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Article

Effect of Photo-Selective Nets on Yield, Fruit Quality and Psa Disease Progression in a 'Hayward' Kiwifruit Orchard

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Abstract: The influence of the colour of photo-selective nets on *Actinidia deliciosa* yield, fruit quality and progression of the bacterial kiwifruit canker (*Pseudomonas syringae* pv. *actinidiae*, Psa) need to be characterised due to increasing use of these nets, mainly to protect from hail and storms. From May 2019 onwards, pearl (Pn), yellow (Yn) and grey (Gn) nets were installed permanently in a 'Hayward' kiwifruit orchard in NW Portugal and uncovered plants were used as the control. Compared to outside conditions for both seasons, the blue:red ratio and the mean air temperature were higher (mean increase of 12.7% and 0.6 °C, respectively) and the photosynthetic active radiation (PAR) was lower (10.8% less between budbreak and bloom) under the Pn. Crop yield, compared to the control, decreased by 40.3% under the three nets in 2020, and by 23.9% under the Yn and Gn in 2021. Yield and fruit grade under the Pn were similar to that of uncovered crops in 2021, and fruit grade was overall higher under the Pn compared to the Yn and Gn. Photo-selective nets did not affect the fruit quality parameters. Psa progression decreased under the Pn compared to the control during two months in both seasons, although this beneficial impact needs further evaluation.

Keywords: *Actinidia deliciosa* 'Hayward'; kiwifruit's yield and quality; low shading photo-selective nets; PAR radiation; *Pseudomonas syringae* pv. *actinidiae*

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1. Introduction

Kiwifruit (*Actinidia* spp.) production is of high economic importance in several European countries, including Italy and Portugal. Kiwifruit yield and quality depend on crop management (fertilization, pruning, irrigation) and environmental factors [1–3]. For physical protection against adverse environmental factors such as hail, excessive temperatures and/or strong winds, photo-selective nets are increasingly being used on *Actinidia* spp. orchards [2,4–7].

Photo-selective nets with different shading characteristics can change the quantity and quality of solar radiation received by the plant [1,5,8–11] and other climatic variables, such as relative humidity [6]. As a consequence, this leads to microclimates, often decreasing the crop's need for water [10,12], influencing the plant's light-regulated physiological responses including growth and development, yield and fruit quality, and even influencing the incidence of pollinators, pests and diseases [5–7,13]. For example, some photo-selective shade nets (mostly the pearl and yellow nets) were found to reduce pest-borne viral diseases [4] and the occurrence of fungal diseases in both pre- and post-harvest stages [14]. However, the type and extension of the effects of different net colours on the species/cultivars' physiological responses remains to be further characterised and compared. Therefore, a proper evaluation of the netting benefits must include a balance between the benefits of shading and the effects associated with the net's colour.

The bacterial kiwifruit canker caused by *Pseudomonas syringae* pv. *actinidiae* (Psa) is responsible for high yield losses worldwide [15,16], and environmental stresses such as frost, wind, rain and hail storms are favourable for the spread and development of this disease [15,17]. Plastic covers, as well as photo-selective nets, have emerged as a promising strategy to manage control of Psa [18,19].

This simple strategy, based on manipulating the light spectrum, is suitable for organic production and aligns with the Farm to Fork strategy of the European Union [20]. Induced resistance to Psa may be affected by the light spectrum, as demonstrated in kiwifruit plants that, when exposed to LED red 670 nm light, expressed greater resistance to Psa leaf spotting than plants under LED red/blue 440 and 670 nm light [21].

This work aims to evaluate the potential of using different colours of photo-selective nets in a kiwifruit orchard, usually used to protect from hail and storms, to (a) manipulate the kiwifruit yield and fruit quality, and (b) control the bacterial kiwifruit canker caused by Psa (pathovar 3), considering the microclimatic changes induced by the nets.

2. Materials and Methods

2.1. Location and Plant Material

The experiment was carried out in a kiwifruit orchard (*A. deliciosa*, 'Hayward') located in Quinta das Picas, Portugal (41°31′ N; 8°27′ W). Soil chemical characteristics were as follows: pH (H_2O) 5.6; organic matter content 35.0 g kg^{-1}; available P_2O_5 122 mg kg^{-1}; and K_2O 297 mg kg^{-1}. The orchard was planted in 1990 with North-South row orientation and a plant spacing of 5 × 2.5 m, trained to pergola system, with the wires located at 2 m height. The irrigation system was micro-sprayers with a 3 m radius and a flow rate of 40 L h^{-1}, placed at 1 m above the ground.

2.2. Experimental Design and Netting Characteristics

Photo-selective nets (Iridium®, Agrintech, Eboli, Italy) were installed in a gable roof shape in May 2019 at 4 m height, with the colours pearl (Pn), yellow (Yn) and grey (Gn) and a nominal shading percentage of 7%, 4%, 19%, respectively (Figure 1). These low shading nets were manufactured with high-density polyethylene (HDPE) and the pearl net particularly was characterised by a prismatic effect that converts the direct radiation into diffused radiation [22]. These nets are denser than traditional anti-hail nets as the mesh size is smaller (2.4 × 4.8 mm). The installation of the nets was carried out at the end of May 2019, in a randomised block design with four treatments (three nets and the control without a net) and three replicates with three plants per replication (Figure 1).

2.3. Physical Measurements

The climatic variables were measured with two meteorological stations (Arable Mark, Arable U.S., San Francisco, CA, USA) placed at 3 m height, starting in July 2019. One station was installed outside the nets (control) for the entire experimental period. Another station was installed under the nets, for 49 days under the pearl net (between July and October), 45 days under the yellow net (between August and November) and 38 days under the grey net (between August and November), to analyse the climatic characteristics of each net. From 22 November 2019 onwards, the meteorological station was installed permanently under the pearl net, for both crop seasons.

(**a**) (**b**)

Figure 1. (**a**) Knitting pattern of the photo-selective nets (HDPE. 2.4 × 4.8 mm); (**b**) application of the pearl, grey and yellow photo-selective nets in Portugal (4°31′ N; 8°27′ W).

The sensors included: air temperature and relative humidity (RH) (HMP50, Vaisala Instruments, Vantaa, Finland); wind speed (anemometer 6410, Davis Instruments, Hayward, CA, USA); net radiation; photosynthetic active radiation (PAR, 400–700 nm); longwave energy (8000–14,000 nm) (CM3, CNR4 Net Radiometer, Kipp and Zonen B.V.; LI-190 Quantum Sensor, LI-COR, Inc. Lincoln, NE, USA); and seven bands of the radiation spectrum, including the blue and the red spectral wavebands, 420–480 nm and 640–700 nm, respectively (Portable Spectrometer, B&W Tek, Plainsboro, NJ, USA; Monochromator, Instruments SA Inc., Edison, NJ, USA). Data were recorded hourly and daily means were calculated.

Winter chilling hours, accumulated from the 1 November to 28 February, were calculated by the Crossa-Raynaud [23] model modified by Sánchez Capuchino [24], often used in the Mediterranean and in sub-tropical climate conditions. This model relates the number of hours below the commonly used 7 °C and the daily maximum and minimum temperatures, and showed increased determination coefficients (R^2) in comparative studies of different chilling models carried out in a sub-tropical climate in Argentina [25].

2.4. Pollination and Biometric Measurements

The artificial pollination was carried out using a blower dry distributor (SoffiaPolline, Biotac, Verona, Italy), in a single step in 2020, at 50–70% open flowers, with 150 g ha^{-1} of pure pollen (Table 1). In 2021, pollen was blown twice, at 50–70% open flowers and at the end of flowering (last 10–20% open flowers), with 75 g ha^{-1} of pure pollen per application. In 2021, seven beehives ha^{-1} of bumblebees (*Bombus terrestris*; Biostásia, Barreiro, Portugal and Biomip, Almería, Spain) were placed outside and under the nets, at the beginning of flowering, and 10 ventilations were performed in the morning, with a turbine coupled to a tractor, from full bloom (three days before applying the pollen) to the end of flowering, both outside and under the nets (Table 1).

Table 1. Dates of some phenological stages and crop management procedures, during 2020 and 2021 growing periods, in outside (Out) and under the nets (Nets) conditions.

	2020	2021
Bud break	15 March	16 March
Beginning of flowering (beehives)	-	14 May
Full bloom (50% open flowers)	24 May	18 May
1st Artificial pollination	28 May: Out; 29 May: Nets	21 May: Out and Nets
2nd Artificial pollination	-	22 May: Out; 24 May: Nets
Ventilation	-	19 to 25 May: Out and Nets
Beginning of fruit growth	2 June	27 May
Harvest	30 October	5 November

The Psa disease severity was evaluated in 18 leaves per kiwifruit plant from June to October for both years through a 0–5 severity scale, according to the percentage of the leaf surface showing necrosis [17], where 0 means 0% necrosis, and from 1 to 5, the percentage of the leaf area necrosed is 1: 1–10%, 2: 11–25%, 3: 26–50%, 4: 51–75% and 5: 76–100%. Harvest occurred 170 and 175 days after full bloom in 2020 and 2021, respectively, after the total soluble solids reach at least 6.5 °Brix in the orchard. The number of fruits and the fresh weight were recorded for each fruit grade clustered in four standard classes according to the EU regulations [26]: extra $\geq$ 90 g fruit^{-1}; 70 g fruit^{-1} < class I < 89 g fruit^{-1}; 65 g < class II < 69 g fruit^{-1}; and waste $\leq$ 64 g fruit^{-1}. At harvest, it was evaluated in 10 fruits per each plant treatment replicate, the fruit dry matter (DM, %; NP EN 12,145:1999), firmness (Newton, N; penetrometer with 8 mm diameter tip), pH (NP EN 1132:1996), total soluble solids content (TSS, °Brix; NP EN 12,143:1999) and titratable acidity (TA, % of citric acid in fresh fruit; NP EN 12,147:1999).

2.5. Statistical Analysis

Statistical analyses were performed with SPSS software (SPSS, Chicago, IL, USA). The significance of differences between treatments for the different measured parameters (dependent variables) was evaluated by one-way ANOVA using the Duncan test as a post hoc test for mean separation ($p \leq 0.05$). Statistical analysis was also performed using two-way analysis of variance (including both years). The two-way ANOVA showed no interaction between factors for the dependent variables analysed, but did show occasional differences between nets and between years. Significant differences between nets, for all dependent variables analysed, were based on the one-way ANOVA to have stronger evidence when distinguishing treatment means for each year.

3. Results

3.1. Climatic Conditions under the Three Photo-Selective Nets

The photo-selective nets, when compared to outside conditions in different observation periods from July to November 2019, consistently decreased the daily mean PAR by 7.9%, 9.2% and 11.3% under the yellow, grey and pearl nets, respectively, but slightly increased incoming longwave solar radiation by about 1% (Table 2).

The composition of the light reaching the plants underneath the nets differed according to the colour of the nets, specifically in the blue and red wavelengths, which are preferentially absorbed by chlorophylls a and b, the major photosynthetic pigments in higher plants. During the monitoring period for each net, the blue and red wavelength were lower underneath the nets compared to outside conditions, but the blue:red ratio was higher underneath the pearl and grey nets and lower under the yellow net (Table 2).

Table 2. Mean, minimum and maximum values of climatic variables outside and the ratio [under the photo-selective nets/outside conditions] (%) for the pearl, yellow and grey nets during different observation periods from July to November 2019.

Climatic Variables			Outside	Pearl Net/Outside (%)	Outside	Yellow Net/Outside (%)	Outside	Grey Net/Outside (%)
PAR	Mean	µmoles m^{-2} s^{-1}	264.2	88.7	238.3	92.1	177.3	90.8
	Min		35.3	87.8	27.9	82.5	28.3	91.0
	Max		436.6	89.1	402.9	92.2	349.2	93.8
Max. PAR	Mean		932.2	91.0	855.9	96.1	704.4	93.9
Longwave solar radiation	Mean	W m^{-2}	352.5	101.3	350.3	101.1	343.4	100.8
Blue wavelength	Mean		4.4	94.8	3.9	90.8	2.8	99.7
Red wavelength	Mean		9.9	91.4	8.9	95.0	6.4	94.3
Blue:red ratio	Mean	-	0.44	103.8	0.43	95.6	0.43	105.8
Air temperature	Mean	°C	18.7	103.9	18.0	102.6	15.1	102.2
	Min.		12.0	103.4	9.9	105.1	5.3	106.7
	Max.		24.0	101.5	23.6	99.8	24.4	98.3
Min. air temperature	Mean		11.9	99.2	11.3	99.0	9.2	95.7
Max. air temperature	Mean		26.1	107.9	25.2	106.9	21.5	110.2
Relative humidity (RH)	Mean	%	82.2	96.9	81.8	97.0	80.8	98.3
Min. RH	Mean		57.8	87.7	57.3	90.3	59.4	90.3
Max. RH	Mean		99.4	99.1	99.0	98.3	96.5	99.2
Precipitation	Total	mm	159.1	87.1	167.2	90.3	92.6	88.9
Wind speed	Mean	km h^{-1}	1.5	32.2	1.9	34.6	2.0	32.8

The mean air temperature under the nets, compared to outside conditions, for the considered periods increased by 0.3 °C, 0.5 °C and 0.7 °C under the grey, yellow, and pearl nets, respectively (Table 2). Under the three nets, the average maximum air temperature also consistently increased by about 2 °C, but the average minimum air temperature slightly decreased (by between −0.1 °C and −0.4 °C), which increased the daily mean thermal amplitude compared to outside conditions. For each monitoring period, the mean daily RH decreased by −1.4%, −2.5% and −2.6% under the grey, yellow and pearl nets, respectively, in comparison to the control outside conditions, and the average minimum and maximum RH also decreased underneath the nets. The wind speed and rainfall decreased by 65%−68% and 10%−13%, respectively, under the nets (Table 2).

3.2. Climatic Conditions in 2020 and 2021

The mean values of climatic variables under the photo-selective pearl net were compared as a percentage of the outside conditions throughout crop development and growth periods in 2020 and 2021 (Table 3). The main difference between both years was the warmer winter and the dryer season in 2020. Chill hours in 2019/20 and 2020/21 were 836 and 1133 h, respectively, outside and were 66 and 126 h less under the pearl net. The rainfall from budbreak to harvest was 243.3 mm and 430.1 mm in 2020 and 2021, respectively.

Table 3. Mean values of climatic variables outside (Out) and the ratio under the photo-selective pearl net (Pearl) and outside conditions (%) throughout crop growth and development in 2020 and 2021.

Climatic Variables 2020		Autumn/Winter to Budbreak (1 November 2019 to 15 March 2020)		Budbreak to Flowering (16 March 2020 to 24 May 2020)		Flowering to End of Aug (25 May 2020 to 31 August 2020)		Until Harvest (1 September 2020 to 30 October 2020)	
		Out	**Pearl/ Out (%)**	**Out**	**Pearl/ Out (%)**	**Out**	**Pearl/ Out (%)**	**Out**	**Pearl/ Out (%)**
PAR	µmoles m^{-2} s^{-1}	262.0	96.0	415.5	89.6	503.6	85.4	270.8	81.8
Mean air temperature	°C	10.8	102.4	15.1	106.1	20.9	103.8	16.3	103.0
Mean min. air temp.		6.1	98.9	9.2	100.8	13.4	97.9	9.4	99.5
Mean max. air temp.		16.4	107.0	21.4	111.0	27.9	110.0	24.1	107.8
Mean relative humidity	%	87.0	97.6	83.9	96.4	75.6	94.0	84.1	98.9
Precipitation	Mm	820.2	86.2	168.5	86.1	54.3	82.5	59.7	83.9
Wind speed	km h^{-1}	2.7	44.8	2.6	47.4	1.5	49.0	1.6	38.3
Climatic Variables 2021		**Autumn/Winter to Budbreak (1 November 2020 to 16 March 2021)**		**Budbreak to Flowering (17 March 2021 to 18 May 2021)**		**Flowering to End of Aug (19 May to 31 August 2021)**		**Until Harvest (1 September to 5 November 2021)**	
		Out	**Pearl/ Out (%)**	**Out**	**Pearl/ Out (%)**	**Out**	**Pearl/ Out (%)**	**Out**	**Pearl/ Out (%)**
PAR	µmoles m^{-2} s^{-1}	270.4	91.2	485.5	88.9	560.3	82.7	320.1	86.4
Mean air temperature	°C	9.9	104.3	14.2	99.2	19.7	105.7	16.7	103.1
Mean min. air temp.		5.1	103.3	7.4	95.3	12.1	99.1	10.6	99.4
Mean max. air temp.		15.6	107.3	21.6	103.3	27.3	111.4	23.8	108.5
Mean relative humidity	%	92.3	97.3	79.8	97.9	76.6	98.2	86.0	95.7
Precipitation	mm	267.0	87.3	91.0	87.5	27.2	88.4	324.2	84.8
Wind speed	km h^{-1}	2.6	48.1	2.6	48.0	2.2	34.5	1.5	33.7

PAR reduction through the pearl net was similar for both crop seasons and changed throughout the season. PAR was reduced by a mean of 6.4% from Autumn/Winter to budbreak, 10.8% during the period between budbreak and bloom and 15.9% onwards, until harvest (Table 3). However, the blue:red ratio under the pearl net was higher compared to outside conditions and also changed throughout the season. In 2020, the blue:red ratio mean was 10.3%, 15.8% and 11.9% higher for the periods of Autumn/Winter to budbreak, budbreak to flowering (50% open flowers) and flowering to the end of August, respectively.

3.3. Disease Severity

In 2020, from June to August, increased Psa leaf symptoms in uncovered plants were not significant compared to covered plants. However, plants under the pearl net showed lower Psa severity in September compared to all other plant treatments, and also in October compared to the control (Figure 2).

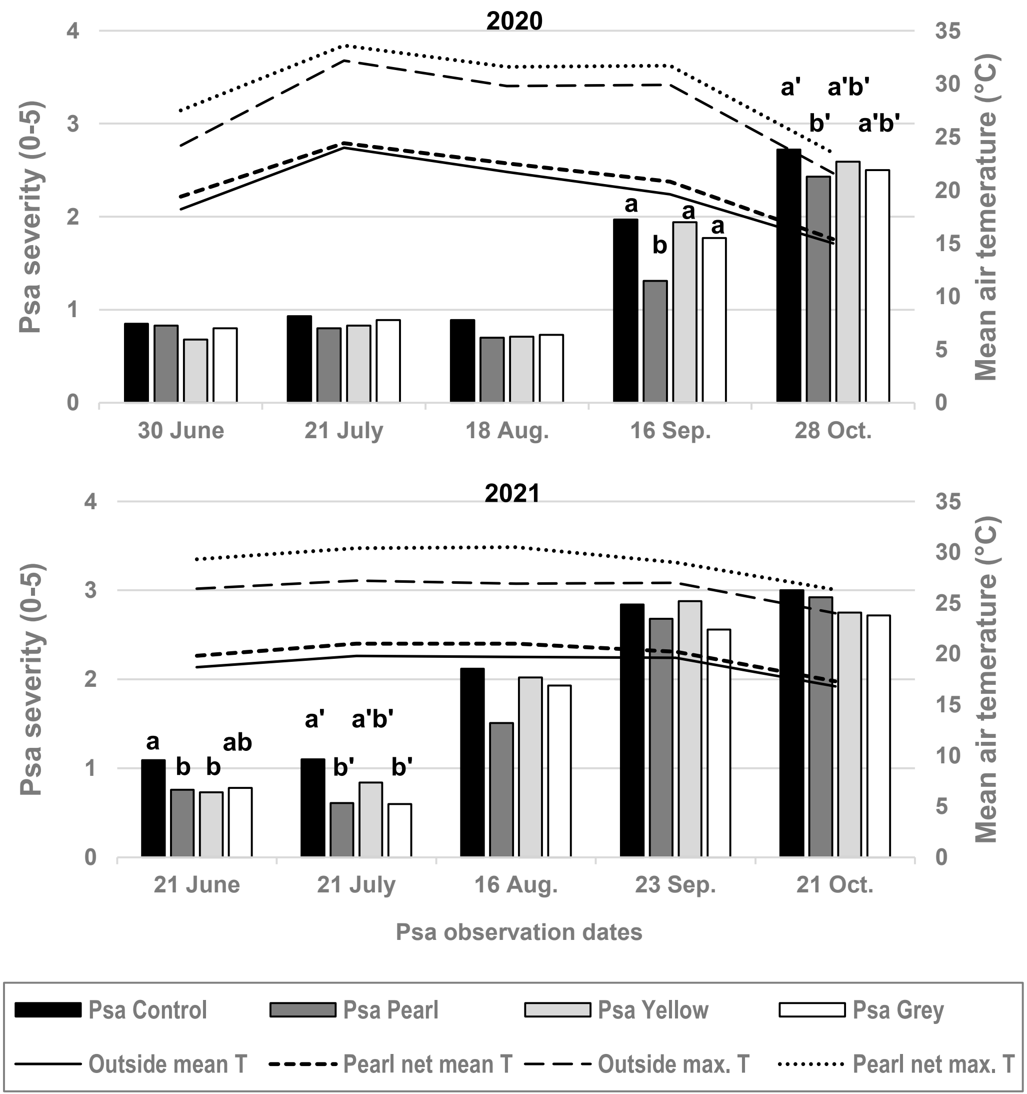

Figure 2. Psa severity outside (control) and under the three photo-selective nets (pearl, yellow and grey) observed in 2020 and 2021, according to a visual severity scale (0–5), at mean air temperature and mean maximum air temperature, outside and under the pearl net, for the period of one month before each Psa evaluation. For each year and each evaluation date, bars with different letters are significantly different ($p < 0.05$) and bars without letters means no significant differences between covered crop treatments.

In 2021, the severity of Psa was lower under the pearl net in June and July compared to the control, and was similar to the other two photo-selective nets. From August onwards, the disease symptoms differences between crop treatments were not significant (Figure 2).

3.4. Crop Yield and Fruit Quality at Harvest

Crop yield and the total number of fruits were higher for uncovered plants (59.7 kg plant^{-1} and 587 fruits plant^{-1}) compared to the three photo-selective nets in 2020. In this crop season, the yield and the total number of fruits were similar for crops under the three nets (mean 35.6 kg plant^{-1} and 401.3 fruits plant^{-1}) (Figure 3). In the following year (2021), uncovered crop yield (71.7 kg plant^{-1}) was not significantly different from crop yield under the pearl net (65.4 kg plant^{-1}), but was increased significantly compared to yields under the other two nets. The yield of crops under the yellow and grey nets was similar (mean 54.5 kg plant^{-1}), although without statistically significant yield differences compared to crops under the pearl net. The differences in the total number of fruits followed a similar pattern to crop yield.

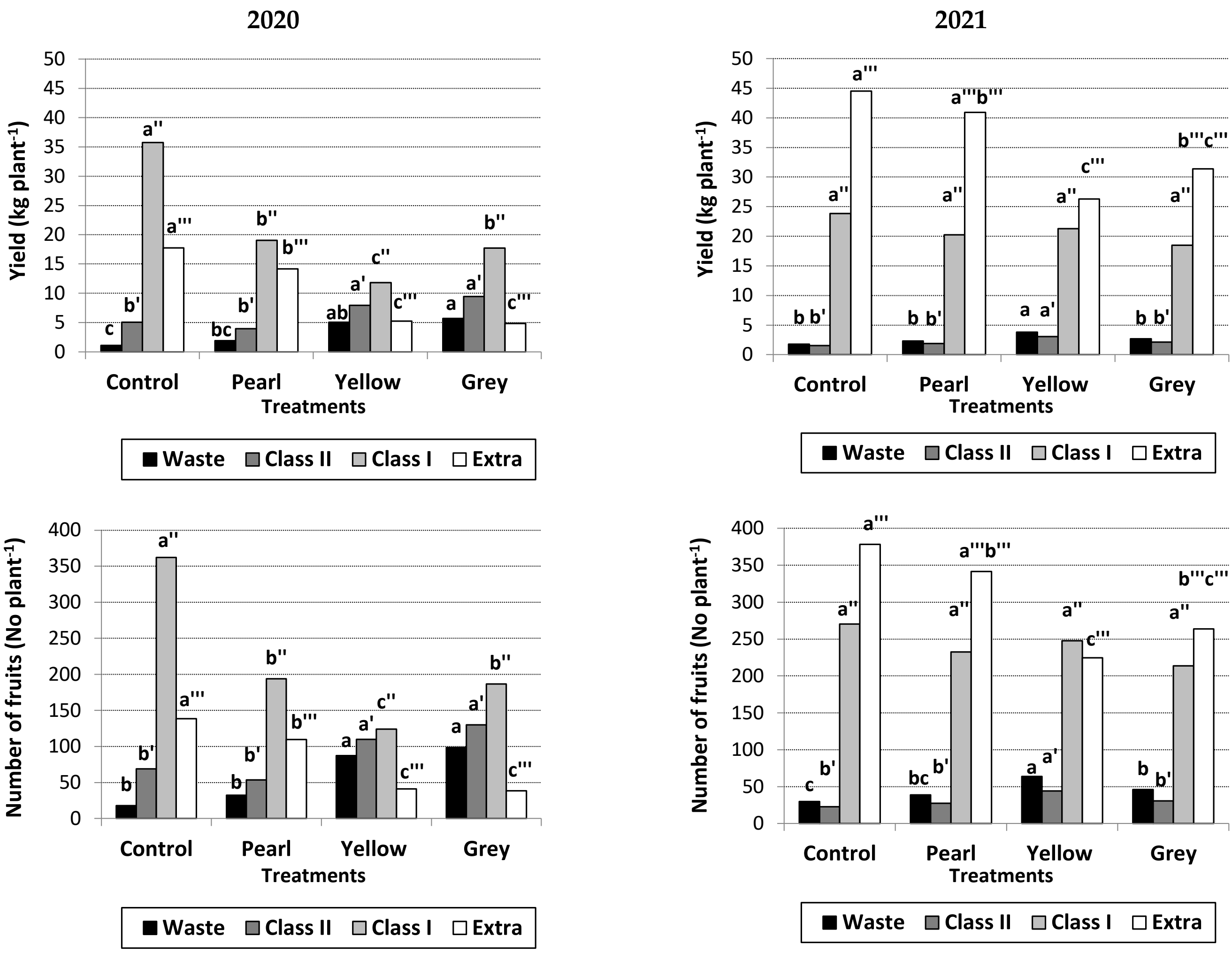

Figure 3. Kiwifruit yield (kg plant^{-1}) and number of fruits (No plant^{-1}) for each grade (Waste, Class II, Class I, Extra) for uncovered plants (control) and plants under the three photo-selective nets (pearl, yellow and grey), in 2020 and 2021. For each year and each grade, bars with different letters are significantly different ($p < 0.05$).

The pearl net showed increased yield and number of fruits for the extra grade fruits ($\geq$90 g fruit^{-1}) compared to the other two nets in 2020. The same was observed in 2021, compared to the yellow net. For this extra grade, fruit yield under the pearl net was similar to uncovered crops in 2021, but was lower in 2020 (Figure 3).

The number and weight of kiwifruit grade class I in 2020, were also higher in the uncovered crop, followed by the crops under the pearl net, which were similar to the grey net, but higher compared to class I fruit number and weight of crops under the yellow net. In 2021 no differences were found between all crop treatments for this grade. Kiwifruit grade class II and waste, for both years, were generally similar for the uncovered and pearl net covered plant treatments, and higher for crops covered with the yellow net compared to the other crop treatments (Figure 3).

The highest percentage of fruits in 2020 were of class I, namely 60.0% for the control, and 48.8%, 39.3% and 47.1%, for the covered crops with the pearl, yellow and grey nets, respectively. In 2021, the highest percentage of fruits were of grade extra and, in the same order, these were 62.1%, 62.6%, 48.3% and 57.4%.

At harvest, for both years, the fruit firmness (N), pH, total soluble solids content (TSS, °Brix) and the titratable acidity (TA, %) were similar for all experimental crop treatments. Fruit dry matter content (DM, %) was also similar for all crop treatments in 2021, but it was higher in kiwifruits grown in 2020 under the pearl net when compared to crops under the yellow net, while similar to the DM content of the control and grey net crop treatments (Table 4).

Table 4. Dry matter (%), firmness (N), pH, total soluble solids content (°Brix) and titratable acidity (%) response (mean ± standard error) to the effect of pearl, yellow and grey photo-selective nets at harvest in 2019 and 2020. For each year, means in the same row followed by different letters are significantly different ($p < 0.05$).

	Control	Photo-Selective Nets		
		Pearl	Yellow	Grey
2020				
Dry Matter (%)	14.5 ± 0.24 ab	14.9 ± 0.17 a	14.1 ± 0.17 b	14.3 ± 0.35 ab
Firmness (N)	62.5 ± 0.26 a	59.5 ± 0.37 a	55.6 ± 0.41 a	56.5 ± 0.19 a
pH	3.5 ± 0.05 a	3.5 ± 0.04 a	3.5 ± 0.05 a	3.4 ± 0.03 a
Total Soluble Solids (°Brix)	7.3 ± 0.17 a	7.6 ± 0.09 a	7.5 ± 0.30 a	7.7 ± 0.12 a
Titratable Acidity (%)	1.6 ± 0.04 a	1.6 ± 0.09 a	1.6 ± 0.03 a	1.6 ± 0.06 a
2021				
Dry Matter (%)	15.1 ± 0.42 a	13.9 ± 0.65 a	14.8 ± 0.16 a	15.6 ± 0.84 a
Firmness (N)	50.1 ± 0.34 a	48.1 ± 0.16 a	44.9 ± 0.16 a	43.3 ± 0.30 a
pH	3.1 ± 0.01 a	3.1 ± 0.03 a	3.1 ± 0.03 a	3.1 ± 0.05 a
Total Soluble Solids (°Brix)	8.7 ± 0.25 a	8.2 ± 0.23 a	8.4 ± 0.20 a	8.5 ± 0.32 a
Titratable Acidity (%)	1.6 ± 0.04 a	1.6 ± 0.04 a	1.7 ± 0.02 a	1.7 ± 0.03 a

4. Discussion

4.1. Climatic Conditions under the Nets

The PAR decrease observed under the nets may be beneficial when plants are exposed to high radiation, which triggers a series of biochemical reactions that reduce photosynthesis [6]. For example, in Florida, with a PAR radiation greater than 1500 µmoles m^{-2} s^{-1}, the photosynthetic efficiency increased by 7% with the use of protective nets [27]. In the current research, the mean maximum PAR was generally below 1000 µmoles m^{-2} s^{-1}. Therefore, outside plants were not stressed by excessive solar radiation. On the contrary, the lower photosynthetic photon flux density at the flower primordia differentiation stage may have reduced specific leaf area and decreased fruit growth under the nets [28]. Richardson et al. [29] also reported that shading reduced floral initiation in kiwifruit plants.

When 'Hayward' vines were grown under a low vs. high photosynthetically active radiation (PAR) and a low vs. high red:far red light, flower production in axillary buds mainly decreased with reduced light quantity and not light quality [28]. For example, shading 'Hayward' vines in late summer and autumn in New Zealand for two seasons reduced the total carbohydrate content of the roots by 40–50% and the canes by 17%, which was correlated with lower floral differentiation occurring from bud swell through to full bloom in the following spring [29]. Therefore, PAR reduction of 10.8% from budbreak to bloom found here under the pearl net for the average of both years, may explain the lower yields under this net in both years compared to outside conditions, although they were only significantly lower in 2020.

The nets are designed to screen various spectral bands of solar radiation and to transform direct light into scattered light, which improves the light penetration into the plant canopy. This is considered an important aspect of photo-selective netting as it has been shown that radiation use efficiency increases when the diffuse component of incident radiation is enhanced under the nets [1,5,9,22,30] or by other means, such as reflective cloths at soil level [11]. Using nets with a higher shading effect of about 30%, Shahak et al. [8] reported that the scattered light—including all non-direct light—was higher in the pearl net, particularly scattering in the UV, compared to other coloured nets including the yellow net and the grey net, which were the least scattering. Here, the pearl net may have this higher scattered light effect. It also showed a higher blue:red ratio, together with the grey net, during the relative observation period, which has been suggested to improve the photosynthetic efficiency of apple trees [31]. These authors [31] showed that changes in red and blue light composition with photo-selective nets could be a useful tool to manipulate the photosynthetic and morphogenetic process regulating fruit carbohydrate availability. Bastías and Corelli-Grappadelli [32] reported that the highest ratio of blue to red light under photo-selective blue nets improved leaf photosynthesis compared to other net colours, increasing the photoassimilate availability for apple fruit growth. Here, the better results of the pearl net compared to the other two nets, mainly the generally higher extra grade fruits yield, may be explained by the higher scattered light effect and, compared to the yellow net, the higher blue:red ratio, shown throughout the relative observation periods.

Mean air temperature under the effect of photo-selective nets has been frequently reported to decrease when compared to outside conditions [2,10]. This can be explained by the higher shading effect of the nets, compared to the low shading nets used in the present study. Indeed, for 'Hayward' kiwifruit in Southern Italy covered with photo-selective red, blue, and grey nets, with 22.8%, 26.9% and 27.3% shading, respectively, the temperature slightly decreased (0.5–1.0 °C, depending on the net and the period of the year) compared to outside conditions [2]. In contrast, an average increase in temperature (0.7 °C) and a decrease in PAR of 15%, were found by Alaphilippe et al. [33] in Northern Italy, using insect exclusion clear nets (Alt'carpo with a mesh size of 5.4 × 2.2 mm) on a pear orchard (row-by-row netting). Here, the increase in mean air temperature was explained by higher levels of incoming longwave solar radiation under the nets compared to outside conditions, and due to the much lower wind speed under the nets decreasing air mixtures [12].

The decrease in mean daily air RH underneath the nets is also contradictory to other studies that indicated an increase in the RH content under the effect of various colour nets [1,34]. For example, Iglesias and Alegre [34] found that the RH increased by between 3 and 6% under the influence of the transparent and black polyethylene nets, and Mahmood et al. [13] reported increases in RH of between 2% and 21%. This can be explained by the positive correlation between air temperature and the saturated water vapour pressure of the air, which is negatively correlated with RH. The decrease in RH under the nets found here was associated with the higher air temperature. For example, under the pearl net, for both crop seasons, RH decreased (−2.5%) and temperature increased (0.6 °C) compared to outside conditions. These are similar to reported values by Alaphilippe et al. [33], of a decrease in RH of 2.3% and an increased air temperature underneath a clear net of 0.7 °C. In addition, less ventilation under the nets decreases air mixing between the more humid outside air and the drier air beneath the nets. For both seasons (2020 and 2021), the mean wind speed decrease was 54.7% under the pearl net, which is comparable to other studies with photo-selective nets that showed wind speed decreased between 40 and 87% [13].

4.2. Disease Severity

Warmer temperatures, particularly the mean maximum air temperature, together with lower RH and the reduction in rainfall under the nets, can explain the trend of decreased severity of Psa disease symptoms under the photo-selective nets, because these climatic conditions limit the bacteria's development [35]. Air temperatures over 20 °C seem to decrease Psa disease symptoms, as well as the dryer leaves limiting pathogen spread within the canopy [16,18,19]. Moreover, other benefits of the nets include protection from wind and hail that can result in physical damage to the vines, predisposing them to infection [18].

Nevertheless, the trend of lower Psa disease symptoms under the nets was only significant for crops under the pearl net during two months in both years compared to the control, and the reduction in disease symptoms ranged from 11% to 45%.

It seems that Psa progression decreased in plants under the pearl net due to net spectral properties inducing photomorphogenic responses, but further research is needed to understand the effect of light composition on the resistance to pathogens and on the relationships between the pathogen and hostgene expression patterns, also stated by Reglinski et al. [21]. In addition, the impact of the photo-selective nets on the kiwifruit's microbiome is critical namely on local bacteria that can compete and be effective in the biocontrol of the disease. A recent study reported promising results with strains of *Pseudomonas putida* and *P. poae*, which belong to the natural kiwifruit phyllosphere and had similar metabolic needs [36].

4.3. Crop Yield

Crop yield decreased on average by 40.3% under the three nets compared to uncovered plants in 2020. In the following year, the yield decrease was 23.9% under the yellow and grey nets. However, the decrease for the pearl net was not significant (8.8% decrease). The yield of extra grade fruits of crops under the pearl net was similar to the uncovered crops in 2021, and was higher than that of crops grown under the yellow and grey nets in 2020 and under the yellow net in 2021.

The higher mean air temperature under the nets from budbreak to harvest and the higher blue:red ratio, at least under the pearl and grey nets, compared to outside conditions, together with the scattered light effect particularly under the pearl net, could contribute to increased yields. However, this was not observed here, probably due to higher cold accumulation in the control compared to the covered crops. Kiwifruit buds become dormant in winter and subsequent bud floral production is influenced by winter chilling. The next spring, the time from budbreak to flowering is advanced by warmer temperatures and here it was 62 to 69 days, which is in agreement with other studies that can vary between 52 and 85 days [3].

Yield differences between crop seasons, as found here, were also reported by other authors [37]. Here, the lower yield found in 2020 for the uncovered crops (50.7 kg plant^{-1}) compared to 2021 (71.7 kg plant^{-1}) could be attributed to a low chilling period in 2020, by about 300 less chill hours. It is estimated that 'Hayward' requires 900 h chilling (Richardson chill hours) [38] and here, the chill hours for 2020 and 2021 were 836 h and 1133 h outside and 770 h and 1007 h under the pearl net, respectively. Under the photo-selective nets, not only were the chill hours lower, but also there was a reduction in wind which can impair efficient pollination. The increased managing of pollination in 2021, namely that bumblebee beehives were placed at the beginning of flowering, artificial pollination was carried out twice and ventilations was increased from full bloom to the end of flowering, both outside and under the nets, certainly contributed to more efficient pollination and increased yield for all crop treatments compared to 2020 crop season. This was also reported with dry pollen application on yellow-fleshed kiwifruit plants [39].

4.4. Fruit Quality at Harvest

At harvest, for both years, the fruit firmness (N), pH, total soluble solids content (TSS, °Brix) and the titratable acidity (TA, %) were similar for all experimental crop treatments. Fruit dry matter content (DM) was also similar for all crop treatments in 2021, but it was higher in kiwifruits grown in 2020 under the pearl net compared to crops under the yellow net.

The TSS content and flesh firmness are important kiwifruit attributes in consumer preferences. Although here the TSS content at harvest was not affected by nets (mean of 7.5 and 8.5 °Brix in 2020 and 2021), photo-selective nets can stimulate different responses. Basile et al. [2] reported that kiwifruits grown under a white net in Italy showed a higher TSS content (9.3 °Brix) at harvest compared to the uncovered control treatment (8.2 °Brix), as well as higher DM content and a lower TA. Kiwifruit firmness generally represents the main limiting factor for long term storage and marketing, as senescence and fruit injuries are directly indicated by softening [40]. Although the firmness of a mature kiwifruit at harvest has been reported to range from 60 to 110 N [41], here it had a mean value of 59 N and 47 N in 2020 and 2021 seasons, respectively.

5. Conclusions

The photo-selective nets used in the present study showed a reduction in incoming PAR. Under the pearl net, for both crop seasons, the PAR reduction increased throughout the season and was on average 6.4% from Autumn/Winter to budbreak, 10.8% between budbreak and bloom and 15.9% onwards, until harvest. However, for the same periods, the blue:red ratio was higher than outside conditions, at 10.3%, 15.8% and 11.9%, respectively, as well as the mean air temperature, which increased on average by 0.3 °C, 0.4 °C and 0.7 °C, respectively, for both crop seasons. In addition, the pearl net showed a potentially higher scattered light effect compared to the other colour nets. The three photo-selective nets seem to cause a similar decrease in the wind speed, rainfall and RH compared to outside conditions and, under the pearl net, the reduction was 54.7%, 13.7% and 3.1%, respectively, on average for both crop seasons. Under the photo-selective nets, the lower PAR from budbreak to bloom may have compromised photosynthesis, together with the lower chill hours and the wind reduction—which might impair efficient pollination—leading to lower yields.

The Psa disease severity decreased for kiwifruit plants under the pearl photo-selective net compared to the uncovered plants during two months in both crop seasons, but did not have a positive influence on the final crop yield. Crop yields under the three nets, compared to the uncovered plants, decreased by 40.3% in 2020, whereas for 2021 this decrease was 23.9% under the yellow and grey nets, but was not significant for the pearl net (8.8% decrease). Nevertheless, the yield of extra grade fruits of crops under the pearl net was similar to the uncovered crops in 2021 and was higher than that of crops grown under the yellow and grey nets in 2020 and the yellow net in 2021. At harvest, photo-selective nets did not affect fruit quality.

When physical crop protection against hail and strong winds is needed, covering the kiwifruit orchard with the pearl photo-selective net, in the orchard's climatic conditions present in this work, seems to have had a beneficial impact on Psa disease progression and produced higher extra grade fruits when compared to the yellow and grey nets.

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