

# Coloured hailnets alter light transmission, spectra and phytochrome, as well as vegetative growth, leaf chlorophyll and photosynthesis and reduce flower induction of apple

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**Abstract** In view of alleged positive effects of coloured (red) hailnets on phytochrome, photosynthesis, yield and fruit quality, the objective of the present work was to investigate a range of red and green hailnets using apple as a model crop with cvs. ‘Pinova’ and ‘Fuji Kiku 8’. Light transmission of green or red hailnets peaked between 500 and 570 nm (green) or above 570 nm (red–orange) and was reduced by 12% (white) or 14% (red–white), 18% (red–black) and 23% (green–black) hailnets; there were no effects on phytochrome. Leaf chlorophyll concentration increased under coloured hailnets by up to 46% under the green–black hailnet, while air temperature was reduced by 0.2°C. Under sunny conditions, photosynthesis of ca. 18  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  was not reduced under coloured hailnets, in contrast with a 21% reduction under cloudy conditions with a concomitant reduction in transpiration by 13%. Vegetative growth was affected in different ways: shaded trees showed smaller trunk diameter, but increased the number and length of their 1-year shoots under coloured hailnets, particularly with cv. ‘Fuji’ when grown under green–

black hailnet. Hailnets reduced flower induction in June and return bloom in the next spring to the same extent as they reduced the light transmission. Overall, tree growth under coloured hailnets was genetically influenced, with cv. ‘Fuji’ being more prone and sensitive to adverse effects of coloured hailnets than cv. ‘Pinova’, but is also influenced by the environment.

**Keywords** Climate change · Flower induction · Gibberellin · Growth · Hailnet · Light · Phytochrome · Photosynthesis · Resource conservation · Sustainability

## Introduction

The increase in hailstorms, probably due to global climate change, resulted in the installation of either black or white hailnets in European fruit orchards as a sustainable measure to ensure fruit quality (Solomakhin and Blanke 2007). Coloured (red or green) hailnets have become available since 2007 with allegedly positive effects on phytochrome, photosynthesis, yield and fruit quality e.g. in apple, grapes and kiwi (e.g. Retamales 2006) based on an increased proportional transmission of red light essential for chlorophyll (663 nm), photosynthesis and phytochrome (666 nm, 730 nm) relative to solar radiation. However, the effects of coloured hailnets on vegetative and reproductive growth, leaf chlorophyll concentration, phytochrome and photosynthesis and

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the underlying mechanisms, to our knowledge, have not been investigated; this is particularly relevant under light limiting conditions at the time of fruit colouration.

Hence, the objective of this short communication was to investigate coloured hailnet effects on vegetative growth, fruit growth, flower induction and return bloom as well as chlorophyll concentration and photosynthesis. Apple was chosen as a model crop due to its widespread distribution.

## Materials and methods

### Apple trees and orchard layout

Four-year-old apple (*Malus domestica* Borkh.) cvs. 'Fuji Kiku 8' and 'Pinova' trees on M.9 rootstock were chosen at Klein-Altendorf Research Centre, University of Bonn, Germany. 'Pinova' was chosen as a mid-sized, German cultivar with poor colouration, whereas cv. Fuji' is a large-fruited Japanese cultivar with ready colouration. Rows of trees were planted in a North–South orientation, at a planting density of 3.5 m × 1 m and trained as slender spindles. This experimental orchard was partially covered either by red–black, red–white, green–black or white hailnets from 15 May 2007, when flowering and pollination had ceased, until 15 October 2007 after harvest. Each coloured hailnet was spread transversely over four tree rows, with the outer two rows serving as unsampled guard rows; uncovered apple trees outside the hailnets served as controls.

### Tree growth, light and fruit quality measurements

The effects of coloured hailnets on vegetative and reproductive growth were measured on 15 trees per hailnet colour as an annual increment of trunk cross-sectional area (CSA), as well as number and length of 1-year-old shoots (on 14 May and 5 December 2007) and the effects on return bloom in the following spring on 5 May 2008 using a 1–9 scale (Yarushnikov and Blanke 2005). Light transmission spectra from 300 to 800 nm of the coloured hailnets were obtained using a laboratory spectrophotometer type Lambda 900 with a resolution of better than 1 nm; light (PAR 400–700 nm) was measured in the orchard using a portable EGM-4 coupled with a TRP-1 (both

from PPSystems, Hitchin, UK) at a 45° angle in the western periphery of the tree canopy ca. 50 cm from the tree trunk at 1.5 m height to mimic the position of the fruits and leaves. All fruit from each tree in the experiment were graded using a Greefa MSE 2000 (Greefa, Gelsersmolen, Holland) with individual fruit assessment which provided percentage fruit skin colouration, mean fruit weight and percentage of class I fruit.

### Leaf photosynthesis, chlorophyll and colour measurements

Chlorophyll content was estimated in-situ from 90 apple leaves under each coloured hailnet and outside the hailnets in the western tree periphery on a cloudy day (13 September 2007; 870  $\mu\text{mol PAR m}^{-2} \text{s}^{-1}$ , 49% rh) using a SPAD 502 chlorophyll meter (Konica Minolta Sensing Inc., Plainfield, IL, USA). Chlorophyll was extracted and measured in 30 apple leaves from the middle of the western tree canopy in line with the light measurements using a standard photometric assay and extraction in DMSO. Photosynthesis was measured on 23 August 2007 using a portable porometer type CIRAS-1 with a PLC B (PPSystems, Hitchin, UK).

### Experimental design and statistical analysis

The experiment comprised ca. 700 apple trees in four rows per variety, two guard rows in between the varieties and one guard tree either side of a hailnet colour. Data from 18 trees (17 replicates) per treatment were statistically processed using SPSS version 13 (SPSS Inc., Chicago, IL, USA). The Kolmogorov-Smirnov test was used to assess the data for normal distribution. The Levene's test was used for homogeneity of variances. For the treatments with homogeneous variances, LSDs were calculated at the 95% confidence level.

## Results

### Light spectra and light (PAR) intensity on a sunny summer day

One objective of the work was to examine the underlying mechanisms of changes in growth under

coloured hailnets. Light transmission of the green or red hailnets peaked in the respective wavelength between 500 and 570 nm (green) or above 570 nm (red–orange), respectively (Fig. 1). Light increased from 70 to 110  $\mu\text{mol PAR m}^{-2} \text{s}^{-1}$  for most of the morning in the shade, but rose to 1,300–1,500  $\mu\text{mol m}^{-2} \text{s}^{-1}$  in the afternoon declining to 1,100–1,250  $\mu\text{mol PAR m}^{-2} \text{s}^{-1}$  at the end of the photoperiod (Fig. 2). On a sunny summer day, light intensities under the white or red–white hailnets were 90–210  $\mu\text{mol PAR m}^{-2} \text{s}^{-1}$  lower for fruit or leaves than outside and under red–black and green–black hailnets ca. 250–340  $\mu\text{mol PAR m}^{-2} \text{s}^{-1}$  lower compared with the outside control.

### Tree growth and return bloom

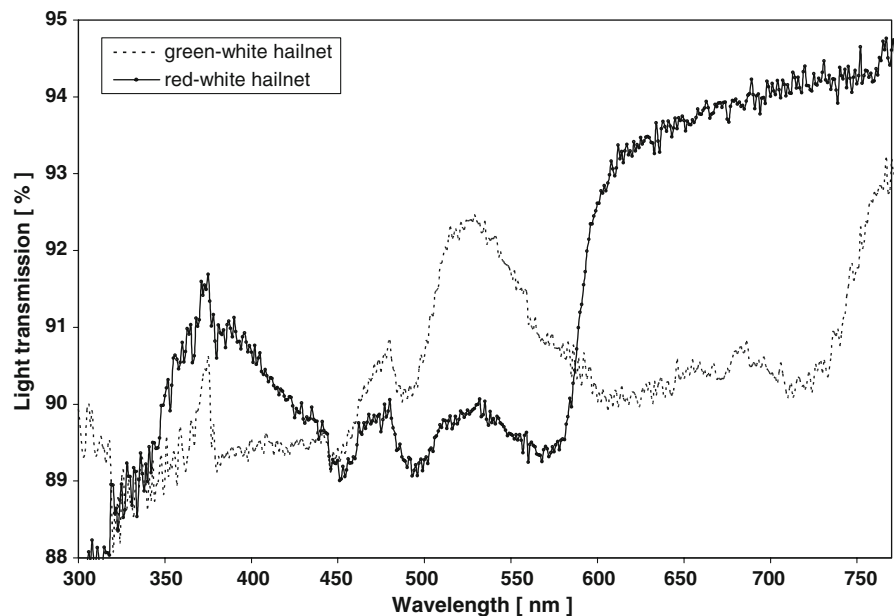
To study the effects of coloured hailnets on vegetative growth, trunk growth was measured when vegetative growth began, viz. before hailnet closure in May and after hailnet opening, i.e. after vegetative growth ceased on 15 trees per hailnet colour. ‘Fuji’ trees, outside without hailnet, grew trunks with 16.9  $\text{mm}^2$  cross-sectional area (CSA) per year, i.e. wider than those under white hailnets with 15.1  $\text{mm}^2$  and under red–white hailnets with 13.4  $\text{mm}^2$  per year. The lowest annual trunk growth was observed in cv. ‘Fuji’ under green–black (9.6  $\text{mm}^2$  CSA) and red–black hailnets (12.9  $\text{mm}^2$  CSA) with statistical differences

compared with the other colours and control outside (Table 1). By contrast, there were no significant differences in bourse (current-year) shoots on cv. ‘Fuji’ trees under red–black (25.9 cm) and green–black (24.4 cm) hailnets followed by red–white, white and the outside control (22.2–22.6 cm). The highest number of current year shoots was observed on trees under the green–black hailnet (91 shoots/tree) and 71, 66 and 62 shoots per tree under red–black, white and red–white hailnets, respectively compared with 69 shoots on control cv. ‘Fuji’ trees. Similarly, in cv. ‘Pinova’ the significantly longer shoots grew on trees under red–black (7.2 m), green black (6.7 m), white and red–white (4.8 and 4.5 m) hailnet than in the control at 2.5 m per tree, i.e. the red hailnets induced intermediate shoot length in between the longest and the shortest shoots under hailnets of other colours (Table 1). Return bloom was reduced by up to 13% (‘Pinova’) or 30% (‘Fuji’) under coloured hailnets (Fig. 3), following the same order as the tree vigour from outside to red–black hailnet, which shows their influence on flower bud formation.

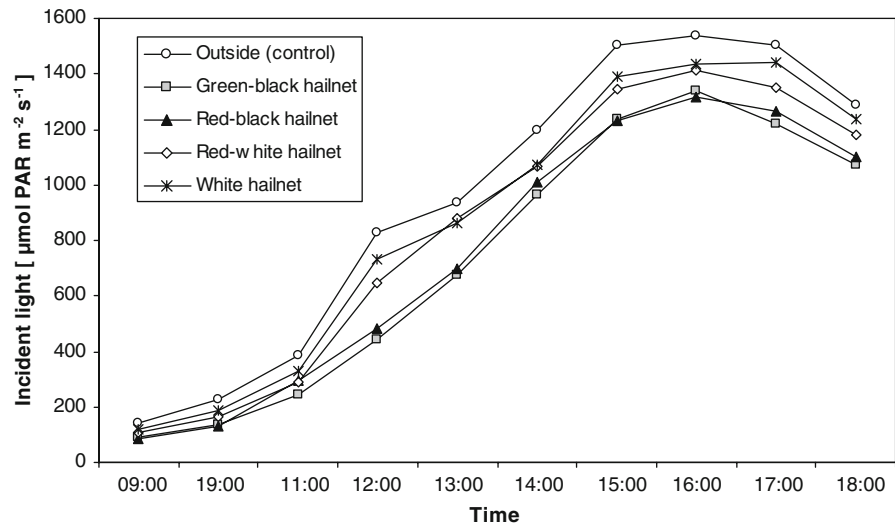
### Leaf chlorophyll content, photosynthesis and transpiration

Chlorophyll content was found to be at the smallest concentration of 35.6 SPAD units in cv. ‘Pinova’ leaves grown outside without hailnets, whereas it was

**Fig. 1** Light spectra (400–800 nm) transmitted by green and red hailnets



**Fig. 2** Light (PAR) transmitted by coloured hailnet and measured at 45° angled light sensor position in the western periphery of the apple tree canopy on a typical sunny day (8 June 2007)



**Table 1** Shoot length and trunk diameter as indicators of vegetative growth of apple trees under coloured hailnets compared to trees grown outside without hailnet

Apple cultivar	Treatment	Mean number of one-year shoots per tree	Mean length of one-year shoot (cm)	Total length of one-year shoots (m per tree)	Trunk cross-sectional area—annual increment (mm <sup>2</sup> )
'Fuji'	Control (outside)	69	22.6	16.65	16.9
	White	66	22.6	15.01	15.1
	Red-white	62	22.2	13.65	13.4
	Red-black	71	25.9	18.35	12.9
	Green-black	91*	24.4	22.10*	9.6
	LSD 5%	15.1	4.02	3.99	0.52
'Pinova'	Control (outside)	23	10.5	2.47	16.0
	White	37*	13.1*	4.81*	14.1
	Red-white	34*	13.4*	4.50*	16.9
	Red-black	51*	14.1*	7.15*	17.7
	Green-black	47*	14.1*	6.66*	14.5
	LSD 5%	8.0	1.11	1.19	n.s.

\* Significant according to LSD at  $P < 0.05$ ; n.s., not significant; values are means of 15 trees per hailnet colour

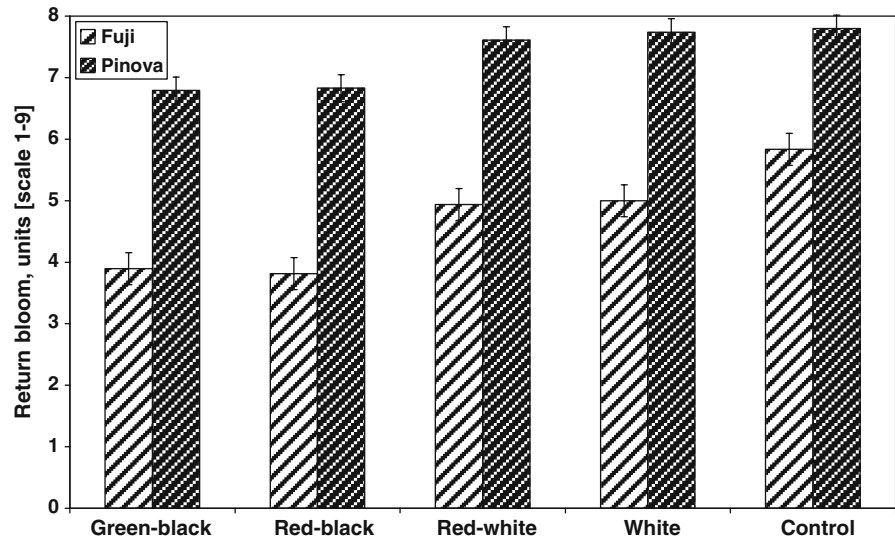
highest (51.8 SPAD units) under the green-black hailnets, i.e. an increase by 46%. Red-black, red-white and white hailnets caused intermediate leaf chlorophyll contents of 47.1, 45.0 and 47.3 SPAD units, respectively, but again without pronounced effects of the red hailnets (Table 2).

Apple cv. 'Fuji' trees of under green-black and red-black hailnets also showed the largest leaf chlorophyll concentrations with 53.7 and 51.5 SPAD units (Table 2), respectively, equivalent to increases of 16% and 11% relative to the control (46.2 SPAD units). Trees under red-white and white hailnets as well as outside control had lower leaf chlorophyll

concentrations of 45.4, 45.6 and 46.2 SPAD units, respectively (Table 2).

Concomitant laboratory chlorophyll assays confirmed the in-situ measurements with the largest chlorophyll content in bourse leaves from trees beneath red-black and green-black hailnets for both cv. 'Fuji' (chlorophyll content 2.58 mg g<sup>-1</sup> FM and 2.78 mg g<sup>-1</sup> FM, respectively) and cv. 'Pinova' (chlorophyll content 2.04 mg g<sup>-1</sup> FM and 2.32 mg g<sup>-1</sup> FM, respectively). The same trend was obtained for red-white and white hailnets with more pronounced differences in cv. 'Pinova' than in 'Fuji' (Table 2).

**Fig. 3** Return bloom assessed on 5 May 2008 on a 1 (very low) to 9 (strong bloom) scale



**Table 2** Chlorophyll measurement in-situ in the field (SPAD units) and laboratory chlorophyll analysis of bourse leaves from apple trees under coloured hailnets and from outside without hailnet (=control)

Apple variety	Hailnet	Chlorophyll <i>a</i> (mg g <sup>-1</sup> FM)	Chlorophyll <i>b</i> (mg g <sup>-1</sup> FM)	Chlorophyll (mg g <sup>-1</sup> FM)	Chlorophyll <i>alb</i> ratio	In-situ chlorophyll measurements (SPAD units)
'Fuji'	Control (outside)	2.244	0.429	2.673	5.2:1	46.2
	White	1.475	0.272	1.747	5.4:1	45.6
	Red–white	1.640	0.291	1.932	5.6:1	45.4
	Red–black	2.155	0.420	2.575	5.1:1	51.5*
	Green–black	2.365	0.418	2.783	5.7:1	53.7*
	LSD 5%	n.a.	n.a.	n.a.	n.a.	1.08
'Pinova'	Control (outside)	1.018	0.180	1.198	5.7:1	35.6
	White	1.610	0.283	1.893	5.7:1	47.3*
	Red–white	1.360	0.218	1.578	6.2:1	45.1*
	Red–black	1.720	0.324	2.044	5.3:1	47.1*
	Green–black	1.968	0.355	2.323	5.5:1	51.8*
	LSD 5%	n.a.	n.a.	n.a.	n.a.	0.62

\* Significant according to LSD at  $P < 0.05$ ; n.a., not applicable

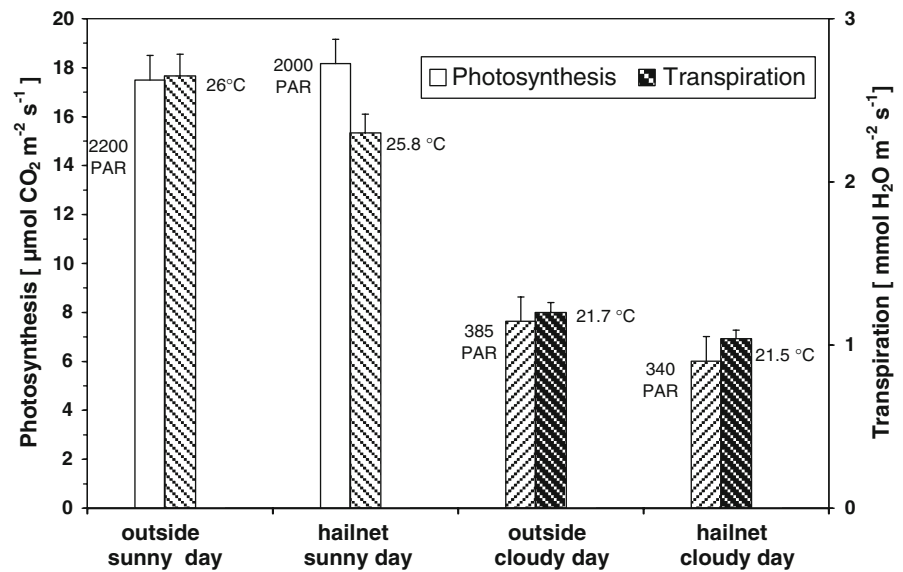
Since the green–black hailnet induced the most severe reductions in PAR (Fig. 2), growth (Table 1) and chlorophyll (Table 2), photosynthesis and transpiration were measured on a day with intermittent shade and sunshine (23 August 2007) under the green–black hailnet and outside at greater (2,000–2,200  $\mu\text{mol PAR m}^{-2} \text{s}^{-1}$ ) and lower (340–385  $\mu\text{mol PAR m}^{-2} \text{s}^{-1}$ ) light intensities. The 10% larger PAR values, viz. 2,200 outside versus 2,000  $\mu\text{mol PAR m}^{-2} \text{s}^{-1}$  and 0.2°C cooler temperature under green–black hailnet, on a sunny day in August in Bonn gave commensurate photosynthesis rates of ca. 18  $\mu\text{mol CO}_2 \text{m}^{-2} \text{s}^{-1}$  with

transpiration exceeding 2  $\text{mmol H}_2\text{O m}^{-2} \text{s}^{-1}$  (Fig. 4). Although PAR was reduced by a similar 12% (from 385 to 340  $\mu\text{mol PAR m}^{-2} \text{s}^{-1}$ ) and temperature also by 0.2°C under cloudy conditions, the green–black hailnet decreased apple leaf photosynthesis by 21% and transpiration by 13% (Fig. 4).

Mean fruit weight, fruit size and red-coloured surface area of apple

Computerised grading of all fruits from trees under a coloured hailnet showed a 11–16% reduction in the

**Fig. 4** Photosynthesis (left columns) and transpiration (right columns) of apple cv. ‘Fuji’ leaves, measured by porometry, outside and under green–black hailnet under sunny and cloudy conditions with PAR and temperatures; other measuring conditions 365 ppm CO<sub>2</sub> and a VPD of ca. 1.3 hPa



**Table 3** Mean fruit mass, percentage fruit skin colouration and fruit size as apple fruit quality parameters assessed by automated fruit grading

Cultivar	Hailnet	Mean fruit mass (g fruit <sup>-1</sup> )	Percentage of fruit with red colour >25% surface	Percentage fruit larger 70 mm
‘Fuji’	Outside (control)	175.5	97.9	69.5
	Green–black	189.9	81.9	75.9
	White	185.4	91.3	71.5
	Red–white	184.3	94.4	71.1
	Red–black	188.8	86.9	75.8
‘Pinova’	Outside (control)	164.6	98.0	66.0
	Green–black	168.1	88.3	69.7
	White	169.2	97.2	62.4
	Red–white	171.5	97.7	68.6
	Red–black	173.4	86.6	75.5

percentage of fruit with >25% skin colouration for both cvs. ‘Fuji’ and ‘Pinova’ relative to the outside control (98%); this reduction was most pronounced for fruits under the red–black and green–black hailnets; outside fruit were smaller and lighter than those grown under a coloured hailnet without differences in yield (Table 3).

## Discussion

### Effect of coloured hailnets on light transmission

Spectral analysis of the light transmitted by the green and red hailnets showed a change in spectrum with

3% more green (500–570 nm) or 6% more red (above 570 nm) light transmission, but not in the red:far red (666 nm:730 nm) ratio (Fig. 1), which would otherwise affect the phytochrome system and plant growth (Brutnell 2006).

Day averages derived from Fig. 2 showed that green–black and red–black hailnets reduced light transmission by 18–20% and by 12–14% under red–white and white hailnets compared with the outside control. These values were obtained with a 45° angled light sensor in the Western tree canopy to mimic the position of the leaves and fruit on a clear and sunny summer day (8 June 2007) and compare favourably with a 33% or 8–12% reduction, measured vertically under a black (Ebert and Casierra

2000) or white hailnet (Solomakhin and Blanke 2007).

#### Effect of coloured hailnets on tree growth and flower induction

The larger number and longer bourse shoots but smaller trunk diameter under coloured hailnets (Table 1) can be explained by shade avoidance and the photoreceptor, phytochrome, located in meristematic tissue in the shoot tip. In the shade, plants redirect photoassimilates for shoot elongation and away from structures dedicated to resource acquisition and to storage, at the expense of leaf development (Brutnell 2006). This shoot extension rate increased as the depth of shade increased thereby enabling young leaves to reach sunnier positions in the tree periphery. Light-grown plants, transferred into shade similar to installing a hailnet, produced less dry matter, retained photosynthates in the shoot at the expense of root and leaf growth, and developed longer internodes and petioles with accelerated extension growth (Marks and Simpson 1999; Brutnell 2006), produced larger thinner leaves, as well as truncate fruit, retarded leaf and chloroplast development, but strengthened apical dominance (Brutnell 2006); this may be due to gibberellin synthesis.

#### Leaf photosynthesis, transpiration and chlorophyll content

The 10% larger PAR values, viz., 2,200 outside versus 2,000  $\mu\text{mol PAR m}^{-2} \text{s}^{-1}$  under green–black hailnet, on a sunny day in August in Bonn gave commensurate photosynthesis rates of ca. 18  $\mu\text{mol CO}_2 \text{m}^{-2} \text{s}^{-1}$  (Fig. 4), because apple leaf photosynthesis was saturated, with respect to light, at 800–1,000  $\mu\text{mol PAR m}^{-2} \text{s}^{-1}$  (Ebert and Cassiera 2000, Tartachnyk and Blanke 2004). Our result resembles those of Widmer (1997), Stampar et al. (2002) and Romo-Chacon et al. (2007), who obtained no significant differences in photosynthesis on a sunny day in Europe or high light conditions in Mexico, between trees with and without black or white hailnets. All these findings contradict the results of Ebert and Cassiera (2000), with black hailnets. In July, in Berlin, they found larger photosynthesis (except for the morning) in the order of 10–14  $\mu\text{mol CO}_2 \text{m}^{-2} \text{s}^{-1}$  under light saturating conditions above 1,000

$\mu\text{mol PAR m}^{-2} \text{s}^{-1}$  without pronounced differences in transpiration values between 1 and 2  $\text{mmol H}_2\text{O m}^{-2} \text{s}^{-1}$  under black hailnet than without hailnet.

Under cloudy conditions at Bonn, the green–black hailnet reduced PAR by 12% (from 385 to 340  $\mu\text{mol PAR m}^{-2} \text{s}^{-1}$ ), associated with a decrease in apple leaf photosynthesis by 21% and transpiration by 13% (Fig. 4). Our result with coloured hailnets resembled the reduction from 17.2 to 14.6  $\mu\text{mol CO}_2 \text{m}^{-2} \text{s}^{-1}$  in cv. ‘Jonagold’ apple under black hailnets on cloudy days in August in Switzerland, reported by Widmer (1997), i.e. 5–10% lesser photosynthesis. Discussion of transpiration does not apply in the absence of any transpiration measurements under hailnets. In essence, leaf photosynthesis is not generally hampered under a coloured hailnet, but is reduced when the amount of light falls below light saturation of ca. 800  $\mu\text{mol PAR m}^{-2} \text{s}^{-1}$ .

The largest leaf chlorophyll synthesis under green–black and red–black hailnets may be due to the leaf response via the phytochrome system to impaired light regime (lack of PAR and UV radiation—data not shown) beneath coloured hailnet. Leaf chlorophyll synthesis depends on the genotype and phenotype, i.e. the variety, and the light transmitted by the hailnet during the leaf growth. Marks and Simpson (1999) showed that increasing irradiance suppressed growth and leaf chlorophyll content of *Disanthus* and *Rhododendron*, in vitro. To our knowledge, no other investigations on apple tree leaf photosynthesis and chlorophyll content under coloured hailnets have been published.

The larger fruit under coloured hailnets is in agreement with Tassara and Battaglia (1992), who found 4.3% and 3.4% larger fruit in cv. ‘Royal Gala’ and ‘Jonagold’, respectively, under black hailnet, compared with fruits grown without net. This appears to contradict Giulivio and Ganzini (1971), where black hailnets reduced the fruit diameter. Our fruit colouration results of a greater percentage green ground colour and lesser (red) top colour of the fruits grown under the white and black hailnets are in agreement with Wagenmakers and Tazelaar (1999).

#### Conclusions

- (1) Light transmission was decreased by 23% for green–black, 18% for red–black, 14% for red–



white and finally 10% for white hailnets. Under green–black hailnet, the lesser PAR and 0.2°C lower temperature resulted in commensurate photosynthesis of ca. 18  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  at light saturation under sunny conditions, but 21% reduced photosynthesis (and 13% decreased transpiration) under cloudy conditions below light saturation.

- (2) Chlorophyll synthesis under the coloured hailnets increased by up to 46% with the lack of solar radiation, especially under green–black and red–black hailnets. Leaves under white and red–white hailnets were presumably saturated for photosynthesis; the greater chlorophyll content under green–black and red–black hailnets, however, did not result in greater photosynthesis rates.
- (3) Vegetative growth was affected in three different ways. The fruit trees responded by (i) reducing their trunk growth, but increased (ii) the amount and (iii) the length of their 1-year shoots under coloured hailnets; these reactions were attributed to shade avoidance. The longest shoots in cv. ‘Pinova’ grew on trees under red–black (7.2 m), green black (6.7 m), white and red–white (4.8 and 4.5 m) hailnet in comparison with the control with 2.5 m per tree per year, i.e. the red hailnets induced intermediate shoot length in between the longest and the shortest shoots under hailnets of other colours. Return bloom in the next spring was reduced under the hailnets to the same extent as they reduced the light transmission and shows their adverse influence on flower bud formation in June. Fruit growth was greater under coloured hailnets than outside, without effect on yield. However, fruit colouration was hampered under the hailnets depending on net colour.

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## References

- Brutnell T (2006) Phytochrome and control of plant development. In: Taiz L, Zeiger E (eds) Plant physiology, 4th edn. Sinauer Associated, Inc., Sunderland, pp 417–440
- Ebert G, Casierra F (2000) Does netting always reduce the assimilation of apple trees? (Verringert die Einnetzung grundsätzlich die Assimilationsleistung von Apfelbäumen?). *Erwerbs-Obstbau* 42:12–14
- Giulivio C, Ganzini M (1971) Observations on the effects of hail protection nets on the orchard microclimate and on the characteristics of Jonathan apple fruits. *Rivista della Ortoflorofruti- coltura Italiana* 55(5):389–414
- Marks TR, Simpson SE (1999) Effect of irradiance on shoot development *in vitro*. *Plant Growth Regul* 28:133–142. doi:[10.1023/A:1006276724956](https://doi.org/10.1023/A:1006276724956)
- Retamales J (2006) Physiological and horticultural effects of the use of coloured shading nets in highbush blueberries in Chile. In: Workshop 10 “Photosselective netting for improved performance of fruit trees.” WS10-5 IHC Seoul August 2006 Abstarct booklet page 49
- Romo-Chacon A, Orozco-Avitia JA, Gardea AA, Guerrero-Prieto V, Soto-Parra JM (2007) Hail net effect on photosynthetic rate and fruit color development of ‘Starkrimson’ apple trees. *J Am Pomol Soc* 61(4):174–178
- Solomakhin A, Blanke MM (2007) Overcoming adverse affects of hailnets on microclimate and fruit quality by reflective mulch. *J Sci Food Agric* 87:2625–2637. doi:[10.1002/jsfa.3022](https://doi.org/10.1002/jsfa.3022)
- Stamper F, Veberic R, Zadavec P, Hudina M, Usenik V, Solar A et al (2002) Yield and fruit quality of apples cv. ‘Jonagold’ under hail protection nets. *Gartenbauwissenschaft—Europ. J Horti Sci* 67(5):205–210
- Tartachnyk I, Blanke MM (2004) Effect of delayed fruit harvest on photosynthesis, transpiration and nutrient remobilization of apple leaves. *New Phytol* 164:442–450
- Tassara MA, Battaglia M (1992) Assessment of a plastic hail net in apples in the Alto Valle de Rio Negro. *Rivista di Agricoltura Subtropicale e Tropicale* 86(2):375–384
- Yarushnykov VV, Blanke MM (2005) Alleviation of frost damage to pear flowers by application of gibberellin. *Plant Growth Regul* 45:21–27. doi:[10.1007/s10725-004-6893-5](https://doi.org/10.1007/s10725-004-6893-5)
- Wagenmakers P, Tazelaar M (1999) Resulting light reduction determines the future of hail nets in the Netherlands. *Fruiteelt (Den Haag)* 89(7):10–11
- Widmer A (1997) Light conditions, assimilation and fruit quality under hail nets. *Obst- und Weinbau* 133(8):197–199