



The use of nets for tree fruit crops and their impact on the production: A review



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ABSTRACT

Protected tree fruit cultivation using sustainable environmentally-friendly practices is considered a promising alternative to meet the challenge of various biotic and abiotic stresses threatening fruit production under climate changes. Nowadays, nets are being globally used to protect the trees against harsh environmental conditions including hail, wind, excess sunlight and pests while improving tree health and enhancing fruit quality. Different types of nets including anti-hail, exclusion and photoselective nets have a different impact on the fruit tree response and production depending on their type, shading factor, mesh size, timing of display in the orchard and the netting system erected in the orchard. This review analyzes the effect of various types of nets on the microclimate, tree growth and management, fruit quality, diseases, disorders, economical insect pests and beneficial insects.

1. Introduction and the different types of nets used in tree fruit production

Nets are widely used in crop production as barriers against abiotic and biotic factors that compromise crop productivity and fruit quality (Sivakumar and Jifon, 2018). Nets also reduce farmer reliance on agrochemicals, making them an environmentally-friendly alternative to chemical pesticides (Briassoulis et al., 2007a).

The earliest application of nets was in the production of fruits and ornamentals such as apricots, grapes, apples and cut flowers. The nets were transparent and were used to prevent damage caused by hailstorms and wind (Briassoulis et al., 2007b).

To protect against wind, dark-colored nets were used (Briassoulis et al., 2007b). Such netting, known as anti-hail, is made of fine wefts, tolerates torrential rains and protects against ultraviolet (UV) radiation. In general, Black-colored nets last for about 15 years while white-colored nets last for 10 years (Amarante et al., 2009). These nets are mostly used in open-field conditions, particularly on fruit trees where one large structure is constructed over numerous trees, or one net is applied over every individual tree (Castellano et al., 2008).

Shading nets that protect plants against extreme solar radiation and increased temperatures were also introduced. These nets, characterized by light transmittance ranging between 20 to 70% (Briassoulis et al., 2007b), offer a protective physical barrier and modify the microclimate without affecting light quality (Stamps, 2009). Shading net efficiency is

influenced by the shading factor (Castellano et al., 2008). The net shading factor is a commercial parameter that describes the ability of the net to absorb or reflect solar radiation; it is dependent on the net color, mesh size and texture (Castellano et al., 2008). Increasing the net shading factor will cause an increase in the amount of radiation blocked from the vegetation under the net, affecting temperature and relative humidity (RH) (Stamps, 2009).

Since the mid-20th century, exclusion nets has been installed to protect crops from pests and their use has become even more common as of the 1990s (Chouinard et al., 2016). The nets are made of transparent threads of small mesh sized (1 to 7 mm of diameter) and protect against insects (Briassoulis et al., 2007b). They are used by growers as an environmentally-friendly alternative to pesticides, especially in organic farming (Castellano et al., 2008). A famous example is 'Alt Carpo Nets' designed in 2005 by the French extension services. These nets cover the whole tree canopy in order to physically protect the fruits from *Cydia pomonella*, *Zeuzera pyrina*, mirids and birds thereby reducing the reliance on pesticides (Alaphilippe et al., 2016; Chouinard et al., 2016).

The different exclusion systems are classified as either complete or incomplete. An example of incomplete exclusion is the full block netting system where the soil is not exempted from the enclosed area such as Alt' carpo mono-block system. Incomplete exclusion allows the major pests to complete their life cycle trapped in the nets. However, in the case of complete exclusion, the soil is exempted (Chouinard et al.,

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2016). An example is Alt' carpo mono-row system (Dib et al., 2010).

In 1996, colored shade nets that scatter light, alter spectral composition and absorb different spectral bands emerged from a partnership between a group of scientists and the manufacturing industry (Ganelevin, 2006). Colored shade nets, also known as photo-selective nets, are made of interlaced polypropylene or knitted polyethylene. They are characterized by various fibers and mesh sizes, based on the desired net shade level (Sivakumar et al., 2017). Photo-selective nets contain diverse chromophores, which are light dispersive/reflective elements brought together during production (Zoratti et al., 2015). Such chromophore combinations allow nets to filter specific solar wavelengths based on the physiological responses desired whilst scattering light in order to ensure sunlight reaches the inner canopy (Zoratti et al., 2015).

Considering the structure supporting the nets, these can be configured and installed in different ways. In some cases, these are placed horizontally at a certain distance above the trees (Basile et al., 2008, 2012; Corvalán et al., 2014; Lee et al., 2015; Lobos et al., 2013); whilst in others, peaked net structures are designed to allow hail to fall off the sloping surface of the net (Amarante et al., 2010, 2011). Some farmers use nets to cover the whole orchard including the soil area (Baiamonte et al., 2016; Kelderer et al., 2010; Lloyd et al., 2005). Others still, cover specific rows of trees where nets are pegged to the ground (Baiamonte et al., 2016; Chouinard et al., 2017; Kelderer et al., 2010; Sauphanor et al., 2012; Ughini et al., 2008). In many cases where exclusion nets are used, individual trees are covered, caging only the canopy, not the soil (Ughini et al., 2008).

This review does not question whether orchards should be netted or not; but rather, it helps the reader question what types of nets should be used based on orchard location, growing conditions, and crop cultivar, and desired plant response.

2. The effect of nets on different factors

2.1. Microclimate

The ability of nets to modify the microclimate may enhance crop quality, uniformity and productivity of the crops growing under it. Nets may also protect plants against undesired environmental elements.

Table 1 presents the effect of different types of nets on the microclimate in several tree fruit species.

2.1.1. Temperature, humidity and wind

It is believed that some nets reduce maximum temperature during the day due to their 'shading effect' which is greater than their 'greenhouse effect'. This is the case of García-Sánchez et al. (2015); Gimeno et al. (2015); Shahak et al. (2004) and Wachsmann et al. (2012) who used shading nets in Mediterranean climates and recorded a reduction in maximum temperature (Table 1).

This decrease in temperature is beneficial to trees in warm climates since it may increase the rate of photosynthesis during the hotter hours of the day and protect against sunburn (Kalcsits et al., 2017; Tanny et al., 2008). Some experiments show that nets increased the nightly minimum temperature due to a greenhouse effect and limited nighttime radiation (Iglesias and Alegre, 2006); Whilst others reported a decrease in the nightly minimum temperature due to reduced longwave radiative cooling effect (Tanny et al., 2008). Other studies where radiation shields protected the radiation/temperature sensors indicated that there was no difference in overall orchard temperature between control and net trials (Kalcsits et al., 2017).

The effect of nets on temperature is still not well understood: Some record an increase whereas others report a decrease in temperature. This is due to the fact that diverse microclimates are created depending on the types of nets used, the method of net application and the regional location of the orchard.

It has been reported that nets increased humidity possibly due to

reduced wind speed under the netting system (Wachsmann et al., 2012) or due to the products of transpiration remaining within the net (Tanny, 2013). However, Solomakhin and Blanke (2010a) who studied the effect of colored nets on apples in Germany indicated that this small increase in humidity does not influence leaf anatomy and plant biology.

In windy regions, nets are considered essential due to their ability to increase the resistance to air flow, reducing the average air velocity inside the nets (Girona et al., 2012). Thus, crop photosynthesis, respiration and transpiration rates are affected. The impact of nets on air movement can be influenced by several factors such as net porosity, net location in relation to crops, and timing of net installation (Stamps, 2009) (Table 1).

2.1.2. Radiation

Transmissivity, shading factor, reflectivity and the ability to modify radiation quality reaching the net are radiometric properties affecting agricultural production (Castellano et al., 2008). The primary radiometric property for nets is the photosynthetic active radiation (PAR, 400–700 nm) transmission which is crucial for photosynthesis and plant growth.

Since traditional black nets are entirely opaque, they do not modify the spectral quality of radiation; but rather, they decrease light intensity without affecting light quality (Arthurs et al., 2013; Ilić and Fallik, 2017). Shade nets are less opaque and scatter radiation which increases the dispersed light penetrating the canopy. This improves radiation use-efficiency (Stamps, 2009). Colored shade nets enhance light scattering which may influence plant development and growth and modify the spectra of radiation reaching the plants underneath, enhancing photo morphogenetic/physiological responses (Castellano et al., 2008; Shahak et al., 2009; Ilić and Fallik, 2017). Indeed, Stamps (2009) reported that colored shade nets "can be used to change red to far-red light ratios that are detected by phytochromes, the amounts of radiation available to activate the blue/ultraviolet-A photoreceptors, blue light involved in phototropic responses mediated by phototropins, and radiation at other wavelengths that can influence plant growth and development".

2.2. Tree growth and management

Table 2 presents the effect of different types of nets on the tree characteristics as reported in the literature.

2.2.1. Photosynthetic activity

In general, nets are not only capable of partially transmitting solar radiation; but they can also diffuse it. This is important for the photosynthesis of shaded leaves at low tree levels (Tanny, 2013). Moderate shading can decrease leaf temperature and evaporative demand, increasing photosynthesis (Table 2). This increase may lead to higher carbohydrate production and enhanced water use efficiency resulting in better yield quality (Sivakumar and Jifon, 2018). Under shade, leaves have a higher photosynthetic activity due to less stomata closing and less photo-inhibitory damage to photosystem II caused by radiation exceeding the photosynthetic saturation point on clear days (Jutamane and Onnom, 2016).

Enhanced microclimate under photo-selective netting characterized by a reduced air velocity and extreme climatic variations may explain improved leaf photosynthetic rate and water use efficiency (Shahak et al., 2008). Retamales et al. (2006) supported this claim by observing that in countries with high levels of radiation, the decrease in stressful conditions during midday hours using shading nets protects crops from extreme light levels, avoiding heat stress and photosynthesis inhibition.

When red and blue light were increased, plants exhibited improved photosynthesis and enhanced productivity. This is due to the fact that chlorophylls a and b, the major photosynthetic pigments in higher plants have a higher absorption potential in the blue and red regions (Rajapakse and Shahak, 2008). The increase in red and blue light can be

Table 1
The effect of different types of nets on windspeed, air temperature, relative air humidity and PAR.

Net type	Country	Crop/cultivar	Windspeed	Air Temperature	Air Humidity	PAR	References
Anti-hail black nets	Brazil	Apple/cv.'Royal Gala', 'Fuji Suprema'		10.7°C(day) ↓0.4°C(night)		↓ 32%	(Bosco et al., 2015)
Anti-hail black nets	Switzerland	Apple (many cv)		↓0.2–0.8°C (overall)			(Kührt et al., 2006)
Anti-hail black nets	Spain	Apple/cv.'Mondial gala'		↓ Max temp(3°C)	↑	↓	(Glasias and Alegre, 2006)
Anti-hail red; blue; pearl (20-23%) nets	Washington, USA	Apple/cv.'Honeycrisp'		No diff	No diff	↓	(Kalcis et al., 2017)
Anti-hail red-black; green-black nets	Germany	Apple/ cv 'Pinoval'; 'Fuji Kiku 8'	↓ by 40%	↓1.3°C	↑ by 2-5%	↓ 18%-20%	(Solomakhin and Blanke, 2010a)
Anti-hail white (50%); gray (35%); red (50%) nets	Chile	Blueberries/cv.'Berkeley'		No diff	No diff	↓	(Retamales et al., 2006)
Anti-hail white nets	Germany	Apple/cv.'Elstar'		↓1.6°C	↑6%	↓ 11-15%	(Solomakhin and Blanke, 2007)
Alt-carpo nets	Italy	Pear	↓	10.7°C	↓2.3%	↓ 15%	(Alaphilippe et al., 2016)
Exclusion nets clear and white Full enclosure-2 mm mesh (compared to bird and bat netting)	Australia	Low-chill stone trees		14.4°C(max temp)			(Lloyd et al., 2005)
Shade nets	Israel	Citrus/ reticulata mandarin var. 'Nektar'	↓ by 40%	↓0.5°C(min temp)			(Tanny and Cohen, 2003)
Shade white (20%) nets	Taiwan	Mandarin/cv.'Ponkan'		↓			(Lee et al., 2015)
Shade (50%) nets	Spain	Lemon /cv.'Fino 49'		↓Max temp			(García-Sánchez et al., 2015)
Shade (50%) nets	Spain	Lemon/cv. 'Fino 49'		↓ Max temp			(Gimeno et al., 2015)
Shade black; red; blue; pearl nets	Florida	–	↓			↓	(Arthurs et al., 2013)
Photoselective red; pearl (20%) nets	Chile	Vines/cv. 'Pinot Noir'		No diff	No diff	↓	(Corvalán et al., 2014)
Photoselective (30%)nets	Israel	–		↑Max temp	↑		(Shahak et al., 2004)
Photoselective red (25%); yellow (24%); white (18%); transparent (13%) nets	Israel	Mandarin /cv.'Ori'	↓	↑Min temp	↑		(Wachsmann et al., 2012)
Photoselective white (20.4%); red (22.8%)nets	Southern Italy	Kiwifruit/cv.'Hayward'		↑Max temp		↓	(Basile et al., 2012)

↑ = Increase; ↓ = Decrease; No diff = No difference; Max temp = Maximum temperature; Min temp = Minimum temperature.

Table 2
The effect of different types of nets on photosynthesis, vegetative and reproductive growth and water use efficiency.

Net type	Country	Crop	Photo-synthesis	Vegetative growth	Reproductive growth	Water use efficiency	References
Anti-hail black; gray nets	Poland	Apple /cv. 'Sampion' seedlings	↑	↑	↑ (fruit buds)		(Tredler et al., 2016)
Anti-hail black; gray nets	Poland	Apple /cv. 'Rubinstar'	No diff	No diff	↓ (fruit buds)		(Tredler et al., 2016)
Anti-hail black nets	Spain	Apple/cv. 'Mondial gala' seedlings	↑	↑			(Iglesias and Alegre, 2006)
Shading black nets (compared to white and control)	Slovenia	Apple/cv. 'Elstar'	↑		No diff		(Stampanar et al., 2001)
Shading (40%) nets	Spain	Lemon/cv. 'Verna'	No diff			↑	(Nicolás et al., 2008)
Shading black nets	Slovenia	Apple/cv. 'Jonagold'			↑ (# of fruits)		(Stampanar et al., 2001)
Shading nets	Thailand	Mango/cv. 'Nam Dok Mai'	↑				(Utamaneee and Omrom, 2016)
Shading nets	Spain	Lemon /cv 'Verna'				↑	(Alarcón et al., 2006)
Shading nets	Spain	Apricot				↑	(Nicolás et al., 2005)
Shading nets (50%)	Brazil	Orange/cv. 'Pera'	↑				(Medina et al., 2002)
Shading nets (50%)	Spain	Lemon/'Fino 4' seedlings	↑				(Gimeno et al., 2015)
Shading nets (50%)	Spain	Lemon/cv. 'Fino 49' seedlings	↑		↓ (# of fruits)		(García-Sánchez et al., 2015)
Anti-hail white nets	Brazil	Apple/cv. 'Gala', 'Fuji'			↓(flowering)		(Amarante et al., 2011)
Anti-hail white (50%); gray (35%); red (50%) nets	Chile	Blueberry/cv. 'Berkeley'	↑		No diff (flower induction)		(Retamales et al., 2006)
Anti-hail white (15%)nets		Pear/cv. 'Bartlett', 'Red Bartlett'			↑ (differentiation of flower buds; fruit set)		(Arsov et al., 2015)
Anti-hail white nets	Brazil	Apple/cv. 'Gala', 'Fuji'			↓(flowering)		(Amarante et al., 2011)
Photoselective red (50%) nets	Punjab	Pomegranate/ cv. 'Mridula'			↑ (flowering)		(Meena et al., 2016)
Photoselective red white nets (15%)	Israel	Apple/cv. 'Smoothie Golden Delicious'			↑fruit set		(Shahak et al., 2004)
Photoselective blue (40%)nets compared to white (20%)	Italy	Apple/cv. 'Fuji'	↑				(Bastías et al., 2012)
Photoselective red; pearl (20%) nets	Chile	Vine/cv. 'Pinot Noir'	↑				(Corvalán et al., 2014)
Photoselective blue; white nets	South Africa	Avocado/cv. 'Hass'					(Tinyane et al., 2018)
Photoselective red (25%); yellow (24%); white (18%); transparent (13%) nets	Israel	Mandarin /cv. 'Ori'	↑		↑ (# of fruits)		(Wachsmann et al., 2012)
Photoselective blue nets 40%(compared to red shade (40%); red hail (20%) nets)	Israel	Apple/cv. 'Fuji'	↑				(Bastías et al., 2012)
Photoselective grey and red nets (compared to white net)	Israel	Apple/cv. 'Fuji'	No diff	No diff			(Bastías et al., 2012)
Photoselective red; gray nets	Italy	Kiwifruit/cv. 'Hayward'	↑ (higher #of shoots longer than 65 mm)	↑	↓ (fruit production)		(Basile et al., 2008)
Photoselective red nets	Croatia	Peach/cv. 'Sugar top', Nectarine/cv. 'Big Bang'	↑				(Vuković et al., 2017)
Photoselective red nets (30%)	Croatia	Peach/cv. 'Sugar Top'			No diff (crop load)		(Vuković et al., 2017)
Photoselective red (30%)compared to white (10%)nets	Israel	Apple	↑				(Shahak et al., 2004)
Alt carpo nets	Italy	Nectarine /cv. 'Laura'	↑		No diff(fruit/tree)		(Giaccone et al., 2012)
	Italy	Pear	↓				(Alaphilippe et al., 2016)

↑ = Increase; ↓ = Decrease; No diff = No difference; # = number

achieved by covering crops with red and blue shade nets. When higher red-light intensity reaches crops, the synthesis of photosynthetic enzymes increases, so does the chlorophyll content per unit leaf area (Sivakumar et al., 2017). Shahak et al. (2004) reported that red nets induce the highest leaf photosynthesis rate in apple trees compared to trees covered with blue, pearl, gray and black nets. Medina et al., (2002); Jutamanee and Onnom (2016) and Gimeno et al. (2015) used shading nets on orange, mango and lemon trees respectively and reported a positive effect on the photochemical efficiency of photosystem II in leaves.

2.2.2. Vegetative growth and water use efficiency

In warm regions, reduced sunlight is not a restraint even under black nets as it may result in lowering the rate of evapotranspiration and plant water stress. This increases photosynthesis and the availability of carbohydrates, increasing vegetative growth (Iglesias and Alegre, 2006) (Table 2). Gimeno et al. (2015) has indicated that the decrease of midday leaf temperature and air vapor pressure shortage caused by shading nets in warm regions has promoted leaf carbon assimilation resulting in increased vegetative growth. García-Sánchez et al. (2015) reported that a reduction of air temperature and solar radiation using 50% shading nets throughout the whole year in a semi-arid region has increased vegetative growth in young lemon trees.

It should be noted that most authors reporting higher vegetative growth under nets used young tree seedling for their experiment and covered them with nets for almost the whole season (Table 2).

In terms of photosensitive nets, these latter can increase light scatter and altering the light spectrum resulting in increased branching, plant compactness and flower number per plant (Sivakumar et al., 2017). Bastías et al. (2012) reported that the shoot growth rate under blue nets was the highest among the different colored nets as blue light reduces red-far red ratio.

Since shading nets have been shown to stimulate vegetative growth in some cases, which in some fruit trees may not be desired and can increase water consumption (Wachsmann et al., 2012), nets of lower shading capacity are currently being used (Shahak, 2014).

Normally, Water use under nets is usually lower when compared to water use in open-field conditions. Nets can decrease the intensity of solar radiation reaching the tree and lowering the level of evapotranspiration. This results in less plant water stress symptoms, higher photosynthesis, a more significant yield and bigger fruit size (Amarante et al., 2010; Treder et al., 2016) (Table 2). Nets can efficiently distribute radiation reaching the trees and help avoid wind turbulence; which results in a humidity blanket that lowers environmental evaporative demand and consequently decreases transpiration and water deficit (Nicolás et al., 2005).

2.2.3. Reproductive growth and thinning

Covering trees with nets modifies the radiation climate, affecting tree reproductive growth (Raveh et al., 2003). Moderate shading of apple and citrus trees decreased heat and water stress and increased gas exchange and carbohydrate availability for fruit formation and growth (Bastías et al., 2012). However, excessive shading lowers photosynthesis efficiency and carbohydrates reserves reducing fruit bud formation and fruit quality (Basile et al., 2008; Morandi et al., 2011).

According to Meena et al., (2016), photosensitive nets may improve fruit set due to their light-scattering ability that results in enhanced plant radiation-use efficiency. This would modify metabolic processes promoting fruit bud differentiation, flowering intensity and ultimately, leading to a higher ratio of fruit set.

Successful fruit production is achieved when high fruit numbers per tree at fruit set is recorded, followed by thinning to reduce that number to the optimum level determined for each tree and cultivar (Zibordi et al., 2009). In order to thin the trees, growers either use manual thinning techniques, which is time consuming and expensive; or use phytochemicals. Since lowering the use of chemicals in fruit production

is a common goal, heavy shading of trees is being considered as an alternative technique that decreases net carbon assimilation resulting in fruitlet abscission. Organic growers also tend to rely on this technique so as to avoid the labor costs associated with manual thinning techniques (Corollaro et al., 2015).

Kelderer et al. (2014) reported that a more significant thinning effect was recorded in Golden Delicious trees netted during bloom (when compared to uncovered trees) leading to increased mean fruit weight. Most authors reporting an improved thinning effect under nets have covered their trees before or during full bloom (Table 2).

Another factor that might limit reproductive growth is the impairment of entomophilous pollination (Amarante et al., 2011). However, this problem can be attenuated by sectioning the nets or by removing them entirely during the flowering stage in order to allow pollination. It should be noted that research is needed to optimize netting systems to allow pollination in self-incompatible fruit tree species and cultivars. In some cases where nets were installed prior to pollination, bee hives were placed inside enclosures during the flowering period (Lloyd et al., 2005).

2.3. Fruit quality

Fruits, characterized by an appealing color, size, firmness and flavor, have high consumer acceptance and market value (Sivakumar et al., 2017). Satisfying market demand while offering fruits of premium quality is a challenge for tree fruit producers

The interaction between trees and environmental conditions differ in netted and un-netted scenarios. This is caused by variations in the climate that might affect fruit quality (Bosco et al., 2015).

2.3.1. External fruit quality

Table 3 presents the effect of different types of nets on the indicators of external fruit quality. This section focuses on research/studies conducted on apple external fruit quality as apple was the most studied fruit in the literature in topics related to external quality.

2.3.1.1. Fruit coloration. Different pigments such as chlorophyll a and b in a ratio of 3:1, anthocyanins and carotenoids are responsible for the primary color of the apple. The formation of carotenoids during apple maturation turns the fruit yellow (Brglez Sever et al., 2015). Red blush on the apple is achieved when high levels of anthocyanin accumulate, combined with low levels of chlorophyll (Reay et al., 1998).

Dussi et al. (2005) have reported that the accumulation of anthocyanin responsible for color development is affected mostly by temperature and light. According to Takos et al., (2006) the transcription of most apple flavonoid genes responsible for anthocyanin synthesis is regulated by a light-responsive mechanism. Optimum levels of anthocyanins are obtained when fruits are subjected to sufficient sunlight for 20 days before harvest.

Studies have shown that covering trees with black nets reduced PAR transmission, reducing fruit coloration (Solomakhin and Blanke, 2010b) (Table 3). The highest PAR recorded under black nets was insufficient for improving fruit color (Dussi et al., 2005). Reduced light availability is correlated with a lower photosynthetic rate and with fewer available carbohydrates crucial for anthocyanin production (Iglesias and Alegre, 2006).

There is confusion when it comes to the effect of colored nets on fruit coloration. Solomakhin and Blanke (2010b) reported that colored nets (red or green) covering apples lead to a significant green background color of the fruit and a poor red cover, the degree of which depends on sunlight transmission into the nets and on the number of black fibers replaced with white ones.

On the other hand, many authors reported that colored nets modify light composition in the ultra-violet, blue and red range influencing phytochrome and cryptochrome plant mediated responses such as color development, shoot and fruit growth. In addition, some studies showed

Table 3
The effect of different types of nets on weight, size and fruit coloration.

Net type (shading factor %)	Country	Crop	Weight	Size	Fruit coloration	References
Anti-hail black nets	Brazil	Apple/cv. 'Royal Gala', 'Fuji Suprema'	No diff	No diff	No diff	(Bosco et al., 2015)
Anti-hail black nets	Spain	Apple/cv. 'Mondial gala'		↓	↓	(Iglesias and Alegre, 2006)
Anti-hail grey/black nets	Poland	Apple/ cv. 'Sampion', 'Rubinstar'		↓	↓	(Freder et al., 2016)
Anti-hail black nets	Switzerland	Apple/cv. 'Jonagold'	No diff	↓	↓	(Widmer, 2000)
Anti-hail black nets compared to white and control	Slovenia	Apple/cv. 'Jonagold'		↓	↓	(Stampar et al., 2002)
Anti-hail red black; green black; white; red white nets	Germany	Apple/cv. 'Pinova', 'Fuji Kiku 8'	↑	↑	↓	(Solomakhin and Blanke, 2010b)
Shading (55% and 15%) black nets	Argentina	Apple/cv. 'Fuji'		↓	↓	(Dussi et al., 2005)
Shading (50%) nets	Spain	Lemon /cv. 'Fino 49'	↓	↓	↓	(García-Sánchez et al., 2015)
Shading (20%) black nets	Turkey	Apple/cv. 'Early Red One'	↓	↓	↓	(Hepaksoy and Dayıoglu, 2016)
Anti-hail white nets	Brazil	Apple/cv. 'Gala'	↑	↑	No diff	(Amarante et al., 2010)
Anti-hail white nets	Brazil	Apple/cv. 'Fuji'	↓	↓	↓	(Amarante et al., 2011)
Shading white nets (compared to control and black nets)	Slovenia	Apple/cv. 'Jonagold', 'Elstar'		↑	↑	(Stampar et al., 2001)
Photoselective white (15%); red-white (15%), red; blue; grey and pearl (30%) nets	Israel	Apple/cv. 'Topred Red Delicious'	↑	↑	↑	(Shahak et al., 2004)
Photoselective white (15%); red-white (15%); red; blue; grey and pearl (30%) nets	Israel	Peach/cv. 'Hermosa'	↑	↑	↑	(Shahak et al., 2004)
Photoselective red net (20%) (compared to blue; yellow; white)	Italy	Apple/cv. 'Fuji'	↑	↑	↑	(Corollaro et al., 2015)
Photoselective red (50%) nets	Punjab	Pomegranate/ cv. 'Mridula'	↑	↑	↑	(Meena et al., 2016)
Photoselective red; white (9%) nets (compared to yellow)	Croatia	Apple/cv. 'Crippis Pink'	↑	↑	↑	(Brkjača et al., 2016)
Photoselective blue net (40%)nets (compared to red)	Italy	Apple/cv. 'Fuji'	↑	↑	↑	(Bastias et al., 2012)
Photoselective blue; gray (40%) nets compared to white (20%)	Italy	Apple/cv. 'Fuji'	↑	↑	↑	(Bastias et al., 2012)
Photoselective blue (15%); pearl (7%); red (9%)nets	Italy	Wild bilberry/(V. myrtillus L.), cultivated blueberry/ (V. corymbosum L., cv 'Brigitta Blue')	↑	↑	↑	(Zoratti et al., 2015)
Photoselective anti-hail red nets (30%) compared to white 10%	Italy	Nectarine/cv. 'Laura'	No diff	No diff	↓	(Giaccone et al., 2012)
Photoselective red nets	Croatia	Peach	↑	↑	↑	(Vuković et al., 2017)
Photoselective red 30% nets compared to white (10%)	Italy	Nectarine/cv. 'Laura'	No diff	No diff	Slightly ↓	(Giaccone et al., 2012)
Alt carpo nets	France	Apple	↑	↑	↑	(Romet et al., 2010)
Alt Carpo 5.5 × 2,2mm nets	Quebec	Apple/cv. 'Cortland'	↑	↑	↑	(Aoun, 2016)

↑ = Increase; ↓ = Decrease; No diff = No difference.

that colored shade nets induce cooler soil temperature, widening the day-to-night difference gap. This improves anthocyanin production and enhances fruit coloration (Solomakhin and Blanke, 2010b).

2.3.1.2. Weight and size. When net shading inhibits photosynthesis or promotes vegetative growth, fruit size and yield are reduced (Amarante et al., 2010) (Table 3). Bastías et al. (2012) reported that early in the season, under sunlight limitation, shoot growth is favored over fruit development for photo-assimilate allocation. However, when nets do not contribute to modifying shoot growth, this latter will not limit carbohydrate allocation to fruits, positively influencing fruit growth. Treder et al. (2016) have stated that in warm regions, less sunlight reaching the canopy may lead to a decrease in leaf transpiration rate; increasing water use efficiency and decreasing water stress symptoms. Also, the crops exhibit better yield and greater fruit size.

In a cold region, exclusion nets installed on apple trees at the pink bud stage in Quebec (Northern Climate) lead to a significant increase of more than 23% in fruit weight and size as compared to that of the control (Aoun, 2016). The author attributed this difference to a positive thinning effect provided by the incomplete full block netting system.

Shahak et al. (2008) found that apple fruit size was the most responsive to photosensitive netting as the environmental factors limiting the fruit size of some cultivars can be attenuated by nets. Bastías and Grappadelli (2012) have reported that the highest ratio of blue to red light under photosensitive blue nets compared to other net colors improved leaf photosynthesis, increasing photo-assimilate availability for fruit development.

2.3.2. Internal fruit quality

Indicators of internal fruit quality (such as firmness, ripeness, sugar content, and acidity) seemed to be less affected by nets compared to external indicators. Some authors stated that there are more important factors than nets responsible for the variation in fruit internal quality such as variety, yield, crop load, planting system, tree age and climatic conditions (Stamper et al., 2002; Widmer, 2000). Other authors believe that nets may have a major influence on fruit internal quality. The effect of different types of nets on internal fruit quality indicators are presented in Table 4.

Starch breakdown, Soluble sugar content (SSC) and titratable acidity are considered major factors influencing fruit flavor while fruit firmness is a major quality attribute reflecting better texture and longer shelf life.

At harvest, fruits subjected to sun are characterized by a higher SSC compared to shaded fruits, whilst no difference in acidity is observed. Klein et al. (2001) have reported that shaded apple fruit reduced the amount of ethylene synthesis thus delaying ripening.

It has been reported that uncovered apples in some cultivars are characterized by an advanced starch breakdown, resulting in sweeter and riper fruits compared to the ones found under dark colored nets. (Table 4). Under shading conditions, structural (cell wall and middle lamellae components) and storage carbohydrates in fruit may decrease, resulting in lower flesh firmness and SSC at commercial maturity (Amarante et al., 2011). Many authors indicated reduced fruit firmness under different types of nets (Table 4). Loreti et al. (1993) attribute this to limited solar radiation, affecting the formation and composition of cell walls. In fact, sunlight deprivation allows cell walls to become more elastic, increasing turgor pressure. Corollaro et al. (2015) used red photosensitive nets on apples and reported lower cell density in apples grown under nets. Furthermore, they observed larger cells with a higher volume of air spaces, decreasing the resistance to compression.

Photosensitive nets however stimulate variable responses. Basile et al. (2012) has reported high fruit soluble solids content in 'Hayward' kiwifruits grown under photosensitive red nets. On the other hand, Giaccone et al. (2012) reported that covering Laura nectarine in Italy with white nets, as opposed to red nets, positively affected fruit sugar content.

Table 4
The effect of different types of nets on fruit firmness, ripeness, Solid Soluble Content (SSC) and titratable acidity.

Net type (shading factor %)	Country	Crop/cultivar	Firmness	Ripeness	SSC	Acidity	References
Anti-hail black nets	Brazil	Apple/cv. 'Royal Gala', 'Fuji Suprema'	Gala: ↓ Fuji: no diff No diff	↓ (delayed maturation)	No diff	↓	(Bosco et al., 2015)
Anti-hail black nets	Spain	Apple/cv. 'Mondial gala'			↓		(Iglesias and Alegre, 2006)
Shading black nets	Slovenia	Apple /cv. 'Elstar'			↑		(Stamper et al., 2001)
Shading black nets	Slovenia	Apple /cv. 'Jonagold'			↓		(Stamper et al., 2001)
Anti-hail black nets	Switzerland	Apple/cv. 'Jonagold'	No diff		No diff	No diff	(Widmer, 2000)
Anti-hail grey; black nets	Poland	Apple/ cv. 'Sampon', 'Rubinstar'	No diff		↓		(Treder et al., 2016)
Shade black (55%,15%) nets	Argentina	Apple/cv. 'Fuji'	↓(55%shading)		↓		(Dussí et al., 2005)
Anti-hail red black; green black nets	Germany	Apple/cv. 'Pinova', 'Fuji Kiku 8'	↓	↓ (starch breakdown)	↓		(Solomakhin and Blanke, 2010b)
Anti-hail white; red-white nets (compared to red black; green black nets)	Germany	Apple/ cv. 'Pinova', 'Fuji Kiku 8'	↑	↑ (starch breakdown)	↑		(Solomakhin and Blanke, 2010b)
Anti-hail white nets (6%compared to black nets)	Mexico	Apple/cv. 'Golden Delicious'	↑	↑ (early maturation many factors)	↑		(Ordóñez et al., 2016)
Anti-hail white nets (6%compared to black)	Brazil	Apple/cv. 'Gala'	↓	↑ (starch breakdown)	↓	No diff	(Amarante et al., 2011)
Shading white (20%) nets	Taiwan	Mandarin/cv. 'Ponkan'	↓		No diff	No diff	(Lee et al., 2015)
Photosensitive red (20% nets (compared to yellow)	Italy	Apple/cv. 'Fuji'	↑		↑		(Corollaro et al., 2015)
Photosensitive red nets (50%)	Punjab	Pomegranate			↓		(Meena et al., 2016)
Photosensitive red:white(9%) nets compared to yellow	Croatia	Apple/cv. 'Cripps pink'		↑ (TA, SSC)			(Brtkjača et al., 2016)
Photosensitive blue; white (20%) nets	South Africa	Avocado/cv. 'Hass'		↑ (fruit softening)			(Tinyane et al., 2018)
Photosensitive nets	Italy	Kiwifruit/cv. 'Hayward'			↑		(Basile et al., 2012)
Photosensitive red:white nets	Michigan USA	Blueberry/cv. 'Elliott'					(Lobos et al., 2013)
Photosensitive anti hail red nets (30%) (compared to white (10%))	Italy	Nectarine/cv. 'Laura'	↑	↓ (Harvest delay)			(Giaccone et al., 2012)
Photosensitive red nets	Croatia	Peach/cv. 'Sugar Top'	↓		No diff		(Vuković et al., 2017)

↑ = Increase; ↓ = Decrease; No diff = No difference; TA = Titratable acidity; SSC = Solid Soluble Content.

Table 5
The effect of different types of nets on major diseases, russetting, disorders, frost and hail damages.

Net type	country	Crop/cultivar	diseases	russetting	disorders	Frost&hail damages	References
Anti-hail white (15%) nets	Spain	Pear/cv. 'Bartlett', 'Red Bartlett'		No diff	↓Sunburn	↓	(Aisov et al., 2015)
Anti-hail white (mesh 4 x 7 mm) nets	Brazil	Apple/cv. 'Gala'			↓Bitter pit (cold storage)		(Amarante et al., 2010)
Anti-hail white nets	Brazil	Apple/cv. 'Gala'			↓Sunburn		(Amarante et al., 2011)
Anti-hail nets	Brazil	Apple/cv. 'Fuji'	↓Apple scab	No diff	↓Bitter pit (cold storage) No diff water core		(Amarante et al., 2011)
Anti-hail black nets	Brazil	Apple/cv. 'Royal Gala', 'Fuji Suprema'		↓	↓Bitter pit (cold storage)		(Bosco et al., 2015)
Anti-hail black (mesh 4 x 7 mm) nets	Brazil	Apple/cv. 'Royal Gala'	↑Glomorella leaf spot				(Bogo et al., 2012b)
Anti-hail black nets	Brazil	Apple/cv. 'Royal gala', 'Fuji'	↑Apple scab				(Bogo et al., 2012a)
Anti-hail pearl; blue; red nets	USA	Apple/cv. 'Honeycrisp'					(Kalcits et al., 2017)
Anti-hail black; white nets	Brazil	Apple/cv. 'Fuji'		No diff	↓Sunburn		(Amarante et al., 2009)
Anti-hail black; white nets	Spain	Apple/cv. 'Mondial gala'			↓Sunburn		(Iglesias and Alegre, 2006)
Anti-hail black; white nets	Slovenia	Apple/cv. 'Jonagold'			↓Sunburn		(Stamper et al., 2002)
Alt- carpo nets	France, Italy	Apple, pear			↓Sunburn		(Alaphilippe et al., 2016)
Exclusion (1.9 x 0.95 mm) nets	Canada	Apple/cv. 'Honeycrisp'	↓Apple scab ↓ <i>Gymnosporangium</i> spp. rusts ↓Sooty blotch and flyspeck complex(SBFS)		↓Sunburn		(Chouinard et al., 2017)
Shading black (50%) nets	USA(California)	Apple/cv. 'Greensleeves'			↑Bitter pit (in storage)		(De Freitas et al., 2013)
Shading black (55%) nets	Argentina	Apple/cv. 'Fuji'			↓Sunburn		(Dussi et al., 2005)
Shading black (15%) nets	Argentina	Apple/cv. 'Fuji'			No diff sunburn		(Dussi et al., 2005)
Shading white (10%), black (20%) nets	Turkey	Apple/cv. 'Granny Smith'			↓Sunburn		(Dayioglu and Hepaksoy, 2015)
Shading white (20%) nets	Taiwan	Mandarin/cv. 'Ponkan'			↓Sunscald		(Lee et al., 2015)
Shading white (10%), black (20%) nets	Turkey	Apple/cv. 'Early red one'			↓Sunburn		(Hepaksoy and Dayioglu, 2016)
Photoselective blue; white (20%) nets	South Africa	Avocado/cv. 'Hass'			↓Sunburn		(Tinyane et al., 2018)

↑ = Increase; ↓ = Decrease; No diff = No difference.

Many authors indicated no differences in titratable acidity of fruits covered with different types of nets (Table 4). When fruits are evaluated at the same stage of ripeness, net color did not influence apples acidity (Ordóñez et al., 2016).

According to Lee et al. (2015), even though incessant shading may negatively affect total soluble content, sunlight may still infiltrate when the shading level of the nylon nets is 20% or less. This is the reason why no substantial differences in total soluble solid and titrate acidity can be recorded when comparing partially shaded netted fruits to uncovered ones.

2.4. Disorders and diseases

Table 5 presents the effect of different types of nets on major Tree fruit diseases, disorders and frost damages.

2.4.1. Hail and Sunburn damages

Hail is capable of affecting fruit trees both directly and indirectly. The primary effect of hail damage is considered the appearance of wounds that would cause the development of necrotic tissue on the fruits and parts of the shoots. Secondary damage includes the development of diseases and infections as well as a decrease in the active leaf area, reducing photosynthetic ability (Arsov et al., 2015).

According to Botzen et al. (2010), hailstorm damage may increase in the future due to global warming. In Brazil, the Apple Producers Association is predicting a 5% year-on-year decrease in apple volumes production as a result of hailstorm damage (Bogo et al., 2012a). Many farmers now cover their trees with nets despite the high initial cost (Amarante et al., 2011). In the major apple-producing countries of the EU and the Americas, the use of anti-hail nets increased in recent decades due to increases in crop insurance costs against hail (Iglesias and Alegre, 2006). Anti-hail netting systems lower the production risk and ensure more sustained yields of premium quality fruits (Table 5).

Sunburn damage may result from rapid fluctuations in temperatures- symptoms of such shifts in climatic conditions are evidenced by the development of white or yellow spots on the fruit. More extreme symptoms include the development of spongy cortex tissue that is dark brown in color (Wünsche et al., 2002). Sunburn may adversely affect 10–50% of apple yield (Wünsche et al., 2001; Le Grange et al., 2002). Furthermore, some cultivars are considered very susceptible to this kind of damage (Dussi et al., 2005).

In regions where temperatures are high, sunburn damage is the primary source of fruit loss. In such regions, nets have proven to protect against sunburn (Table 5). Black nets seem more effective than white nets in decreasing sunburn damage because black nets reduce light transmission (Amarante et al., 2011).

With the climate going rogue, mitigating the effect of high temperature will be crucial in maintaining orchard productivity and fruit quality (Kalcsits et al., 2017).

2.4.2. Bitter pit

Bitter pit is considered a main physiological disorder resulting from Ca^{2+} deficiency in fruit tissues (De Freitas et al., 2010). Even though bitter pit is a postharvest problem, it is due to pre-harvest aspects associated with the final phases of fruit production.

Jackson et al. (1977) reported that apples covered with anti-hail nets with levels of shading ranging between 63 and 89% resulted in higher Ca content in fruits and lower bitter pit incidences but a decrease in fruit size (Table 5). However, Amarante et al. (2011) did not report a decrease in fruit size and still observed reduced bitter bit incidence. This suggests that nets modify the orchard microclimate by decreasing atmospheric water demand and leaf transpiration resulting in increased xylem transport of Ca^{2+} to the fruits.

Nevertheless, De Freitas et al. (2013) cautioned that even though shading nets increase fruit Ca^{2+} uptake, vulnerability to bitter pit can increase under extreme shading conditions. In fact, under extreme

shading conditions, fruit cortical tissue had a higher capacity to strongly bind Ca^{2+} ions in the water-insoluble pectin network in the cell wall matrix, reducing the levels of Ca^{2+} available for other cellular functions (De Freitas et al., 2013).

2.4.3. Apple scab

Apple scab caused by *Venturia inaequalis* is one of the most common diseases affecting apple production worldwide. The disease can lead to drastic losses in the spring (Bogo et al., 2012a, b; Bolar et al., 2000). Both fruits and leaves may be infected resulting in compromised trees yielding fruits unfit for consumption.

Some authors believe apple scab and other fungal infections occurrence under nets may be due to limited wind speed and solar radiation resulting in slower drying rates of leaves after rainfall (Bogo et al., 2012a). Other studies suggest that covering trees with nets decreases disease incidences since nets reduce mechanical damage caused by hailstorms and decrease impaction between shoots and fruits since wind speeds are slowed (Iglesias and Alegre, 2006).

Aoun (2016) who used full block and single row exclusion netting systems on apple trees reported that full block netting offered a microclimate conducive to the development of apple scab compared to single row netting which had a positive effect on the control of this disease. The author attributed this result to the fact that rain does not flow easily over a full block netting structure which retains more water and increase the wetting time of the leaves, promoting fungal spread. In addition, single row netting may further protect the trees against the spores found on the ground leaves due to the netting closure under the trees. It is likely that fewer spores are able to reach the leaves, thus limiting the primary infection (Aoun, 2016).

2.5. Economical insect pests and beneficial insects

Table 6 presents the effect of different types of nets with specified mesh sizes on economical insect pests and beneficial insects.

Fruit tree orchards usually require multiple pesticide applications to sustain tree structure and fruit commercial quality (Sauphanor et al., 2012). Due to the high impact of insecticides on the environment and their limited efficiency on exotic invasive species such as the brown marmorated stink bug, alternative methods targeting major fruit insects are required. Applying exclusion nets is a non-chemical alternative method that was shown able to protect against codling moth (*Cydia pomonella*), fruit fly and lepidopteran species. Furthermore, exclusion nets have been shown to be more effective than chemicals on some pests (Table 6).

2.5.1. Codling moth

Alt'Carpo nets were most extensively studied with regards to the exclusion of codling moth. Both the row-by-row complete exclusion system and the full block incomplete exclusion system when erected after full bloom and before the first codling moth adults emerge and kept until harvest, showed reduction of codling moth damages; though better results were obtained with the row-by-row system (Alt'Carpo) (Alaphilippe et al., 2016). The efficacy of row-by-row netting is attributed to the small space around the trees which limits insect reproduction and by the partial inhibition of codling moth access to trees, affecting egg laying (Chouinard et al., 2016).

According to Alaphilippe et al. (2016), netting has a dual effect: As a physical barrier inhibiting codling moth from reaching the tree and as a behavioral constraint limiting insect reproduction under nets (reduced space available around the trees) (Sauphanor et al., 2012). Tasin et al. (2008) reported that nets negatively affected males during mating season, hindering their ability to locate a female and mate by inhibiting their ability to trace females or any synthetic source of sex pheromone. According to Amarante et al. (2010), nets are considered physical barriers that visually disturb codling males trying to locate females, decreasing mating success.

Table 6
The effect of different types of nets on insect pests and beneficial insects.

Net type	Mesh size	Country	Crop/cultivar	Insect pests	Beneficial insects	References
Alt-carpo nets	4 x 7 mm	Brazil	Apple/cv. 'gala'	↓Fruit fly		(Amarante et al., 2010)
Alt-carpo nets	2.2 x 5.4 and/or 3 x 7.4 mm	France	Apple	↓Codling moth (<i>Dysaphis pomonella</i>) ↑Rosy apple aphid (<i>Dysaphis pomonella</i>) ↑Woolly aphid (<i>Brissonia lanigerum</i>) ↑Oriental fruit moth (<i>Grapholita molesta</i>) ↑Summer fruit tortrix (<i>Adoxophyes orana</i>) ↓Codling moth (<i>Cydia pomonella</i>) ↓Citrus flatid planthopper (<i>Metacalfa pruinosa</i>) ↓Tingidae ↓Rosy aphid <i>Dysaphis pomonella</i>		(Alaphilippe et al., 2016)
Alt-carpo nets	2.2 x 5.4 and/or 3 x 7.4 mm	Italy	Pear			(Alaphilippe et al., 2016)
Alt-carpo nets	3 x 7.4 mm	France	Apple/cv. 'Royal Gala', 'Granny Smith'		↓Coccinellidae ↓Syrphidae No diff earwig ↑Earwigs (<i>Forficula auricularia</i>) ↓Coccinellids ↓Spiders	(Dib et al., 2010)
Alt-carpo nets	2.2 x 5 mm; 3 x 7.4 mm	France	Cherry	↓Cherry fruit fly		(Romet et al., 2010)
Alt-carpo nets	2.2 x 5 mm; 3 x 7.4 mm	France	Apple	↓Codling moth (<i>Cydia pomonella</i>)		(Romet et al., 2010)
Alt-carpo nets	2.2 x 5.4 mm	France	Apple/cv. 'Royal Gala', 'Granny Smith'	↓Codling moth (<i>Cydia pomonella</i>)		(Sauphanor et al., 2012)
Exclusion net (compared to black bird and bat netting) nets	Full enclosure -2 mm mesh	Australia	Low-chill stone fruit	↓Fruit fly (<i>Bactrocera</i> spp.) ↑Tip moth (<i>Grapholita molesta</i>) ↓Apple maggot <i>Rhagoletis pomonella</i> (tarnished plant bug <i>Lygus lineolaris</i> ↓Codling moth (<i>Cydia pomonella</i>) ↑Oblique banded leafroller <i>Choristoneura rosaceana</i>) ↓Spotted wing drosophila (<i>Drosophila suzukii</i>) ↓Codling moth (<i>Cydia pomonella</i>) The brown marmorated stink bug (<i>Halyomorpha halys</i>) ↓Cherry fruit fly (<i>Rhagoletis cerasi</i>) ↓Codling moth (<i>Cydia pomonella</i>)		(Lloyd et al., 2005)
Exclusion nets	1.9 x 0.95 mm	Canada	Apple/cv. 'Honeycrisp'			(Chouinard et al., 2017)
Exclusion nets	1 x 0.6 mm	Canada	Blueberry			(Cormier et al., 2015)
Exclusion nets	1 x 1 mm; 3 x 8 mm; 2 x 6 mm	Italy	Apple			(Kelderer et al., 2010)
Exclusion photoselective pearl net Nets	2.4 x 4.8 mm	Italy	Nectarine and apple			Candian et al., 2018
Anti-hail black nets	1.6 x 1.6 mm 3 x 7.1 mm	Brazil	Cherry/cvs. 'Giorgia', 'Van'			(Ughini et al., 2008)
Anti-hail gray nets	3 x 7 mm	Italy	Apple/cv. 'Braeburn'			(Baïamonte et al., 2016)
Anti-hail gray nets	3 x 7 mm	Italy	Apple/cv. 'Golden delicious'			(Tasin et al., 2008)

↑ = Increase; ↓ = Decrease; No diff = No difference.

2.5.2. Fruit flies

Researchers studying exclusionary nets reported a decrease in fruit fly infestation and fruit damage in fruit trees (Table 6). Lloyd et al. (2005) reported that the use of exclusion netting (full enclosure - 2 mm mesh) resulted in zero infestation on fruit: It decreased fruit fly entry into the enclosure. It is important to note that covering the entire canopy and sealing nets under the lower branches from the first fruit fly capture up until harvest inhibited oviposition more effectively than fixing the net to the soil (Ughini et al., 2008).

2.5.3. Aphids

Despite the fact that complete exclusion nets are capable of excluding some major pests, (Alaphilippe et al., 2016) reported that netting enhanced the development of *Dysaphis plantaginea*, *Eriosoma lanigerum* and *Adoxophyes orana* among others. Aoun (2016) and Aoun et al. (2013) also reported the abundance of *Aphis pomi* and *Dysaphis plantaginea* colonies and damages under single row netting compared to full block netting and control. This may be due to an increase in humidity under nets or to the exclusion of beneficial insects that normally keep the aphids under control through predation. Lupien et al. (2014) used single row netting system that were not fully enclosed and introduced ladybugs for aphid control. They reported that ladybugs control aphid populations early in the season. However, since they seem to leave apple trees in July, late aphid population including *Eriosoma lanigerum* and *Aphis pomi* appeared later in the season.

According to Sivakumar et al. (2017), photoselective nets induce a moderate cooling effect useful in pest control. However, the effect of these types of nets on insects affecting fruit trees is still not fully understood. It should be noted that photoselective nets may decrease the likelihood of aphids, thrips and whitefly infestation not quietly controlled by exclusion nets. This might be explained by two hypotheses: The first one is that the light passing through photoselective nets is invisible to the pest as it contains less UV light. The second hypothesis is that greater levels of scattered sunlight discourage pest landing (Ben-Yakir et al., 2008).

2.5.4. Beneficial insects

When it comes to beneficial insects, the effects of exclusion nets are still contested. Some studies reported the development of natural enemies' populations under nets whilst others reported the opposite warranting the use of commercially available natural enemies (Chouinard et al., 2016). These contradictions may be explained by the type of exclusion net installed. Complete singlerow exclusion systems seem to have the side effect of excluding beneficial insects with pests, thus increasing the occurrence of minor pests such as aphids and mites. On the other hand, the full-block incomplete exclusion system seems to allow to an extent the presence of beneficial insects (Aoun, 2016).

3. Conclusions

Considering the progress of climate change, using nets against the risks imposed by abiotic stresses such as heat, light and wind will play an essential role (Kalcsits et al., 2017). In warm regions, nets can protect against extreme light intensity and high temperatures that cause fruit damage whilst increasing water use efficiency (Nicolás et al., 2008). In cold regions, netting protects fruits from hail, torrential rains and wind that may lead to drastic yield losses.

Parameters such as the type of net, time of application netting material and the structure system can differently affect crop responses. A better understanding of the effect of such factors is necessary for improving crop responses and ensuring quality fruit yield (Lee et al., 2015). Furthermore, the color of the net can elicit different physiological responses in the crop based on the type of crop, and location of the farm (Brkljača et al., 2016).

Considering the timing of net application, most studies installed nets after full bloom until harvest, permitting better insect pollination

(Arsov et al., 2015; Amarante et al., 2011). In some cases where nets were installed prior to pollination, bee hives were placed inside enclosures during the flowering period (Lloyd et al., 2005).

Nets can differently affect the vegetative and reproductive behavior of crops. Further studies are needed in order to understand the mechanisms involved in productivity increase. Such understanding would help researchers and farmers decide the type of net to be used, and the period of shading necessary for the desired crop response (García-Sánchez et al., 2015).

Determining the effect of various types of nets such as photo-selective nets on fruit quality can be very complex especially considering that nets may differently affect environmental conditions including temperature, light quality and quantity (Basile et al., 2012). Covering trees with nets is an intricate process due to the different chemical, physical and physiological processes involved in plant growth (Tanny, 2013). Non-the-less, photo-selective nets of different colors seem to be a promising candidate solution for fruit tree growers.

According to several studies, nets reduced the occurrence of some physiological disorders of fruits such as bitter bit and sunburn and may reduce the occurrence of some diseases (apple scab). Exclusion nets have proven to be effective in controlling major pests in orchards such as codling moth, and fruit flies. This technique has been favored in regions where pests are difficult to control or when pesticide use is constrained including organic agriculture (Alaphilippe et al., 2016).

In conclusion, protected cultivation of tree fruit crops is an innovative alternative solution that needs to be further developed and commercialized in face of climate change issues and invasive exotic pests to insure orchards sustainability. Netting systems will also help the flourishing of sustainable production systems such as organic and low-input systems for fruit tree production.

Declarations of interest

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