructural carbohydrates. **Journal of the American Society for Horticultural Science**, Alexandria, VA, v. 125, n. 2, p. 169–176, 2000.

ZHU, H. *et al.* Transcriptomics of shading-induced and NAA-induced abscission in apple (*Malus domestica*) reveals a shared pathway involving reduced photosynthesis, alterations in carbohydrate transport and signaling and hormone crosstalk. **BMC Plant Biology**, London, v. 11, n. 1, [art.] 138, 2011.

ZIBORDI, M.; DOMINGOS, S.; CORELLI GRAPPADELLI, L. Thinning apples via shading: an appraisal under field conditions . **Journal of Horticultural Science and Biotechnology**, Ashford, v. 84, n. 6, p. 138–144, 2009.

ZORATTI, L. *et al.* Modification of sunlight radiation through colored photo-selective nets affects anthocyanin profile in *Vaccinium* spp. berries. **PLoS ONE**, San Francisco, v. 10, n. 8, [art.] e0135935, 2015.

3 ARTIGO 1

Competence of a fruitlet growth model in predicting chemical thinning effectiveness in apple orchards covered and uncovered with anti-hail netting*

*Artigo formatado conforme as normas do periódico Scientia Horticulturae

Competence of a fruitlet growth model in predicting chemical thinning effectiveness in apple orchards covered and uncovered with anti-hail netting

Lucas De Ross Marchioretto [(a)]*, Andrea De Rossi [(b)], Gilmar Arduino Bettio Marodin [(a)]

[(a)] Universidade Federal do Rio Grande do Sul (UFRGS), Faculdade de Agronomia, Departamento de Horticultura e Silvicultura. Av Bento Gonçalves, 7712, CEP 91540-000, Porto Alegre -RS, Brasil. lucas.marchioretto@ufrgs.br, marodin@ufrgs.br

[(b)] Embrapa Uva e Vinho, Br 285, s/n - Km 115, CEP 95200-000, Vacaria-RS, Brasil. andrea.derossi@embrapa.br

*Corresponding author: lucas.marchioretto@ufrgs.br (Lucas De Ross Marchioretto)

Abstract

The use of hail netting in apple orchards is widespread as it brings safety to the crop production. Although, due to microclimatic changes, many producers face a higher natural fruitlet drop and apprehension on using chemical thinners. The fruitlet growth model developed by Duane Greene and collaborators has evidence of being a tool to help to predict thinning response in a short period and could be useful in orchards covered with hail netting. Thus, the objective of this study was to evaluate the accuracy of the fruitlet growth model in predicting fruit set and fruit number of apple trees, in an areas covered and uncovered with white hail netting. The experiment was carried out in the cropping seasons of 2020/21 and 2021/22 in a 14-year commercial orchard with ‘Galaxy’ and ‘Fuji Suprema’ grafted on M9 rootstocks, in plots with and without hail netting. The treatments consisted of an Untreated Control (UC) and Metamitron (MM) sprayed at the growth stage of fruitlets with 15 mm of diameter. It was evaluated the accuracy of the model on predicting fruit set and final number of fruits per tree, and fruitlet growth pattern as a function of netting and treatments. In both cultivars, net shading, and MM reduced fruitlet growth rate. In ‘Fuji Suprema’, the growth model was accurate to predict both fruit set and fruit number per tree using as parameters into the model spreadsheet, 15 fruitlets with

---

Abbreviations: PGR: Plant Growth Regulator; PAR: Photosynthetically Active Radiation; UC: Untreated Control; MM: Metamitron.

the fastest growth rate and 0.5 as the cut-off factor in both treatments and netting conditions. ‘Galaxy’ was accurately predicted using 30 fruitlets with the fastest growth rate and 0.7 as the cut-off factor for the UCs in the covered and uncovered plots, and MM in the uncovered plot, while for MM under netting, 30 fruitlets with the fastest growth rate and the cut-off factor of 0.5 was adequate to accurately predict both variables.

Keywords: Plant growth regulators; Metamitron; Crop load management; *Malus domestica* Borkh.

3.1. Introduction

Apple trees produce much more flowers than they can actually sustain until the complete development of the fruit; although only the natural fruit drop is not sufficient to adjust crop load to an adequate level that enhances fruit weight and quality, being necessary the use of fruit thinning to complete this task (Lakso & Goffinet, 2013). In an unshaded environment, 10 to 12 leaves are required to begin to export assimilates from the extension shoots to the fruitlets, but when the environment is shaded, up to 20 leaves are required, as the tree prioritizes vegetative growth in such condition (Grappadelli et al., 1994; Lakso & Goffinet, 2013), reducing the phloem unloading to the fruitlets, decreasing their growth rate, and making them prone to abscission (Greene, 2017; Morandi et al., 2011).

In Southern Brazil, producers face the problem of low fruit set with ‘Gala’ (de Sousa et al., 2019), and under hail netting this problem is aggravated (Brglez-Sever et al., 2021), making chemical thinning to be risky and quite unpredictable in such condition. Among the various methods of assessing fruitlet abscission when still attached to the flower cluster, such as cellulase activity, starch/sucrose, or hormone levels, the fruitlet diameter assessment is rather the quickest and most effective method looking for estimating the interference of short-term stresses caused by PGRs, and so their fruitlet thinning response (Greene et al., 2013). Seven days after spraying a PGR used as chemical thinner, it is possible to detect diminished fruitlet growth rate of the ones deemed to abscise (Curetti et al., 2021; Greene et al., 2013), being possible to determine the need of additional sprays before the previous spray have actually begun to drop fruitlets.

The fruitlet growth model developed by Greene et al. (2013) is a tool for predicting the effectiveness of chemical thinning based on the assumption that the fruitlets that grow above the threshold of 50% of the fastest growing fruitlets will not undergo abscission, bringing an estimate whether or not additional thinning will be required seven to nine days after a PGR spray. In some preliminary experiments in uncovered orchards, in Southern Brazil, the model has been shown good precision and potential to be used (Brighenti et al., 2020; De Rossi et al., 2020).

With the widespread use of anti-hail netting and the setbacks on the microclimatic conditions, especially reduction of solar radiation and wind speed (Bosco et al., 2018), increase of minimum temperatures and decrease of maximum temperatures (Solomakhin & Blanke, 2010), bring negative consequences like higher vegetative growth and lower fruit set (Brglez-Sever et al., 2021; Leite et al., 2002). So, the use of the fruitlet growth model could be an important tool to bring accuracy, predictability, and certainness of the chemical thinning done in areas covered with anti-hail netting. Thus, the objective of this experiment was to evaluate the accuracy and effectiveness of the fruitlet growth model developed by Greene et al. (2013) in predicting fruit set and fruit number per tree of ‘Galaxy’ and ‘Fuji Suprema’ apples in an areas covered and uncovered with white anti-hail netting.

3.2. Material and methods

The experiment was carried out over two cropping seasons (2020/21 and 2021/22) in a commercial orchard located in Bom Jesus-RS, Brazil (28°35’55.49”S;

50°29’49.26”W, with elevation of 1033 m above sea level). The climate of the region is classified as a Cfb, according to the Köppen’s classification, with typically subtropical weather, mild-temperature summer, annual precipitation between 1600 and 1900 mm, mean annual temperatures ranging from 12 to 14 ^{o}C (Alvares et al., 2013). The meteorological data of daily maximum and minimum temperatures (°C), precipitation (mm), and solar radiation (Mj m^{2}) were retrieved from a meteorological station belonging to the Instituto Nacional de Meteorologia (INMET, 2022) located at 38 Km west from the experimental area.

Photosynthetically active radiation (PAR) was determined in the cropping season of 2021/22 along eight days throughout the period between the spray of Metamitron done at fruitlet diameter of 15 mm (Oct. 18th, 2021) until the second measurement of fruitlet diameter (Oct. 26th, 2021). PAR was measurement with an Arduino Uno board coupled with an Adafruit v.1.1 datalogger programed to make simultaneous registers every 15 minutes from one luminance sensor installed above the anti-hail netting level, and the other installed below the hail netting, just above the canopies level. The luminance sensor used was a BH1750FVI manufactured by ROHM Semiconductor® that measures visible light (from 400 to 700 nm). The output data given in Lumens.m^{-2} was converted to Megajoule.m^{-2} according to Michael et al. (2020) and Reis & Ribeiro (2020).

The orchard was implemented in 2006 with ‘Galaxy’ and ‘Fuji Suprema’, both grafted on M.9 rootstock. Plant density was 4166 trees.ha^{-1} (4 x 0.6 m) for ‘Galaxy’ and 1666 trees.ha^{-1} (4 x 1.5 m) for ‘Fuji Suprema’. The orchard was fully covered with white anti-hail netting with a mesh of 4x8 mm, and for the treatments in the uncovered area, the netting was opened right before full bloom for ‘Fuji Suprema’ and remained uncovered until the third week of December on both cropping seasons, whereas for ‘Galaxy’, the orchard was always uncovered. In addition, only in ‘Galaxy’ at phenological stages of E2 and F2, on both cropping seasons, it was sprayed Thidiazuron (TDZ) (25+25 mg.L^{-1}) to increase fruit set. At pink bud stage, trees were selected based on flower intensity and uniformity, and five trees per treatment were selected.

The treatments consisted of an untreated control (UC) and Metamitron (MM) (4-Amino-4,5-dihydro-3-methyl-6-phenyl-1,2,4-triazin-5-one: CAS number 41394-05-2), for ‘Galaxy’ and ‘Fuji Suprema’, both in the covered and uncovered area, totalizing four treatments and five replicates of each treatment. The UC consisted of apple trees that received no thinning i.e., neither manual nor chemical. MM was sprayed at a concentration of 140 g.ha^{-1} or 340 g.ha^{-1} on ‘Galaxy’ and ‘Fuji Suprema’, respectively, of the commercial formulation Goltix® (70% of Metamitron v/v) used as PGR for chemical thinning. The PGR was sprayed after 25 days of full bloom (DAFB), in the first season, and 27 DAFB in the second season, when the mean fruitlet diameter was 15 mm. In both cropping seasons, for the fruitlet growth model, 15 clusters on every replicate were tagged and numbered. In addition, all flower clusters of each replicate tree (5 per treatment) were counted. After three days of MM spray, the first measurement of fruitlet diameter was performed using a digital caliper Mitutoyo®, and the measurements of the fruitlets of each cluster of each tree were recorded on a printed spreadsheet. The second measurement was taken nine days after the spray.

The data of both measurements were arranged in descending order within each cluster, as it was considered that the fruitlet growth rate would remain constant between the measurements, and then input into the model’s MS Excel® spreadsheet developed by Greene et al. (2013). The output from the spreadsheet was the predicted fruit set (%), expected number of fruits per tree, as well as the other parameters of the model to predict these variables, i.e.: the model takes into consideration the number of fruitlets that were measured and divided by 75 clusters (15 clusters multiplied by 5 trees = 75 clusters) to estimate the mean number of fruits per cluster. Then, based on the average number of clusters per tree (mean from the five evaluated trees), the model multiplies the mean number of clusters with the mean number of fruits per cluster to obtain the expected number of fruits per tree after pruning. Then, with the difference of diameter from the two measurements it's obtained the fruitlet growth rate, so the model takes the mean diameter of the fastest growing fruitlets (top n in the spreadsheet) and considers that the ones that grew less than 50% of the growth rate of the fastest growing fruitlets will abscise, to stablish the cut-off point (0.5). The number of fruitlets above the cut-off point is divided by the number of measured fruitlets to obtain the estimated fruit set (%). The estimated fruit set is then multiplied by the expected number of fruits per tree after pruning to obtain the estimated number of fruits per tree.

The variables analyzed on the evaluated trees were fruit set (fruits counted at harvest/ n^o initial flower clusters*5)*100, and the fruit number per tree counted at harvest. The data of fruit set and fruit number per tree were subjected to the Shapiro-Wilk test to check the assumption of normality, and then were compared with the predicted value of the model output through the one-sample t-test ($p \leq 0.05$). In addition, for each treatment mean, confidence intervals ($p \leq 0.05$) were calculated. The data of fruitlet diameter difference between both measurements, performed for the model, were sorted into frequency distribution plots to determine the daily growth pattern distribution of the fruitlets of each treatment. Fruitlet daily increment in diameter from the first until the second measurement used in the fruitlet growth model were subjected to mixed effect ANOVA, in which seasons and treatments were fixed effects, and subject (replicates) was set as random effect. Treatment means were separated through LSD test ($p \leq 0.05$).

3.3. Results

In the first season (2020/21), the meteorological conditions that are favorable for fruit set such as high solar radiation, elevated diurnal temperatures, and cool night temperatures (Lordan et al., 2019) were most predominant, although right after full bloom, there were cloudy days (Figure 1). However, in the second season, during the initial fruit development there were lower temperatures and solar radiation, and more precipitation, which are deleterious conditions for fruit set. PAR reduction caused by the white anti-hail netting during the measured period was 16% in total (Figure 2).

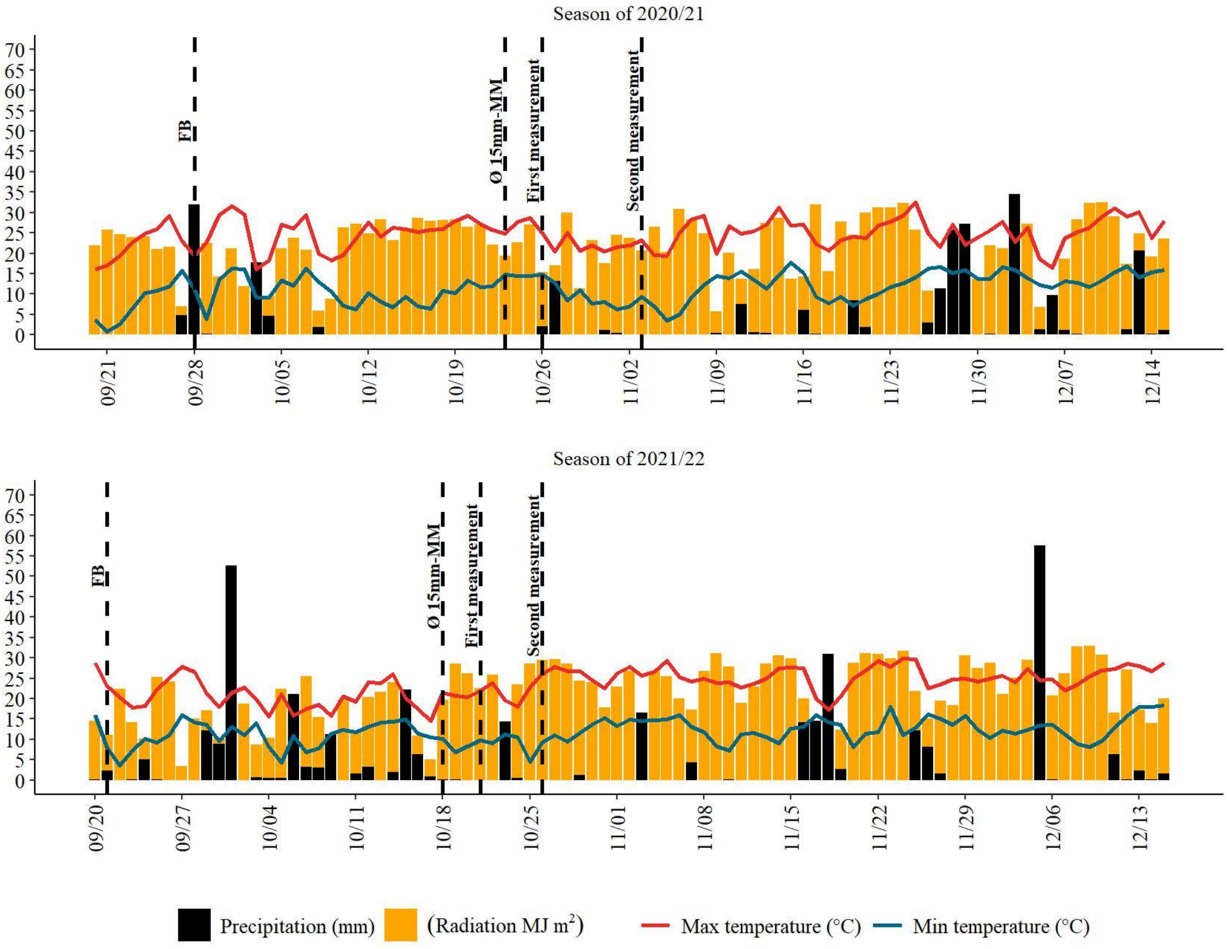


Figure 1. Meteorological conditions from full bloom until “December drop” in the cropping seasons of 2020/21 and 2021/22.

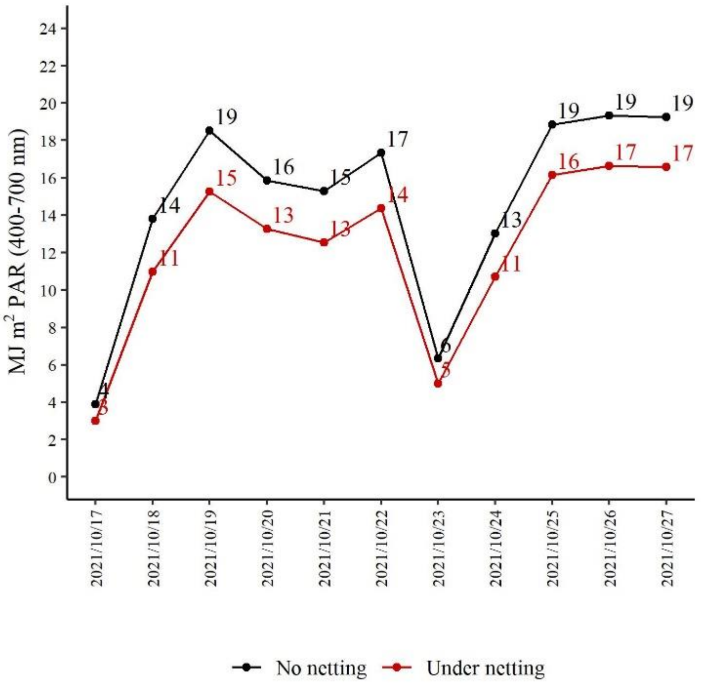


Figure 2. Photosynthetically active radiation (PAR) measured above (no netting) and below (under netting) white hail netting of an orchard of ‘Galaxy’ and ‘Fuji Suprema’ apples at the cropping season of 2021/22. Bom Jesus-RS, Brazil.

With ‘Galaxy’, in a first attempt with the growth model spreadsheet, it was set the commonly used threshold of 15 as the sample of fruitlets with the fastest growth rate (top n), and 0.5 as the cut-off factor (50% of the growth rate of the fastest growing fruitlets), but for both UCs (with and without netting) and MM without netting, the model overestimated fruit set between 25 and 33% from the actual value found at harvest, in the first season, and in the second season the model was accurate only with both MM (with and without netting); in contrast, for MM under netting, these variables were accurately predicted by the model (data not shown).

When adjusting the model parameters to 0.7 as the cut-off factor, and to 30 the sample of fruitlets with the fastest growth rate on both UCs (with and without netting) and MM without netting, fruit set of ‘Galaxy’ was accurately predicted in both cropping seasons, whereas for MM under netting, 30 fruitlets in the “top n” parameter, and 0.5 as the cut-off factor were adequate for the model to accurately predict fruit set (Figure 3). On the other hand, the predicted fruit set of ‘Fuji Suprema’ was accurate for all treatments in both cropping conditions and seasons using the standard parameters of 15 sampled fruitlets with the fastest growth (top n), and 0.5 as the cut-off factor (Figure 3).

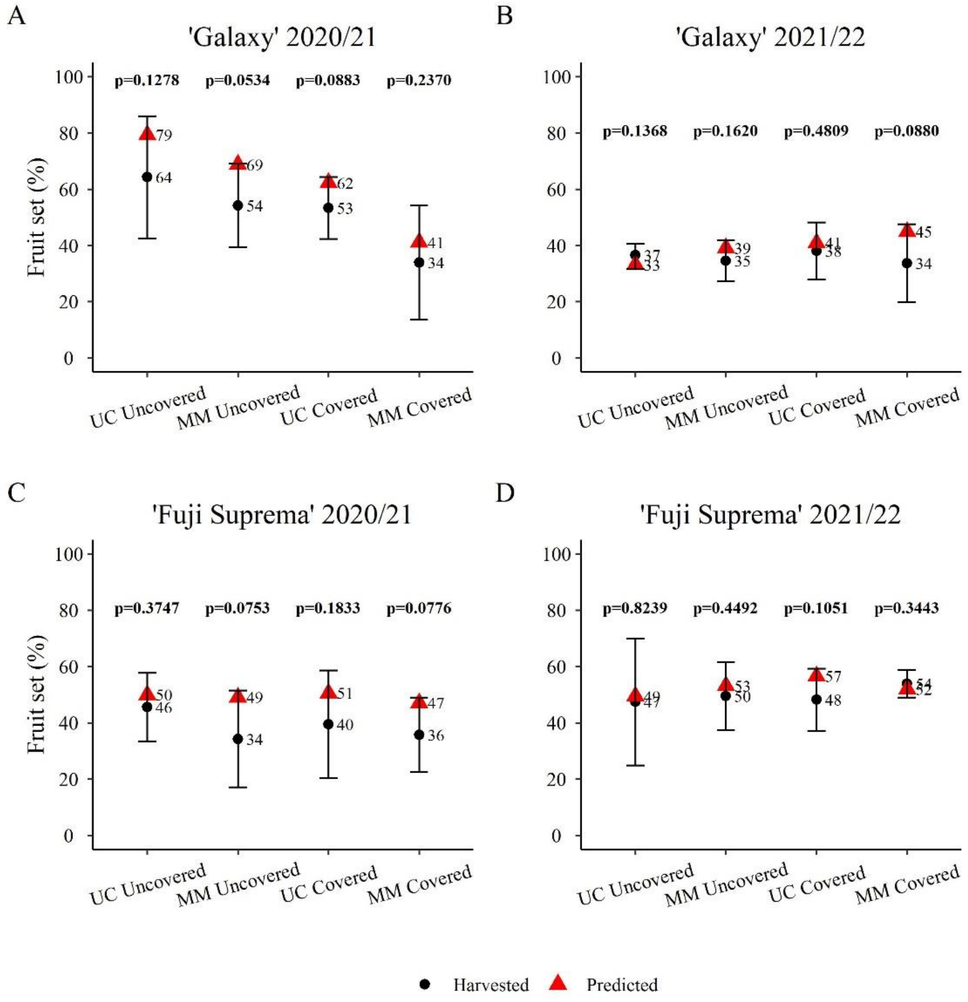


Figure 3. Fruit set found at harvest (black dots) and predicted by the fruitlet growth model (red triangles) of ‘Galaxy’ (A and B) and ‘Fuji Suprema’ (C and D) apple trees as a function of Metamitron (MM) in comparison

with an Untreated Control (UC) in areas covered and uncovered with white anti-hail netting. Bars indicate the confidence intervals at 95% of confidence. p: p-value of the t test.

The predicted fruit number per tree in ‘Galaxy’ was also inconsistent when using the standard parameters of 15 fruitlets with the fastest growth rate (top n), and 0.5 as the cut-off factor, as in the first season, the model accurately predicted this variable to all the treatments, but in the second season except for the UC without netting, all other treatments were underestimated (data not shown).

The change of the parameters “top n” from 15 to 30 in all treatments on ‘Galaxy’, and the change of the cut-off factor from 0.5 to 0.7 in both UCs (with and without netting) and MM without netting, made the predicted number of fruits to be accurate, whereas for MM under netting, keeping the cut-off factor in 0.5 was enough for the predictability of the growth model. With ‘Fuji Suprema’, the fruitlet growth model was accurate to predict the final fruit number at the harvest with the standard parameters of 15 fruitlets with the fastest growth rate (top n), and 0.5 as the cut-off factor in both cropping seasons, with all treatments in both cropping conditions, i.e., with or without netting (Figure 4).

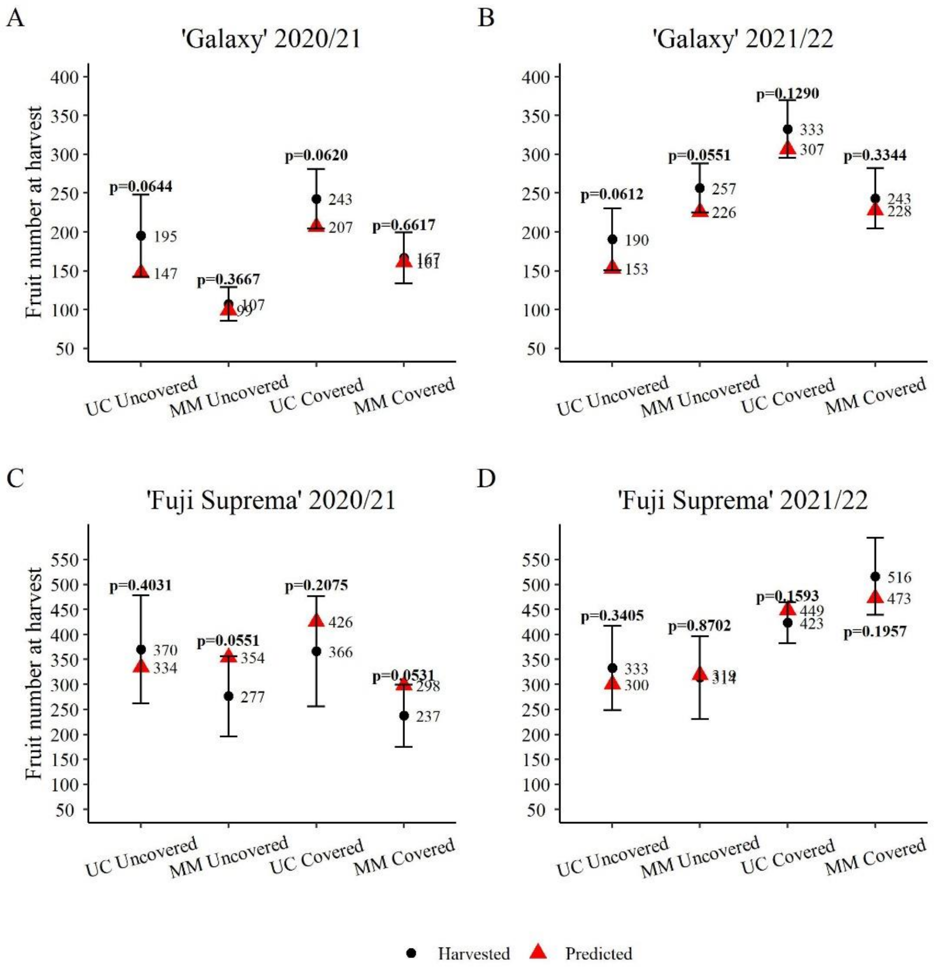


Figure 4. Fruit number at harvest (black dots) and predicted by the fruitlet growth model (red triangles) of ‘Galaxy’ (A and B) and ‘Fuji Suprema’ (C and D) apple trees as a function of Metamitron (MM) application in comparison with an Untreated Control (UC) in areas covered and uncovered with white anti-hail netting. Bars indicate the confidence intervals at 95% of confidence. p: p-value of the t test.

In the first season, ‘Galaxy’ alternated bearing and the trees had initially an estimated number of 400 fruits per tree, whereas in the following season, the estimated initial number of fruits was 861 per tree, and summed up with unfavorable meteorological conditions, fruitlet growth rate was lower than the first season; however, with ‘Fuji Suprema’, there was no bearing alternance on both seasons (est. 850 and 835 initial fruits per tree, in 2020/21 and 2021/22, respectively), although the higher fruitlet diameter increment in the second season may have been due to more rainfall in the days before MM spray, which certainly improved the hydric condition of the soil and improved fruitlet growth (Table 1). Nevertheless, ‘Galaxy’ in both cropping seasons had the lowest growth increment with MM under hail netting, whereas in the first season, ‘Galaxy’ fruitlets treated with MM in the uncovered condition also had low growth increment, along with MM under netting. With this cultivar, the treatments that had high growth rate, also overestimated fruit set prediction by the model.

In the first season, ‘Fuji Suprema’ had overall lower fruitlet growth increment in relation to the second season, although MM on both netting conditions caused a stress on the fruitlets and reduced the growth increment, whereas in the following season, no difference among treatments was found (Table 1).

Table 1. Daily increment of diameter of ‘Galaxy’ and ‘Fuji Suprema’ fruitlets between three and nine days after the spray.

	Daily fruitlet diameter increment (mm/day)			
Treatment	Galaxy		Fuji Suprema	
	2020/21	2021/22	2020/21	2021/22
UC uncovered	0.56 a	0.44* a	0.37 a	0.43 * a
UC covered	0.55 a	0.47* a	0.39 a	0.45* a
MM uncovered	0.48 b	0.47 ^{ns} a	0.29 b	0.45* a
MM covered	0.28 c	0.31 ^{ns} b	0.31 b	0.42* a

Means in a column followed by different letters are significantly different according to the LSD test ($p \leq 0.05$). ^{ns} and *: mean comparison of two seasons are non-significant and significant, respectively.

MM and hail netting impaired fruitlet growth rate in the first season of 'Galaxy' (Figure 5). Under netting, the UC had less fruitlets into the growth rate class of 0.5 to 0.6 mm/day, and almost twice more fruitlets into the growth rate classes of 0.4 to 0.5 and -0.1 to 0 mm/day (no growth), in relation to the UC in the uncovered area, indicating a stressing condition in this environment (under netting).

With MM the change in the frequency distribution of 'Galaxy' was dramatic when comparing the fruitlets treated with this PGR in the covered and uncovered areas (Figure 5). Under netting MM-treated fruitlets had almost three times less fruitlets into the class of 0.6 to 0.7 mm/day and even almost three, and 13 times more fruitlets into the classes of -0.1 to 0, and 0 to 0.1 mm/day, respectively, meaning that the combination of MM and netting substantially impaired growth rate in the first season.

Within each netting condition (Figure 5), in the first season, in the uncovered condition MM reduced the proportion of 'Galaxy' fruitlets into the class of 0.7 to 0.8 mm/day in relation to the UC, and almost doubled, and tripled the proportion of fruitlets into the classes of -0.1 to 0 and 0 to 0.1 mm/day, respectively, demonstrating at some extent the stress promoted by this PGR on reducing fruitlet growth rate. However, under netting, in the comparison of MM with the UC, it was found a dramatic increase in the classes of low fruitlet growth rate due to the combined effect of MM and netting (shading).

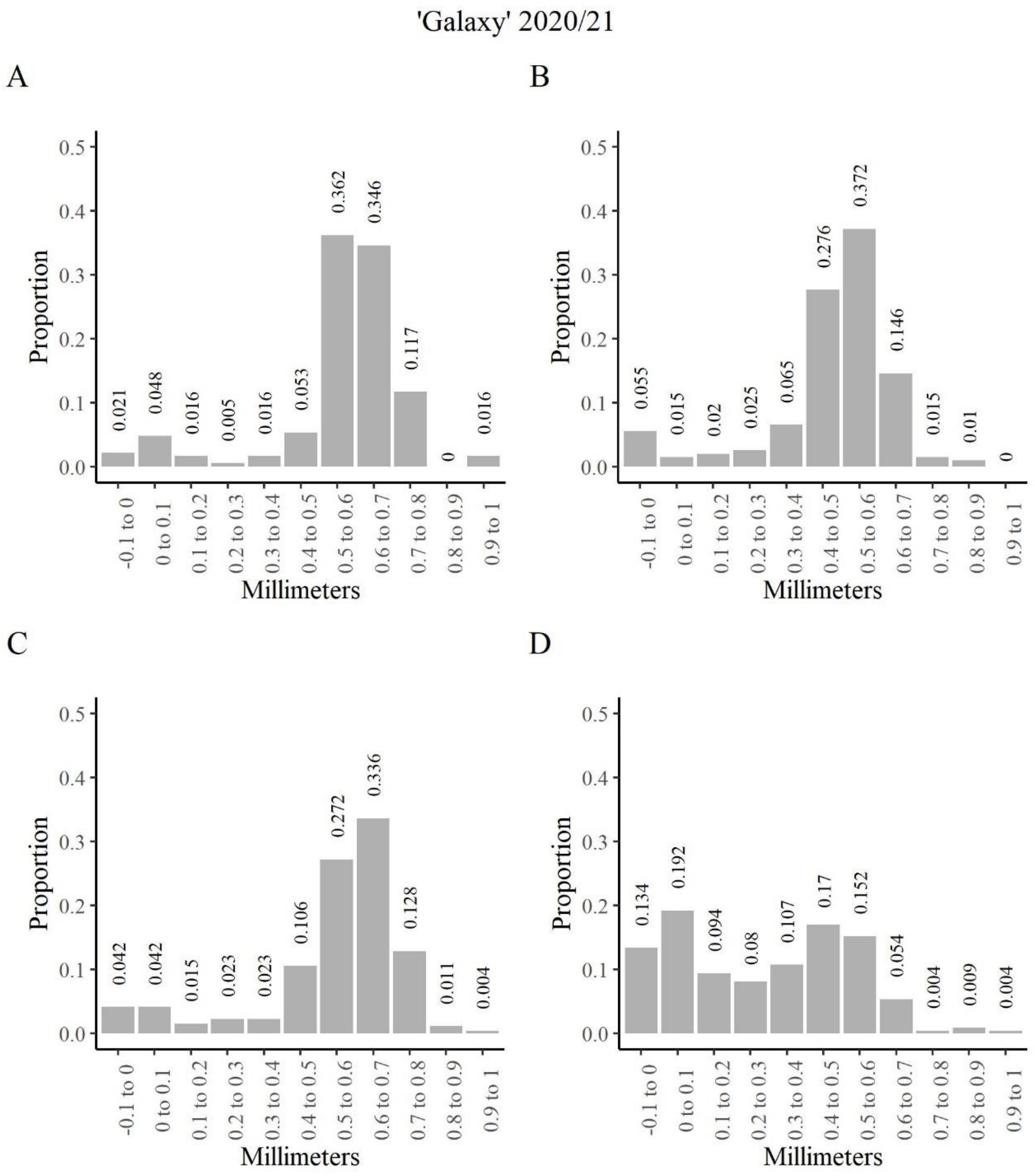


Figure 5. Frequency distribution of the daily growth rate increment (mm/day) of ‘Galaxy’ fruitlets between three days (first measurement) and nine days (second measurement) after metamitron spray in the cropping season of 2020/21. A: Untreated control (UC) in the uncovered plot; B: Metamitron (MM) in the uncovered plot; C: Untreated control (UC) in the covered plot; D: Metamitron (MM) in the covered plot.

In the second season, the UC of ‘Galaxy’ in the covered and uncovered areas had different behaviors (Figure 6). Without netting, there were less fruitlets with a high growth rate (>0.5 to 0.6 mm/day), but also less fruitlets with slow growth rate (<0.1 to 0.2 mm/day), whereas under netting, the distribution was the opposite, so that there were more fruitlets with impaired growth rate (-0.1 to 0 mm/day), and more fruitlets with a high growth rate i.e., above the classes of 0.5 to 0.6 mm/day.

MM-treated ‘Galaxy’ trees had different fruitlet growth distributions when comparing the orchards with and without netting (Figure 6). Under netting there were almost equal parts of fruitlets of the classes of -0.1 to 0, 0 to 0.1, 0.1 to 0.2, 0.3 to 0.4, 0.4 to 0.5, and 0.5 to 0.6 mm/day, indicating a strong fruitlet growth reduction, as with MM without netting, there was a high quantity of fruits into the class of 0.5 to 0.6 mm/day and above.

On the comparison of MM with the UC in each netting condition of ‘Galaxy’, in the uncovered condition there were 1.35 times more fruitlets into the class of 0.5 to 0.6 mm/day with MM in relation to the UC, and the UC had 1.39 times more fruitlets into the class of 0.4 to 0.5 mm/day, and 1.74 times more fruitlets into the class of 0.2 to 0.3 mm/day in relation to MM, indicating that with this PGR the fruitlets had a higher growth rate (Figure 6). On the other hand, in the covered condition, MM substantially decreased fruitlet growth rate in relation to the UC.

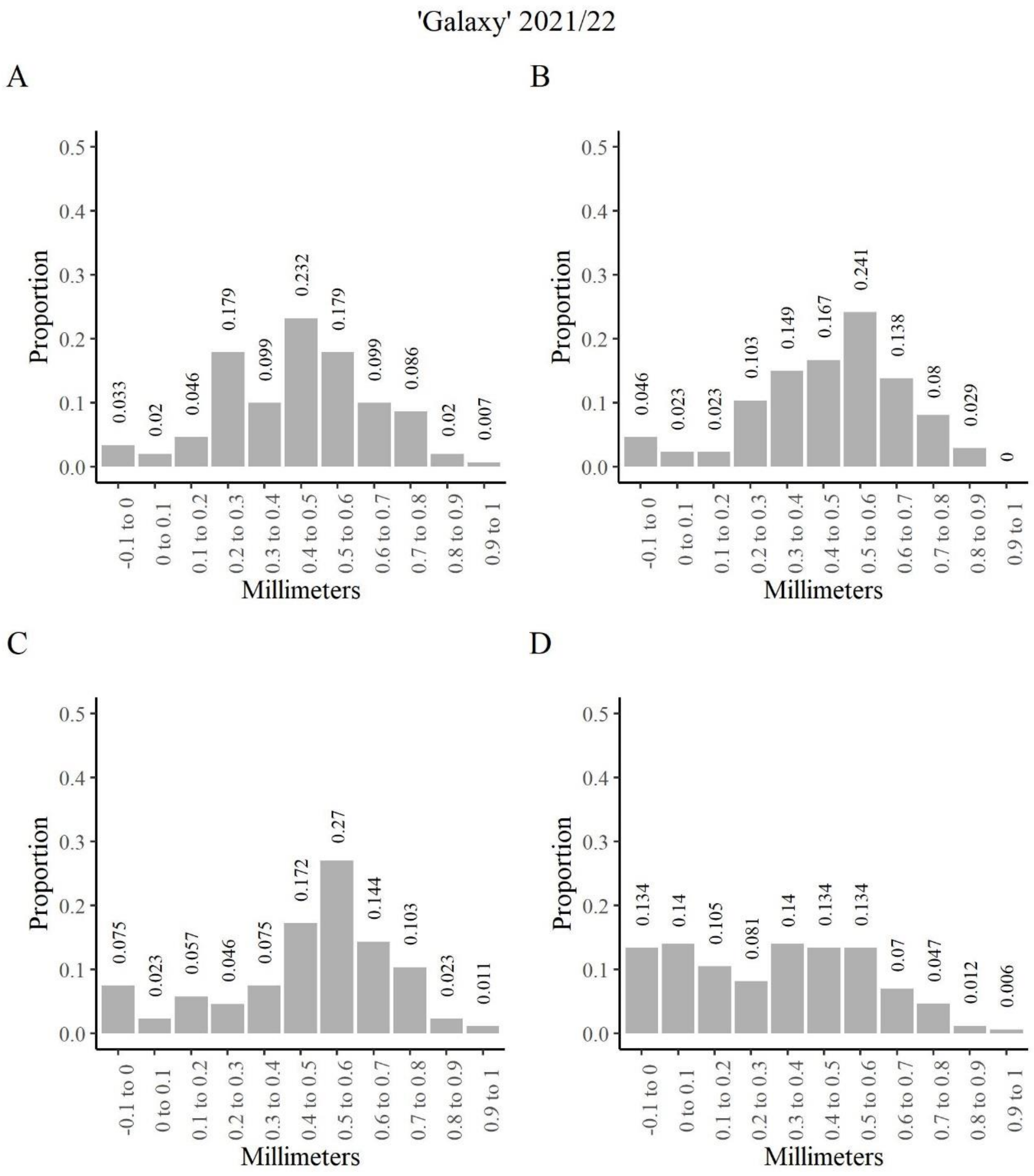


Figure 6. Frequency distribution of the daily growth rate increment (mm/day) of ‘Galaxy’ fruitlets between three days (first measurement) and nine days (second measurement) after metamitron spray in the cropping season of 2021/22. A: Untreated control (UC) in the uncovered plot; B: Metamitron (MM) in the uncovered plot; C: Untreated control (UC) in the covered plot; D: Metamitron (MM) in the covered plot.

In the first season, the UC of ‘Fuji Suprema’ under netting, had less fruitlets in the classes of -0.1 to 0, 0 to 0.1, 0.5 to 0.6, and 0.6 to 0.7 mm/day, but more fruitlets with high growth rate (0.7 to 0.8 and 0.8 to 0.9 mm/day) (Figure 7), indicating that in this environment, the majority of fruitlets have slower growth rate, but a small portion of them present very high growth rate.

Netting also affected fruitlet growth rate distribution on the trees treated with MM (Figure 7). Under netting, there was less fruitlets into the class of 0.4 to 0.5 mm/day, but more fruitlets into the classes of high growth rate (0.6 to 0.7, and 0.7 to 0.8 mm/day), in relation to the uncovered condition, indicating that trees treated with MM under netting had similar growth pattern of the uncovered condition, although some fruitlets had very high growth rate, especially on the classes of 0.6 to 0.7 and 0.7 to 0.8 mm/day.

In the comparison of MM against the UC in the uncovered area, the former increased the proportion of fruitlets with slow growth (0.1 to 0.2, 0.2 to 0.3, and 0.3 to 0.4 mm/day), and decreased the proportion of fruitlets with high growth rate (0.5 to 0.6 mm/day, and the upper growth classes), depicting the short-term stress caused by the PGR (Figure 7). Similar pattern was observed in the covered area.

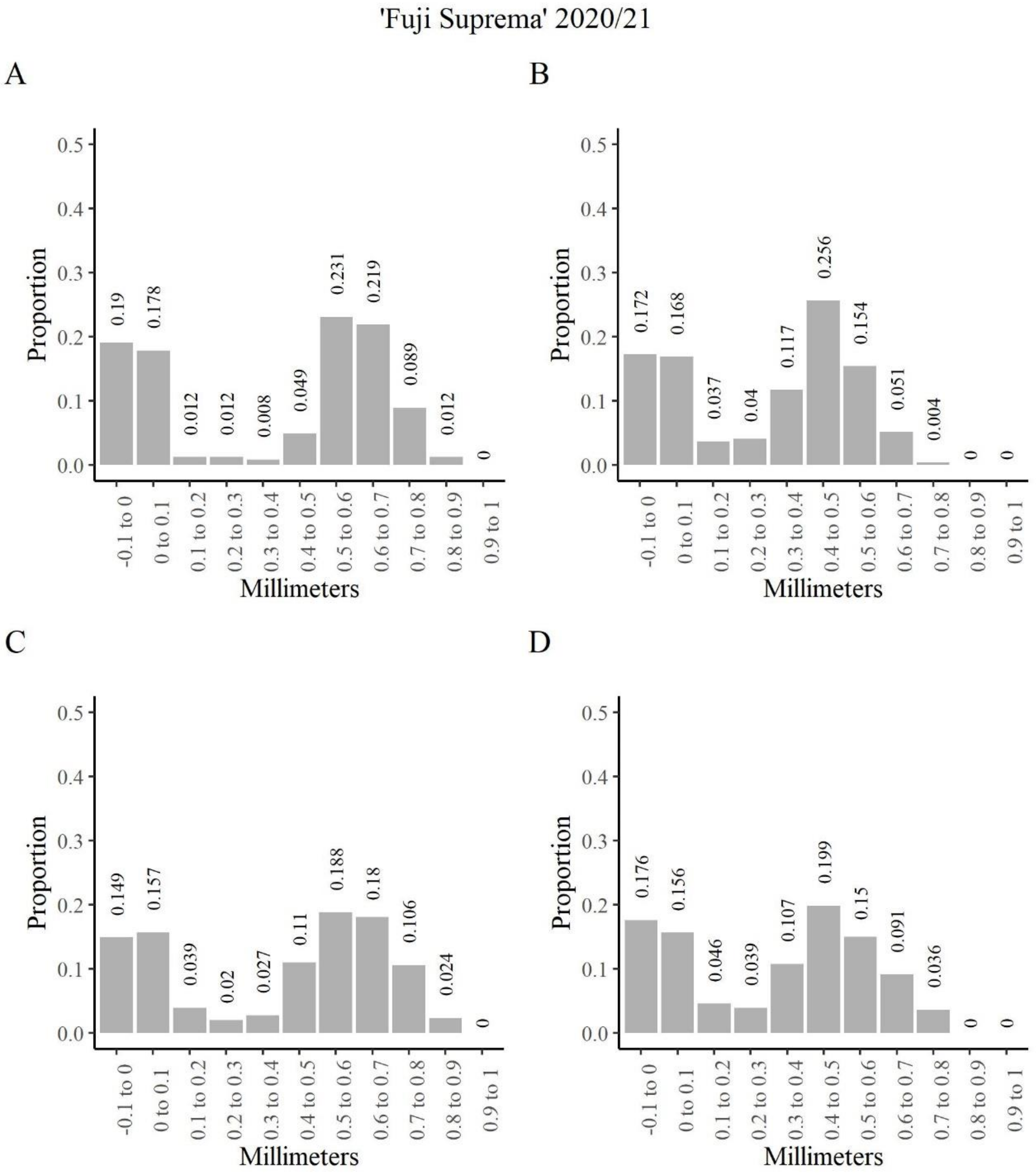


Figure 7. Frequency distribution of the growth rate increment (mm/day) of ‘Fuji Suprema’ fruitlets between three days (first measurement) and nine days (second measurement) after metamitron spray in the cropping season of 2020/21. A: Untreated control (UC) in the uncovered plot; B: Metamitron (MM) in the uncovered plot; C: Untreated control (UC) in the covered plot; D: Metamitron (MM) in the covered plot.

In the second season, an accentuated although similar pattern of the previous season was found with the UC, where under netting there was an increased amount of fruitlets with reduced growth rate, as well as an increased amount of fruitlets in the into the classes of high growth rate (0.6 to 0.7 mm/day and above growth classes), indicating that under netting the competition among the fruitlets was higher, and two cohorts were formed i.e., slow and fast growth rate (Figure 8).

The trees treated with MM under netting had impaired growth in relation to the ones in the uncovered area, as from the classes of 0.6 to 0.7 mm/day and upper, the proportion of fruitlets was lower in the covered area, in relation to the uncovered area, and in the covered area there was an increase in the proportion of fruitlets with slow growth rate 0.3 to 0.4 mm/day and lower (Figure 8).

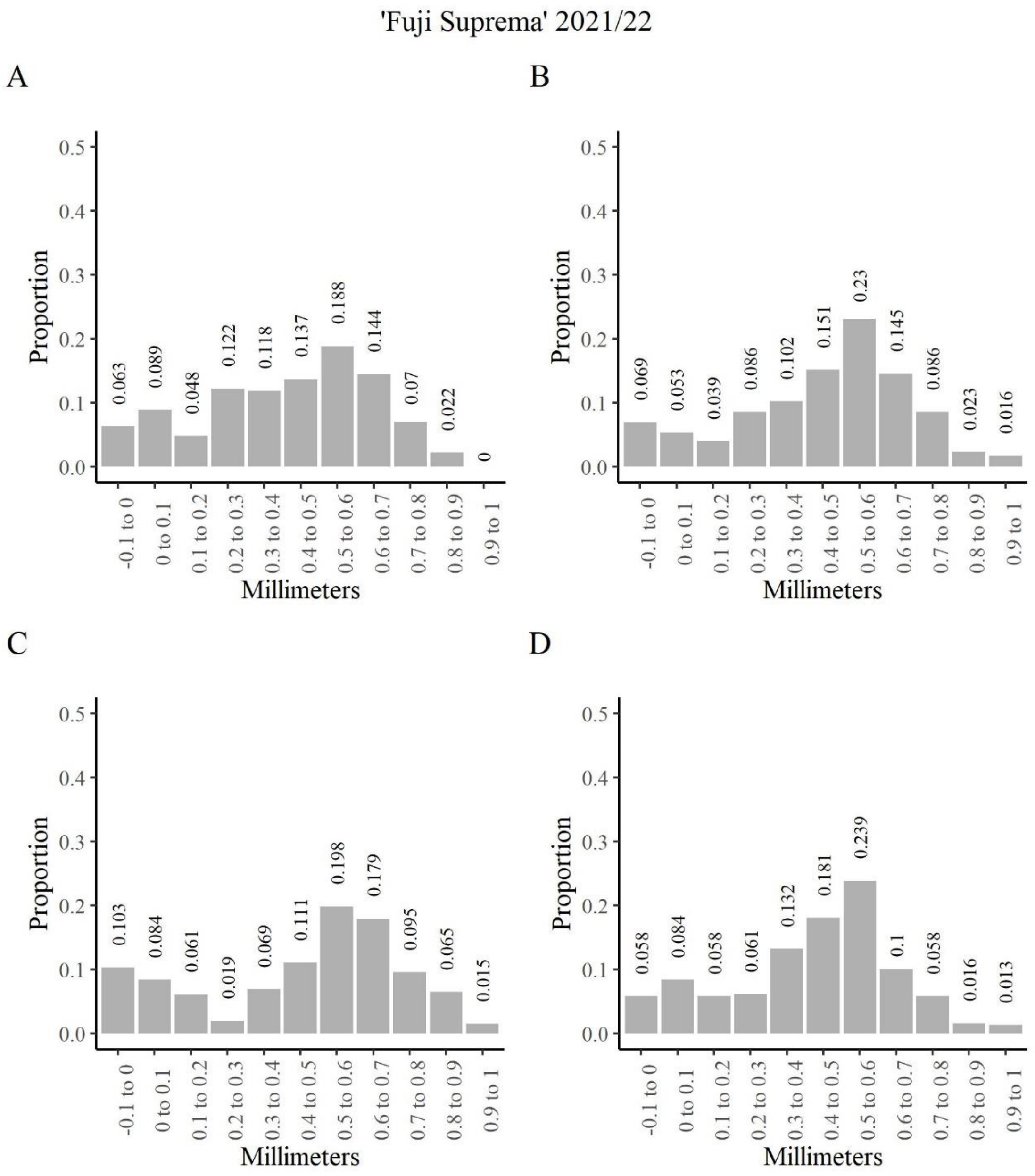


Figure 8. Frequency distribution of the growth rate increment (mm/day) of ‘Fuji Suprema’ fruitlets between three days (first measurement) and nine days (second measurement) after metamitron spray in the cropping season of 2021/22. A: Untreated control (UC) in the uncovered plot; B: Metamitron (MM) in the uncovered plot; C: Untreated control (UC) in the covered plot; D: Metamitron (MM) in the covered plot.

3.4. Discussion

The fruitlet growth model developed by Greene et al. (2013) assumes that in fruitlets ranging from seven to 25 millimeters of diameter, the ones deemed to abscise will grow less than 50% of the growth rate of the fastest growing fruitlets. In this experiment, ‘Galaxy’ had simultaneously fruit set and fruit number per tree accurately predicted by the model only when the parameters cut-off factor and “top n” were adjusted to 0.7 and 30, respectively, for the treatments UC with and without netting, and MM without netting, although with MM under netting, the cut-off factor and “top n” of 0.5 and 30, respectively were adequate to ascertain the prediction of both variables.

The estimated fruit set and fruit number per tree in ‘Fuji Suprema’ were both accurately predicted by the model using the cut-off factor of 0.5, and “top n” of 15 fruitlets with the fastest growth rate. Because with ‘Galaxy’, the prediction with MM under netting was accurate without modifying the cut-off factor, and was accurate with ‘Fuji Suprema’, there was an indication that the quick fruitlet growth rate of ‘Galaxy’ with the other treatments changed the cut-off factor to 0.7, i.e., the fruitlets were in intense growth speed and a lower amount of fruitlets with slow growth speed (below 3 mm, between both measurements). As observed on Figures 5 and 6, both UCs and MM without netting had fruitlets with a high growth rate, indicating that ‘Galaxy’ fruitlets grew in constant and intense competition with other fruitlets, contrarily to MM under netting.

Regarding the predicted fruit number per tree in ‘Galaxy’, when using the growth rate of 15 of the fastest growing fruitlets, the model underestimated the predicted fruit number per tree, and super estimated fruit set, especially on the second season, although when switching to 30 fruitlets, the prediction was accurate. It is likely that with the smaller sample (15), some fruitlets grew way more than the normal, and made the model to inflate too much the cut-off threshold, whereas with 30 fruitlets set in the model this “error” was more dissolved, and decreased the cut-off threshold, thus predicting a higher and accurate number of fruits per tree, as this variable is based on the fruit set of the expected number of fruits after pruning (mean count of flower clusters per tree).

The higher cut-off factor found in ‘Galaxy’ (0.7) in less stressing conditions was an indicative of intense growth rate among fruitlets, whereas MM under netting had the normal cut-off factor of 50%, as both stresses (netting and MM) caused less competition due to lower fruitlet growth rate. This was likely to be due to the use of Thidiazuron (TDZ) to improve fruit set. This compound has high affinity for the citokinic receptors, as well as a high resistance against cytokinin oxidase/dehydro-genase (a cytokinin degrador), acting as a strong effect on cell multiplication at low concentrations (Nisler, 2018). In horticulture, it is used to increase fruit set, as it promotes quick cell multiplication in the fruitlet cortex, favoring sink strength of fruitlets as it is sprayed early in the season when predominantly flower clusters are sprouted, avoiding abscission due to constant growth rate, and also acting as an antistress by antagonizing ethylene (Nisler, 2018; Petri et al., 2001). Thus, in our experiment, the fruitlets that should drop, keep the growth rate, and do not undergo abscission.

The quick increment in the fruitlet diameter certainly made more fruitlets to keep elevated growth rate, which on a normal situation, i.e., without TDZ, they would keep a slower and uniform growth rate (alike ‘Fuji Suprema’), therefore making more fruitlets to keep growth rate above the threshold of 50% of the fastest growing ones, and making the model to super estimate the predicted fruit set, as this value is the percentage of fruitlets above the cut-off threshold within the sampled fruitlets (from the 15 clusters of the five trees). McArtney & Obermiller (2010) found that the growth model slightly overestimated fruit set on the trees treated with chemical thinners, but with the UC the model was accurate. They also reported that with chemical thinners, it was formed two cohorts of fruitlet growth patterns: one with no or slow growth, and the other with a high growth rate. Brighenti et al. (2020) and Rufato et al. (2017) also found that the growth model overestimated fruit set of ‘Maxi-Gala’ and ‘Royal Gala’, respectively, corroborating with this study. As in this experiment, it is likely that the quick growth pattern of fruitlets of ‘Gala’ apples treated with Benzyladenine (also a cytokinin) in these experiments inflated this variable, and especially in our experiment with the use of TDZ. Benzyladenine used as chemical thinner, promotes fruitlet drop, but also has a direct effect on increasing cell multiplication and fruit growth (Milić et al., 2017).

At budbreak of pome fruits, flower clusters along with leaves and branches grow simultaneously, and all organs are still sink of assimilates, then competing for the stored reserves from the previous season, until the moment where a sufficient amount of leaves are expanded and begin to export assimilates to the sink tissues; in addition, in shaded branches, a higher number of expanded leaves are necessary to increase net production of assimilates to export to the sinks, as in this condition the apple tree focuses of increasing light interception and vegetative growth (Bepete & Lakso, 1998; Grappadelli et al., 1994; Lakso & Goffinet, 2013). This could be seen in our experiment, as the hail netting shade reduced the fruitlet growth rate on both cultivars, along with MM used as chemical thinner. This effect was more pronounced with ‘Galaxy’ than with ‘Fuji Suprema’, likely due to the lower sink strength found with ‘Gala’ clones in the Southern Brazilian conditions, so that, in traditional regions of apple production, both cultivars are considered as hard-to-thin (Iwanami et al., 2012; Robinson et al., 2017).

Net shading or reduced sunlight due to cloudy weather reduce the carbon fixation and so the source strength of the apple canopy, reducing the gradient of assimilates from leaves to fruitlets, thus decreasing the phloem transport rate (Morandi et al., 2011). The assimilate shortage promoted by MM (PSII inhibitor) (Gonzalez et al., 2019b), or shading (Greene, 2017; Morandi et al., 2011) create a stressful condition in the fruitlet cortex, leading to an elevation in the levels of cytotoxic reactive oxygen species until a threshold that halts embryo development, as the accumulation of sucrose in the cortex due to weakened sink strength leads to a backwards feedback in both fruitlet cortex and embryo, through the T6P enzyme, halting the development or aborting the embryo. As a consequence, it breaks the polar auxin efflux through the fruitlet pedicel, leading to the increment of ethylene sensitivity in the tissue through the elevation of the synthesis of ethylene receptors, and finally the creation of the abscission zone (Botton et al., 2011; Schröder et al., 2013).

The source-sink balance is impacted by the current meteorological conditions, which play an important role in modulating the availability of assimilates for growth (Breen et al., 2020; Lakso, 2011), besides the initial flower number, as a high number of flowers lead to more competition, and consequently to higher natural abscission (Breen et al., 2020; Lordan et al., 2019). Although, for ‘Fuji’, the availability of assimilates, for the growing fruitlets, and their sink strength, is highly influenced by the number of leaves present at the base of the cluster, thus the higher the leaf number, the lower the fruitlet abscission rate, whereas for other apple cultivars this plays little influence (Iwanami et al., 2012). Additionally, ‘Gala’ trees are more susceptible to Metamitron than ‘Fuji’ possibly due to the inherent interaction of each cultivar with the environment, and also to the rate of absorption, as this compound causes photoinhibition for longer than in ‘Fuji’ (Gonzalez et al., 2019a; Gonzalez et al., 2019b).

There are evidence that fruit crops under hail netting exhibit a higher natural fruit drop in relation to an uncovered condition (Brglez-Sever et al., 2021; Clever, 2022; Salazar-Canales et al., 2021). The most outstanding alterations in the microclimate are the reduction of solar radiation and elevation of the minimum temperatures at night, which are regarded to an increment of the natural fruitlet drop, and correspondingly increment of the vegetative growth (Solomakhin & Blanke, 2010). As discussed above, these environmental conditions negatively impact net carbon balance, leading to a decreased fruitlet growth rate and abscission. In our experiment, these dynamics modulated by the environment on the fruitlet growth could be captured by the fruitlet growth model, and in environmentally stressful conditions, the model was even more precise due to lower fruitlet growth rate.

3.5. Conclusions

The fruitlet growth model developed by Greene and collaborators is precise in predicting the post-blossom thinning response of Metamitron sprayed on fruitlets with 15 mm of diameter of ‘Fuji Suprema’ and ‘Galaxy’ of orchards with and without hail netting.

The parameters recommended to input in the model spreadsheet for ‘Fuji Suprema’ is to set the cut-off factor to 0.5, and “top n” to 15 fruitlets, for the mean fastest diameter, independently of the presence of hail netting. Due to the use of Thidiazuron to increase the fruit set of ‘Galaxy’, the parameters cut-off factor of 0.7, and 30 fruitlets, for the mean fastest diameter are adequate in uncovered orchards, and the cut-off factor of 0.5, and 30 fruitlets for the mean fastest diameter, are adequate in trees treated with Metamitron in orchards covered with hail netting.

Acknowledgements

The authors acknowledge the company AGROSPE for the experimental throughout these three cropping seasons, especially Fábio Varela and André Zamban De Pieri.

Funding: This work was supported by EMBRAPA Uva e Vinho; and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) [grant number 141123/2019-2]

3.6. References

Alvares, C.A., Stape, J.L., Sentelhas, P.C., de Moraes Gonçalves, J.L., Sparovek, G., 2013. Köppen’s climate classification map for Brazil. Meteorologische Zeitschrift 22, 711–728. https://doi.org/10.1127/0941-2948/2013/0507

Bepete, M., Lakso, A.N., 1998. Differential Effects of Shade on Early-season Fruit and Shoot Growth Rates in `Empire’ Apple. HortScience 33, 823–825. https://doi.org/10.21273/HORTSCI.33.5.823

Bosco, L.C., Bergamaschi, H., Cardoso, L.S., Paula, V.A. de, Marodin, G.A.B., Brauner, P.C., 2017. Microclimate alterations caused by agricultural hail net coverage and effects on apple tree yield in subtropical climate of Southern Brazil. Bragantia 77, 181–192. https://doi.org/10.1590/1678-4499.2016459

Botton, A., Eccher, G., Forcato, C., Ferrarini, A., Begheldo, M., Zermiani, M., Moscatello, S., Battistelli, A., Velasco, R., Ruperti, B., Ramina, A., 2011. Signaling pathways mediating the induction of apple fruitlet abscission. Plant Physiol 155, 185–208. https://doi.org/10.1104/pp.110.165779

Breen, K., Tustin, S., Palmer, J., Boldingh, H., Close, D., 2020. Revisiting the role of carbohydrate reserves in fruit set and early-season growth of apple. Sci Hortic 261, 109034. https://doi.org/10.1016/j.scienta.2019.109034

Brglez-Sever, M., Tojnko, S., Fakin, D., Stajnko, D., Unuk, T., 2021. Natural June thinning of fruitlets and yield characteristics of apple trees growing under coloured anti-hail netting. Eur J Hortic Sci 86, 136–145. https://doi.org/10.17660/eJHS.2021/86.2.4

Brighenti, A.F., Pasa, M.S., Brighenti, E., Ciotta, M.N., Souza, Z.S., 2020. Fruitlet growth model to predict chemical thinning response on apples in southern Brazil, in: Acta Horticulturae. International Society for Horticultural Science, pp. 265–272. https://doi.org/10.17660/ActaHortic.2020.1281.36

Clever, M., 2022. Relationships among hail net and thinning efficacy. Acta Hortic 31–38. https://doi.org/10.17660/ActaHortic.2022.1341.5

de Rossi, A., Marchioretto, L.D.R., Serafim, H., da Silva, M.T.S., 2020. Emprego do modelo da taxa de crescimento de frutos em programa de raleio de macieira “Fuji Suprema.” Bento Gonçalves.

de Sousa, A.M., Ayub, R.A., Viencz, T., Botelho, R.V., 2019. Fruit set and yield of apple trees cv. Gala treated with seaweed extract of Ascophyllum nodosum and thidiazuron. Rev Bras Frutic 41. https://doi.org/10.1590/0100-29452019072

Gonzalez, L., Bonany, J., Alegre, S., Àvila, G., Carbó, J., Torres, E., Recasens, I., Martin, B., Asin, L., 2019a. Brevis thinning efficacy at different fruit size and fluorescence on ‘Gala’ and ‘Fuji’ apples. Sci Hortic 256. https://doi.org/10.1016/j.scienta.2019.05.053

Gonzalez, L., Torres, E., Carbó, J., Alegre, S., Bonany, J., Àvila, G., Martin, B., Recasens, I., Asin, L., 2019b. Effect of different application rates of metamitron as fruitlet chemical thinner on thinning efficacy and fluorescence inhibition in Gala and Fuji apple. Plant Growth Regul 89, 259–271. https://doi.org/10.1007/s10725-019-00531-0

Grappadelli, L.C., Lakso, A.N., Flore, J.A., 1994. Early Season Patterns of Carbohydrate Partitioning in Exposed and Shaded Apple Branches. Journal of the American Society for Horticultural Science 119, 596–603. https://doi.org/10.21273/JASHS.119.3.596

Greene, D.W., 2017. Fruit thinning guided by physiological principles. Acta Hortic 1177, 41–50. https://doi.org/10.17660/ActaHortic.2017.1177.4

Greene, D.W., Lakso, A.N., Robinson, T.L., Schwallier, P., 2013. Development of a Fruitlet Growth Model to Predict Thinner Response on Apples. HortScience 48, 584–587. https://doi.org/10.21273/HORTSCI.48.5.584

INMET, 2022. Dados históricos anuais [WWW Document]. URL https://portal.inmet.gov.br/dadoshistoricos (accessed 8.7.22).

Iwanami, H., Moriya-Tanaka, Y., Honda, C., Wada, M., Moriya, S., Okada, K., Haji, T., Abe, K., 2012. Relationships among apple fruit abscission, source strength, and cultivar. Sci Hortic 146, 39–44. https://doi.org/10.1016/j.scienta.2012.08.017

Lakso, A.N., 2011. Early fruit growth and drop - the role of carbon balance in the apple tree. Acta Hortic 903, 733–742. https://doi.org/10.17660/ActaHortic.2011.903.102

Lakso, A.N., Goffinet, M.C., 2013. Apple Fruit Growth. New York Quarterly 21, 11–14.

Leite, G.B., Petri, J.L., Mondardo, M., 2002. Effects of net shield against hailstorm on feature of apples production and fruit quality. Rev. Bras. Frutic. 24, 714–716. https://doi.org/10.1590/S0100-29452002000300037

Lordan, J., Reginato, G.H., Lakso, A.N., Francescatto, P., Robinson, T.L., 2019. Natural fruitlet abscission as related to apple tree carbon balance estimated with the MaluSim model. Sci Hortic 247, 296–309. https://doi.org/10.1016/j.scienta.2018.11.049

McArtney, S.J., Obermiller, J.D., 2010. Evaluation of a model to predict the response of "Gala" apples to chemical thinners. Acta Hortic 884, 581–586. https://doi.org/10.17660/ActaHortic.2010.884.75

Michael, P.R., Johnston, D.E., Moreno, W., 2020. A conversion guide: Solar irradiance and lux illuminance. Journal of Measurements in Engineering 8, 153–166. https://doi.org/10.21595/jme.2020.21667

Milić, B., Tarlanović, J., Keserović, Z., Zorić, L., Blagojević, B., Magazin, N., 2017. The Growth of Apple Central Fruits as Affected by Thinning with NAA, BA and Naphthenic Acids. Erwerbs-Obstbau 59, 185–193. https://doi.org/10.1007/s10341-016-0310-x

Morandi, B., Zibordi, M., Losciale, P., Manfrini, L., Pierpaoli, E., Grappadelli, L.C., 2011. Shading decreases the growth rate of young apple fruit by reducing their phloem import. Sci Hortic 127, 347–352. https://doi.org/10.1016/j.scienta.2010.11.002

Nisler, J., 2018. TDZ: Mode of Action, Use and Potential in Agriculture, in: Thidiazuron: From Urea Derivative to Plant Growth Regulator. Springer Singapore, Singapore, pp. 37–59. https://doi.org/10.1007/978-981-10-8004-3_2

Petri, J.L., Schuck, E., Leite, G.B., 2001. Effects of thidiazuron (tdz) on fruiting of temperate tree fruits. Rev. Bras. Frutic., Jaboticabal-SP 23, 513–517. https://doi.org/10.1590/S0100-29452001000300012

Reis, M.G. dos, Ribeiro, A., 2020. Conversion factors and general equations applied in agricultural and forest meteorology. Agrometeoros 27. https://doi.org/10.31062/agrom.v27i2.26527

Robinson, T.L., Lakso, A.N., Greene, D.W., 2017. Precision crop load management: the practical implementation of physiological models. Acta Hortic 1177, 381–390. https://doi.org/10.17660/ActaHortic.2017.1177.55

Rufato, A.D., Robinson, T.L., Rufato, L., 2017. Precision thinning of 'Royal Gala' apple trees using the fruit growth model. Acta Hortic 1177, 399–404. https://doi.org/10.17660/ActaHortic.2017.1177.57

Salazar-Canales, F., Bastías, R.M., Calderón-Orellana, A., Wilckens, R., González, E., 2021. Photo-selective nets differentially affect microclimatic conditions, leaf physiological characteristics, and yield in hazelnut (Corylus avellana L.). Hortic Environ Biotechnol 62, 845–858. https://doi.org/10.1007/s13580-021-00365-8

Schröder, M., Link, H., Bangerth, K.F., 2013. Correlative polar auxin transport to explain the thinning mode of action of benzyladenine on apple. Sci Hortic 153, 84–92. https://doi.org/10.1016/j.scienta.2013.02.001

Solomakhin, A., Blanke, M., 2010. The microclimate under coloured hailnets affects leaf and fruit temperature, leaf anatomy, vegetative and reproductive growth as well as fruit colouration in apple. Annals of Applied Biology 156, 121–136. https://doi.org/10.1111/j.1744-7348.2009.00372.x

4 ARTIGO 2

Effect of anti-hail netting on microclimatic parameters and their influence on the effectiveness of chemical thinning of ‘Galaxy’ apple trees*

*Artigo formatado conforme as normas do periódico European Journal of Agronomy

EFFECT OF ANTI-HAIL NETTING ON MICROCLIMATIC PARAMETERS AND THEIR INFLUENCE IN THE EFFECTIVENESS OF CHEMICAL THINNING OF ‘GALAXY’ APPLE TREES

Lucas De Ross Marchioretto (a)*, Andrea De Rossi (b), Gilmar Arduino Bettio Marodin (a)

(a) Universidade Federal do Rio Grande do Sul (UFRGS), Faculdade de Agronomia, Departamento de Horticultura e Silvicultura. Av Bento Gonçalves, 7712, CEP 91540-000, Porto Alegre -RS, Brasil. lucas.marchioretto@ufrgs.br, marodin@ufrgs.br

(b) Embrapa Uva e Vinho, Br 285, s/n - Km 115, CEP 95200-000, Vacaria-RS, Brasil. andrea.derossi@embrapa.br

*Corresponding author: lucas.marchioretto@ufrgs.br (Lucas De Ross Marchioretto)

Abstract

Hail netting is a widely adopted strategy in modern orchards to overcome fruit and tree damage by hailstorms. However, due to the observed higher natural fruitlet drop, many producers have concerns regarding chemical thinners in covered orchards. Thus, the objective of this study was to evaluate the impact of white anti-hail netting on microclimatic parameters and evaluate their impact on the effectiveness of chemical thinning programs to adjust crop load and improve fruit quality of ‘Galaxy’ apples. The experiment was conducted over three consecutive cropping seasons. Nine chemical thinning programs were tested both in covered and uncovered with white hail netting areas. The treatments consisted of an [1] untreated control; [2] naphthalene acetic acid (NAA); [3] benzyladenine (BA); [4] metamitron (MM); [5] NAA+BA; [6] NAA+MM;

Abbreviations: PGR: Plant Growth Regulator; PAR: Photosynthetically Active Radiation; UC: Untreated Control; NAA: Naphthalene Acetic Acid; BA: Benzyladenine; MM: Metamitron; MTO: Manual Thinning Only.

[7] BA+MM; [8] NAA+BA+MM; [9] manual thinning only control. NAA was sprayed at full bloom, BA on fruitlet diameter of 8 mm, and MM on fruitlet diameter of 15 mm. Netting affected the microclimate by reducing photosynthetically active radiation in 16%, increasing minimum temperature in 2%, and decreasing maximum temperature in 3%. These modifications on the microclimate led to an increase of the natural fruitlet abscission, and also extended the abscission period by the chemical thinners. However, it did not cause overthinning, as seemingly the increase of abscission promoted by the netting decreased the competition promoted by the PGRs. The combination of netting and chemical thinners did not cause overthinning. The netting decreased fruit skin russeting, but decreased fruit red color. The PGRs used as chemical thinners NAA at full bloom followed by BA at fruitlet diameter 8 mm are effective to adjust crop load, improve fruit weight and fruit appearance.

Keywords: naphthalene acetic acid; benzyladenine; metamitron; shading; plant growth regulators; *Malus domestica* Borkh.

4.1. Introduction

In recent decades Brazil has shifted from an importer of apples to an exporter (Petri et al., 2011). In the year of 2020, the Brazilian apple production ranked as the 15th highest worldwide, with a production of 983,247 tonnes of fruit, and a cropping yield of 30.3 tonnes.ha^{-1} (FAO, 2022). In addition, in 2021, total apple production of Brazil was 1,297,424 tonnes, and yield of 39.4 tonnes.ha^{-1} (FAO, 2022). In Brazil, apple orchards occupy an area of 32,890 hectares, and most of the areas are located in Southern Brazil (IBGE, 2022) due to the more suitable climate (Alvares et al., 2013).

The Southern region of Brazil accounts for more than 60% of the hail occurrences in the country, and the occurrence is mostly concentrated on the months from August to November, which coincides with the transition from winter to spring (Martins et al., 2017). To overcome this problem most new orchards are implemented under anti-hail netting, which is the most effective way of protecting the fruits and the trees against hail damage (Lazzarotto & Fioravanço, 2020). On the other hand, the reduced availability of the Photosynthetically Active Radiation (PAR) promoted by the netting brings some setbacks to the apple trees, such as higher vegetative growth, increased leaf expansion with diminished thickness, higher rate of fruitlet abscission, and reduced fruit skin red color (Brglez-Sever et al., 2021; Solomakhin & Blanke, 2010).

The Plant Growth Regulators (PGRs) commonly used for fruitlet thinning: Naphthalene Acetic Acid (NAA), Benzyladenine (BA), and Metamitron (MM), act on modulating the source:sink relation of the apple trees (Eccher et al., 2013; Zhu et al., 2011), by enhancing the natural stress that happens post-blossom due to all growing organs to be in intense competition for assimilates, and the availability to support this growth is switching from the starch stored from the previous season to the leaves currently photosynthesizing (Lordan et al., 2019). In this context, there are few studies that show higher natural fruitlet drop of apple trees under netting (Brglez-Sever et al., 2021; Solomakhin & Blanke, 2008), and hazelnut (Salazar-Canales et al., 2021), although little is known about the effect of the hail net shading on the fruitlet thinning effect of the PGRs. Thus, the objective of this study was to evaluate the impact of anti-hail netting on microclimatic parameters and evaluate their impact on the effectiveness of chemical thinning programs in adjusting crop load and improve fruit quality.

4.2. Material and methods

Study site, treatments, and experimental design

The experiment was carried out on three consecutive cropping seasons (2019/20, 2020/21, and 2021/22) in a commercial orchard located in Bom Jesus, Rio Grande do Sul State, Brazil (28°35’58.18”S, 50°29’47.43”O, elevation of 1032 m above sea level). The orchard was implemented in 2006 with ‘Galaxy’ apple trees grafted on M9 rootstocks, and ‘Fuji Suprema’ as the pollinizer. Tree spacing was 4 m between rows and 0.6 m between trees (4167 trees.ha^{-1}), and the training system was a tall spindle. The orchard was covered with white color anti hail netting of mesh 4 x 8 mm. The soil of the region is classified as an Entisol, which is characterized as shallow, stony, and with a high organic matter content on the top layer (UFSM, 2023). The climate of the region according to the Koppen’s classification is a Cfb with temperatures ranging from 15 to 25 °C in the summer, and 7 to 16 °C in the winter, and mean annual precipitation of 1789 mm (Alvares et al., 2013). The experiment was conducted in a randomized complete block in a split-plot arrangement, where netting environments (with and without netting) was the main plots, and nine thinning programs were the subplots. For each treatment into the subplots, the treatments were arranged into three blocks (3 apple rows), and for each treatment into each block, there was three replicates (trees), totalizing nine replicate trees per treatment.

The treatments evaluated in the environments with and without netting were: [1] Untreated Control (UC); [2] Naphthalene acetic acid (NAA) (ANA técnico, 9.5 g a.i. ha^{-1}, 10 g.ha^{-1}), sprayed at full bloom; [3] Benzyladenine (BA) (Maxcel, 100 g a.i. ha^{-1}, 5 L.ha^{-1}), sprayed at fruitlet diameter of 8 mm, [4] Metamitron (MM) (Goltix, 98 g a.i. ha^{-1}, 140 g.ha^{-1}), sprayed at fruitlet diameter of 15 mm; [5] NAA + BA; [6] NAA+MM; [7]

BA+MM; [8] NAA+BA+MM; [9] Manual Thinning Only (MTO). These concentrations were used in the first season, and for the second and third seasons, BA and MM were increased to 120 g a.i. ha^{-1}, and 196 g a.i. ha^{-1}, respectively due to low effectiveness in the first season. The treatments were sprayed with a motorized backpack sprayer calibrated to deliver 1000 L.ha^{-1} of water. It was added the surfactant adjuvant Break thru at 0.15 v/v in all sprayed treatments.

The phenological stages, dates and correspondingly days after full bloom (DAFB) of the PGR applications were as follows: in 2019/20, full bloom (FB) was on Oct 10th, 2019 [NAA]; fruitlet diameter of 8 mm was at 15 DAFB [BA]; and fruitlet diameter of 15 mm was at 27 DAFB [MM]. In 2020/21, FB was on Sept 28th, 2020 [NAA]; fruitlet diameter of 8 mm was at 15 DAFB [BA], and fruitlet diameter of 15 mm was at 25 DAFB [MM]. In 2021/22, FB was on Sept 21st, 2021 [NAA]; fruitlet diameter of 8 mm was at 13 DAFB [BA], and fruitlet diameter of 15 mm was at 27 DAFB [MM].

Measurement of temperature, relative humidity, and solar radiation of apple orchards covered and uncovered with white anti-hail netting

In the cropping season of 2021/22, meteorological data of temperature and relative humidity were obtained from two meteorological stations: a Campbell Scientific (Logan, USA) station equipped with a CR10X datalogger to record temperature and relative humidity. The other station was a Solar model SL2000 E8C (Florianópolis, Brazil) unit also equipped with temperature and relative humidity sensors. Both meteorological stations were programmed to record data every 15 minutes. Prior to installing in the experimental area, the stations were installed side by side and data recorded throughout three days were compared to check any difference between the sensors. No differences was found for both variables. The Photosynthetically Active Radiation (PAR: 400-700 nm) was simultaneously measured with two BH1750FVI luminosity sensors (Rohm, Kyoto, Japan) attached to an Arduino Uno board (Sparkfun, Niwot, USA) equipped with a datalogger shield (Adafruit, New York City, USA), which was programmed to record simultaneous data every 15 minutes. The output luminosity data was expressed in Lummens.m^{-2}, then converted into Watts.m^{-2} according to (Michael et al., 2020), and into µmol.m^{-2}.s^{-1} according to (Reis & Ribeiro, 2020). PAR, temperature, and relative humidity data were compared with an official (INMET, 2022) meteorological station. Again, no differences were found.

The Campbell meteorological station was installed in the orchard covered with white hail netting between two apple trees, where there was a space with no tree in the row. In this station, the luminosity sensors along with the Arduino Board were connected to an USB output from the solar energy controller to supply energy for the Arduino. Then, one sensor was installed above the netting level, to obtain the luminosity without netting, and the other sensor was installed 60 cm above the canopy level and 2 meters below the netting level, to avoid shading from the trees, and measure only the luminosity underneath the netting. The Solar meteorological station was installed about 80 m of distance in an uncovered orchard.

Determination of the fruitlet abscission dynamic as a function of hail netting and PGRs used as chemical thinners

On the cropping seasons of 2019/29 and 2020/21, it was constructed collectors made of bamboo and hail netting underneath the canopy projection of three apple trees, looking for collecting the dropped fruitlets every three or four days per week, from pink balloon stage until the end of December drop (~December 20th). This was done with the treatments NAA, BA, MM, and UC in the covered and uncovered areas. Also, the dropped fruitlets were counted, and a sample of 50 fruitlets was taken to measure the diameter with a digital caliper.

Yield and fruit quality assessments

At pink balloon stage, three branches on opposite sides of the canopy were tagged with the number of flower clusters recorded. After December drop, the remaining fruits of each branch were counted to determine fruit set (fruits/flower cluster).

The harvest in the first, second, and third seasons occurred on Feb 17th, 2020, Jan 26th, 2021, and Feb 01st, 2022, respectively. At harvest, the number of fruits and the yield of each tree was determined. Trunk perimeter was measured after harvest to determine the trunk cross sectional area (TCSA).

At harvest, a sample of 30 fruits per replicate tree was collected to determine fruit coverage with red color into the classes: 0-25, 25-50, 50-75, and 75-100 percent of fruit surface covered with red color, and skin russeting into the classes: 0, ≤10, 10-30, 30-50, and ≥50 percent of fruit surface covered with russeting. Then, a subsample of 20 fruits was collected to determine seed number, flesh firmness, and total soluble solids (TSS). Firmness was determined with a hand-held analogic penetrometer equipped with an 11 mm Magness-Taylor plunger. TSS were determined with a digital refractometer Atago PAL-1 (Atago Brasil Equipamentos Ltda, Ribeirão Preto, Brazil). Mean fruit weight was determined by dividing the yield by the number of fruits of each tree. Return bloom was assessed on the following spring, by selecting three branches of each tree to count the total number of buds and the number of floral buds to calculate the percentage.

Statistical analysis

The counting data of the fruitlet abscission dynamic were converted into cumulative frequency. A three-parameter logistic regression (“S” shaped curve) was calculated to obtain the parameters α, β, and λ, which represent the asymptote, the xmid (inflection point), and the angular coefficient at the inflection point, respectively. The parameters were calculated using R software v.4.2.3, and self-starting logistic models with the function “nls” of the package “stats”.

The meteorological data for PAR, mean, maximum, and minimum temperatures (°C), and mean, minimum, and maximum relative humidity, as well as the diameter of the dropped fruitlets were subjected to linear regression through the origin ($y=a*x$), where y was the output under netting, and x was the same output outside netting, and “a” was the slope. The outputs were calculated using R software v.4.2.3, and the regression through the origin with the function “lm” of the package “stats”.

The data of yield and fruit quality assessments were subjected to mixed-model analysis of variance using the R package “lme4”. The factors years, netting, and PGRs were set as fixed effects, whereas blocks, year*blocks*trees were set as random effects. Mean comparisons were done using the R package “emmeans”. The means of the interactions of PGRs*netting were separated though the Tukey’s HSD test ($p\leq0.05$), and interactions of netting*PRGs were separated through confidence intervals ($p\leq0.05$). Fruit set data were analyzed through linear contrasts.

4.3. Results

Effect of hail netting on the microclimate

Throughout FB on September 21st, 2021, until harvest on February 1st, 2022, the presence of white anti-hail netting modified some microclimatic parameters (Table 1). The most affected parameter was PAR, as the netting reduced it in 16%. Also, under netting the mean temperature was 1% lower, and maximum daily temperature was 3% lower than the uncovered area. On the other hand, minimum temperatures were 2% higher than the uncovered area. Likewise, the mean, minimum and maximum relative humidity were 4%, 8%, and 2% higher in the covered area, respectively.

Table 1. Microclimatic parameters determined from a covered and uncovered orchard analyzing data through linear correlation through the origin (y=a.x) where “y” is the output under netting and “x” is the output of the uncovered ‘Galaxy’ orchard in the season of 2021/22 at Bom Jesus, RS/Brazil.

Parameter	Slope (a)	Netting effect (%)	R^2
Photosynthetically active radiation ($\mu mol.m^{-2}.s^{-1}$)	0.84	-16	0.99
Mean temperature (°C)	0.99	-1	0.99
Maximum temperature (°C)	0.97	-3	0.99
Minimum temperature (°C)	1.02	+2	0.99
Mean relative humidity (%)	1.04	+4	0.99
Minimum relative humidity (%)	1.08	+8	0.99
Maximum relative humidity (%)	1.02	+2	0.99

Effect of hail netting on the fruitlet abscission dynamic as a function of the sprays of PGRs

The three-parameter logistic regression calculated from the cumulative frequency of the abscised fruitlets (Table 2, and Appendix A and B) brought as the output the parameters α, which represents the asymptote (point of saturation), the parameter β, which represents the midpoint (inflection point), and the parameter λ, which represents the angular coefficient at the inflection point (steepness at the inflection point).

In the first season, in the uncovered orchard, NAA slightly advanced the inflection point in one day (β=18.30), in relation to its UC (β=19.22), and in the covered orchard, it advanced more than two days the β parameter (NAA β=17.28; UC β=19.53); also, in the uncovered area, the λ parameter was similar, although in the covered area, in the comparison of this parameter with the UC, it was higher for NAA than the UC (λ = 3.90 vs 4.49) (Table 3, and Appendix A and B). Both parameters indicate that NAA advanced fruitlet drop in both environments. However, NAA in the covered condition advanced the inflection point and had a steeper λ than in the uncovered condition. In addition, the UC had similar β, but in the covered condition, the λ was steeper, indicating higher speed of abscission, as well as higher α, indicating a higher plateau in such condition.

In the uncovered orchard, BA seemed to retard fruitlet abscission in a first moment, as the β was higher than its UC, although it had a higher plateau, indicating that the abscission effect occurred latter (Table 3, and Appendix A and B). In contrast, in the covered orchard both BA and the UC had lower β than the uncovered condition, as the netting advanced the inflection point in seven days with BA, and three days in the UC; Also, the λ was steeper for both treatments in the covered orchard, indicating higher speed of fruitlet drop. With MM, the influence of the netting was negligible, although, in the covered orchard, the UC presented lower β.

On the second season, there was alternate bearing. Nevertheless, the abscission behavior was different than in the previous season (Table 3, and Appendix A and B).

Overall, BA and MM presented a higher β than their UCs, as well as a higher λ, indicating that their effect on the abscission took longer, i.e., fruitlet drop extended for longer in both netting conditions (with and without netting). Same trend could be observed for the PGRs on each netting condition, where under netting the fruitlet drop was slower but longer. Overall, it could be observed that with a high initial but load, the PGRs accelerate fruitlet drop, and the netting made the abscission faster, whereas on the alternate bearing season, the netting made fruitlet drop at more reduced rates, and with the PGRs in the covered orchard, fruitlet drop was slower but lasted longer.

Table 2. Coefficients α (saturation point), β (point of inflection), and λ (angular coefficient) of logistic regressions calculated upon cumulative frequency (%) of the abscised fruitlets of ‘ Galaxy’ apple trees as a function of different PGR treatments for fruitlet thinning and their untreated controls.

Season	Netting	Treatment	3-parameter logistic regression coefficients[1]			
			Plant growth regulators	R^2	Untreated control	R^2
2019/20	No netting	NAA	α=91.83, β=18.30, λ=5.41	$R^2 = 0.97$	α=91.81, β=19.22, λ=5.15	$R^2 = 0.98$
		BA	α=99.82, β=27.68, λ=7.21	$R^2 = 0.97$	α=96.61, β=23.84, λ=7.14	$R^2 = 0.93$
		MM	α=99.47, β=38.11, λ=3.66	$R^2 = 0.99$	α=98.67, β=38.60, λ=3.68	$R^2 = 0.99$
	Under netting	NAA	α=96.67, β=17.28, λ=4.49	$R^2 = 0.99$	α=95.18, β=19.53, λ=3.90	$R^2 = 0.99$
		BA	α=93.49, β=20.20, λ=2.94	$R^2 = 0.95$	α=93.32, β=21.02, λ=3.22	$R^2 = 0.96$
		MM	α=100,00 β=38.35 λ=3.84	$R^2 = 0.99$	α=97.92, β=36.65, λ=3.87	$R^2 = 0.98$
2020/21	No netting	NAA	α=99.06, β=19.23, λ=3.75	$R^2 = 0.99$	α=99.58, β=18.02, λ=3.77	$R^2 = 0.99$
		BA	α=97.36, β=23.48, λ=3.56	$R^2 = 0.97$	α=98.38, β=22.05, λ=2.46	$R^2 = 0.97$
		MM	α=97.62, β=30.16, λ=2.91	$R^2 = 0.96$	α=97.28, β=28.94, λ=1.58	$R^2 = 0.99$
	Under netting	NAA	α=96.87, β=21.76, λ=3.66	$R^2 = 0.99$	α=97.83, β=21.54, λ=4.54	$R^2 = 0.99$
		BA	α=98.01, β=26.87, λ=5.11	$R^2 = 0.99$	α=95.92, β=24.62, λ=3.34	$R^2 = 0.97$
		MM	α=100.00, β=39.15, λ=5.17	$R^2 = 0.98$	α=98.49, β=32.69, λ=3.99	$R^2 = 0.97$

[1] Note: α=asymptote; β=inflection point; λ=angular coefficient at the inflection point.

There were different behaviors regarding the effect of hail net covering on the diameter of the abscised fruitlets (Table 3). In the spring of 2019/20, in all treatments, the diameter of the abscised fruitlets were bigger in the uncovered area than under hail netting. In the following season, that same outcome was only observed in the UC trees. In the first season, for the UC, the difference was negligible, but for the PGRs, the abscised fruitlets were 12 to 14% bigger in the uncovered condition. On the following season, the opposite occurred for all PGRs, although for BA and MM the difference between growth conditions was outstanding with 13 and 14% bigger fruitlets were abscised under netting in relation to the uncovered area.

This difference of diameter on both seasons may have been due to the initial bud load, as in the first season was high (est. 226 clusters per tree, ON year), and in the second season was low (est. 96 clusters per tree, OFF year). As the intensity of competition under netting was higher, and the dropped fruitlets were smaller, it is likely that fruitlets under netting abscised earlier than outside; whereas in the second season, under netting it’s likely that the fruitlets abscised later than outside, as due to less competition, the trees could sustain fruitlet growth for longer.

Table 3. Effect of white anti-hail netting on the diameter of abscised fruitlets of ‘Galaxy’ apples from full bloom until December Drop of a covered orchard in comparison to an uncovered orchard determined through linear correlation through the origin (y=a.x) where “y” is the output of the covered orchard and “x” is the output of the uncovered orchard in the seasons of 2019/20 and 2020/21 at Bom Jesus, RS/Brazil.

	2019/20			2020/21		
Parameters	Slope (a)	Netting effect (%)	R^2	Slope (a)	Netting effect (%)	R^2
UC	0.99	-1	0.98	0.82	-18	0.93
NAA	0.88	-12	0.98	1.02	+2	0.92
BA	0.88	-12	0.98	1.14	+14	0.96
MM	0.86	-14	0.99	1.13	+13	0.99

Effect of hail netting on fruit set, crop load, yield efficiency, and return bloom as a function of sprays of PGRs

In the first season (2019/20), none of the PGR treatments differed from the UC for fruit set in the covered area, although, in the uncovered area, the treatments NAA+BA, NAA+MM, BA+MM (trend), and NAA+BA+MM presented lower fruit set then the UC. In addition, the control trees presented lower fruit set in the uncovered area (Table 4). In the following season (2020/21), in the covered area, only NAA had lower fruit set than the UC, while the other PGR treatments did not differ from the UC; however, in the uncovered area, NAA, NAA+BA, and BA+MM had lower fruit set than the UC. In addition, the treatments NAA+BA and BA+MM had lower fruit set in the uncovered area, while the FB UC was higher in the uncovered area. In the third season (2021/22), in the covered area, NAA and NAA+MM had lower fruit set in comparison to the UC, while in the uncovered area MM had lower fruit set, whereas NAA+BA and BA+MM had a trend to have lower fruit set than the UC. In addition, the UC 15 mm had higher fruit set in the uncovered area, while NAA+BA (trend) and NAA+MM had lower fruit set in the uncovered area.

It is noteworthy that with the UCs, there was a decreasing gradient of fruit set from FB until fruitlets with 15 mm in the covered orchard; therefore, this gradient was quite mild in the uncovered orchard, depicting the higher natural fruitlet drop under netting.

Table 4. Fruit set (fruitlets/cluster) of ‘Galaxy’ apple trees as a function of different combinations of PGRs used as chemical thinners on growing conditions with and without anti-hail netting.

	2019/2020-1		2020/2021[1]		2021/2022[1]	
Treatments	Covered	Uncovered	Covered	Uncovered	Covered	Uncovered
UC FB	1.30	1.37^{ns}	1.62	2.25*	0.95	0.77^{ns}
UC 8 mm	1.18	1.35^{ns}	1.52	1.17^{ns}	0.71	0.90^{ns}
UC 15 mm	1.05	1.24^{ns}	1.06	1.17^{ns}	0.52	1.25**
NAA	1.43	1.26^{ns}	1.04	1.28^{ns}	0.36	0.64^{ns}
BA	1.01	1.33^{ns}	1.49	1.15^{ns}	0.74	0.92^{ns}
MM	1.19	0.97^{ns}	1.06	1.45^{ns}	0.81	0.74^{ns}
NAA+BA	1.03	0.83^{ns}	1.90	0.58***	0.85	$0.43^{\cdot}$
NAA+MM	1.08	0.79^{ns}	1.65	1.97^{ns}	0.46	0.95*
BA+MM	1.17	0.90^{ns}	1.39	0.58**	0.81	0.49^{ns}
NAA+BA+MM	1.13	0.57*	1.74	1.83^{ns}	0.72	0.72^{ns}
Contrasts						
UC FB vs NAA	ns	ns	*	**	**	ns
UC 8 mm vs BA	ns	ns	ns	ns	ns	ns
UC 15 mm vs MM	ns	ns	ns	ns	ns	*
UC FB vs NAA+BA	ns	*	ns	***	ns	.
UC FB vs NAA+MM	ns	*	ns	ns	*	ns
UC 8 mm vs BA+MM	ns	.	ns	**	ns	.
UC FB vs NAA+BA+MM	ns	**	ns	ns	ns	ns

Note: [1]Data transformed through $\sqrt{y} + 0.5$. Data analyzed through linear contrasts. ^{ns}, $\cdot$, *, **, *** denote non-significance, significance at p.≤0.1, p.≤0.05, p≤0.01, and p≤0.0001, respectively.

Crop load in the first season was significantly lower than the UC with NAA+BA and NAA+BA+MM in the covered area, and in the uncovered area only NAA+BA+MM and the MTO had lower crop load than the UC (Table 5). In addition, NAA, NAA+BA, and NAA+BA+MM presented higher crop loads in the uncovered area than in the covered area. In the second season, in both covered and uncovered areas, NAA+BA, NAA+MM, and NAA+BA+MM presented lower crop loads than the UC, however, in the uncovered area, NAA alone also had lower crop load than the UC. In the third season, except BA and BA+MM in the covered area, all other treatments had lower crop load in comparison to the UC. In the uncovered area, all treatments had lower crop load than the UC, and the treatments BA, BA+MM, NAA+BA+MM, and the MTO had lower crop load in the uncovered area.

The crop load target in ‘Galaxy’ apple trees was around 3.56 fruits.cm^{-2} TCSA, in the covered orchard, and 3.82 fruits.cm^{-2} TCSA in the uncovered orchard to achieve 135 fruits per tree. In the first season (ON), only NAA+BA+MM in the covered area adjusted crop load near the target. In the second season (OFF), due to lower initial flower bud load, the treatments NAA, MM, and BA+MM reduced crop load adequately in the covered area, and BA and BA+MM in the uncovered area. In the third season (ON), all treatments containing NAA reduced crop load adequately in the covered area, whereas in NAA alone was adequate in the uncovered area.

Yield efficiency, which represents a relation of Kg of fruit per canopy volume, in the first season was significantly reduced in comparison to the UC, in the covered area, by the treatment NAA+BA+MM. In the uncovered area, only the MTO was significantly lower than the UC (Table 6). In addition, with NAA and NAA+BA+MM yield efficiency was higher in the uncovered area than the covered area. In the second season, in the covered area, only NAA+BA, and NAA+BA+MM had lower yield efficiency than the

UC, whereas in the uncovered area only NAA+MM had significantly lower yield efficiency than the UC. In the third season, in the covered area the treatments NAA+BA, NAA+MM, and NAA+BA+MM had lower yield efficiency than the UC. In the uncovered area, except BA and MM alone, all other treatments had lower yield efficiency than the UC. On the other hand, BA, MM, and NAA+BA+MM had significantly lower yield efficiency in the uncovered area.

Return bloom, in the first season, was impacted by treatment only in the covered area (Table 6). Overall, all treatments had return bloom similar to the UC, although NAA, and NAA+MM had lower return bloom in relation to NAA+BA+MM, even though all treatments did not differ from the UC. Moreover, the netting effect played a role with NAA+MM, as a higher return bloom was observed in the uncovered area. In the second season, for both growth conditions no treatment effect was determined. Regarding the netting effect, return bloom for the MTO treatment in the uncovered area was higher. In the third season, in the covered area BA, NAA+BA, NAA+MM, and NAA+BA+MM had higher return bloom than the UC. On the other hand, in the uncovered area, no treatment differed from the UC.

The targeted return bloom for this orchard was around 43% for an initial bud load of at least 60 clusters per tree. In this experiment, minimum return bloom was achieved with all treatments containing PGRs in the second and third seasons, likely due to the increase of the concentrations of BA and MM, as in the first season, thinning and return bloom was poor.

Table 5. Crop load, yield efficiency, and return bloom of ‘Galaxy’ apple trees as a function of different combinations of PGRs used as chemical thinners on growing conditions with and without anti-hail netting.

Treatments	Crop Load (fruits.cm^{-2} TCSA)^{1}		Yield Efficiency (Kg.cm^{-2} TCSA)^{1}		Return Bloom (%)^{1}	
2019/20 season	Covered	Uncovered	Covered	Uncovered	Covered	Uncovered
UC	8.5 a	10.4^{ns} a	0.65 a	0.80^{ns} a	21 ab	16^{ns} a
NAA	6.7 abc	9.4 * ab	0.56 ab	0.76 * ab	11 b	15^{ns} a
BA	7.9 ab	7.8^{ns} abc	0.60 a	0.64^{ns} ab	20 ab	20^{ns} a
MM	8.1 ab	9.8^{ns} ab	0.62 a	0.77^{ns} a	19 ab	16^{ns} a
NAA+BA	5.6 bc	8.1 * abc	0.51 ab	0.65^{ns} ab	23 ab	18^{ns} a
NAA+MM	6.7 ab	8.2^{ns} abc	0.57 ab	0.71^{ns} ab	12 b	25 * a
BA+MM	7.8 ab	7.6^{ns} abc	0.58 a	0.62^{ns} ab	17 ab	21^{ns} a
NAA+BA+MM	4.4 c	7.0 * bc	0.37 b	0.61 * ab	31 a	19^{ns} a
MTO	6.3 abc	6.4^{ns} c	0.59 a	0.54^{ns} b	18 ab	21^{ns} a
2020/21 season						
UC	5.1 a	4.7^{ns} a	0.49 a	0.43^{ns} a	33 a	45^{ns} a
NAA	3.9 abc	2.9^{ns} b	0.45 ab	0.33^{ns} ab	43 a	58^{ns} a
BA	5.1 a	3.9^{ns} ab	0.44 ab	0.38^{ns} ab	46 a	54^{ns} a
MM	3.9 abc	2.8^{ns} ab	0.40 ab	0.31^{ns} ab	39 a	58^{ns} a
NAA+BA	2.3 c	2.3^{ns} b	0.30 b	0.28^{ns} ab	42 a	52^{ns} a
NAA+MM	2.4 bc	2.3^{ns} b	0.34 ab	0.28^{ns} b	39 a	46^{ns} a
BA+MM	3.4 abc	3.8^{ns} ab	0.34 ab	0.41^{ns} ab	45 a	61^{ns} a
NAA+BA+MM	2.6 bc	2.6^{ns} b	0.31 b	0.34^{ns} ab	43 a	62^{ns} a
MTO	4.2 ab	2.8^{ns} ab	0.45 ab	0.34^{ns} ab	36 a	61 * a
2021/22 season						
UC	10.0 a	8.5^{ns} a	0.69 a	0.66^{ns} a	19 b	57 * abc
NAA	4.0 cd	3.2^{ns} cd	0.48 abc	0.37^{ns} bcd	34 ab	62 * abc
BA	8.5 ab	5.8 * b	0.66 ab	0.48 * abc	39 a	58 * abc
MM	6.8 bc	6.0^{ns} b	0.54 abc	0.51 * ab	33 ab	50^{ns} abc
NAA+BA	4.0 d	2.6^{ns} d	0.45 c	0.31^{ns} cd	40 a	67 * ab
NAA+MM	4.1 d	2.8^{ns} d	0.45 c	0.31^{ns} cd	47 a	69 * a
BA+MM	7.5 ab	4.8 * bc	0.59 abc	0.37^{ns} bcd	30 ab	41^{ns} c
NAA+BA+MM	4.1 d	2.4 * d	0.46 bc	0.29 * d	42 a	58^{ns} abc
MTO	7.1 bc	4.9 * bc	0.57 abc	0.42^{ns} bcd	31 ab	43^{ns} bc

Note: ^{1}Data transformed through $\sqrt{y}$. Treatment means into each level of netting followed by different letters in a column are significantly different according to the Tukey's HSD test ($p \leq 0.05$). Growth condition into each level of treatment means followed by * and ^{ns} in a row are significant and non-significant, respectively according to confidence intervals ($p \leq 0.05$).

Effect of hail netting on fruit weight, seed number, and total soluble solids as a function of sprays of PGRs

Flesh firmness was not affected by treatment or netting (data not shown). Fruit weight in the first season was not improved by the PGR treatments in the covered area and in the uncovered area (Table 6). In the second season, for both the covered and uncovered areas, bigger fruits were obtained with all the treatments containing NAA. In addition, in the uncovered area, these treatments were equivalent to the MTO control. Even though BA had fruit weight equivalent to the UC, in the uncovered area the fruit weight was higher. Similarly, the MTO presented heavier fruits in the uncovered area. In the third season, for both growing conditions, all treatments containing NAA presented heavier fruits.

Fruit seed number in the first season was not affected by treatment in the covered condition, although in the uncovered area, the fruits from the UC had the highest seed number, while NAA+BA and NAA+BA+MM had the lowest. The latter treatment also presented lower seed count in the uncovered condition (Table 6). In the second season, in the covered condition, the treatments BA, NAA+BA, and NAA+BA+MM induced lower seed number in relation to the UC, whereas in the uncovered area, all treatments were equivalent to the UC. In the third season, the treatments NAA, and NAA+MM reduced fruit seed number in relation to the UC, whereas in the uncovered area besides NAA and NAA+MM, also NAA+BA, and NAA+BA+MM negatively affected seed development.

Total soluble solids (TSS) in the first season was not impacted by treatments in both growing conditions (Table 6). Although, the netting induced lower TSS for NAA+BA, NAA+MM, and the MTO treatment. In the second season, in the covered area, all treatments presented higher TSS values than the UC. No treatment effect was found in the uncovered area. Regarding the netting effect, the UC, MM, and NAA+MM had higher TSS concentrations in the uncovered area. In the third season, no treatment effect was found in the covered area, however in the uncovered condition all treatments had higher TSS concentration, except with BA and MM. Also, in the uncovered area, higher TSS concentrations were found for all treatments, except MM.

Table 6. Fruit weight, seed number, and total soluble solids of 'Galaxy' apple fruits as a function of different combinations of PGRs used as chemical thinners on growing conditions with and without anti-hail netting.

Treatments	Fruit Weight (g)		Seed Number		Total Soluble Solids (°Brix)	
2019/20 season	Covered	Uncovered	Covered	Uncovered	Covered	Uncovered
UC	77 ab	76 ^{ns} a	4.1 a	4.0 ^{ns} a	11.5 ab	12.0 ^{ns} a
NAA	82 ab	82 ^{ns} a	3.9 a	3.1 ^{ns} abc	11.5 ab	11.9 ^{ns} a
BA	78 ab	84 ^{ns} a	4.2 a	3.2 ^{ns} abc	11.5 ab	12.0 ^{ns} a
MM	77 ab	79 ^{ns} a	4.1 a	3.9 ^{ns} ab	11.7 ab	12.1 ^{ns} a
NAA+BA	91 ab	80 ^{ns} a	3.5 a	3.0 ^{ns} bc	11.0 b	12.1 * a
NAA+MM	86 ab	86 ^{ns} a	3.6 a	3.2 ^{ns} abc	11.4 ab	12.3 * a
BA+MM	74 b	83 ^{ns} a	3.8 a	3.6 ^{ns} abc	11.9 a	12.1 ^{ns} a
NAA+BA+MM	84 ab	87 ^{ns} a	3.9 a	2.8 * c	12.2 a	12.2 ^{ns} a
MTO	94 a	84 ^{ns} a	3.9 a	3.4 ^{ns} abc	11.5 ab	12.5 * a
2020/21 season						
UC	97 de	92 ^{ns} d	5.9 a	5.7 ^{ns} ab	11.8 b	12.8 * a
NAA	114 abcd	125 ^{ns} ab	4.8 abc	5.3 ^{ns} ab	12.3 ab	13.0 ^{ns} a
BA	86 e	104 * cd	4.2 c	4.7 ^{ns} b	12.5 ab	13.0 ^{ns} a
MM	104 cd	110 ^{ns} bc	5.8 a	5.9 ^{ns} a	12.4 ab	13.2 * a
NAA+BA	129 a	130 ^{ns} a	4.0 c	4.6 ^{ns} b	12.7 a	12.9 ^{ns} a
NAA+MM	126 ab	122 ^{ns} ab	5.3 ab	5.1 ^{ns} ab	12.4 ab	13.1 * a
BA+MM	105 cd	111 ^{ns} bc	4.9 abc	5.1 ^{ns} ab	12.6 ab	13.0 ^{ns} a
NAA+BA+MM	121 abc	133 ^{ns} a	4.3 bc	4.9 ^{ns} ab	12.8 a	13.2 ^{ns} a
MTO	109 bcd	124 * ab	5.8 a	6.1 ^{ns} a	12.2 ab	12.9 ^{ns} a
2021/22 season						
UC	70 b	79 ^{ns} b	3.7 a	3.8 ^{ns} a	11.9 a	13.1 * ab
NAA	103 a	117 ^{ns} a	2.8 b	2.6 ^{ns} d	11.4 a	13.2 * a
BA	79 b	90 ^{ns} b	3.4 ab	3.7 ^{ns} abc	11.6 a	12.3 * bc
MM	81 b	91 ^{ns} b	3.6 ab	3.6 ^{ns} abc	11.9 a	12.1^{ns} c
NAA+BA	112 a	122 ^{ns} a	3.0 ab	2.7 ^{ns} d	11.5 a	12.9 * abc
NAA+MM	113 a	117 ^{ns} a	2.8 b	2.9 ^{ns} bcd	11.6 a	12.8 * abc
BA+MM	80 b	82 ^{ns} b	3.3 ab	3.2 ^{ns} abcd	11.7 a	12.6 * abc
NAA+BA+MM	117 a	124 ^{ns} a	2.9 ab	2.8 ^{ns} cd	11.7 a	12.8 * abc
MTO	81 b	93 ^{ns} b	3.4 ab	3.7 ^{ns} ab	11.3 a	12.9 * abc

Note: Treatment means into each level of netting followed by different letters in a column are significantly different according to the Tukey's HSD test (p≤0.05). Growth condition into each level of treatment means followed by * and ^{ns} in a row are significant and non-significant, respectively according to confidence intervals ($p \leq 0.05$).

Fruits had more incidence of moderate skin russeting (10-30%) in the uncovered area (Table 7) in all seasons. In the first season, more fruits had no russeting of low coverage (<10%) with NAA+BA+MM in the covered area, although in the uncovered orchard, more fruits had severe russeting (>50% with this treatment) in comparison to the other treatments. In the second and third seasons no treatment differed from the UC in all classes of russeting, except MTO in the third season, which had more fruits with no russeting in the uncovered area.

Table 7. Fruit coverage with russeting of ‘Galaxy’ apple trees as a function of different combinations of PGRs used as chemical thinners on growing conditions with and without anti-hail netting.

Treatments	Classes of fruit surface covered with russeting (%)									
	0		≤10		10-30		30-50		≥50	
2019/20 season	Covered	Uncovered	Covered	Uncovered	Covered	Uncovered	Covered	Uncovered	Covered	Uncovered
UC	19 bc	9* a	52 a	43^{ns} a	29 ab	44* a	0 a	3* a	0 a	0^{ns} b
NAA	22 abc	11* a	47 a	39^{ns} a	30 ab	43^{ns} a	1 a	7* a	0 a	0^{ns} b
BA	20 bc	13* a	54 a	41^{ns} a	26 ab	40* a	0 a	7* a	0 a	0^{ns} ab
MM	27 abc	17* a	47 a	35^{ns} a	26 ab	37* a	0 a	4^{ns} a	0 a	0^{ns} b
NAA+BA	32 ab	13* a	45 a	35^{ns} a	22 ab	49* a	1 a	2^{ns} a	0 a	2^{ns} ab
NAA+MM	20 bc	11* a	49 a	41^{ns} a	32 a	44^{ns} a	0 a	3^{ns} a	0 a	1^{ns} ab
BA+MM	23 abc	8* a	53 a	45^{ns} a	23 ab	41* a	0 a	3* a	0 a	0^{ns} b
NAA+BA+MM	38 a	11* a	47 a	40^{ns} a	16 b	39* a	0 a	7* a	0 a	2* a
MTO	15 c	14^{ns} a	56 a	45^{ns} a	29 ab	33^{ns} a	0 a	8* a	0 a	0^{ns} ab
2020/21 season										
UC	7 a	3* a	74 a	55^{ns} a	19 a	42* abc	0 a	0^{ns} a	0 a	0^{ns} a
NAA	5 a	4^{ns} a	62 a	66^{ns} a	33 a	29^{ns} bc	0 a	0^{ns} a	0 a	0^{ns} a
BA	5 a	3^{ns} a	68 a	63^{ns} a	26 a	34^{ns} abc	0 a	0^{ns} a	0 a	0^{ns} a
MM	8 a	2^{ns} a	68 a	54^{ns} a	24 a	44* ab	0 a	0^{ns} a	0 a	0^{ns} a
NAA+BA	6 a	1* a	73 a	50* a	21 a	48* a	0 a	0^{ns} a	0 a	0^{ns} a
NAA+MM	4 a	2^{ns} a	68 a	57^{ns} a	28 a	40* abc	0 a	0^{ns} a	0 a	0^{ns} a
BA+MM	3 a	2^{ns} a	74 a	72^{ns} a	24 a	26^{ns} c	0 a	0^{ns} a	0 a	0^{ns} a
NAA+BA+MM	4 a	4^{ns} a	63 a	55^{ns} a	32 a	41^{ns} abc	0 a	0^{ns} a	0 a	0^{ns} a
MTO	11 a	2* a	69 a	67^{ns} a	21 a	30* abc	0 a	0^{ns} a	0 a	0^{ns} a
2021/22 season										
UC	1 a	1^{ns} b	20 a	12* ab	71 a	68^{ns} a	7 a	16* a	1 ab	3* a
NAA	0 a	2^{ns} ab	18 a	14^{ns} ab	69 a	71* a	11 a	10^{ns} ab	2 a	3^{ns} a
BA	0 a	3^{ns} b	18 a	16^{ns} ab	68 a	70^{ns} a	13 a	11^{ns} ab	1 ab	0^{ns} b
MM	1 a	3^{ns} ab	21 a	10* b	70 a	76^{ns} a	8 a	11^{ns} ab	0 ab	0^{ns} b
NAA+BA	0 a	4^{ns} ab	14 a	19^{ns} ab	72 a	67^{ns} a	13 a	10^{ns} ab	1 ab	1^{ns} ab
NAA+MM	0 a	7* ab	21 a	15* ab	70 a	71^{ns} a	9 a	6^{ns} b	0 b	1^{ns} ab
BA+MM	0 a	5* ab	16 a	20^{ns} ab	71 a	64^{ns} a	11 a	11^{ns} ab	2 a	0* b
NAA+BA+MM	0 a	2^{ns} b	14 a	9* b	70 a	78^{ns} a	14 a	11^{ns} ab	1 ab	0^{ns} b
MTO	1 a	11* a	18 a	24^{ns} a	70 a	56* a	10 a	7^{ns} b	1 ab	1^{ns} ab

Note: ^{1}Data transformed through $\sqrt{y} + 0.5$. Treatment means into each level of netting followed by different letters in a column are significantly different according to the Tukey’s HSD test (p≤0.05). Growth condition into each level of treatment means followed by * and ^{ns} in a row are significant and non-significant, respectively according to confidence intervals (p≤0.05).

Fruit coverage with red color was impacted by PGRs and growth conditions (Table 8). In the first season, there were less fruits with low red color coverage with NAA+BA+MM, in the covered orchard, followed by NAA+BA, although in the class of 75-100 of red color coverage, there were more fruits with the treatment NAA+BA+MM. For the other treatments and classes, no treatment differed from the UC. Likewise, in the uncovered area, no treatment differed from the UC in all classes of color coverage.

In the second season, except MM, all other treatments had less fruits into the class of low color (0-25%) in the covered area (Table 8), although with the other classes, no treatment differed from the UC. Within environments, MM had more fruits into the classes of 25-50% and 50-75%, and less fruits into the class of 75-100% in the covered orchard. In the uncovered area no treatment differed from the UC.

In the third season, with the treatment NAA+BA+MM, fruits were more reddish in the covered orchard, as there were less fruits into the classes of low red color coverage (0-25 and 25-50%) (Table 8). Also in the covered orchard, all treatments containing NAA or BA had more fruits into the class of 75-100% of red color coverage. In the uncovered orchard, no treatment differed from the UC in all classes of color coverage. In addition, the treatments BA and NAA+BA, were negatively impacted by netting and fruits had low red color coverage.

Table 8. Fruit coverage with red color of ‘Maxi Gala’ apple trees as a function of different combinations of PGRs used as chemical thinners on growing conditions with and without anti-hail netting.

Treatments	Classes of fruit surface covered with red color (%)[1]							
	0-25		25-50		50-75		75-100	
2019/20 season	Covered	Uncovered	Covered	Uncovered	Covered	Uncovered	Covered	Uncovered
UC	60 a	46^{ns} ab	23 a	29^{ns} a	13 a	16^{ns} ab	4 b	9^{ns} a
NAA	44 ab	49^{ns} ab	29 a	21^{ns} a	20 a	19^{ns} ab	6 b	11^{ns} a
BA	45 ab	62^{ns} a	28 a	23^{ns} a	16 a	9^{ns} b	11 b	6^{ns} a
MM	45 ab	38^{ns} ab	27 a	23^{ns} a	19 a	23^{ns} ab	9 b	16^{ns} a
NAA+BA	29 bc	39^{ns} ab	26 a	22^{ns} a	22 a	20^{ns} ab	23 ab	18^{ns} a
NAA+MM	53 ab	35* b	31 a	23^{ns} a	13 a	25^{ns} ab	4 b	18^{ns} a
BA+MM	38 abc	47^{ns} ab	27 a	30^{ns} a	21 a	16^{ns} ab	13 ab	7^{ns} a
NAA+BA+MM	17 c	28^{ns} b	20 a	23^{ns} a	26 a	28^{ns} a	38 a	21^{ns} a
MTO	35 abc	32^{ns} b	30 a	26^{ns} a	22 a	22^{ns} ab	14 ab	20^{ns} a
2020/21 season								
UC	21 a	5* a	30 a	20^{ns} a	31 a	37^{ns} ab	18 a	38^{ns} ab
NAA	4 b	1^{ns} a	19 a	11^{ns} a	36 a	22* b	41 a	66^{ns} ab
BA	4 b	3^{ns} a	19 a	19^{ns} a	47 a	45^{ns} a	30 a	33^{ns} b
MM	5 ab	1^{ns} a	25 a	8* a	44 a	29* ab	26 a	61* ab
NAA+BA	5 b	5^{ns} a	17 a	13^{ns} a	45 a	43^{ns} a	33 a	39^{ns} ab
NAA+MM	1 b	2^{ns} a	13 a	9^{ns} a	44 a	28* ab	42 a	61^{ns} ab
BA+MM	3 b	6^{ns} a	20 a	21^{ns} a	42 a	36^{ns} ab	35 a	37^{ns} ab
NAA+BA+MM	4 b	1^{ns} a	16 a	10^{ns} a	35 a	21* b	46 a	68^{ns} a
MTO	2 b	1^{ns} a	24 a	17^{ns} a	38 a	35^{ns} ab	36 a	47^{ns} ab
2021/22 season								
UC	18 a	9* a	28 ab	13^{ns} ab	44 a	33^{ns} a	11 c	45* ab
NAA	3 ab	0^{ns} a	19 ab	3* b	41 a	19* ab	36 abc	78* a
BA	13 ab	1* a	30 ab	8* ab	34 a	19* ab	23 bc	72* ab
MM	13 ab	9^{ns} a	32 a	19^{ns} a	41 a	34^{ns} a	15 c	37* b
NAA+BA	7 ab	0* a	21 ab	4* b	36 a	16* b	36 abc	81* a
NAA+MM	6 ab	2^{ns} a	16 ab	7^{ns} ab	23 a	18^{ns} ab	56 a	73^{ns} ab
BA+MM	6 ab	5^{ns} a	27 ab	17^{ns} ab	44 a	33^{ns} ab	23 abc	45^{ns} ab
NAA+BA+MM	3 b	0^{ns} a	13 b	3^{ns} b	42 a	17* ab	42 ab	80* a
MTO	9 ab	6^{ns} a	22 ab	12* ab	34 a	27^{ns} ab	36 abc	56^{ns} ab

Note: [1]Data transformed through $\sqrt{y} + 0.5$. Treatment means into each level of netting followed by different letters in a column are significantly different according to the Tukey’s HSD test ($p \leq 0.05$). Growth condition into each level of treatment means followed by * and ^{ns} in a row are significant and non-significant, respectively according to confidence intervals ($p \leq 0.05$).

4.4. Discussion

The leading effect of hail netting on the orchard’s microclimate was on reducing the PAR under the netting (-16%), and the threshold found in this experiment agrees with the values reported by authors such as Abdelkader et al. (2021), McCaskill et al. (2016), and Solomakhin & Blanke (2010). Mean temperature was also slightly decreased by netting (-1% in this study), which agrees with Bosco et al. (2018) (-1%), and Abdelkader et al. (2021) (-2%). The netting acts as a buffer, by slightly decreasing the daily maximum temperature and increasing the minimum temperature (Bosco et al., 2018; Solomakhin & Blanke, 2010). Also, the hail netting has a direct effect on intercepting part of the direct sunlight beams and scattering over the canopies, while absorbing and also reflecting a small portion of the radiation, although with clear color nets, more radiation is scattered and transmitted than the darker ones (Abdel-Ghany & Al-Helal, 2010; Serra et al., 2020).

The lower radiation underneath the netting creates an unfavorable environment for heating the air, even though wind speed is in average 30~40% less than in an uncovered orchard, as the wind favors heat exchange and cooling (Bosco et al., 2018; McCaskill et al., 2016). This could explain the lowering effect of the maximum temperatures and the elevation of the minimum temperature under netting. In addition, under white hail netting, Solomakhin & Blanke (2007) and Solomakhin & Blanke (2010) reported that the soil temperature 5 cm underneath the surface between 0.5 °C and 0.9 °C higher than the uncovered orchard. The warmer soil bounces back more long wave radiation at night, heating up the air, and summed up with the lower wind speed under netting (Bosco et al., 2018) the air temperature cools down at a slower pace (Bergamaschi & Bergonci, 2017).

Relative humidity was slightly higher under netting in this experiment, especially the minimum relative humidity, which was 8% higher under netting. This was similar to the findings of Aoun & Manja (2020), Bosco et al. (2018), and Solomakhin & Blanke (2010), as the authors similarly reported slightly higher relative humidity or even no significant difference between covered and uncovered orchards. The higher relative humidity in covered areas or inside greenhouses are a consequence of low wind speed (Bergamaschi & Bergonci, 2017).

Overall, from full bloom until the end of the natural fruitlet abscission, the meteorological parameters were similar in 2019/20 and 2020/21 (Appendix C). In the first season, accumulated radiation was 1335 $Mj.m^{-2}$, mean maximum temperature was 18.33 °C, and mean minimum temperature was 17.00 °C, whereas in the second season, accumulated radiation was 1385 $Mj.m^{-2}$, mean maximum temperature was 17.71 °C, and mean minimum temperature was 16.21 °C (INMET, 2022).

In 2019/20, as the temperature was higher and the initial bud load was high (est. 226 clusters/tree, ON year) the netting speeded up fruitlet abscission, and overall, the abscised fruitlets had a lower diameter than in the uncovered area; whereas in the second season, with slightly cooler temperatures and lower initial bud load (est. 96 clusters/tree, OFF year), under netting the speed of abscission was lower and the fruitlets remained abscising for longer than in the uncovered area in all treatments, although with the PGRs the diameter of the abscised fruitlets were bigger under netting than in the uncovered area, indicating that they promoted abscission of bigger fruits under netting, representing that the PGRs induced more competition at later growth stages, whereas in the UC in the second season and all treatments in the first season had smaller diameter under netting, of the abscised fruitlets, indicating precocious halting of fruitlet growth, indicating competition early in the season.

In 'Gala' apple trees, the influence of the stored carbohydrates from the previous fall play little role on the fruit set of the current blooming, as even when the threshold of these non-structural carbohydrates are low, the trees can still maintain the supply of soluble sugars to the growing organs, being the current photosynthesis the responsible for the supplement of assimilates after full bloom onwards (Breen et al., 2020). At full bloom, as the reserves from the previous fall are mostly depleted, the current photosynthesis has to supply the carbon skeletons demand for fruitlets growth, which are also competing with the growing leaves and branches; in addition, the fruitlet respiration in this phase is extremely high, as during the cell division many cell organelles and cell wall are being formed, requiring a lot of energy, being the respiration rate the main factor to contribute to the fruitlet sink strength (Penzel et al., 2020).

In net-shaded apple orchards, Solomakhin & Blanke (2010) reported that the higher natural fruitlet abscission leads to more assimilates to be driven towards vegetative growth. Even though, leaf area is highly correlated to light interception and photosynthesis, as more leaves grow (during the season), more leaves are necessary per fruit due to shading of the inner canopy (Penzel et al., 2020). However, in hail net shaded apple trees, Bosco et al. (2018) found no difference in light interception of the canopies under netting and without netting. Although, shaded leaves from the inner canopy have less carbon assimilation capacity compared to the ones directly exposed to the sunlight, the presence of sinks stimulate the assimilation of carbon, whereas low sink strength decreases photosynthesis (Poirier-Pocovi et al., 2018), and when fruitlets are outnumbered, the assimilates produced by leaves are driven towards vegetative growth (Boini et al., 2022; Solomakhin & Blanke, 2010).

The levels of sorbitol present in the apple phloem sap is high at one week after full bloom and declines from the second to the fourth week, and then returns to a high level five weeks after bloom, indicating that during this phase of low sorbitol, only the current photosynthesis supplies assimilates to the growing fruitlets, and as the competition increases, the seed activity of sorbitol dehydrogenase decreases, indicating a low sink strength and future abscission (Archbold et al., 2011). PGRs used as chemical thinners, or shading, act on decreasing the unloading and consequently the availability of assimilates to the growing fruitlets, leading to the abscission of the weaker ones (Eccher et al., 2013; Morandi et al., 2011; Zhu et al., 2011). The shading promoted by hail netting has been reported as an inducer of early fruitlet abscission in apple and hazelnut orchards, which eventually may increase fruit weight, although not due to light spectra modification, but due to less competition (Brglez-Sever et al., 2021; Salazar-Canales et al., 2021).

The shading promoted by hail netting reduces the transmission of red in relation to far red light, which leads to some morphological and physiological adaptation of the apple tree, such as thinner leaves with thinner palisade parenchyma, and lower palisade/spongy parenchyma ratio, as well as more chlorophyll synthesis, as a shade avoidance strategy to compensate the setbacks, which compensates an eventual reduced fruit number with increment in size (Amarante et al., 2007; Bastías et al., 2021).

In our experiment it was possible to observe a pattern in which the PGRs promoted fruitlet thinning in the uncovered area, especially the treatments NAA+BA and BA+MM, which consistently reduced fruit set in all three seasons. Even though under netting the microclimatic conditions were more favorable for PGRs absorption (i.e., higher relative humidity and higher drying time) and warmer night temperature (Lordan et al., 2020; Stover & Greene, 2015), the thinners were less effective in promoting fruitlet abscission. As the netting increased the natural fruitlet abscission, it is likely that more reserves were available to the remaining growing fruitlets; then, with a better supply of assimilates, the thinners were not able to promote abscission. The extinction of floral buds or flower thinning decreases the intra-cluster competition and increases the potential of the fruitlets not to undergo to abscission (Breen et al., 2020; Breen et al., 2015).

Return bloom was lower in apple trees under netting, and with regards to the treatments, the results were not totally correlated to crop load or timing of the application of the PGRs. When crop load is high during the flower induction phase, due to the high competition, there is a high demand for soluble carbohydrates to sustain growth, and the level of soluble sugars in the buds are high, as the sugar metabolism is high; in addition, there is intense cell division/expansion which stimulates a high synthesis of IAA, GAs, ABA (repressors of flower induction), as well as a high synthesis of hormones such as cytokinins and JA, which are flower inducers, although, depending on the crop load, the balance inducers/repressors of flower induction tend to repress when crop load is high, and to induct when crop load is low (Samuolienė et al., 2016). In addition, in the ON year, apple trees have a higher level of expression of GAs related pathways, whereas, the opposite is found for OFF year apple trees, although, in this case there is a higher expression of genes related to bud induction for the following differentiation (*MdSCL1*, *MdSPY*, *MdSPL*) (Zuo et al., 2018). In ‘Fuji’ apples both heavy crop load and 50% shading overexpresses the gene *MdTFL1*, which is regarded to maintain the bud vegetative, whereas the over expression of this gene suppresses the expression of *MdFT1*, which is related to bud differentiation (Kittikorn et al., 2011). This could explain the reason for lower return bloom under netting.

In the present experiment, even though natural fruitlet drop was higher under netting, there was no impact of netting on fruit weight. With exception of the first season, fruit weight was higher with the treatments containing NAA (sprayed at FB), which likely removed early competition, and allowed a lower number of fruitlets to have access to a higher quantity of assimilates, and had a higher initial rate of cell multiplication, increasing potential weight/size (Lakso & Goffinet, 2013; Meland, 2009). In our experiment, BA sprayed at 8 mm of fruitlet diameter decreased seed number, and in some extent, this was also true with NAA. Similarly, Stover et al. (2001) reported that BA sprayed at 10 mm of fruitlet diameter decreased seed number, although NAA did not, even when sprayed at FB. BA promotes whole canopy competition, leading to a decreased level of assimilates to the embryos, leading to abscission, and seed number reduction of the remaining fruits (Yuan & Greene, 2000). In the case of NAA, Marchioretto et al. (2019) found that NAA sprayed at full bloom reduced the pollen tube growth in the pistils, and this hampered ovule fertilization, which in the case of this experiment, could be the cause of reduction in seed number.

In this experiment, overall, in all seasons, netting negatively affected red color buildup only for the treatments UC, NAA, MM, and NAA+MM (75-100% coverage); in addition, all treatments containing NAA had better color coverage under netting, whereas in the uncovered area besides all treatments containing NAA, also MM alone induced better coloration. There are basically three factors that affect anthocyanin synthesis in apple fruits: light intensity, temperature, and sugar contents. Reduction of UV-B and violet/blue light, and reduction of visible light directly reduces the skin red color development. Low temperatures enhance anthocyanin synthesis, whereas high temperatures has the opposite effect; Soluble sugars, especially UDP-galactose, are the precursors of anthocyanins, and the higher is the content, the higher is the substrate to synthetize anthocyanins (Chen et al., 2021). In our experiment, overall, the TSS concentration was lower under netting, as well as sunlight, while the night temperature was higher and diuturnal temperature was lower than the uncovered condition, which delayed red color induction. In addition, the treatments containing NAA had better color development in both conditions, this may be due to the better thinning and fruit development, which favored a better exposure of the fruits to sunlight. Also, NAA temporarily paralyzes vegetative growth (Zhu et al., 2011), which favors better light exposure early in the season, and enhances ethylene evolution , which already occurs at 7 DAFB, and this is highly correlated to red color development early in the season (Whale & Singh, 2007). The authors reported two peaks of ethylene evolution and blush development, being one early season and other pre-harvest.

The influence of treatments on fruit skin russeting does not evidence a definite tendency, although into the classes of moderate (10-30%) and severe (30-50%), a lower number of fruits with russeting was observed in the covered orchard. Under netting, Szabó et al. (2021) found that the mean temperature was 2.91% lower than without netting, and mean relative humidity 3.16% higher, similarly to the values found in the present experiment. The authors also reported that under netting, the tree´s water potential was higher than without netting, so in the present experiment, under netting the fewer daily variations in the fruitlets likely improved water potential due to the reduced solar radiation, and lower maximum temperatures, as well as more humidity in the air, rendering the fruitlets less prone to intraday shrinking (Boini et al., 2022), thus avoiding the microcracks on the epidermis and the formation of epidermal russeting.

4.5. Conclusions

The white hail netting modifies the orchard’s microclimate by decreasing photosynthetically active radiation, increasing nighttime temperature, and decreasing maximum daytime temperature. These modifications lead ‘Galaxy’ apple trees under white hail netting to have higher natural fruitlet abscission. However, this enhanced natural fruitlet drop decreases the competition of the remaining fruitlets, then not affecting the effect of the PGRs used as chemical thinners, without causing overthinning.

Fruit quality is affected by chemical thinners and hail netting. Under netting, the fruits have less epidermal russeting but have less red color coverage, in relation to the uncovered orchard. The treatment NAA sprayed at full bloom, followed by BA sprayed at fruitlet diameter of 8 mm consistently adjusts crop load, and improves fruit weight and quality (appearance) in both netting conditions.

Acknowledgements

The authors acknowledge the company AGROSPE for the experimental throughout these three cropping seasons, especially Fábio Varela and André Zamban De Pieri.

Funding: This work was supported by EMBRAPA Uva e Vinho; and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) [grant number 141123/2019-2]

4.6. References

Abdel-Ghany, A. M., & Al-Helal, I. M. (2010). Characterization of solar radiation transmission through plastic shading nets. *Solar Energy Materials and Solar Cells*, *94*(8), 1371–1378. https://doi.org/10.1016/j.solmat.2010.04.005

Abdelkader, AB., Tagliavini, M., & Zanotelli, D. (2021). Effects of hail nets and reflective ground covers on microclimate and evapotranspiration demand in an apple orchard. *Acta Horticulturae*, *1327*(1327), 647–654. https://doi.org/10.17660/ActaHortic.2021.1327.85

Alvares, C. A., Stape, J. L., Sentelhas, P. C., de Moraes Gonçalves, J. L., & Sparovek, G. (2013). Köppen’s climate classification map for Brazil. *Meteorologische Zeitschrift*, *22*(6), 711–728. https://doi.org/10.1127/0941-2948/2013/0507

Amarante, C. V. T. do, Steffens, C. A., Mota, C. S., & Santos, H. P. dos. (2007). Radiação, fotossíntese, rendimento e qualidade de frutos em macieiras “Royal Gala” cobertas com telas antigranizo. *Pesquisa Agropecuária Brasileira*, *42*(7), 925–931. https://doi.org/10.1590/S0100-204X2007000700003

Aoun, M., & Manja, K. (2020). Effects of a photoselective netting system on Fuji and Jonagold apples in a Mediterranean orchard. *Scientia Horticulturae*, *263*, 109104. https://doi.org/10.1016/j.scienta.2019.109104

Archbold, D. D., Nosarzewski, M., Wu, B., & Vuppalapati, P. (2011). Does availability of soluble carbohydrate reserves determine apple fruit set? *Acta Horticulturae*, *903*, 795–801. https://doi.org/10.17660/ActaHortic.2011.903.110

Bastías, R. M., Losciale, P., Chieco, C., & Corelli-Grappadelli, L. (2021). Red and blue netting alters leaf morphological and physiological characteristics in apple trees. *Plants*, *10*(1), 1–16. https://doi.org/10.3390/plants10010127

Bergamaschi, H., & Bergonci, J. I. (2017). *As plantas e o clima: princípios e aplicações*. Agrolivros.

Boini, A., Casadio, N., Bresilla, K., Perulli, G. D., Manfrini, L., Grappadelli, L. C., & Morandi, B. (2022). Early apple fruit development under photoselective nets. *Scientia Horticulturae*, *292*. https://doi.org/10.1016/j.scienta.2021.110619

Bosco, L. C., Bergamaschi, H., Cardoso, L. S., de Paula, V. A., Marodin, G. A. B., & Brauner, P. C. (2018). Microclimate alterations caused by agricultural hail net coverage and effects on apple tree yield in subtropical climate of southern Brazil. *Bragantia*, *77*(1), 181–192. https://doi.org/10.1590/1678-4499.2016459

Breen, K. C., Tustin, D. S., Palmer, J. W., & Close, D. C. (2015). Method of manipulating floral bud density affects fruit set responses in apple. *Scientia Horticulturae*, *197*, 244–253. https://doi.org/10.1016/j.scienta.2015.09.042

Breen, K., Tustin, S., Palmer, J., Boldingh, H., & Close, D. (2020). Revisiting the role of carbohydrate reserves in fruit set and early-season growth of apple. *Scientia Horticulturae*, *261*, 109034. https://doi.org/10.1016/j.scienta.2019.109034

Brglez-Sever, M., Tojnko, S., Fakin, D., Stajnko, D., & Unuk, T. (2021). Natural June thinning of fruitlets and yield characteristics of apple trees growing under coloured anti-hail netting. *European Journal of Horticultural Science*, *86*(2), 136–145. https://doi.org/10.17660/eJHS.2021/86.2.4

Chen, Z., Yu, L., Liu, W., Zhang, J., Wang, N., & Chen, X. (2021). Research progress of fruit color development in apple (Malus domestica Borkh.). *Plant Physiology and Biochemistry*, *162*, 267–279. https://doi.org/10.1016/j.plaphy.2021.02.033

Eccher, G., Botton, A., Dimauro, M., Boschetti, A., Ruperti, B., & Ramina, A. (2013). Early induction of apple fruitlet abscission is characterized by an increase of both isoprene emission and abscisic acid content. *Plant Physiology*, *161*(4), 1952–1969. https://doi.org/10.1104/pp.112.208470

FAO. (2022). *Food and agriculture organization of the United Nations*. Crops and Livestock Products. https://www.fao.org/faostat/en/#data/QCL

IBGE. (2022). *Produção agrícola municipal*. https://sidra.ibge.gov.br/tabela/5457#resultado

INMET, 2022. Dados históricos anuais [WWW Document]. URL https://portal.inmet.gov.br/dadoshistoricos (accessed 8.7.22).

Kittikorn, M., Okawa, K., Ohara, H., Kotoda, N., Wada, M., Yokoyama, M., Ifuku, O., Yoshida, S., & Kondo, S. (2011). Effects of fruit load, shading, and 9,10-ketol-octadecadienoic acid (KODA) application on MdTFL1 and MdFT1 genes in apple buds. *Plant Growth Regulation*, *64*(1), 75–81. https://doi.org/10.1007/s10725-010-9538-x

Lakso, A. N., & Goffinet, M. C. (2013). Apple Fruit Growth. *New York Quarterly*, *21*(1), 11–14.

Lazzarotto, J. J., & Fioravanço, J. C. (2020). *Impactos do granizo sobre o desempenho econômico e financeiro da produção de maçã em pomares protegidos com tela ou com seguro agrícola*.

Lordan, J., Reginato, G. H., Lakso, A. N., Francescatto, P., & Robinson, T. L. (2019). Natural fruitlet abscission as related to apple tree carbon balance estimated with the MaluSim model. *Scientia Horticulturae*, *247*, 296–309. https://doi.org/10.1016/j.scienta.2018.11.049

Lordan, J., Reginato, G. H., Lakso, A. N., Francescatto, P., & Robinson, T. L. (2020). Modelling physiological and environmental factors regulating relative fruit set and final fruit numbers in apple trees. *Journal of Horticultural Science and Biotechnology*, *95*(5), 600–616. https://doi.org/10.1080/14620316.2020.1718555

Marchioretto, L. D. R., De Rossi, A., Amaral, L. O. do, & Ribeiro, A. M. A. de S. (2019). Efficacy and mode of action of blossom thinners on ‘Fuji More’ apple trees. *Scientia Horticulturae*, *246*, 634–642. https://doi.org/10.1016/j.scienta.2018.11.039

Martins, J. A., Brand, V. S., Capucim, M. N., Felix, R. R., Martins, L. D., Freitas, E. D., Gonçalves, F. L. T., Hallak, R., Dias, M. A. F. S., & Cecil, D. J. (2017). Climatology of destructive hailstorms in Brazil. *Atmospheric Research*, *184*, 126–138. https://doi.org/10.1016/j.atmosres.2016.10.012

McCaskill, M. R., McClymont, L., Goodwin, I., Green, S., & Partington, D. L. (2016). How hail netting reduces apple fruit surface temperature: A microclimate and modelling study. *Agricultural and Forest Meteorology*, *226–227*, 148–160. https://doi.org/10.1016/j.agrformet.2016.05.017

Meland, M. (2009). Effects of different crop loads and thinning times on yield, fruit quality, and return bloom in *Malus × domestica* Borkh. 'Elstar' . *The Journal of Horticultural Science and Biotechnology*, *84*(6), 117–121. https://doi.org/10.1080/14620316.2009.11512607

Michael, P. R., Johnston, D. E., & Moreno, W. (2020). A conversion guide: Solar irradiance and lux illuminance. *Journal of Measurements in Engineering*, *8*(4), 153–166. https://doi.org/10.21595/jme.2020.21667

Morandi, B., Zibordi, M., Losciale, P., Manfrini, L., Pierpaoli, E., & Grappadelli, L. C. (2011). Shading decreases the growth rate of young apple fruit by reducing their phloem import. *Scientia Horticulturae*, *127*(3), 347–352. https://doi.org/10.1016/j.scienta.2010.11.002

Penzel, M., Lakso, A. N., Tsoulias, N., & Zude-Sasse, M. (2020). Carbon consumption of developing fruit and the fruit bearing capacity of individual RoHo 3615 and Pinova apple trees**. *Int. Agrophys*, *34*, 409–423. https://doi.org/10.31545/intagr/12754

Petri, J. L., Leite, G. B., Couto, M., & Francescatto, P. (2011). Avanços na cultura da macieira no Brasil. *Revista Brasileira de Fruticultura*, *33*(spe1), 48–56. https://doi.org/10.1590/S0100-29452011000500007

Poirier-Pocovi, M., Lothier, J., & Buck-Sorlin, G. (2018). Modelling temporal variation of parameters used in two photosynthesis models: Influence of fruit load and girdling on leaf photosynthesis in fruit-bearing branches of apple. *Annals of Botany*, *121*(5), 821–832. https://doi.org/10.1093/aob/mcx139

Reis, M. G. dos, & Ribeiro, A. (2020). Conversion factors and general equations applied in agricultural and forest meteorology. *Agrometeoros*, *27*(2). https://doi.org/10.31062/agrom.v27i2.26527

Salazar-Canales, F., Bastías, R. M., Calderón-Orellana, A., Wilckens, R., & González, E. (2021). Photo-selective nets differentially affect microclimatic conditions, leaf physiological characteristics, and yield in hazelnut (Corylus avellana L.). *Horticulture Environment and Biotechnology*, *62*(6), 845–858. https://doi.org/10.1007/s13580-021-00365-8

Samuolienė, G., Čeidaitė, A., Sirtautas, R., Duchovskis, P., & Kviklys, D. (2016). Effect of crop load on phytohormones, sugars, and biennial bearing in apple trees. *Biologia Plantarum*, *60*(2), 394–400. https://doi.org/10.1007/s10535-015-0581-3

Serra, S., Borghi, S., Mupambi, G., Camargo-Alvarez, H., Layne, D., Schmidt, T., Kalcsits, L., & Musacchi, S. (2020). Photoselective protective netting improves ”honeycrisp” fruit quality. *Plants*, *9*(12), 1–20. https://doi.org/10.3390/plants9121708

Solomakhin, A. A., & Blanke, M. M. (2007). Overcoming adverse effects of hailnets on fruit quality and microclimate in an apple orchard. *Journal of the Science of Food and Agriculture*, *87*(14), 2625–2637. https://doi.org/10.1002/jsfa.3022

Solomakhin, A., & Blanke, M. (2010). The microclimate under coloured hailnets affects leaf and fruit temperature, leaf anatomy, vegetative and reproductive growth as well as fruit colouration in apple. *Annals of Applied Biology*, *156*(1), 121–136. https://doi.org/10.1111/j.1744-7348.2009.00372.x

Solomakhin, A., & Blanke, M. M. (2008). Coloured hailnets alter light transmission, spectra and phytochrome, as well as vegetative growth, leaf chlorophyll and photosynthesis and reduce flower induction of apple. *Plant Growth Regulation*, *56*(3), 211–218. https://doi.org/10.1007/s10725-008-9302-7

Stover, E., Fargione, M., Risio, R., Yang, X., & Robinson, T. (2001). Fruit Weight, Cropload, and Return Bloom of “Empire” Apple Following Thinning with 6-Benzyladenine and NAA at Several Phenological Stages. *HortScience*, *36*(6), 1077–1081. https://doi.org/10.21273/HORTSCI.36.6.1077

Stover, E. W., & Greene, D. W. (2015). Environmental Effects on the Performance of Foliar Applied Plant Growth Regulators: A Review Focusing on Tree Fruits. *HortTechnology*, *15*(2), 214–221.

Szabó, A., Tamás, J., & Nagy, A. (2021). The influence of hail net on the water balance and leaf pigment content of apple orchards. *Scientia Horticulturae*, *283*. https://doi.org/10.1016/j.scienta.2021.110112

UFSM. (2023, May 8). *Solos do Rio Grande do Sul*. Solos Do Rio Grande Do Sul.

Whale, S. K., & Singh, Z. (2007). Endogenous ethylene and color development in the skin of ‘Pink Lady’apple. Journal of the American Society for Horticultural Science, 132(1), 20-28. https://doi.org/10.21273/JASHS.132.1.20

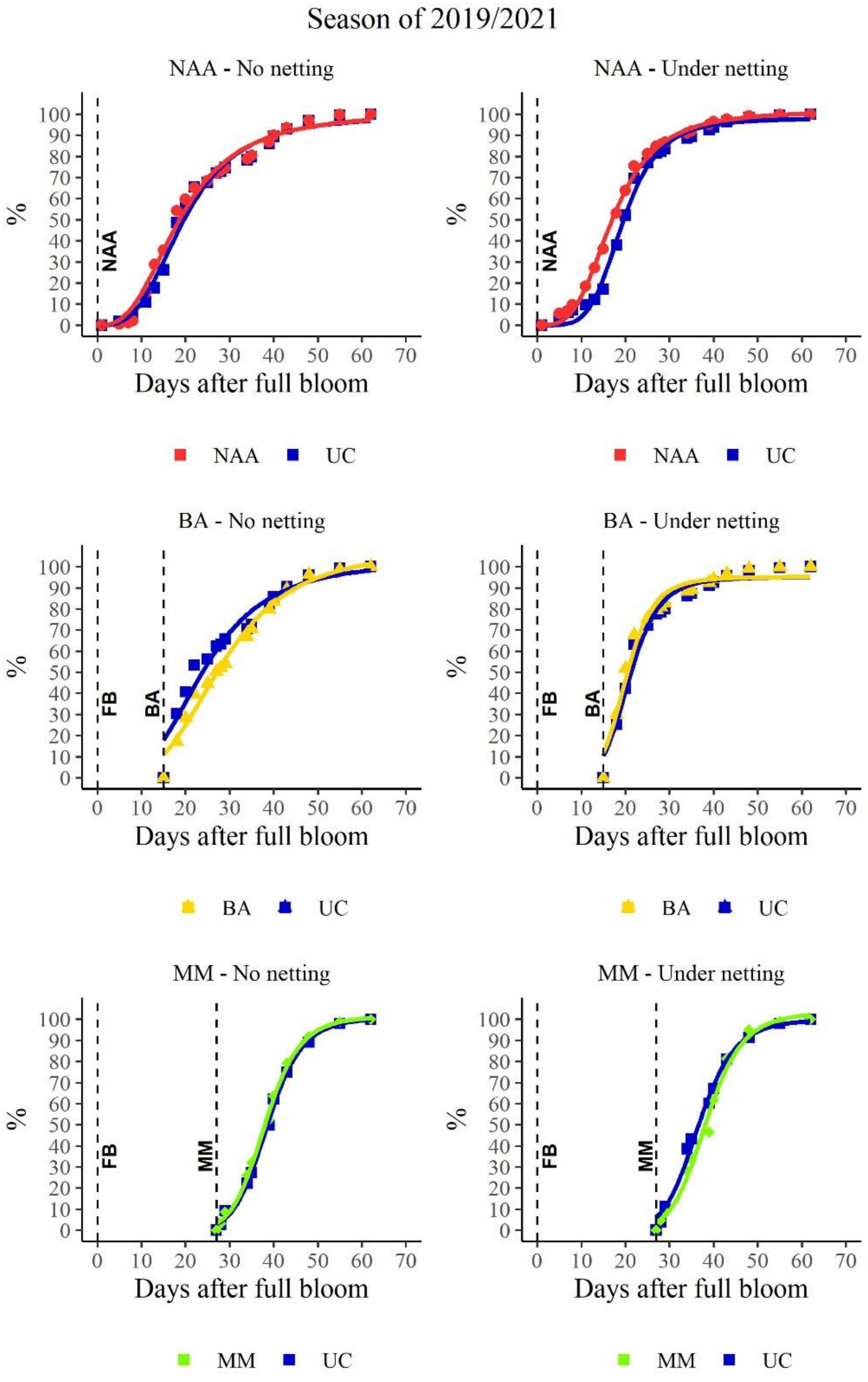
Yuan, R., & Greene, D. W. (2000). ‘McIntosh’ apple fruit thinning by benzyladenine in relation to seed number and endogenous cytokinin levels in fruit and leaves.

Scientia Horticulturae, *86*(2), 127–134. https://doi.org/10.1016/S0304-4238(00)00142-4

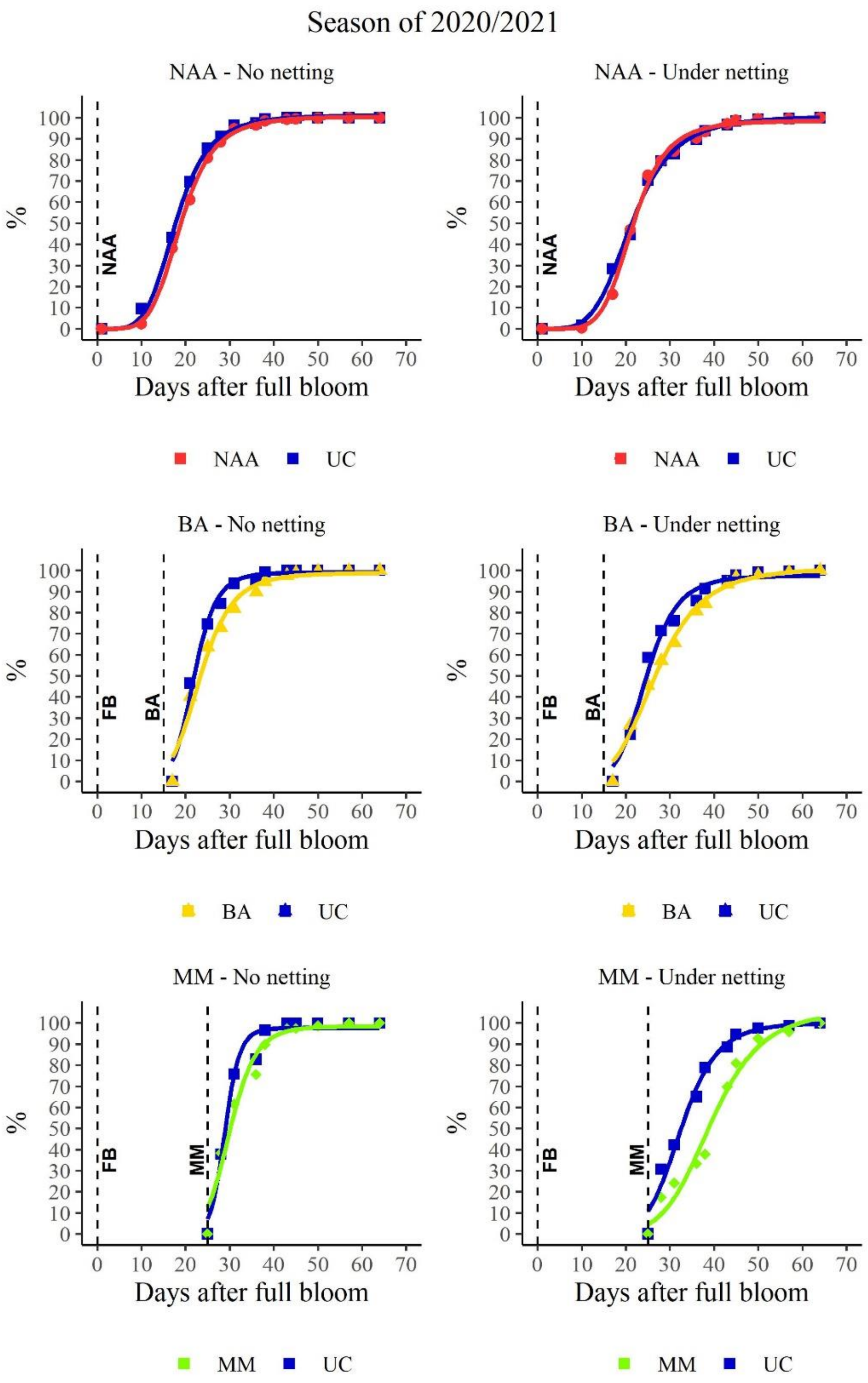
Zhu, H., Dardick, C. D., Beers, E. P., Callanhan, A. M., Xia, R., & Yuan, R. (2011). Transcriptomics of shading-induced and NAA-induced abscission in apple (*Malus domestica*) reveals a shared pathway involving reduced photosynthesis, alterations in carbohydrate transport and signaling and hormone crosstalk. *BMC Plant Biology*, *11*. https://doi.org/10.1186/1471-2229-11-138

Zuo, X., Zhang, D., Wang, S., Xing, L., Li, Y., Fan, S., Zhang, L., Ma, J., Zhao, C., Shah, K., An, N., & Han, M. (2018). Expression of genes in the potential regulatory pathways controlling alternate bearing in 'Fuji' (Malus domestica Borkh.) apple trees during flower induction. *Plant Physiology and Biochemistry*, *132*, 579–589. https://doi.org/10.1016/j.plaphy.2018.10.003

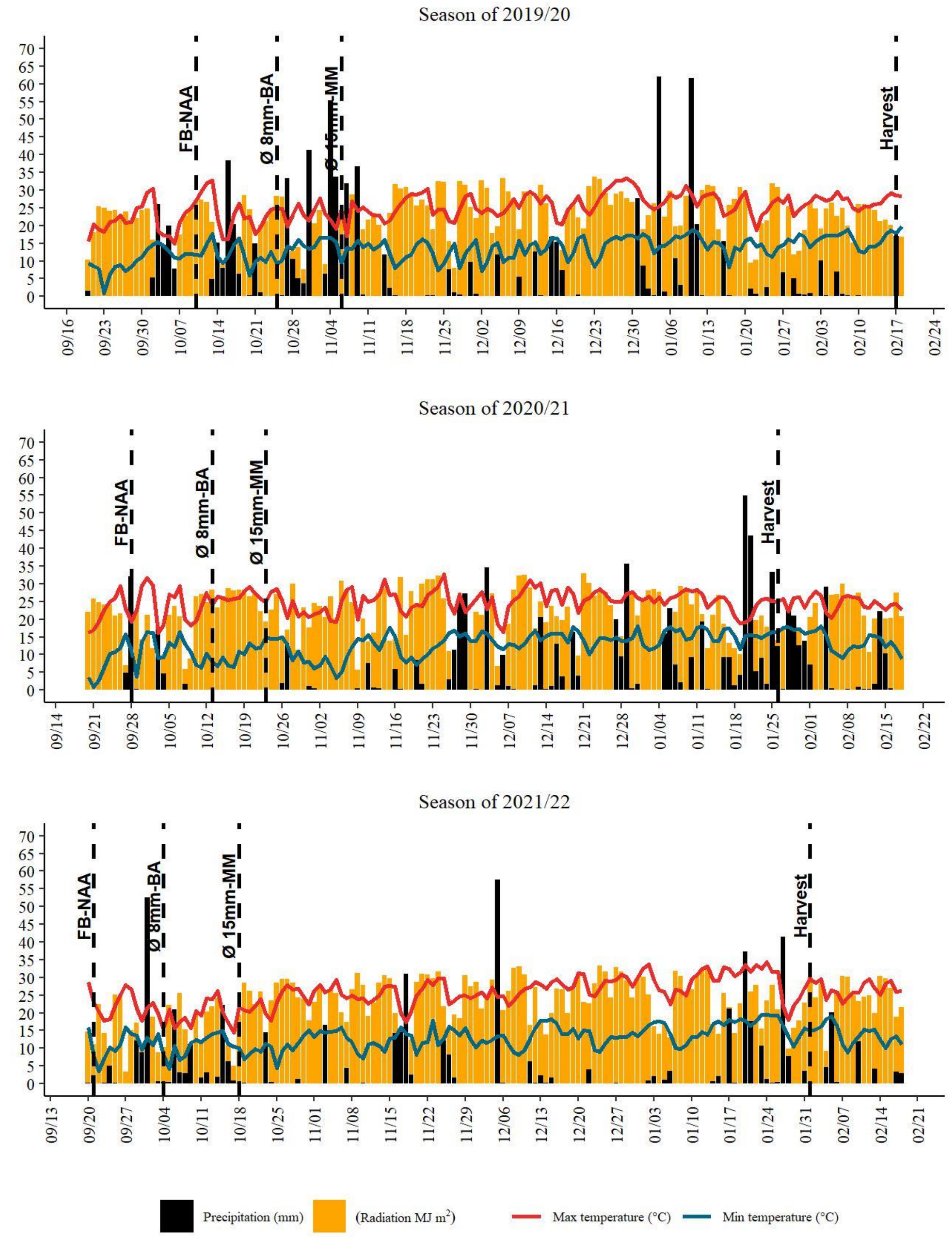
Appendices



Appendix A. Logarithmic curves of the accumulated frequency of the abscised fruitlets collected weekly during the season of 2019/20. For NAA, BA, and MM it was calculated different logistic curves using the same UC. For BA and MM, the UC was considered from the moment of the application of these PGRs until the end of fruit drop.



Appendix B. Logarithmic curves of the accumulated frequency of the abscised fruitlets collected weekly during the season of 2020/21. For NAA, BA, and MM it was calculated different logistic curves using the same UC. For BA and MM, the UC was considered from the moment of the application of these PGRs until the end of fruit drop.



Appendix C. Meteorological conditions of Precipitation, Solar Radiation, Maximum Temperature, and Minimum Temperature throughout the seasons of 2019/20, 2020/21, and 2021/22. FB: full bloom; Ø: fruitlet diameter.

5 ARTIGO 3

Effect of anti-hail netting on microclimatic parameters and their influence on the effectiveness of chemical thinning of 'Fuji Suprema' apple trees*

Artigo formatado conforme as normas do periódico Plant Growth Regulation

EFFECT OF ANTI-HAIL NETTING ON MICROCLIMATIC PARAMETERS AND THEIR INFLUENCE ON THE EFFECTIVENESS OF CHEMICAL THINNING OF ‘FUJI SUPREMA’ APPLE TREES

Lucas De Ross Marchioretto (1) (0000-0002-6677-4696), Andrea De Rossi (2) (0000-0001-8038-622X), and Gilmar Arduino Bettio Marodin (1) (0000-0002-7932-2074)

(1) Universidade Federal do Rio Grande do Sul (UFRGS), Faculdade de Agronomia, Departamento de Horticultura e Silvicultura. Av Bento Gonçalves, 7712, CEP 91540-000, Porto Alegre -RS, Brasil. lucas.marchioretto@ufrgs.br, marodin@ufrgs.br

(2) Embrapa Uva e Vinho, Br 285, s/n - Km 115, CEP 95200-000, Vacaria-RS, Brasil. andrea.derossi@embrapa.br

*Corresponding author: lucas.marchioretto@ufrgs.br (Lucas De Ross Marchioretto)

Abstract

In Southern Brazil, it is observed higher natural fruitlet drop in covered apple orchards and many producers get refrained to use chemical thinners. Thus, the objective of this study was to evaluate the impact of anti-hail netting on microclimatic parameters and evaluate their impact on the effectiveness of chemical thinning programs in adjusting crop load and improve fruit quality of ‘Fuji Suprema’ apples. The experiment was conducted over three consecutive cropping seasons on ‘Fuji Suprema’ trees grafted on M9 rootstocks. Nine chemical thinning programs were tested both in covered and uncovered with white hail netting areas. The treatments consisted of an [1] untreated control; [2] naphthalene acetic acid (NAA) at full bloom; [3] benzyladenine (BA) at fruitlet diameter of 8 mm; [4] metamitron (MM) at fruitlet diameter of 15 mm; [5]

Abbreviations: PGR: Plant Growth Regulator; PAR: Photosynthetically Active Radiation; UC: Untreated Control; NAA: Naphthalene Acetic Acid; BA: Benzyladenine; MM: Metamitron; MTO: Manual Thinning Only.

NAA+BA; [6] NAA+MM; [7] BA+MM; [8] NAA+BA+MM; [9] manual thinning only control. Netting affected the microclimate by reducing photosynthetically active radiation in 16%, decreasing both temperature range and cumulative degrees-day in 9%. These modifications on the microclimate led to an increased natural fruitlet abscission, and also increased the length of the abscission promoted by the chemical thinners. However, it did not cause overthinning, as seemingly the increase of abscission promoted by the netting decreased the competition promoted by the thinners, and the rebalance of the source-sink relation was self-compensatory. The PGRs used as chemical thinners NAA+BA, NAA+MM, or NAA+BA+MM are effective to adjust crop load and improve fruit weight of ‘Fuji Suprema’ apples with or without hail netting coverage.

Keywords: naphthalene acetic acid; benzyladenine; metamitron; shading; *Malus domestica* Borkh.

5.1. Introduction

Apple production in Brazil is mostly concentrated in the Southern region, where the climate is more suitable for the crop, especially in high altitude places (Alvares et al., 2013; IBGE, 2022). However, this region is frequently stricken by hailstorms occurring in the spring and summer, as a result of convective storms due to the encounter of high temperature and humidity flows coming from the Amazon region with the cold and dry flows coming from the South of the continent (Martins et al., 2017). To overcome the loss of quality of the fruits and to assure the integrity of the apple trees, the installation of anti-hail nets is the most appropriate management to assure profitability and sustainability (Lazzarotto & Fioravanço, 2020).

Depending on the region, the color, and the type of the hail netting, apple cultivar, rootstock, etc., there are many studies indicating that hail netting has no impact on fruit quality (Bosco et al., 2015), or in the effectiveness of chemical thinners (Gonzalez et al., 2020), as the netting creates a less stressful environment for the trees due to less solar radiation and lower wing speed (Bosco et al., 2018), which improves the hydric status of the apple trees, and the chlorophyll content in leaves (Szabó et al., 2021). In contrast, other studies report that photosynthesis is lower under black and white netting (Amarante et al., 2007) due to shading, and higher nighttime temperatures (Solomakhin & Blanke, 2010).

In apple trees, the availability of assimilates from the previous fall lasts until full bloom, and thereafter the supply is done by the current photosynthesis, in which the fruitlets are competing with growing leaves and branches for assimilates (Breen et al., 2020). Under the circumstances of less solar radiation and higher night temperatures, net CO_2 assimilation could become impaired and lead to a higher fruitlet drop. In this sense, in Southern Brazil many apple producers with covered orchards are refrained to use chemical thinners, as it is empirically observed a higher natural fruitlet drop in such condition, contrasting uncovered orchards. Higher fruitlet drop under hail netting is also reported in other studies (Brglez-Sever et al., 2021; Clever, 2022).

Plant Growth Regulators (PGRs) used as chemical thinners (e.g.: Naphthalene Acetic Acid, Benzyladenine, Metamitron) act on decreasing the supply of assimilates to the fruitlets (Eccher et al., 2013; Zhu et al., 2011), making the development rate of the weaker fruitlets (likely weaker embryos) to be impaired, and consequently, the export rate of endogenous auxin through their pedicels to be reduced, inducing ethylene buildup and activation of the abscission zone (Eccher et al., 2013; Schröder et al., 2013). It could be hypothesized that the unfavorable condition for fruit set found under hail netting, such as less solar radiation, and higher minimum temperatures would possibly lead to an intensified effect of the chemical thinners. Thus, the objective of this study was to assess the microclimatic effects under hail netting on the effectiveness of chemical thinning programs in relation to an uncovered orchard on adequately adjusting crop load and improve fruit quality.

5.2. Materials and methods

Study site, treatments, and experimental design

The experiment was carried out over three consecutive cropping seasons (2019/20, 2020/21, and 2021/22) in a commercial orchard located at Bom Jesus, Rio Grande do Sul, Brazil (28°35’58.18”S, 50°29’47.43”O, elevation of 1032 m above sea level). The orchard was implemented in the year of 2006 with ‘Fuji Suprema’ apple trees grafted on M9 rootstocks. The pollinizer cultivar was ‘Galaxy’ grafted on M9. Tree spacing was 4 m between rows and 1.5 m between trees (1667 trees.ha^{-1}). The training system was a tall spindle. The orchard was covered with white color anti-hail netting of mesh 4 x 8 mm.

The soil of the region is classified as an Entisol, which is characterized as shallow, stony, and with a high organic matter content in the top layer (UFSM, 2023). The climate of the region according to the Koppen’s classification is a Cfb with mean temperatures ranging from 15 to 25 °C in the summer, and 7 to 16 °C in the winter, and mean annual precipitation of 1789 mm (Alvares et al., 2013). The experiment was conducted in a randomized complete block in a split-plot arrangement, where netting environments (with and without netting) were the main plots, and nine treatments (thinning programs) were the subplots. The treatments were arranged into three blocks (3 apple rows), and for each treatment, there were three replicate trees, totalizing nine replicates per treatment.

In the environments with and without netting the evaluated treatments were: [1] Untreated Control (UC); [2] Naphthalene acetic acid (NAA) (ANA técnico, 19 g a.i. ha^{-1}), sprayed at full bloom; [3] Benzyladenine (BA) (Maxcel, 140 g a.i. ha^{-1}), sprayed at fruitlet diameter of 8 mm, [4] Metamitron (MM) (Goltix, 196 g a.i. ha^{-1}), sprayed at fruitlet diameter of 15 mm; [5] NAA + BA; [6] NAA+MM; [7] BA+MM; [8] NAA+BA+MM; [9] Manual Thinning Only (MTO). These concentrations were used in the first season, and for the second and third seasons, BA and MM were increased to 160 g a.i. ha^{-1}, and 238 g a.i. ha^{-1}, respectively, due to low thinning in the first season. The treatments were sprayed with a motorized backpack sprayer calibrated to deliver 1000 L.ha^{-1} of water. For all sprayed treatments, it was added the surfactant adjuvant Break thru at 0.03 v/v.

In 2019/20, full bloom was on Oct 10th, 2019; fruitlet diameter 8 mm was on Oct 25th, 2019, at 15 DAFB; and fruitlet diameter 15 mm was on Nov 6th, 2019, at 27 DAFB. In 2020/21, full bloom was on Sept 28th, 2020; fruitlet diameter 8 mm was on Oct 13th, 2020, at 15 DAFB and fruitlet diameter 15 mm was on Oct 23rd, 2020, at 25 DAFB; In 2021/22, full bloom was on Sept 21st, 2021, fruitlet diameter 8 mm was on Oct 4th, 2021, at 13 DAFB, and fruitlet diameter 15 mm was on Oct 18th, 2021, at 27 DAFB.

Measurement of temperature and solar radiation of apple orchards covered and uncovered with white anti-hail netting

In the cropping season of 2021/22, meteorological data of temperature and relative humidity were obtained from two meteorological stations, being one meteorological station a Campbell Scientific® equipped with a CR10X datalogger, and temperature and relative humidity sensors, and a second meteorological station Solar® model SL2000

E8C, equipped with temperature and relative humidity sensors. Both meteorological stations were programmed to record data every 15 minutes. The Photosynthetically Active Radiation (PAR, 400-700 nm) was simultaneously measured with two BH1750FVI luminosity sensors (Rohm®) attached to an Arduino® Uno board equipped with a datalogger shield (Adafruit®), programmed to record data every 15 minutes. The output radiation data was expressed in Lummens.m^{-2}, then it was converted into Watts.m^{-2} according to (Michael et al., 2020), and into µmol.m^{-2}.s^{-1} according to (Reis & Ribeiro, 2020). Prior to installing in the experimental area, the stations were installed side by side, and data retrieved from three days were compared to check any difference among the sensors, and no difference was found. PAR, temperature, and relative humidity data were compared with an official meteorological station from INMET (2022), and no difference was found.

One meteorological station (Campbell®) was installed in the orchard covered with white hail netting between two apple trees, where there was a space with no tree in the row. In this station, the luminosity sensors, and the Arduino® Board were connected to an USB output from the solar energy controller, to supply energy for the Arduino® controller. Then, one sensor was installed above the netting surface, to obtain the luminosity without netting, and the other sensor was installed 60 cm above the canopies level and 2 meters below the netting, to avoid shading from the trees, and measure only the luminosity underneath the netting. The other meteorological station (Solar®) was installed about 80 m of distance in an uncovered orchard.

Determination of the fruitlet abscission dynamic as a function of hail netting and PGRs used as chemical thinners

On the cropping seasons of 2019/20 and 2020/21, at pink balloon stage, for the PGRs NAA, BA, and MM, and also to the UC, in both the covered and uncovered conditions, it was installed under the canopy's projection of three apple trees into one of the blocks of the experimental design, collectors made with bamboo and hail netting, for collecting every three or four days the dropped fruitlets, until the end of December drop. The dropped fruitlets were then counted, and, in a sample of 50 fruitlets it was measured the diameter with a digital caliper.

Yield and fruit quality assessments

At pink balloon stage, three branches in opposite sides of the canopy were tagged with the number of flower clusters. After December drop (around the third week of December), it was counted the remaining fruits of each branch, to determine the fruit set (fruits/flower cluster). The harvest in the first, second, and third seasons occurred on Mar 16th, 2020, Mar 09th, 2021, and Mar 08th, 2022, respectively. At harvest, it was counted the number of fruits per tree, and the yield of each tree. It was also measured the trunk perimeter to determine the trunk cross sectional area (TCSA). Also, it was collected a sample of 30 fruits per replication tree to visually determine fruit coverage with red color, in the classes of 0-25%, 25-50%, 50-75%, and 75-100 % of red color coverage, and skin russeting into the classes of 0%, ≤10%, 10-30%, 30-50%, and ≥50% of fruit coverage. A subsample of 20 fruits was collected to determine seed number, flesh firmness with an analogic penetrometer equipped with a 11 mm tip, and total soluble solids with a digital refractometer Atago PAL-1. Fruit weight was determined by dividing the yield by the number of fruits of each replicate tree. Return bloom was assessed on the following spring, by selecting three branches in each tree and counting the total number of buds, and the number of floral buds to determine the percentage.

Statistical analysis

The counting data of fruitlet abscission dynamic was converted into cumulative frequency, and then calculated a three-parameter logistic regression (“S” shaped curve) to obtain the parameters α, β, and λ, which represents the asymptote, the xmid (inflection point), and the angular coefficient at the inflection point, respectively. The parameters were calculated using R software v.4.2.3, and self-starting logistic models with the function “nls” of the package “stats” .

The diameter of the dropped fruitlets were subjected to linear regression through the origin (y=a*x), where “y” is the output under netting, and “x” is the same output outside netting, and “a” was the slope. It was used the R software v.4.2.3, and the regression through the origin was calculated with the function “lm” of the package “stats”.

Data of yield and fruit quality assessments were subjected to mixed-model analysis of variance using R package “lme4”. The factors years, netting, and PGRs were set as fixed, whereas blocks and trees were set as random effects. Mean comparisons were done using the R package “emmeans”. The means of the interactions of PGRs*netting were separated though the Tukey´s HSD test ($p \leq 0.05$), and interactions of netting*PRGs were separated through confidence intervals ($p \leq 0.05$). Fruit set data were analyzed through linear contrasts.

5.3. Results

Under white hail netting, total accumulated PAR from apple tree’s balloon stage until harvest of ‘Fuji Suprema’ was 20,401,975.40 mmol photons m^{-2} s^{-1}, whereas without netting, total accumulated PAR was 24,426,906.32 mmol photons m^{-2} s^{-1}, which corresponded to a reduction of roughly 16 % of PAR supply.

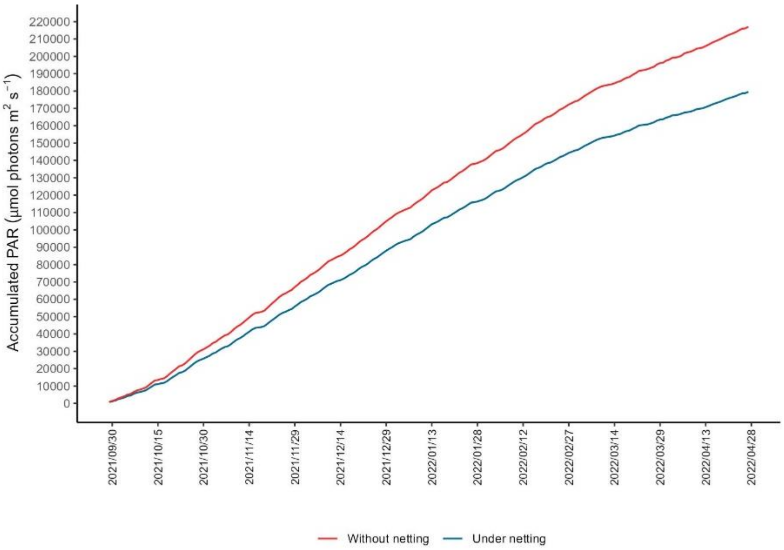


Figure 1. Accumulated solar radiation (µmol photons m^{-2} s^{-1}) in an orchard covered and uncovered with anti-hail netting from balloon stage until fruit harvest. Daily data from one measurement every 15 minutes, totalizing 96 measurements per day. The measurements were done in the cropping season of 2021/22. Bom Jesus-RS, Brazil.

Under netting, mean temperature range was 14.26 °C (difference between minimum and maximum temperatures), while in the uncovered orchard it was 15.62 °C; thus, the netting roughly reduced temperature range in 9% (Figure 2).

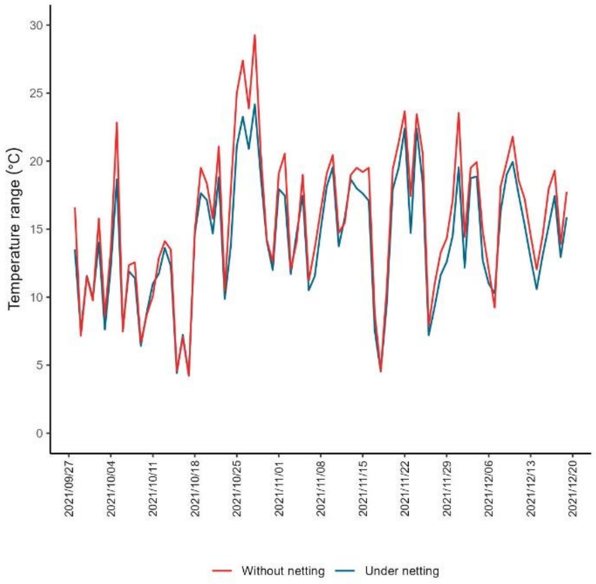


Figure 2. Temperature range (°C) in an orchard covered and uncovered with anti-hail netting from balloon stage until the end of December drop (June drop in NH). Daily data from one measurement every 15

minutes, totalizing 96 measurements per day. The measurements were done in the cropping season of 2021/22. Bom Jesus-RS, Brazil.

Due to the lower mean temperature range found under netting, the cumulative degrees-day were also lower than in the area without netting, totalizing, from full bloom until harvest, an accumulated degrees-day (basal temperature of 4.4 °C) of 1296.38 degrees-day in the uncovered area, and 1183.37 degrees-day under the covered area, corresponding to a reduction of approximately 9% on this variable (Figure 3).

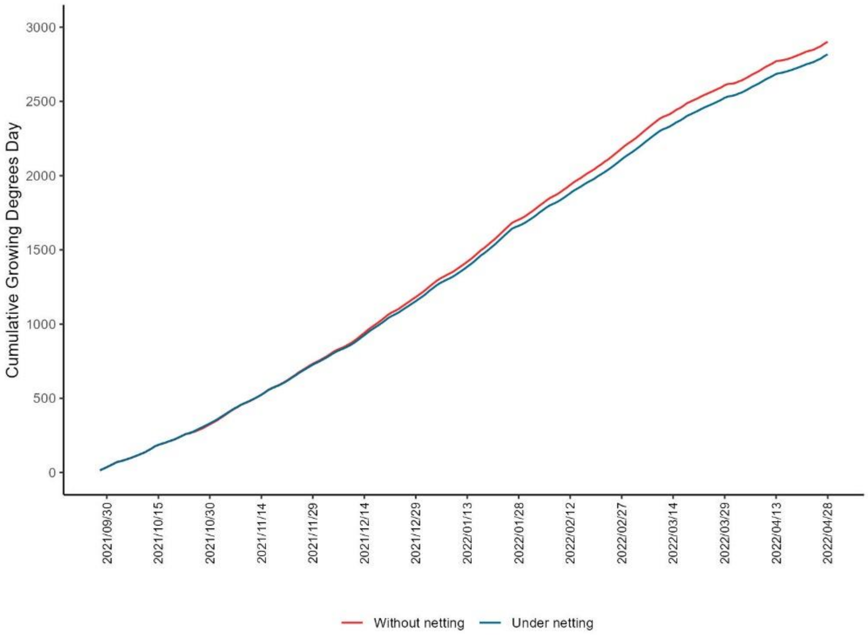


Figure 3. Cumulative degrees day (basal temperature of 4.4 °C) in an orchard covered and uncovered with anti-hail netting from balloon stage until fruit harvest. The measurements were done in the cropping season of 2021/22. Bom Jesus-RS, Brazil.

On the three-parameter logistic regression, in the first season, in the uncovered orchard, only NAA impacted the fruitlet drop dynamic, as it advanced the β in 4 days (Table 1, and Appendixes A and B). On the covered orchard, NAA and MM had advanced the β parameter, in relation to their UCs. The lower β could indicate that in the uncovered orchard, NAA advanced abscission, and in the covered orchard, both NAA and MM did it, as their λ parameter were very similar. However, when comparing each treatment on both netting conditions, all PGR treatments had higher β and λ, indicating that the fruitlet drop was a bit slower, although extended, in the covered orchard.

On the second season, in the uncovered orchard, both NAA and MM had contrasting effects in relation to their UCs: NAA had lower β and λ parameters, indicating that it accelerated fruitlet abscission, whereas MM had higher values for these parameters, indicating that this PGR extended the abscission period in which the speed of abscission was lower (λ less steep) (Table 1, and Appendixes A and B). In the covered orchard, both BA and MM also pushed abscission period to be longer and slower than their UCs, whereas NAA accelerated fruitlet drop. As the effect of netting on each treatment, the comparison of each UC on both environments, and each PGR in both environments, all UCs and PGRs had a higher β and λ under netting. Based on those observations, under netting, the fruitlet abscission lasts longer and at a slower pace.

Table 1. Three-parameter logistic regression calculated from the accumulated frequency of fruitlet abscission as a function of Plant Growth Regulators used as chemical thinners of ‘Fuji Suprema’ apple trees.

Season	Netting	Treatment	3-parameter logistic regression coefficients[1]			
			Plant growth regulators	R^2	Untreated control	R^2
2019/20	No netting	NAA	α=96.91, β=14.63, λ=2.66	$R^2 = 0.99$	α=97.37, β=18.40, λ=2.61	$R^2 = 0.99$
		BA	α=97.60, β=19.75, λ=2.70	$R^2 = 0.96$	α=97.29, β=19.52, λ=2.57	$R^2 = 0.96$
		MM	α=83.44, β=27.61, λ=1.00	$R^2 = 0.87$	α=90.31, β=27.35, λ=0.81	$R^2 = 0.95$
	Under netting	NAA	α=97.78, β=16.55, λ=3.65	$R^2 = 0.99$	α=91.17, β=19.54, λ=3.49	$R^2 = 0.98$
		BA	α=95.09, β=21.84, λ=4.21	$R^2 = 0.96$	α=90.93, β=21.25, λ=3.76	$R^2 = 0.95$
		MM	α=100,00 β=33.86 λ=4.51	$R^2 = 0.97$	α=100.00, β=35.55, λ=6.76	$R^2 = 0.90$
2020/21	No netting	NAA	α=96.75, β=18.40, λ=3.47	$R^2 = 0.99$	α=96.70, β=23.90, λ=4.51	$R^2 = 0.99$
		BA	α=96.61, β=26.83, λ=4.29	$R^2 = 0.99$	α=95.78, β=25.11, λ=3.97	$R^2 = 0.98$
		MM	α=100.00, β=37.18, λ=5.53	$R^2 = 0.97$	α=96.43, β=32.20, λ=4.11	$R^2 = 0.96$
	Under netting	NAA	α=94.88, β=20.60, λ=3.75	$R^2 = 0.98$	α=96.90, β=23.46, λ=5.54	$R^2 = 0.98$
		BA	α=99.36, β=29.45, λ=5.45	$R^2 = 0.99$	α=96.23, β=26.33, λ=4.96	$R^2 = 0.96$
		MM	α=99.52, β=37.91, λ=5.53	$R^2 = 0.98$	α=99.38, β=35.19, λ=4.66	$R^2 = 0.98$

* α: Asymptote; β: Inflection point; λ: Angular coefficient at the inflection point

The netting effect on the abscised fruitlet was contrasting on both seasons (Table 2). In the first season, under netting fruitlet diameter was 15% and 13% bigger than the diameter of fruitlets from the uncovered area, for the treatments UC and MM, respectively. In contrast, with NAA the abscised fruitlets were 10% smaller in the covered than in the uncovered area. On the second season, under netting the abscised fruitlets were 6%, 12%, and 10% bigger, respectively, for UC, NAA, and BA than the uncovered area, while for MM the abscised fruitlets were 3% smaller under netting.

Table 2. Comparison of the fruitlet diameter of 'Fuji Suprema' from the stage of petal fall until the end of the December drop of the hail netting covered and uncovered areas subjecting the data to regression through the origin (y=a.x), where "x" is the diameter without netting, "y" is the diameter under netting, and "a" is the slope.

	2019/20			2020/21		
Parameters	Slope (a)	Netting effect (%)	R^2	Slope (a)	Netting effect (%)	R^2
UC	1.15	+15	0.93	1.06	+6	0.97
NAA	0.90	-10	0.74	1.12	+12	0.95
BA	0.99	-1	0.91	1.10	+10	0.94
MM	1.13	+13	0.80	0.97	-3	0.93

In the season of 2019/20, in the covered area, only the treatments with two or three sprays (NAA+BA, BA+MM, NAA+BA+MM) reduced fruit set, while in the uncovered area only NAA and NAA+BA+MM reduced fruit set. For the UC 8 mm, BA, and NAA, fruit set was lower in the uncovered area (Table 3). In the second season (2020/21), in both environments, except BA and MM alone, all other treatments reduced fruit set on both environments. In addition, no effect of netting was found on the treatments. In the third season (2021/22), except for MM in both environments, NAA+BA in the covered condition and BA+MM in the uncovered condition, all other treatments reduced fruit set. Moreover, MM and BA+MM had lower fruit set in the covered condition.

Table 3. Fruit set of 'Fuji Suprema' apple trees as a function of PGR sprays used as chemical thinners in orchards covered and uncovered with anti-hail netting.

	2019/2020		2020/2021		2021/2022	
Treatments[1]	Covered	Uncovered	Covered	Uncovered	Covered	Uncovered
UC FB	2.95	2.35^{ns}	1.72	1.56^{ns}	1.77	2.18^{ns}
UC 8 mm	3.21	2.35*	1.82	1.44^{ns}	1.77	2.12^{ns}
UC 15 mm	3.42	2.86^{ns}	2.26	1.62^{ns}	2.22	2.63^{ns}
NAA	2.61	1.89*	1.21	1.19^{ns}	1.39	1.52^{ns}
BA	3.13	2.12**	1.66	1.44^{ns}	1.11	2.69***
MM	3.44	2.73$^{\cdot}$	1.81	1.52^{ns}	2.38	2.63^{ns}
NAA+BA	2.57	2.15^{ns}	0.84	0.86^{ns}	1.49	1.25^{ns}
NAA+MM	2.33	2.46^{ns}	1.14	1.13^{ns}	1.00	1.36^{ns}
BA+MM	2.56	2.63^{ns}	0.91	0.91^{ns}	1.32	2.47***
NAA+BA+MM	2.07	1.86^{ns}	0.54	0.58^{ns}	1.39	1.39^{ns}
Contrasts						
UC FB vs NAA	ns	*	*	.	.	*
UC 8 mm vs BA	ns	ns	ns	ns	**	.
UC 15 mm vs MM	ns	ns	ns	ns	ns	ns
UC FB vs NAA+BA	ns	ns	***	**	ns	**
UC FB vs NAA+MM	*	ns	**	.	**	**
UC 8 mm vs BA+MM	*	ns	***	*	.	ns
UC FB vs NAA+BA+MM	**	*	***	***	*	**

[1] Data evaluated through linear contrasts. ^{ns}, *, **, ***$\cdot$indicates non-significance, and significance at (p≤0.05), (p≤0.01), (p≤0.001), respectively.

In the first season (2019/20), crop load was affected by treatment only in the covered area, and only the manual thinning treatment (MTO) effectively reduced crop load, whereas all other treatments did not differ from the UC (Table 4). Also, netting affected only the treatment BA, which had lower crop load in the uncovered area. In the second season (2020/21), no effect of treatment or netting was found for crop load. In the third season (2021/22), no effect of netting on each treatment was found, however, in the covered area, the treatments NAA, NAA+BA, and NAA+BA+MM had lower crop load than the UC. In the uncovered area, only MM did not differ from the UC, and all other treatments were equivalent and presented lower crop load than the UC. The targeted crop load of the orchard was 2.71 fruits.cm^{-2} TCSA (for 150 fruits per tree), and only in the third season the treatments adjusted this variable to an adequate level.

Yield efficiency was not affected by treatment or netting in the first and second seasons (Table 4). In the third season, in the covered area, NAA, NAA+BA, and NAA+BA+MM had lower yield efficiency than the UC, whereas in the uncovered area, except MM and BA+MM, all other treatments had lower yield efficiency than the UC. In addition, in this season, with the treatment NAA+BA+MM, yield efficiency was higher in the uncovered area.

Return bloom was in general low in all seasons and in both environments; Although, in the third season, in the uncovered area, NAA+BA had higher return bloom than the UC (Table 4). In addition, this was the only treatment that yielded an adequate return bloom, as the targeted was 36% for the production of at least 100 flower buds per tree. Even though some treatments reduced crop load near the targeted threshold, return bloom was not improved.

Table 4. Crop load, yield efficiency, and return bloom of ‘Fuji Suprema’ apple trees as a function of PGR sprays used as chemical thinners on orchards covered and uncovered with anti-hail netting.

Treatments	Crop Load (fruits.cm^{-2} TCSA)		Yield Efficiency (Kg.cm^{-2} TCSA)		Return Bloom (%)	
2019/20 season	Covered[1]	Uncovered	Covered	Uncovered	Covered	Uncovered
UC	7.1 ab	6.4^{ns} a	0.49 a	0.43^{ns} a	10 a	9^{ns} a
NAA	5.9 abc	4.4^{ns} a	0.36 a	0.35^{ns} a	10 a	12^{ns} a
BA	8.2 a	5.2* a	0.51 a	0.35^{ns} a	11 a	18^{ns} a
MM	5.3 abc	6.0^{ns} a	0.38 a	0.40^{ns} a	5 a	10^{ns} a
NAA+BA	4.3 abc	3.0^{ns} a	0.36 a	0.26^{ns} a	15 a	15^{ns} a
NAA+MM	4.9 abc	4.2^{ns} a	0.34 a	0.30^{ns} a	13 a	14^{ns} a
BA+MM	5.5 abc	3.7^{ns} a	0.36 a	0.28^{ns} a	5 a	15^{ns} a
NAA+BA+MM	3.7 bc	4.3^{ns} a	0.29 a	0.35^{ns} a	12 a	13^{ns} a

MTO	2.6 c	3.6^{ns} a	0.27 a	0.33^{ns} a	17 a	22^{ns} a
2020/21 season						
UC	6.0 a	6.0^{ns} a	0.66 a	0.63^{ns} a	4 a	0^{ns} a
NAA	5.4 a	4.8^{ns} a	0.56 a	0.54^{ns} a	6 a	11^{ns} a
BA	4.6 a	4.0^{ns} a	0.53 a	0.49^{ns} a	4 a	1^{ns} a
MM	4.7 a	4.8^{ns} a	0.49 a	0.54^{ns} a	10 a	9^{ns} a
NAA+BA	3.3 a	3.3^{ns} a	0.45 a	0.45^{ns} a	5 a	2^{ns} a
NAA+MM	3.6 a	3.8^{ns} a	0.43 a	0.51^{ns} a	7 a	9^{ns} a
BA+MM	2.9 a	2.7^{ns} a	0.40 a	0.34^{ns} a	11 a	1^{ns} a
NAA+BA+MM	2.9 a	3.0^{ns} a	0.37 a	0.45^{ns} a	5 a	7^{ns} a
MTO	3.0 a	3.5^{ns} a	0.41 a	0.45^{ns} a	10 a	10^{ns} a
2021/22 season						
UC	9.8 a	11.7^{ns} a	0.83 a	1.03^{ns} ab	1 a	8^{ns} b
NAA	3.7 bc	5.1^{ns} b	0.42 bc	0.54^{ns} c	17 a	24^{ns} ab
BA	5.8 ab	3.7^{ns} b	0.54 abc	0.36^{ns} c	18 a	28^{ns} ab
MM	8.9 a	11.5^{ns} a	0.79 a	1.07^{ns} a	2 a	12^{ns} b
NAA+BA	3.1 bc	3.6^{ns} b	0.37 bc	0.42^{ns} c	14 a	40* a
NAA+MM	4.1 ab	3.2^{ns} b	0.46 abc	0.39^{ns} c	14 a	22^{ns} ab
BA+MM	6.2 ab	5.9^{ns} b	0.59 ab	0.59^{ns} bc	7 a	20^{ns} ab
NAA+BA+MM	2.4 c	4.4^{ns} b	0.28 c	0.51* c	16 a	18^{ns} ab
MTO	5.8 abc	5.0^{ns} b	0.57 abc	0.52^{ns} c	12 a	26^{ns} ab

[1] Means followed by the same letter in a column do not differ according to the Tukey HSD test ($p \leq 0.05$) for treatments into each netting condition. ^{ns} and * in the row correspond to non-significance and significance for netting condition into each treatment.

Fruit weight, in the first season, in the covered area was slightly improved by NAA+BA, and NAA+BA+MM, besides the MTO, which was the highest weight (Table 5). In the uncovered area, no treatment improved fruit weight, and it was overall low. In addition, netting only affected NAA, which induced heavier fruits in the uncovered condition. In the second season, in the covered area, the treatments NAA+BA, NAA+MM, BA+MM, and MTO presented improved weight, whereas in the uncovered area, NAA+BA, NAA+MM, and NAA+BA+MM improved fruit weight. In this season, the netting effect only influenced NAA+BA+MM, which presented higher fruit weight in the uncovered condition. In the third season, in the covered area, fruit weight was improved by all treatments containing NAA, whereas in the uncovered condition, except

MM, all other treatments improved fruit weight. Also, no effect of netting influenced fruit weight.

Seed number was not affected by treatment in the covered condition, in all three seasons (Table 5). However, in the uncovered condition, in the first season, the treatments BA, and BA+MM reduced seed number. In addition, regarding the netting effect, the treatments BA, MM, NAA+MM, BA+MM, and NAA+BA+MM presented fruits with less seed in the uncovered condition. In the second season, no effect of treatment was found in the uncovered area, and also no effect of netting on the treatments. In the third season, only NAA+BA presented lower seed number than the UC or MTO, although, the netting effect was found for NAA+BA, NAA+MM, and BA+MM, which had fruits with less seeds in the uncovered condition.

Total soluble solids (TSS) was not affected by treatment in both covered and uncovered conditions in the first season, although on the treatments BA+MM, and MTO, TSS was higher in the uncovered condition (Table 5). On the second season, there was no effect of treatment nor netting on TSS. In the third season, in the covered condition, no treatment effect was found, however, in the uncovered condition only NAA+BA had higher TSS than the UC. In addition, with UC, NAA, BA, MM, BA+MM, and MTO, the TSS concentration was higher in the uncovered condition.

It is noteworthy to mention that in the third season this difference in TSS concentration of the covered and uncovered orchards, likely was not due to the environmental changes directly (hail netting), but due to the higher quantity of fruits being produced in clusters with 3 or more fruitlets in the uncovered area, whereas more fruits were produced in single fruitlet clusters in the covered condition (Appendix D). This may have slightly decreased fruit size in the uncovered orchard and made TSS concentration to be higher, and this size difference was not captured by the variable fruit weight.

Table 5. Fruit weight, seed number, and total soluble solids of ‘Fuji Suprema’ apple fruits as a function of PGR sprays used as chemical thinners on orchards covered and uncovered with anti-hail netting.

Treatments	Fruit Weight (g)		Seed Number		Total Soluble Solids (°Brix)	
2019/20 season	Covered[1]	Uncovered	Covered	Uncovered	Covered	Uncovered
UC	72 bc	73^{ns} a	5.9 a	6.1^{ns} a	14.0 a	14.3^{ns} a
NAA	64 c	86* a	5.9 a	5.4^{ns} abc	14.0 a	14.3^{ns} a
BA	66 bc	78^{ns} a	6.2 a	5.0* bc	13.9 a	14.5^{ns} a
MM	76 bc	73^{ns} a	6.0 a	5.2* abc	13.7 a	14.3^{ns} a
NAA+BA	87 ab	85^{ns} a	5.9 a	5.7^{ns} abc	14.2 a	14.4^{ns} a
NAA+MM	72 bc	82^{ns} a	6.2 a	5.5* abc	14.3 a	14.4^{ns} a
BA+MM	66 bc	79^{ns} a	6.4 a	4.9* c	14.0 a	15.7* a
NAA+BA+MM	81 abc	88^{ns} a	6.2 a	5.4* abc	13.9 a	14.8^{ns} a
MTO	103 a	92^{ns} a	6.2 a	6.0^{ns} ab	13.9 a	15.6* a
2020/21 season						
UC	115 bc	106^{ns} d	7.8 a	7.9^{ns} a	11.4 a	10.9^{ns} a
NAA	114 bc	117^{ns} bcd	7.6 a	7.4^{ns} a	11.5 a	11.6^{ns} a
BA	114 bc	125^{ns} bcd	7.1 a	7.6^{ns} a	11.8 a	12.1^{ns} a
MM	107 c	113^{ns} cd	7.5 a	7.5^{ns} a	12.6 a	11.8^{ns} a
NAA+BA	139 a	137^{ns} ab	7.4 a	7.7^{ns} a	11.9 a	11.6^{ns} a
NAA+MM	128 abc	134^{ns} abc	7.4 a	7.9^{ns} a	12.0 a	11.8^{ns} a
BA+MM	140 a	128^{ns} bcd	7.3 a	7.6^{ns} a	12.2 a	12.1^{ns} a
NAA+BA+MM	130 ab	152* a	7.7 a	7.5^{ns} a	11.9 a	12.2^{ns} a
MTO	135 ab	128^{ns} bcd	7.4 a	7.7^{ns} a	12.3 a	12.1^{ns} a
2021/22 season						
UC	87 d	94^{ns} c	7.5 a	6.9^{ns} a	11.9 a	14.4* b
NAA	118 abc	120^{ns} a	6.4 a	6.8^{ns} a	13.0 a	14.5* ab
BA	95 d	101^{ns} abc	6.6 a	6.2^{ns} ab	12.6 a	14.5* ab
MM	93 d	96^{ns} bc	7.1 a	6.5^{ns} ab	11.8 a	14.0* ab
NAA+BA	127 a	121^{ns} a	6.9 a	5.6* b	13.1 a	15.0^{ns} a
NAA+MM	121 ab	124^{ns} a	7.1 a	6.2* ab	12.9 a	13.6^{ns} ab
BA+MM	97 cd	107^{ns} abc	7.2 a	6.4* ab	12.9 a	14.4* ab
NAA+BA+MM	120 ab	124^{ns} a	6.4 a	6.0^{ns} ab	13.5 a	14.1^{ns} ab
MTO	104 bcd	118^{ns} ab	7.3 a	6.9^{ns} a	12.5 a	14.4* ab

[1] Means followed by the same letter in a column do not differ according to the Tukey HSD test ($p \leq 0.05$) for treatments into each netting condition. ^{ns} and * in the row correspond to non-significance and significance for netting condition into each treatment.

5.4. Discussion

Microclimatic alterations such as reduction of the PAR, reduced temperature range and reduced cumulative degrees-day, all caused by the netting, accelerated the speed of fruitlet abscission of the UC on first and second evaluated seasons, as seen in Table 1, indicating that netting increased natural fruitlet abscission. Similarly, Solomakhin & Blanke (2010) found that the microclimate under netting was slightly cooler during the day, and slightly warmer during the night, as soil temperature under netting was almost 1 °C higher than the uncovered area. Moreover, in our experiment, the dropped fruitlets of the UC were 15% and 6% larger under netting than outside, for the first and second seasons, respectively, indicating that under netting fruitlet abscission extended for longer, dropping larger fruits.

Higher fruitlet drop under hail netting has been reported by Brglez-Sever et al. (2021), and Salazar-Canales et al. (2021). Although the former study attributed the higher fruitlet drop only to lower PAR, the latter found that even though shading and lower temperature under netting promoted some shade avoidance strategies by hazelnut trees, such as higher leaf specific weight and stomatal density, the clear color net transmitted more diffused light, which may have compensated the setbacks by making available more light into the inner canopy of the trees, increasing nut quality. Although the authors did not measure this variable, they reported a higher natural nut drop under nets, which may have contributed to enhance nut quality.

The threshold of fruits that will set on the tree depends on the current photosynthesis at early spring, as the fruitlets are competing for assimilates along with the growing leaves and branches (Breen et al., 2020; Lakso & Goffinet, 2013). As the canopies of apple trees grown under hail netting have equivalent solar radiation interception capacity of the ones grown outside netting (Bosco et al., 2018), it seems that the carbon balance plays an important role on determining how many fruitlets will set (Breen et al., 2015; Breen et al., 2020; Lordan et al., 2019). This higher natural drop also leads the assimilates to be driven towards vegetative growth, increasing the canopy vigor (Middleton & McWaters, 2002; Solomakhin & Blanke, 2008, 2010).

The unfavorable conditions for carbon balance, and consequently fruit set, such as lower solar radiation and lower temperature range caused by higher night temperatures, may increase mitochondrial respiration decreasing the net carbon balance (Lordan et al., 2020), and the shading promoted by white or black hail net also reduces carbon assimilation (Amarante et al., 2007). In addition, on cloudy days, the shading of the covered apple orchards is quite remarkable, as well as the reduction of photosynthesis (Solomakhin & Blanke, 2008). Similar to the netting effects discussed so far, the PGRs NAA, BA, and MM used as chemical thinners also promote fruitlet drop by creating a temporary shortage of assimilates (Eccher et al., 2013; Yuan & Greene, 2000a; Zhu et al., 2011), which intensifies the competition of the fruitlets, leading to a decreased growth rate of the embryos, which decreases the export of endogenous auxin through the pedicel, leading to an increment of the synthesis of ethylene, leading to abscission (Schröder et al., 2013). The effects of these PGRs are enhanced by high night temperatures, as this condition is unfavorable for the carbon balance (Clever, 2022; Gonzalez et al., 2020b; Yuan & Greene, 2000a).

In our experiment, from full bloom until petal fall, accumulated degrees-day was 100, and 97, for the first and second seasons, respectively (data not shown), which is considered as adequate for apple trees. A higher accumulation of degrees-day during this period is beneficial for quicker leaf development and resupply of assimilates for the fruitlets when they enter into the exponential growth phase, which demands high amounts of assimilates; therefore, when there are more leaves expanded during this phase, the better the supply is, and the higher is the capacity of the trees to maintain fruit set (Lakso & Goffinet, 2013; Lordan et al., 2020). In addition, during the phases from full bloom (0 degrees-day) until 60 degrees-day, and from 300 to 350 degrees-day, favorable meteorological conditions for carbon balance improve fruit set (Lordan et al., 2019). Although, in our experiment, both first and second seasons were very similar in this parameter (Supplement 1). It is important to point out that in 2019/20, the estimated initial flower buds per tree was 103 in the covered area, and 133 in the uncovered area. In 2020/21, the estimated initial flower buds per tree was 203 in the covered area, and 265 in the uncovered area. Thus, in our experiment, it is likely that the predominant factor influencing fruit set was the initial flower bud load, as there is a negative correlation between these variables (Lordan et al., 2019).

NAA dropped larger fruitlets in the uncovered area, whereas, in the second season, larger fruitlets were dropped in the covered area. This contradictory pattern may be explained by the rainy conditions found in the first season, and lower solar radiation (Supplement 1). NAA acts on diminishing the transportation of auxin of the least developed fruitlets, which increases the correlative dominance of the more developed ones, temporarily halting growth (Bangerth, 2000), leading to a decreased photosynthesis, and very high respiration rates (Stopar et al., 2001; Untiedt & Blanke, 2001). This assimilate deficit increases the natural abscission pattern (Lakso & Goffinet, 2013). All tested PGRs used in this experiment (NAA, BA, and MM), and the shading after a period of shortage of assimilates, lead to the evolution of ethylene and formation of the abscission zone (Eccher et al., 2013; Kolarič et al., 2011).

It is likely that the unfavorable meteorological conditions right after full bloom increased the effect of halting fruitlet growth by NAA, in 2019/20. In the second season, as a consequence of the higher initial bud load, and the microclimatic changes promoted by the netting, yielded dropped fruitlets of larger diameter under netting. Similarly, for BA in the second season, and MM in the first season, the fruitlets of the trees under netting and treated with these PGRs were larger. Shading has a synergic effect on fruitlet drop when combined with chemical thinners, as it intensifies the shortage of assimilates, or even increase the absorption due to the higher humidity and less sunlight, avoiding molecule degradation by UV light (Byers et al., 1990; Kolarič et al., 2011; Rosa et al., 2020; Stopar et al., 2001; Untiedt & Blanke, 2001).

Overall, there was no effect of both environments on the effectiveness of the PGRs on promoting fruitlet thinning, corroborating with Gonzalez et al. (2020a), although contrasting Clever (2018) and Clever (2020). As seen in our experiment, the presence of hail netting in fact increased and speeded up the natural fruitlet abscission, or made the abscission period to last longer, and the PGRs had an intensified fruitlet dropping effect under netting. Although, the combination of netting and PGRs was not enough to cause overthinning or even reduce crop load adequately.

Concerning the microclimatic parameters, the higher degrees-day and temperature found outside netting also favors the uptake of PGRs, as there is a quicker leaf area development, and temperature is positively correlated to foliar uptake (Black et al., 1995; Lordan et al., 2020). In our experiment, these environmental factors were self-compensatory on affecting fruitlet drop by the PGRs, i.e., under netting the microclimate induced faster fruitlet drop, and the remaining ones were in lower number when the PGRs were sprayed, which rebalanced the source-sink relations, and made the remaining fruitlets to be more resilient to the assimilate shortage promoted by the PGRs, whereas outside, the higher uptake of the PGRs and the higher fruitlet number at the moment of the spray (due to slower drop rate), favored their thinning effect due to the intensification of the competition already existing. Another variable that could support this statement, is the fact that, in the case of the first and third seasons, fruit seed number was lower outside netting. In such condition, the PGRs had a stronger effect on increasing the shortage of assimilates, which led to more competition, then embryo abortion, and consequently less seeds. Competition negatively affects seed number as the cytokinin-like PGRs are known for increasing cell multiplication (Milić et al., 2017) and increasing whole canopy sink-strength, making the fruitlets with less seeds to be abscised, as they are weaker sinks compared to the ones with more seeds, and also decreasing fruit seed number, or even producing fruits with no seeds (Greene, 1995; Yuan & Greene, 2000b). The competition and lack of sufficient assimilates lead to saturation of the ethylene receptors in the embryos, trigging the abscission process; moreover, this competition can be originated anyway from the natural environment, PGRs, high flower bud load, etc (Eccher et al., 2015). Then, outside, as more fruitlets persisted for longer, it's likely that they were subjected to higher competition by the higher number of fruitlets and the PGRs, then struggling embryo development and seed number.

Concerning the chemical thinners, it is likely that the higher natural fruitlet abscission under netting made the assimilates shortage, and consequently the stress caused by the PGRs, to be shortened, as there was less intracluster competition, leaving more assimilates to be available for the fruitlets that were not prone to drop (Black et al., 2000; Breen et al., 2020; Breen et al., 2015). The most important factor influencing the effectiveness of chemical thinners is the tree's carbon balance, e.g., when before and after the spray the night temperatures are high, or there are many cloudy days, the thinning intensity of the PGRs tend to be high, and concentrations should be reduced (Clever, 2018, 2022; Cline et al., 2022; Gonzalez et al., 2020b; Lakso & Robinson, 2015; Lordan et al., 2020; Robinson & Lakso, 2004, 2011).

The treatments that consistently reduced fruit set in the covered condition were NAA+MM, BA+MM, and NAA+BA+MM, whereas, in the uncovered condition were NAA alone and NAA+BA+MM. However, fruit weight was consistently enhanced by the treatments containing NAA associated with BA, or MM, or BA+MM, in both netting environments. NAA influences fruit size/weight by increasing cell enlargement and consequently size, while BA effects the fruit by increasing the rate of cell multiplication. In both cases, this effect of cell enlargement or multiplication is observed when there is effective fruit thinning (Milić et al., 2017). MM as a photosystem II inhibitor, has no direct effect on cell wall dynamics or cell cycle, but when it promotes fruitlet thinning, it increases fruit weight by increasing cell number and area (Gabardo et al., 2019). The findings of these authors corroborate with this experiment, as only the direct effect of the PGRs had little influence on enhancing fruit weight, but the reduction of fruit set by the treatments with two or three sprays were effective in improving this variable.

The treatments had little influence on the TSS, although, in the uncovered area the concentration of solids in the fruits was higher, even though among the seasons the pattern for treatments was different. On the other hand, return bloom was not influenced by treatment or netting, except in the third season, in which NAA+BA had higher return bloom than the UC. In all seasons and netting conditions, return bloom was low. Numerically, there was a trend of the trees in the uncovered condition to have slightly higher return bloom.

The setbacks brought by lower solar radiation under netting increase natural fruit drop, stimulate vegetative growth, decreases photosynthesis, and increase the shading in the inner canopy, decrease the accumulation of total soluble solids in the fruits, decrease fruit blush buildup, and hinder flower bud induction (Amarante et al., 2011; Middleton & McWaters, 2002; Solomakhin & Blanke, 2008; Treder et al., 2016). In our experiment, fruit red color was not affected by netting or treatments (data not shown). When there is a condition of high fruit load, the soluble sugars are driven towards fruit development, decreasing the levels for vegetative growth and bud initiation, leading to alternate bearing in the following season, as there are less assimilates for bud regeneration; moreover, in OFF-year buds, there is a surplus of sucrose, which is an important signal for floral induction; and high levels of sucrose lead to the upregulation of *MdTPS1* which is related to sugar metabolism, and this gene also triggers the expression of *FT* genes which are related to flower differentiation; also, in OFF-year buds, high levels of ABA are found which may be antagonistic to GAs (flower inhibitor), and GAs inhibit the flower promoting effects of cytokinins (Zuo et al., 2018). So, under netting, it is likely that the higher natural fruitlet drop leads the soluble sugars to be driven towards vegetative growth, increasing the levels of GAs, then antagonizing ABA, and inhibiting the flower bud differentiation by the cytokinins, leading to low return bloom.

5.5. Conclusion

The reduction of temperature range, degrees-day, and cumulative photosynthetically active radiation promoted by the white hail netting increases the length of the natural fruitlet drop period and increases the speed of abscission of the PGRs used as chemical thinners. Although, the earlier reduction of competition due to higher natural fruitlet drop under netting, decreases the competition on the remaining fruitlets, without increasing the thinning effect of the PGRs used as chemical thinners, with no risk of overthinning in the covered orchard. For both covered and uncovered conditions, the chemical thinning programs NAA+BA, NAA+MM, or NAA+BA+MM consistently adjust crop load and enhance fruit weight of ‘Fuji Suprema’ apple trees.

Acknowledgements

The authors acknowledge the company AGROSPE for the experimental throughout these three cropping seasons, especially Fábio Varela and André Zamban De Pieri.

Funding: This work was supported by EMBRAPA Uva e Vinho; and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) [grant number 141123/2019-2]

5.6 References

Alvares, C. A., Stape, J. L., Sentelhas, P. C., de Moraes Gonçalves, J. L., & Sparovek, G. (2013). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, *22*(6), 711–728. https://doi.org/10.1127/0941-2948/2013/0507

Amarante, C. V. T. do, Steffens, C. A., & Argenta, L. C. (2011). Yield and fruit quality of "Gala" and "Fuji" apple trees protected by white anti-hail net. *Scientia Horticulturae*, *129*(1), 79–85. https://doi.org/10.1016/j.scienta.2011.03.010

Amarante, C. V. T. do, Steffens, C. A., Mota, C. S., & Santos, H. P. dos. (2007). Radiação, fotossíntese, rendimento e qualidade de frutos em macieiras "Royal Gala" cobertas com telas antigranizo. *Pesquisa Agropecuária Brasileira*, *42*(7), 925–931. https://doi.org/10.1590/S0100-204X2007000700003

Bangerth, F. (2000). Abscission and thinning of young fruit and their regulation by plant hormones and bioregulators. *Plant Growth Regulation*, *31*, 43–59. https://doi.org/10.1023/A:1006398513703

Black, B. L., Bukovac, M. J., & Stopar, M. (2000). Intraspur fruit competition and position influence fruit size at harvest and response to chemical thinning agents in spur-type delicious apple. *Acta Horticulturae*, *527*, 119–126. https://doi.org/10.17660/ActaHortic.2000.527.13

Black, B. L., Petracek, P. D., & Bukovac, M. J. (1995). The Effect of Temperature on Uptake of NAA by Redchief `Delicious' Apple Leaves. *Journal of the American*

Society for Horticultural Science, *120*(3), 441–445. https://doi.org/10.21273/JASHS.120.3.441

Bosco, L. C., Bergamaschi, H., Cardoso, L. S., de Paula, V. A., Marodin, G. A. B., & Brauner, P. C. (2018). Microclimate alterations caused by agricultural hail net coverage and effects on apple tree yield in subtropical climate of southern Brazil. *Bragantia*, *77*(1), 181–192. https://doi.org/10.1590/1678-4499.2016459

Bosco, L. C., Bergamaschi, H., Cardoso, L. S., de Paula, V. A., Marodin, G. A. B., & Nachtigall, G. R. (2015). Apple production and quality when cultivated under anti-hail cover in Southern Brazil. *International Journal of Biometeorology*, *59*(7), 773–782. https://doi.org/10.1007/s00484-014-0893-6

Breen, K. C., Tustin, D. S., Palmer, J. W., & Close, D. C. (2015). Method of manipulating floral bud density affects fruit set responses in apple. *Scientia Horticulturae*, *197*, 244–253. https://doi.org/10.1016/j.scienta.2015.09.042

Breen, K., Tustin, S., Palmer, J., Boldingh, H., & Close, D. (2020). Revisiting the role of carbohydrate reserves in fruit set and early-season growth of apple. *Scientia Horticulturae*, *261*, 109034. https://doi.org/10.1016/j.scienta.2019.109034

Brglez-Sever, M., Tojnko, S., Fakin, D., Stajnko, D., & Unuk, T. (2021). Natural June thinning of fruitlets and yield characteristics of apple trees growing under coloured anti-hail netting. *European Journal of Horticultural Science*, *86*(2), 136–145. https://doi.org/10.17660/eJHS.2021/86.2.4

Byers, R. E., Barden, J. A., & Carbaugh, D. H. (1990). Thinning of Spur `Delicious’ Apples by Shade, Terbacil, Carbaryl, and Ethephon. *Journal of the American Society for Horticultural Science*, *115*(1), 9–13. https://doi.org/10.21273/JASHS.115.1.9

Clever, M. (2018). Effects of solar irradiation and night-time temperature on the thinning efficacy of metamitron (Brevis®) in apple. *Acta Horticulturae*, *1221*, 23–30. https://doi.org/10.17660/ActaHortic.2018.1221.4

Clever, M. (2022). Relationships among hail net and thinning efficacy. *Acta Horticulturae*, *1341*, 31–38. https://doi.org/10.17660/ActaHortic.2022.1341.5

Cline, J. A., Bakker, C. J., & Beneff, A. (2022). Multi-year investigation on the rate, timing, and use of surfactant for thinning apples with post-bloom applications of metamitron. *Canadian Journal of Plant Science*, *102*(3), 628–655. https://doi.org/10.1139/cjps-2021-0206

Eccher, G., Botton, A., Dimauro, M., Boschetti, A., Ruperti, B., & Ramina, A. (2013). Early induction of apple fruitlet abscission is characterized by an increase of both isoprene emission and abscisic acid content. *Plant Physiology*, *161*(4), 1952–1969. https://doi.org/10.1104/pp.112.208470

Eccher, G., Begheldo, M., Boschetti, A., Ruperti, B., & Botton, A. (2015). Roles of ethylene production and ethylene receptor expression in regulating apple fruitlet abscission. Plant Physiology, 169(1), 125–137. https://doi.org/10.1104/pp.15.00358

Gabardo, G. C., Kretzchmar, A. A., Petri, J. L., De Martin, M. S., Sezerino, A. A., & Blattmann, E. (2019). Influence of Post-Flowering Chemical Thinning on Development and Fruit Quality of "Fuji Suprema" and "Maxigala" Apple Trees. *Journal of Experimental Agriculture International*, 1–13. https://doi.org/10.9734/jeai/2019/v32i430107

Gonzalez, L., Àvila, G., Carbó, J., Bonany, J., Alegre, S., Torres, E., Martin, B., Recasens, I., & Asin, L. (2020a). Hail nets do not affect the efficacy of metamitron for chemical thinning of apple trees. *The Journal of Horticultural Science and Biotechnology*, *95*(1), 128–135. https://doi.org/10.1080/14620316.2019.1631128

Gonzalez, L., Torres, E., Àvila, G., Bonany, J., Alegre, S., Carbó, J., Martín, B., Recasens, I., & Asin, L. (2020b). Evaluation of chemical fruit thinning efficiency using Brevis® (Metamitron) on apple trees ('Gala') under Spanish conditions. *Scientia Horticulturae*, *261*. https://doi.org/10.1016/j.scienta.2019.109003

Greene, D. W. (1995). Thidiazuron Effects on Fruit Set, Fruit Quality, and Return Bloom of Apples. *HortScience*, *30*(6), 1238–1240. https://doi.org/10.21273/HORTSCI.30.6.1238

IBGE. (2022). *Produção agrícola municipal*. https://sidra.ibge.gov.br/tabela/5457#resultado (accessed 8.7.22)

INMET, 2022. Dados históricos anuais [WWW Document]. URL https://portal.inmet.gov.br/dadoshistoricos (accessed 8.7.22).

Kolarič, J., Mavrič Pleško, I., Tojnko, S., & Stopar, M. (2011). Apple Fruitlet Ethylene Evolution and MdACO1, MdACS5A, and MdACS5B Expression after Application of Naphthaleneacetic Acid, 6-Benzyladenine, Ethephon, or Shading. *HortScience*, *46*(10), 1381–1386. https://doi.org/10.21273/HORTSCI.46.10.1381

Lakso, A. N., & Goffinet, M. C. (2013). Apple Fruit Growth. *New York Quarterly, 21*(1), 11–14.

Lakso, A. N., & Robinson, T. L. (2015). Decision support for apple thinning based on carbon balance modeling. *Acta Horticulturae*, *1068*(1068), 235–242. https://doi.org/10.17660/ActaHortic.2015.1068.29

Lazzarotto, J. J., & Fioravanço, J. C. (2020). *Impactos do granizo sobre o desempenho econômico e financeiro da produção de maçã em pomares protegidos com tela ou com seguro agrícola*. https://ainfo.cnptia.embrapa.br/digital/bitstream/item/219319/1/Doc119.pdf

Lordan, J., Reginato, G. H., Lakso, A. N., Francescatto, P., & Robinson, T. L. (2019). Natural fruitlet abscission as related to apple tree carbon balance estimated with the MaluSim model. *Scientia Horticulturae*, *247*, 296–309. https://doi.org/10.1016/j.scienta.2018.11.049

Lordan, J., Reginato, G. H., Lakso, A. N., Francescatto, P., & Robinson, T. L. (2020). Modelling physiological and environmental factors regulating relative fruit set and final fruit numbers in apple trees. *Journal of Horticultural Science and Biotechnology*, *95*(5), 600–616. https://doi.org/10.1080/14620316.2020.1718555

Martins, J. A., Brand, V. S., Capucim, M. N., Felix, R. R., Martins, L. D., Freitas, E. D., Gonçalves, F. L. T., Hallak, R., Dias, M. A. F. S., & Cecil, D. J. (2017). Climatology of destructive hailstorms in Brazil. *Atmospheric Research*, *184*, 126–138. https://doi.org/10.1016/j.atmosres.2016.10.012

Michael, P. R., Johnston, D. E., & Moreno, W. (2020). A conversion guide: Solar irradiance and lux illuminance. *Journal of Measurements in Engineering*, *8*(4), 153–166. https://doi.org/10.21595/jme.2020.21667

Middleton, S., & McWaters, A. (2002). Hail Netting of Apple Orchards— Australian Experience. *The Compact Fruit Tree*, *35*(2), 51–55.

Milić, B., Tarlanović, J., Keserović, Z., Zorić, L., Blagojević, B., & Magazin, N. (2017). The growth of apple central frutis as affected by thinning with NAA, BA, and Naphthenic acids. *Erwerbs-Obstbau*, *59*(3), 185–193. https://doi.org/10.1007/s10341-016-0310-x

Reis, M. G. dos, & Ribeiro, A. (2020). Conversion factors and general equations applied in agricultural and forest meteorology. *Agrometeoros*, *27*(2). https://doi.org/10.31062/agrom.v27i2.26527

Robinson, T. L., & Lakso, A. N. (2004). Between year and within year variation in chemical fruit thinning efficacy of apple during cool springs. *Acta Horticulturae*, *636*(636), 283–294. https://doi.org/10.17660/ActaHortic.2004.636.34

Robinson, T. L., & Lakso, A. N. (2011). Predicting chemical thinner response with a carbohydrate model. *Acta Horticulturae, 903*(903), 743–750. https://doi.org/10.17660/ActaHortic.2011.903.103

Rosa, N., Àvila, G., Carbó, J., Verjans, W., Pais, I. P., da Silva, A. B., Martins, L. L., Mourato, M. P., Carvalho, L. C., Scotti-Campos, P., Bonany, J., Asín, L., Ramalho, J. C., & Oliveira, C. M. (2020). Metamitron and shade effects on leaf physiology and thinning efficacy of *Malus* × *domestica* Borkh. *Agronomy*, *10*(12). https://doi.org/10.3390/agronomy10121924

Salazar-Canales, F., Bastías, R. M., Calderón-Orellana, A., Wilckens, R., & González, E. (2021). Photo-selective nets differentially affect microclimatic conditions, leaf physiological characteristics, and yield in hazelnut (*Corylus avellana* L.). *Horticulture Environment and Biotechnology, 62*(6), 845–858. https://doi.org/10.1007/s13580-021-00365-8

Schröder, M., Link, H., & Bangerth, K. F. (2013). Correlative polar auxin transport to explain the thinning mode of action of benzyladenine on apple. *Scientia Horticulturae*, *153*, 84–92. https://doi.org/10.1016/j.scienta.2013.02.001

Solomakhin, A., & Blanke, M. (2010). The microclimate under coloured hailnets affects leaf and fruit temperature, leaf anatomy, vegetative and reproductive growth as well as fruit colouration in apple. *Annals of Applied Biology*, *156*(1), 121–136. https://doi.org/10.1111/j.1744-7348.2009.00372.x

Solomakhin, A., & Blanke, M. M. (2008). Coloured hailnets alter light transmission, spectra and phytochrome, as well as vegetative growth, leaf chlorophyll and photosynthesis and reduce flower induction of apple. *Plant Growth Regulation*, *56*(3), 211–218. https://doi.org/10.1007/s10725-008-9302-7

Stopar, M., Resnik, M., & Pongrac, V. Ž. (2001). Non-structural carbohydrate status and CO2 exchange rate of apple fruitlets at the time of abscission influenced by shade, NAA or BA. *Scientia Horticulturae, 87*(1–2), 65–76. https://doi.org/10.1016/S0304-4238(00)00169-2

Szabó, A., Tamás, J., & Nagy, A. (2021). The influence of hail net on the water balance and leaf pigment content of apple orchards. *Scientia Horticulturae*, *283*. https://doi.org/10.1016/j.scienta.2021.110112

Treder, W., Mika, A., Buler, Z., & Klamkowski, K. (2016). Effects of hail nets on orchard light microclimate, apple tree growth, fruiting and fruit quality. *Acta Sci. Pol. Hortorum Cultus*, *15*(3), 17–27. www.acta.media.pl

UFSM. (2023, May 8). *Solos do Rio Grande do Sul*. Unidade Bom Jesus. https://www.ufsm.br/museus/msrs/unidade-de-solos

Untiedt, R., & Blanke, M. (2001). Effects of fruit thinning agents on apple tree canopy photosynthesis and dark respiration. *Plant Growth Regulation*, *35*, 1–9. https://doi.org/10.1023/A:1013894901621

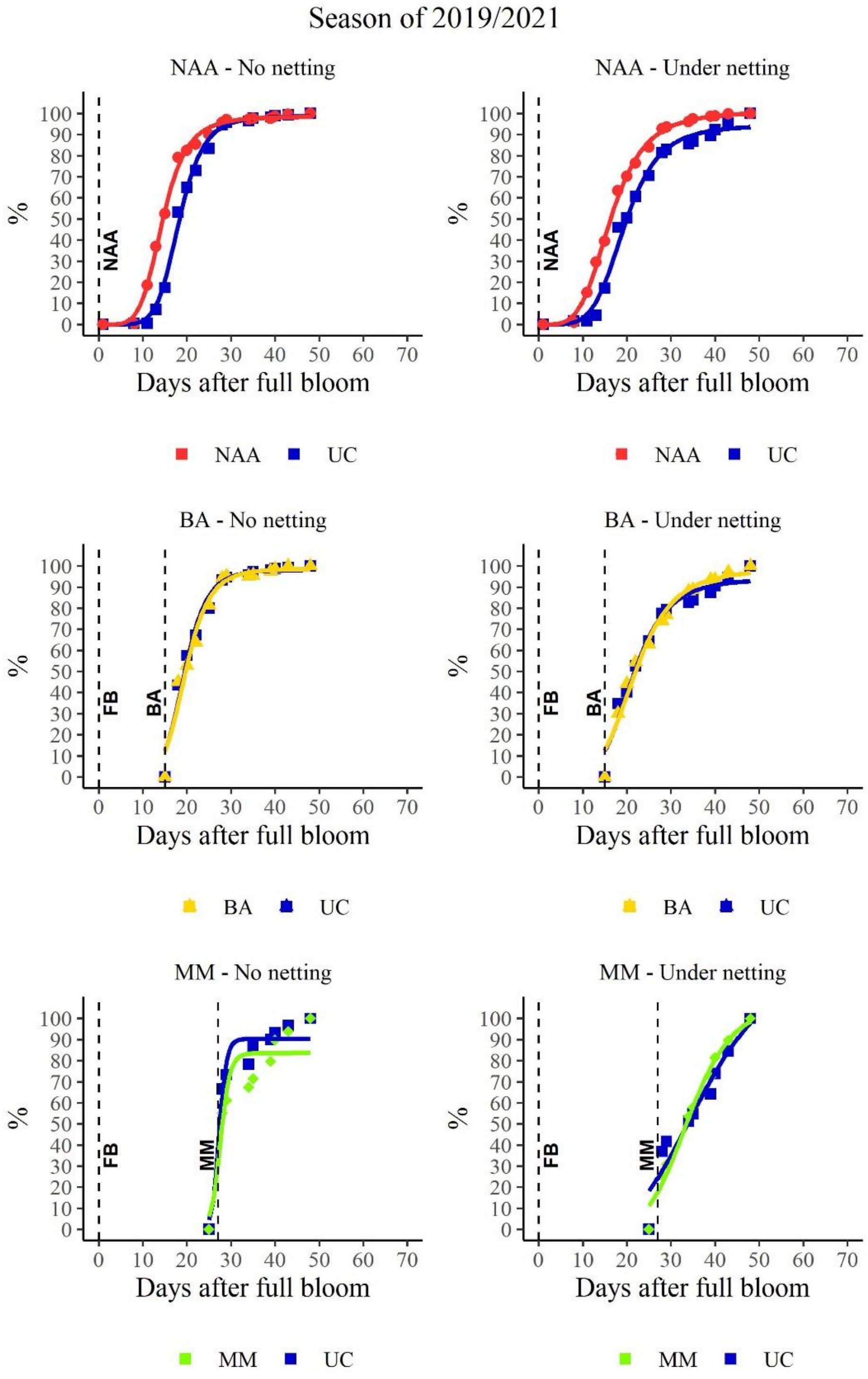
Yuan, R., & Greene, D. W. (2000a). Benzyladenine as A Chemical Thinner for `McIntosh' Apples. I. Fruit Thinning Effect1s and Associated Relationships with Photosynthesis, Assimilate Translocation, and Nonstructural Carbohydrates. *Journal of the American Society for Horticultural Science*, *125*(2), 169–176. https://doi.org/10.21273/JASHS.125.2.169

Yuan, R., & Greene, D. W. (2000b). ‘McIntosh’ apple fruit thinning by benzyladenine in relation to seed number and endogenous cytokinin levels in fruit and leaves. *Scientia Horticulturae*, *86*(2), 127–134. https://doi.org/10.1016/S0304-4238(00)00142-4

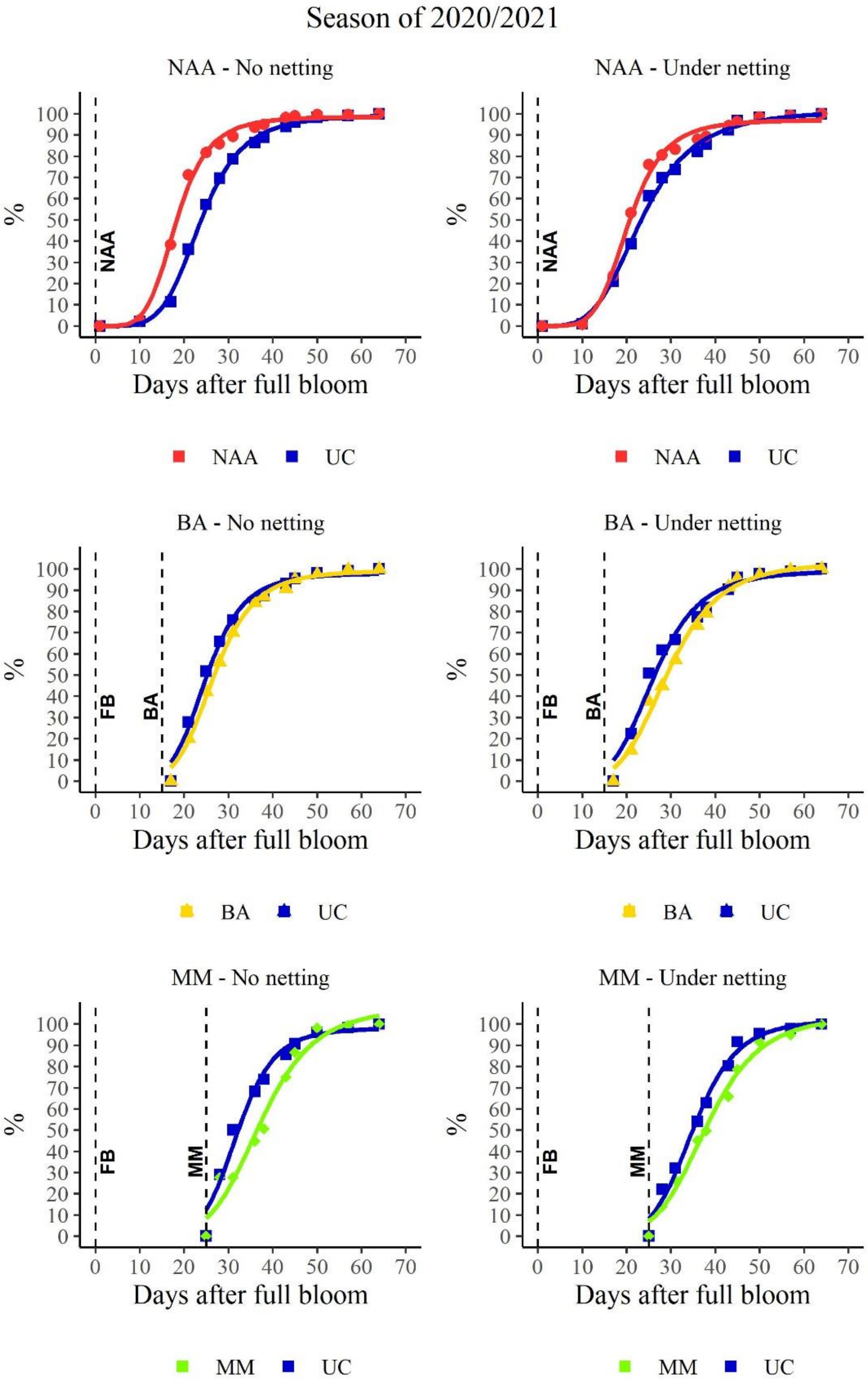
Zhu, H., Dardick, C. D., Beers, E. P., Callanhan, A. M., Xia, R., & Yuan, R. (2011). Transcriptomics of shading-induced and NAA-induced abscission in apple (Malus domestica) reveals a shared pathway involving reduced photosynthesis, alterations in carbohydrate transport and signaling and hormone crosstalk. *BMC Plant Biology*, *11*. https://doi.org/10.1186/1471-2229-11-138

Zuo, X., Zhang, D., Wang, S., Xing, L., Li, Y., Fan, S., Zhang, L., Ma, J., Zhao, C., Shah, K., An, N., & Han, M. (2018). Expression of genes in the potential regulatory pathways controlling alternate bearing in ‘Fuji’ (Malus domestica Borkh.) apple trees during flower induction. *Plant Physiology and Biochemistry*, *132*, 579–589. https://doi.org/10.1016/j.plaphy.2018.10.003

Appendices



Appendix A. Three-parameter logistic curves as a function of the cumulative frequency of abscised fruitlets of ‘Fuji Suprema’ on the season of 2019/20. UC: Untreated Control; NAA: Naphthalene Acetic Acid; BA: Benzyladenine; MM: Metamitron.



Appendix B. Three-parameter logistic curves as a function of the cumulative frequency of abscised fruitlets of ‘Fuji Suprema’ on the season of 2020/21 UC: Untreated Control; NAA: Naphthalene Acetic Acid; BA: Benzyladenine; MM: Metamitron.

Appendix D. Cluster size as a function of PGRs used as chemical thinners on ‘Fuji Suprema’ apple trees in a covered and uncovered orchard with hail netting.

	Cluster Size					
Treatments	Singles (%)		Doubles (%)		Triples or More (%)	
2019/20 season	Covered	Uncovered	Covered	Uncovered	Covered	Uncovered
UC	19 a	21^{ns} a	17 ab	24^{ns} a	64 abc	55^{ns} a
NAA	20 a	28^{ns} a	21 ab	19^{ns} a	59 abc	46^{ns} a
BA	14 a	22^{ns} a	19 ab	32^{ns} a	66 ab	42* a
MM	7 a	21* a	13 b	24^{ns} a	80 a	55* a
NAA+BA	21 a	26^{ns} a	27 ab	14^{ns} a	52 bc	53^{ns} a
NAA+MM	24 a	17^{ns} a	20 ab	24^{ns} a	53 abc	58^{ns} a
BA+MM	18 a	19^{ns} a	22 ab	23^{ns} a	56 abc	58^{ns} a
NAA+BA+MM	25 a	32^{ns} a	37 a	22* a	38 c	42^{ns} a
2020/21 season						
UC	43 ab	33^{ns} ab	27 a	30^{ns} ab	31 a	34^{ns} a
NAA	37 ab	33^{ns} ab	28 a	28^{ns} ab	28 ab	24^{ns} a
BA	35 ab	51^{ns} a	37 a	28^{ns} ab	24 ab	21^{ns} a
MM	33 ab	37^{ns} ab	32 a	37^{ns} a	31 a	26^{ns} a
NAA+BA	44 ab	56^{ns} a	26 a	20^{ns} a	12 b	13^{ns} a
NAA+MM	45 ab	40^{ns} ab	21 a	21^{ns} b	20 ab	32^{ns} a
BA+MM	29 b	44^{ns} ab	27 a	28^{ns} ab	21 ab	16^{ns} a
NAA+BA+MM	56 a	32* b	21 a	20^{ns} b	8 b	15^{ns} a
2021/22 season						
UC	29 b	28^{ns} ab	32 a	28^{ns} a	39 ab	44^{ns} a
NAA	22 b	35^{ns} a	34 a	25^{ns} a	36 abc	37^{ns} a
BA	55 a	14* b	28 a	24^{ns} a	17 c	62* a
MM	28 ab	16* ab	20 ab	25^{ns} a	52 a	59^{ns} a
NAA+BA	26 b	30^{ns} ab	33 a	22^{ns} a	38 abc	43^{ns} a
NAA+MM	40 ab	26^{ns} ab	12 b	31* a	41 abc	39^{ns} a
BA+MM	45 ab	20* ab	30 a	26^{ns} a	25 bc	53* a
NAA+BA+MM	26 b	22^{ns} ab	39 a	27^{ns} a	36 abc	44^{ns} a

[1] Means followed by the same letter in a column do not differ according to the Tukey HSD test ($p \leq 0.05$) for treatments into each netting condition. ^{ns} and * in the row correspond to non-significance and significance for netting condition into each treatment.

6. CONSIDERAÇÕES FINAIS

A tela antigranizo e suas alterações no microclima aumentaram a queda natural dos frutos de macieiras ‘Galaxy’ e ‘Fuji Suprema’ em relação ao ambiente sem tela. Porém, quando a carga inicial de flores foi alta, e devido à maior competição entre os órgãos em crescimento, os frutos que sofreram abscisão foram menores sob cobertura de tela, em relação ao ambiente sem tela, o que indicou maior velocidade de abscisão, enquanto que quando a cara inicial de frutos foi menor (ano de alternância), no ambiente coberto por tela, a queda dos frutos foi mais longa, com frutos maiores sofrendo abscisão, em relação ao ambiente sem tela.

Apesar de ter havido queda de frutos de maneira ou mais veloz ou um período mais alongado, não houve sobre raleio na área coberta, sendo o efeito de maior velocidade ou duração estendida da queda de frutos na área coberta promoveu maior quantidade de assimilados aos frutos remanescentes, diminuindo assim a competição e o efeito raleante dos reguladores de crescimento. Portanto, a presença de tela antigranizo não afetou a ação dos raleantes.

A utilização do diâmetro de frutos é uma forma bastante eficiente em estratificar os frutos que continuarão crescendo e não sofrerão abscisão, e os frutos que irão sofrer abscisão. Os fatores de estresse como a presença de tela e o uso de raleantes reduziram a taxa de crescimento dos frutos. Porém, como o ácido naftaleno acético é utilizado em plena floração, não sendo possível a utilização do modelo da taxa de crescimento dos frutos, a sua utilização como raleante deve ser feita quando há plena certeza sobre o pegamento das flores, caso contrário, um raleante utilizado em frutos maiores é mais indicado.

No Brasil, principalmente os clones da macieira Gala apresentam problemas de fixação de frutos, e maior taxa de abscisão, sendo, portanto, necessários estudos com diferentes cultivares polinizadoras, com melhor coincidência de florada, ou até mesmo insetos polinizadores alternativos, tendo em vista que em outras regiões do mundo essa cultivar apresenta alta capacidade de fixação de frutos. Aumentando-se a capacidade de fixação dos frutos de forma natural (polinização), o manejo do raleio pode tornar-se mais previsível.