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The effect of anti-hail nets on fruit protection, radiation, temperature, quality and profitability of 'Mondial Gala' apples

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Abstract

The effects of crystal (transparent) and black nets on the protection of fruits from hail, the interception of light, temperature, humidity and fruit quality were evaluated over four seasons (from 2000 to 2003) at the IRTA-Experimental Station, Lleida (NE-Spain) on 'Mondial Gala' apples (*Malus x domestica* Borkh.). Nets demonstrated their efficiency for fruit protection against hail; decreased maximum orchard temperatures and increased minimum temperatures and relative humidity. Based on PAR values, on sunny days, the black net intercepted 25% more incident radiation than the control and the crystal net intercepted 12% more. The use of black net resulted in a significant reduction of colour intensity and days taken for maturity, and provided lower average yields for fruit harvested at the first picking. The crystal net was associated with intermediate values between black net and control, or similar values to those of the control. Both nets reduced fruit temperature and the incidence of sunburn improving global skin quality. The black net increased the vigour of the trees. Fruit firmness was not affected by the use of nets. Soluble solid content decreased when black net was used, while maturity was delayed in some seasons. There were no consistent effect with respect to titratable acidity and fruit cracking. The annual cost of the anti-hail nets was 1874 to 1612 € ha^{-1}, respectively, for crystal and black nets, depending mainly on the durability of the net. The annual cost of insurance was 760 € ha^{-1} and was determinated by site, cultivar, yield and price insured, and was lower than that of covering by nets. The gross profit corresponding to the crystal net (8896 € ha^{-1}) was lower to the control/insurance (9223 € ha^{-1}) and greater to the black net (7842 € ha^{-1}) because of the reduction in fruit colour. With 'Mondial Gala' apples, the use of both colour nets was not economically beneficial compared to the control.

Key words: Apple, *Malus x domestica* Borkh., 'Mondial Gala', net, hail protection, insurance, radiation, temperature, humidity, vigour, fruit colour, quality, cost, benefit.

Introduction

Apple production is important in Spain, which had a total surface area of 44674 ha in 2002. The Ebro Valley is the main area of production, and Catalonia - with 15292 ha - is the most important region (MAPA, 2003). The main cultivars are 'Golden' and 'Gala', which together account for around 60% of the total area dedicated to apple production. An increase in the damage to crops caused by hail storms has been observed over the last 15 years, particularly in the months of April and May. This has encouraged fruit growers in the Lleida area to establish a network of silver iodure burners covering almost the whole area. Even so, in some years and under certain conditions, this remedy does not produce completely satisfactory results.

In addition to using silver iodure burners, spanish fruitgrowers have also insured their crops with the public company Agroseguro, which receives subsidies from both national and regional governments. One of the most common options is to insure crops against hail damage with lower cost than anti-hail nets, but in the case of hail, the loss of production presents a problem for fruit industry companies that wish to maintain customers and also results in an increase in total costs (associated with unused grading machines, cold store facilities, *etc.*). Furthermore, in the case of some new cultivars that have been developed according to the "club" formula, insurance companies establish a maximum price payable (0.31 € kg^{-1} in the case of 'Pink Lady'), whereas their planting/production costs and added value are much higher than those of standard cultivars. In the main apple producing countries of the EU (Italy, France, Austria, *etc.*) and America (Argentina, Chile, Mexico, *etc.*), the nets have been increasingly employed to protect fruit against hail damage in recent decades mainly because the huge increase of the insurance cost. This technique now constitutes the only effective way to protect fruit against this threat. The efficiency of nets in fruit protection and their effects on the interception of light, fruit colour and quality, sunburn, installation systems, costs, and modifications of orchard climate have all been widely documented by authors from Italy, France, Austria, Argentina, Chile, Mexico and South Africa, *etc.* (Andrews and Johnson, 1996; Bru, 1996; Coreau *et al.*, 1997; Reigne, 1997; Vercammen *et al.*, 1998; Vercammen, 1999; Crété, 2000; Yuri *et al.*, 2000; Peano *et al.*, 2001; Dussi *et al.*, 2005; Gindaba and Wand, 2005, 2006; Vittone *et al.*, 2006). However, little information is available relating to the effects and efficiency of this technique with respect to deciduous fruit crops grown in Spain, although some preliminary results have been reported in NE-Spain by Iglesias and Alegre (2004).

This paper is a synthesis of data collected during the 2000-2003 growing seasons at the IRTA-Experimental Station of Lleida with 'Mondial Gala' apples. The objective of the trial was to evaluate the effects of two different coloured nets on the protection of fruit against hail, fruit colour and quality and the effect on orchard climate (temperature and humidity) and light interception. Also an economical analysis of using the two colours of nets has been done.

Materials and methods

Study site, plant material, climatic conditions and net characteristics: The study was conducted in the 2000, 2001, 2002 and 2003 seasons in a plantation of ‘Mondial Gala’ apple trees on M9 Pajam 2 rootstock, planted at the IRTA-Estació Experimental de Lleida (Mollerussa, NE Spain), in 1994. The rows were oriented from NE to SW. Trees were trained with a modified central-leader system, spaced at 4 x 1.4 m and grown on Tipic Xerofluvent, coarse-silty, mixed (calcareous), mesic soil, with an average depth of 0.85 m. Irrigation was same for all the treatments and applied based on evapotranspiration (Etc) minus the effective rainfall; was provided daily by means of a drip system, which consisted of two 4 L h^{-1} drippers per tree. This particular area of Spain is subjected to periods of high summer temperatures (>30ºC) and very low rainfall (413, 296, 430 and 528 mm, respectively, for the 2000, 2001, 2002 and 2003 seasons). In the pre-harvest and harvest period (from 1st July to 15th August), important differences between seasons were recorded with respect to temperature and rainfall. Lower temperatures were registered in 2000 and 2002, temperatures were normal in 2001 and extremely dry and atypically hot conditions occurred in 2003 (Fig. 1).

Nets were installed in May 1998. The orchard was covered with nets from the end of April (after blooming) to October. The net characteristics were:

Black net: Black polyethylene net, diameter 0.28 mm, Beniagro GVM 2.5 x 3 (cell size 3 x 7.4 mm). Non-overlapping system with a slight inclination towards the centre of the interrows. Estimated lifespan: 15 years.

Crystal net: Transparent polyethylene net, diameter 0.28 mm, Beniagro GVM 2.5 x 3 (cell size 3 x 7.4 mm), with the same system as the black net. Estimated lifespan: 8 years.

Five-metre high poles, with 14/16 cm diameter, located at 12.5 m intervals, were used to support the nets. Estimated lifespan: 24 years.

Experimental design: A completely randomised block design was used, with four blocks assigned to each of three treatments: black net, crystal net and control. This design was used to control the effect due to the possible variations in tree vigour due to the effect of nets. Each treatment and block consisted of five rows of 15 trees. Two trees per treatment were selected from the central row of each block based on uniform crop load and vigour.

Light interception by nets: The effect of nets on the interception of light was measured annually as a percentage of total above-canopy Photosynthetically Active Radiation (PAR), using a Ceptometer mod. Sun Scan SS1-UM-1.05 (Delta-T Devices Ltd Cambridge, UK) with a 64 sensor photodiode linearly sorted in a 100 cm length sword. Sun Scan response was almost entirely within the PAR wavelength band of 400-700 nm. The sword ceptometer was placed in the middle of two rows and also parallel to them for each treatment, positioned 1.10 m above ground level. Five readings per treatment were taken at 2 hour intervals, between 9.00 and 21.00 (7.00 and 19.00 solar time) several times in each season (July-August), after shoot growth had stopped, on both sunny and cloudy days. Light distribution in relation to tree height was also measured at 7 heights between 0.5 and 3.5 m above the ground on 10th August 2000 at 14.00 and 18.00 (12.00 and 16.00 solar time) and compared with incident radiation recorded at a height of 4.5 m for each treatment.

Orchard temperature, fruit temperature and relative humidity: The effect of nets on orchard temperature and relative humidity was recorded using Hobo®Pro RH/Temp/2x External mod H08-007-02 automatic sensors (Equipos de Instrumentación y Control S.L., Madrid, Spain), installed within the canopy, and located 1.2 m above the ground level at the centre of the block of each treatment.

Fruit temperature was measured three times in sunny days

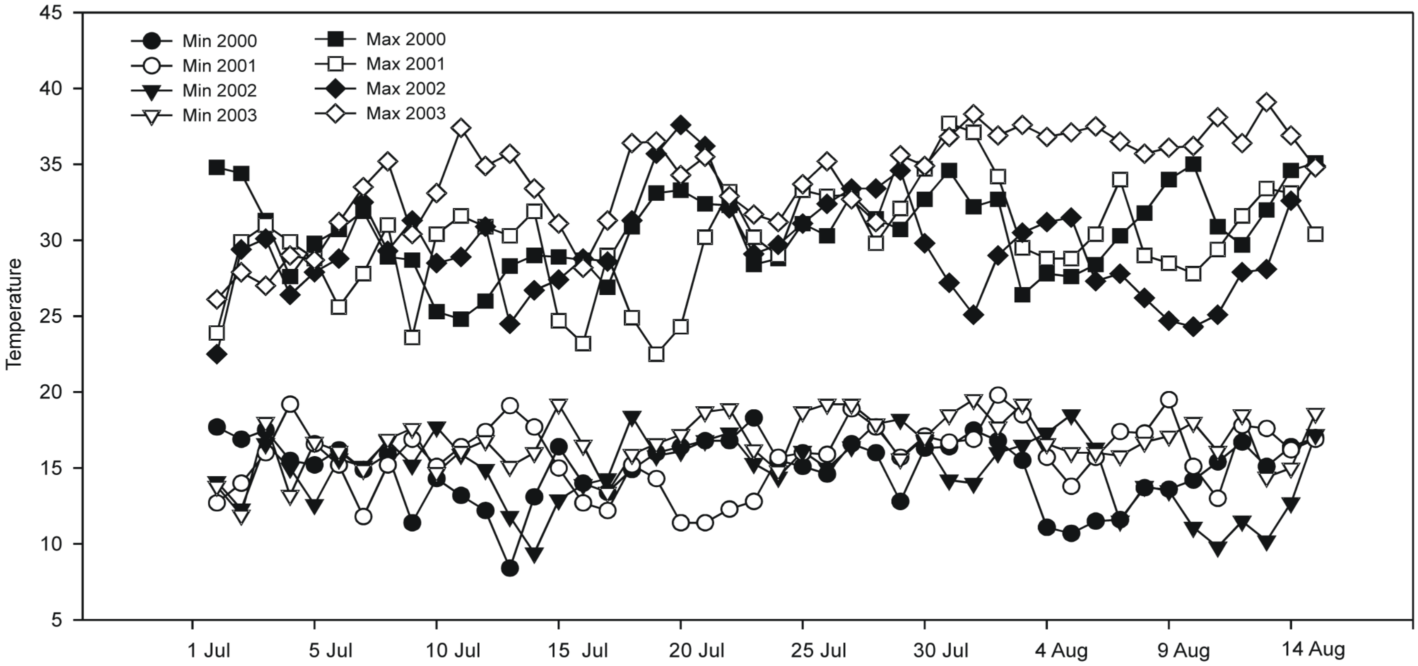

Fig. 1. Daily maximum and minimum temperatures over the period 1st July – 15th August for the 2000, 2001, 2002 and 2003 seasons

and three more times in cloudy days of July and August 2000. These measurements were made using a Crison Model 637 (Crison Instruments, Barcelona, Spain) digital thermometer. The temperature sensor was introduced 3 mm under the apple skin tangentially to the surface of the exposed side of the fruit, as proposed by Ryall and Pentzer (1982). At each measurement date, fruit temperature was recorded for 10 fruits per treatment (5 fruits/tree x 2 trees) picked at around 1.6-2.0 m above ground level on the side directly exposed to sunlight during the period of maximum daily temperature, from 15:00 to 15:30 (13:00 to 13:30 solar time).

Fruit colour and size measurements: Apple colour was measured with a Minolta Chroma Meter CR-200 portable tristimulus colorimeter (Minolta Corp, Osaka, Japan) and fruit chromaticity was recorded according to Commission Internationale d'Eclairage L*, a* and b* colour space coordinates (Hunter, 1975). Hue angle was calculated as described by McGuire (1992) and expressed in degrees.

In each season, from 2000 to 2003, 20 fruits were selected and marked in the inner (around the central axis) and outer (periphery area) canopies on each of two trees per treatment-block on 25th June; 10 fruits were selected from each of two tree sides; five from the top (1.2-2.0m above ground level) and five from the bottom (0.6-1.2 cm). Fruit colour measurements were recorded *in situ* on each one of the four sampling dates (five sampling dates in 2002 and 2003), from 5th July through to commercial harvest on 10th August (Fig. 4). Colour values were measured at both the reddest (exposed side) and greenest (shaded side) points on the fruit equator. Harvest date was 138 days after full bloom, when flesh firmness was <17.5 lb and soluble solid content was >13.0%.

Commercial value of the crop depends on both, fruit size and fruit colour. At commercial harvest, fruit size distribution based on 5 mm-interval fruit diameter categories and average of red colour fruit-surface coverage were determined for the whole crop for two trees per treatment and block on which fruit colour was recorded by using an electronic grading machine (SAMMO s.r.l., Model S2010, Italy). Four complementary trees per replication were marked and their fruits were picked in two harvests. The criteria established for the first harvest were: fruit colour >40% of fruit surface and fruit size diameter >70 mm. Professional pickers were used and instructed to harvest only those fruits which had a sufficiently red colour to comply with the EU extra colour grade (1/2 of their surface with a good red colour).

Fruit quality parameters: The same 20 fruits marked per tree (40 fruits per block-treatment) were also used at commercial harvest for fruit quality determinations. Flesh firmness was determined with a table penetrometer (Penefel, Copa technologies, France) with an 11 mm diameter tip and expressed in lb. Two readings were taken from opposite peeled sides of 40 fruits per block-treatment on which colour was recorded. Soluble solid concentration (SSC) were determined by measuring the refractive index of a blended composite of wedges taken from 40 unpeeled apples per block/treatment, using an Atago-Palette 100 digital refractometer (Atago Co., Tokyo, Japan) and expressed as %. Titratable acidity (TA) was determined for the same composite by titrating to a final pH value of 8.2 with 0.1 N NaOH and expressed in g of malic acid L^{-1}. The effect of nets on fruit maturity was based on starch conversion and determinated using the Ctifl-Eurofru code with values ranging from 1 (immature) to 10 (mature).

Complementary determinations: The average number of fruits damaged by hail was visually recorded for the whole production when fruits were graded at commercial harvest. The effect of nets on the incidence of sunburn was evaluated with respect to the same sample used to determine fruit quality parameters. Tree vigour was determinated on the basis of measurements of trunk-cross-sectional-areas (TCSA) taken 20 cm above the graft union, measured at the start of the experiment and annually in winter time.

Data analysis: Analysis of variance was preformed separately each year for PAR values, orchard and fruit temperature, chromaticity values, yields, fruit size, fruit colour and quality, according to a complete randomized block model with each block being a replication unit, using the Statistical Analysis System software (SAS Institute Cary, N.C., 1997): statistical significance was tested at $P = 0.05$. In the case of chromaticity values, data from each block represented the mean for two fruit sides (E: exposed side, S: shaded side) for 20 fruits per tree and two trees per block and treatment. Plots were arranged in a randomized complete block design. When the analysis was statistically significant (F-test), mean separation was carried out by Tukey's test at P=0.05, using the mean square error for each sampling date and parameter evaluated. Differences between treatments and seasons were evaluated by analysis of variance and were tested using the General Linear Model procedure (PROC GLM of SAS) as a randomized complete block design to determine the statistical significance of single and double-way interactions. Season and treatment were considered as fixed effects, while blocks, trees, and fruits were designated as random effects.

Results and discussion

Effects of nets on the interception of radiation, orchard temperature and humidity: The values for radiation and light interception were similar for all four seasons (2000-2003). PAR values recorded under the nets on a sunny day (19th July) and on a cloudy day (17th July) in 2000, are presented in Fig. 2. Greater average values for interception were recorded between 13:00 and 15:00 (11:00 and 13:00 solar time), the period when the incidence of sunlight is most vertical. On sunny days, both nets intercepted more light radiation than the control without a net: average light interception values were 25 and 12% for black and crystal nets, respectively. Light interception by black nets was twice as great as for crystal nets on sunny days, whereas the difference was smaller on cloudy days. Clouds caused a reduction in total incident radiation of around 50% (Fig. 2). In the period from the 1st July to 17th August of the four seasons studied (2000-2003) only a mean of 5 days were cloudy, the rest were sunny as usual in warm areas.

Absolute values of PAR and the effects of nets on light interception were similar to those reported by Peano *et al*. (2001), Vercammen (1999) and Crété *et al*. (2001). Dussi *et al*. (2005) recorded respective decreases in PAR of 28 and 45%, using 15 and 55% density shade nets in Argentina (Alto Valle).

The solar radiation registered on sunny days resulted in high PAR values (maximum 1600-2000 μmol m^{-2} s^{-1}), which are common in southern Europe arid conditions. On cloudy days (complete clouds cover), the maximum values ranged from 800-900 μmol m^{-2} s^{-1}. In both cases, the registered values were twice as great as those for northern Europe (Belgium, Germany, *etc.*) and for this reason radiation disponibility is not a limitation even when black nets is used (maximum PAR values around 1200 μmol m^{-2} s^{-1}).

Measurements of light intercepted at different tree heights (from 0.50 to 3.50 m) in the middle row of each treatment were taken, before harvest, at two different times on 28th July 2000 at 14:00 and 18:00 (12:00 and 16:00 solar time) provided similar values. The recorded differences between treatments were significant and very similar at both measurement times. At 14:00, the average of light intercepted, did not depend on tree height because the incidence of sunlight was vertical. At 18:00, the interception of sunlight increased with increased tree height due to the shading of the lower parts of the trees (data not shown). This explains the increased exposure to light of the upper parts of the trees and their consequent better fruit colouration, because sunlight is the most important factor regulating anthocyanin synthesis and colour as reported by Saure (1990) and Lancaster (1992) in apple skin and Dussi and Huysamer (1995) in pear skin.

Maximum, mean and minimum daily temperatures for the period 1st July- 17th July 2001 (period representative of summer conditions in warm regions) showed that the use of nets exerted a limited influence on orchard temperature (Fig. 3). Maximum temperatures tended to be lower under the nets (3 ºC), due to the interception of radiation or "shade effect" which is greater than the gain of temperature caused by the use of nets due to their role in the interception of air circulation or "greenhouse effect". Bigger differences were recorded on bright and sunny days (1st, 2nd July,..) and lesser ones on cloudy days (8th July, 18th July). Minimum temperatures tended to be lower in the control

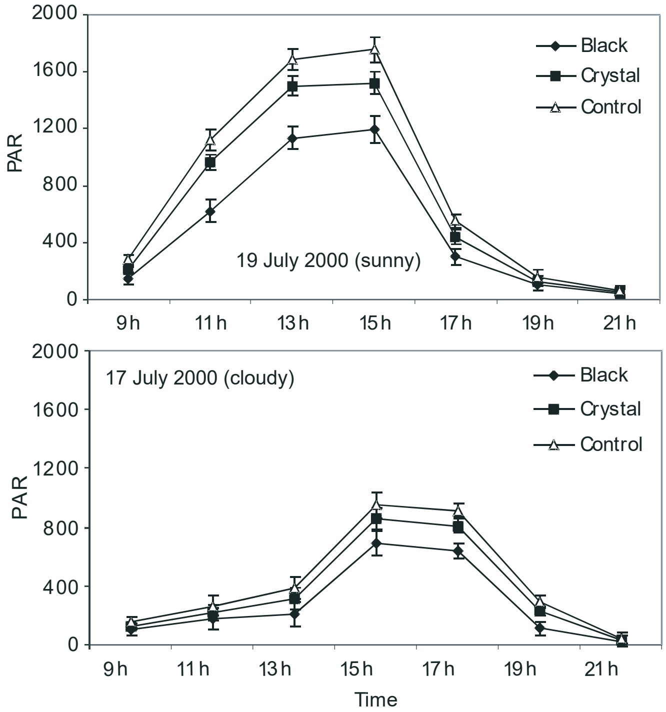

Fig. 2. Diurnal curve of photosynthetically active radiation (PAR±SE) (μmol m^{-2} s^{-1}) as affected by different coloured nets or no net on a sunny day (19th July) and a cloudy day (17th July) 2000.

by 1 ºC (Fig. 3) than in the nets because of the greenhouse effect and the low radiation at this time of the day. Similar results were reported by Vercammen (1999) and Crété *et al*. (2001), indicating that the influence of nets upon maximum orchard temperatures and their role in increasing minimum temperatures was not clearly demonstrated. Reigne (1997) found a moderate increase in maximum temperatures associated with the use of nets and Vaysse (1997) reported a moderate decrease (<1 ºC). Peano *et al*. (2001) did not find any clear temperature effect associated with the use of nets and only noted that maximum

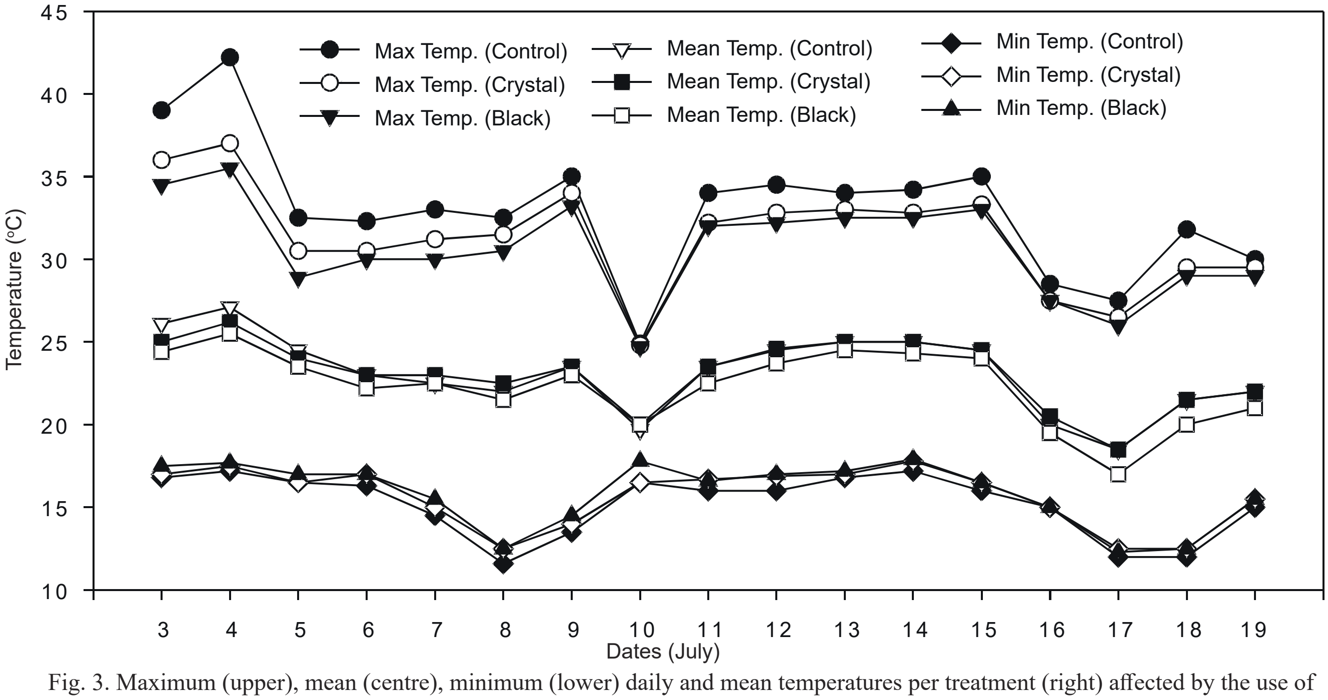

Fig. 3. Maximum (upper), mean (centre), minimum (lower) daily and mean temperatures per treatment (right) affected by the use of two different coloured nets during the period 3rd -19th July 2001

were slightly increased. It would be interesting to quantify the interception of air circulation by the nets in order to know the greenhouse effect.

Orchard humidity increased by the use of both nets but no significant differences were observed with respect to maximum relative humidity (data not shown). These results were in line with those reported by Crété *et al*. (2001), indicating a 2-6% increase in humidity associated with the use of nets. These authors also reported a decrease in evaporation by11% in July associated with the use of nets and a significant reduction in wind speed, which also resulted in a decrease in skin bruising.

Fruit temperature: Temperature measurements registered during the maximum daily orchard temperatures, in summer 2000, showed the positive effects of nets on both, reductions in fruit temperature (Table 1) and in the incidence of sunburn (Table 3). This reduction in temperature was related to radiation intercepted by the nets (Fig. 2). The black net was associated with a greater temperature reduction (around 4 ºC) than the crystal net (2.5 ºC) when compared to the control. On cloudy days, without direct sun radiation over the canopy, fruit temperatures were lower and differences among treatments were minor (1-2 ºC). Also the differences between air and fruit temperatures were smaller compared to sunny days. It is also interesting to note that the higher fruit temperatures associated with sunny days in summer (47.1 ºC), were around 12 ºC higher than air temperatures due to direct exposure to sunlight (Table 1). For this reason the use of shade nets, evaporative cooling and kaolin-based particle film technology were the three techniques commonly used to reduce radiation and fruit temperature in apple and pear, as reported by Dussi *et al*. (1997, 2005), Gindaba and Wand (2006) and Iglesias *et al*. (2002, 2005).

Table 1. Internal fruit temperature[y] and orchard air temperature (°C) of `Mondial Gala' apples affected by the use of two different coloured nets under different conditions at 15:00 (13.00 solar time) on six different dates in 2000

Treatment/ conditions	Date			Mean	Nets vs control
	25th July	6th Aug.	10th Aug.		
Sunny					
Black	41.6*	39.1	40.1	40.2 c	-4.1
Crystal	42.6	41.4	41.9	41.9 b	-2.4
Control	47.1	43.1	42.9	44.3 a	
Air temperature	34.1	31.8	32.6	32.8	
Cloudy	21th July	3th Aug.	14th Aug.		
Black	36.3	33.3	36.4	35.3 b	-1.9
Crystal	36.9	34.9	36.9	36.2 ab	-1.0
Control	38.1	35.6	37.8	37.2 a	
Air temperature	35.1	33.8	35.6	34.8	

(*):Each value is the mean of 10 measurements on the exposed side of the fruit.
[Y] Different letters in the same column represent significant difference at $P < 0.05$ by Tukey range test if the F-test was significant in the ANOVA.

Fruit colour: The evolution of fruit colour, based on Hue values (with higher values indicating less colour), over the 4 weeks before commercial harvest and Hue values at commercial harvest, revealed significant differences between treatments both at harvest and also during the 2-3 weeks before harvest, for all seasons except 2000 (Fig. 4), as a result of optimal temperatures for colour development. This was because this is the period of maximum anthocyanin biosynthesis in 'Gala' apples (Iglesias, 1996; Iglesias *et al*., 2005). When four seasons were compared, Hue values prior to harvest and at commercial harvest showed significant differences from season to season, and the interaction *season x treatment* was significant. The crystal net produced either similar values to the control (2001 and 2002) or values between the black net and the control (2003). The higher values associated with use of the black net paralleled a reduction in fruit colour with respect to the control and also evidenced a delay and reduction in fruit colour development. This could be explained by a lower availability of carbohydrates necessary for anthocyanin biosynthesis due to the reduction of light disponibility. It is well known that anthocyanin biosynthesis in apple is directly affected by light (Lancaster, 1992; Arakawa, 1988) and temperature (Faragher, 1983; Arakawa, 1991). The reduction of radiation is responsible for down-regulation of photosynthetic capacity of leaves and consequently a lower light saturated photosynthetic rate compared to the control (Gindaba and Wand, 2006). Takos *et al*. (2006), more recently, reported that in red skin apple cultivars several flavonoid genes required for anthocyanin synthesis were coordinately transcribed in reponse to light exposure.

When fruit colour on both sides of the tree (east-west) and for different heights were compared, lower values were recorded on the west sides and in the upper parts of trees (data not shown). This was related to the greater exposure to light on the higher parts of the canopy and into the sunset side of the tree, as reported by Jackson *et al*. (1977) and Dussi *et al*. (2005). The interactions *treatment x tree side* and *treatment x canopy height* were not significant, and the black net reduced fruit colour for the whole canopy. In 2003, temperatures were unusually high during the summer period and this resulted in poor colour development compared with 2000 and 2002, even in the case of optimum exposure to light on the exposed sides of fruits without nets. Under these conditions the effect of both high temperatures and significant reductions in exposure to light associated with the use of nets explained the dramatic reduction in fruit colour with respect to other seasons. Under these critical conditions, even the slight reduction in exposure to light occasioned by the crystal net resulted in a reduction in fruit colour with respect to the control in 2003, but this did not occur in 2000, 2001 and 2002 (Fig. 4), when temperatures were more favourable for colour development.

Average of fruit colour are important in order to determine its commercial value, and a minimum of 50% of fruit surface should be coloured to comply with the EU Extra colour grade requirements and more than 80% for Extra Fancy requirements. Average values for fruit colour distribution for the total yield of each treatment at commercial harvest are presented in Fig. 5. Significant differences were observed between seasons and the interaction *season x treatment* was significant with respect to fruit colour and Hue values. The greatest values for fruits with <40% of fruit colour were recorded in 2003. Intermediate values were obtained in 2001 and the lowest values in 2000 and 2002. When the averages of fruits >80% of fruit colour were compared, the greatest values were obtained for 2000 and 2002 seasons. These results were similar to those discussed above for Hue values (Fig. 4), and showed the negative effect of the black net in reducing average values for fruits with >80% and 40-80% of fruit colour.

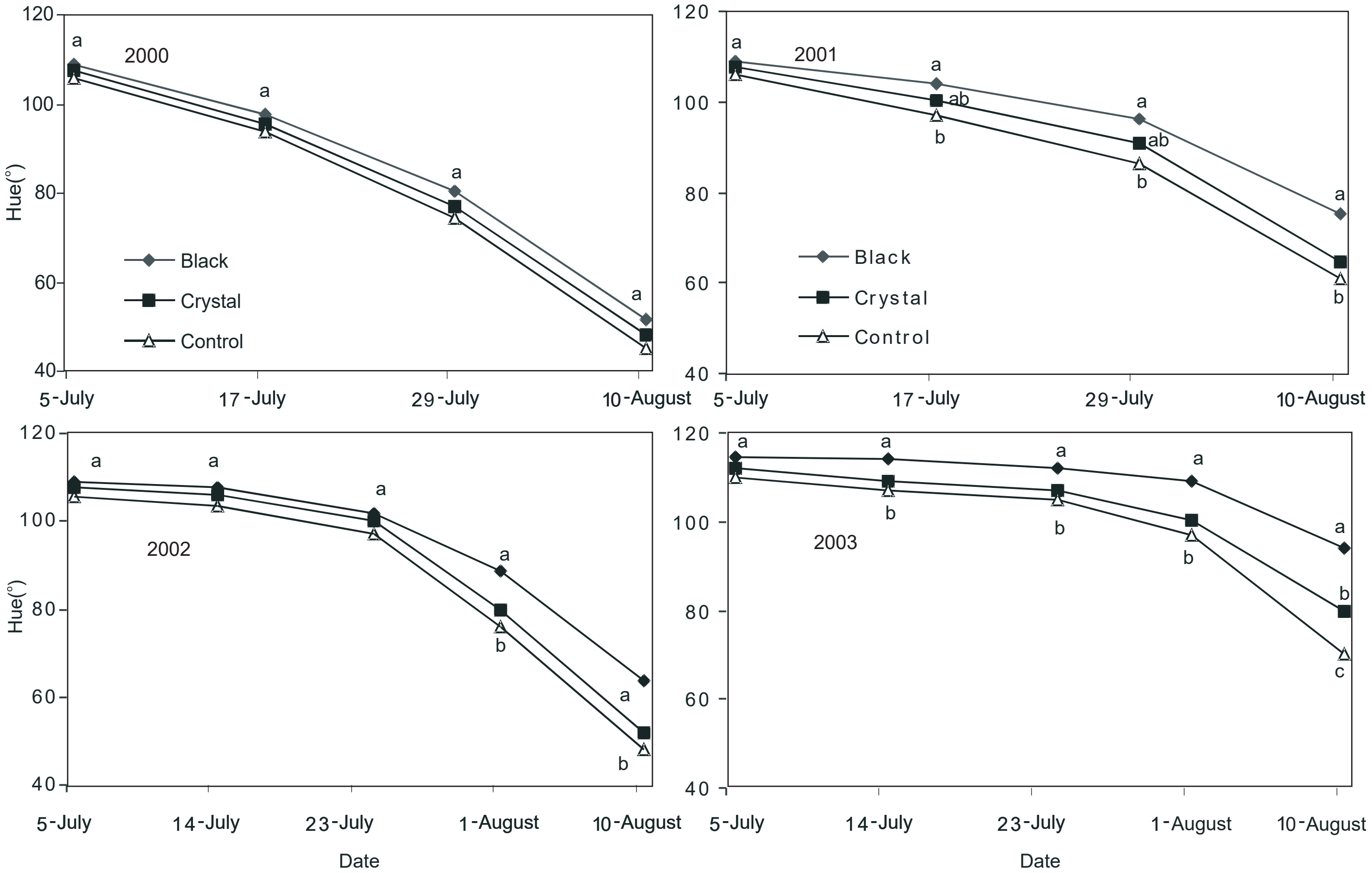

Fig. 4. The effect of two different coloured nets on fruit colour evolution (Hue) for ‘Mondial Gala’ apples in the preharvest period of the 2000, 2001, 2002 and 2003 seasons. Treatments with the same letter for the same season and data are not statistically different according to the Tukey Test ($P<0.05$). (Season x treatment interaction for hue values at harvest was significant at $P<0.01$). Each point represents the mean of two fruit sides of 20 fruits per tree and 8 trees per treatment (2 trees.block-1 x 4 blocks).

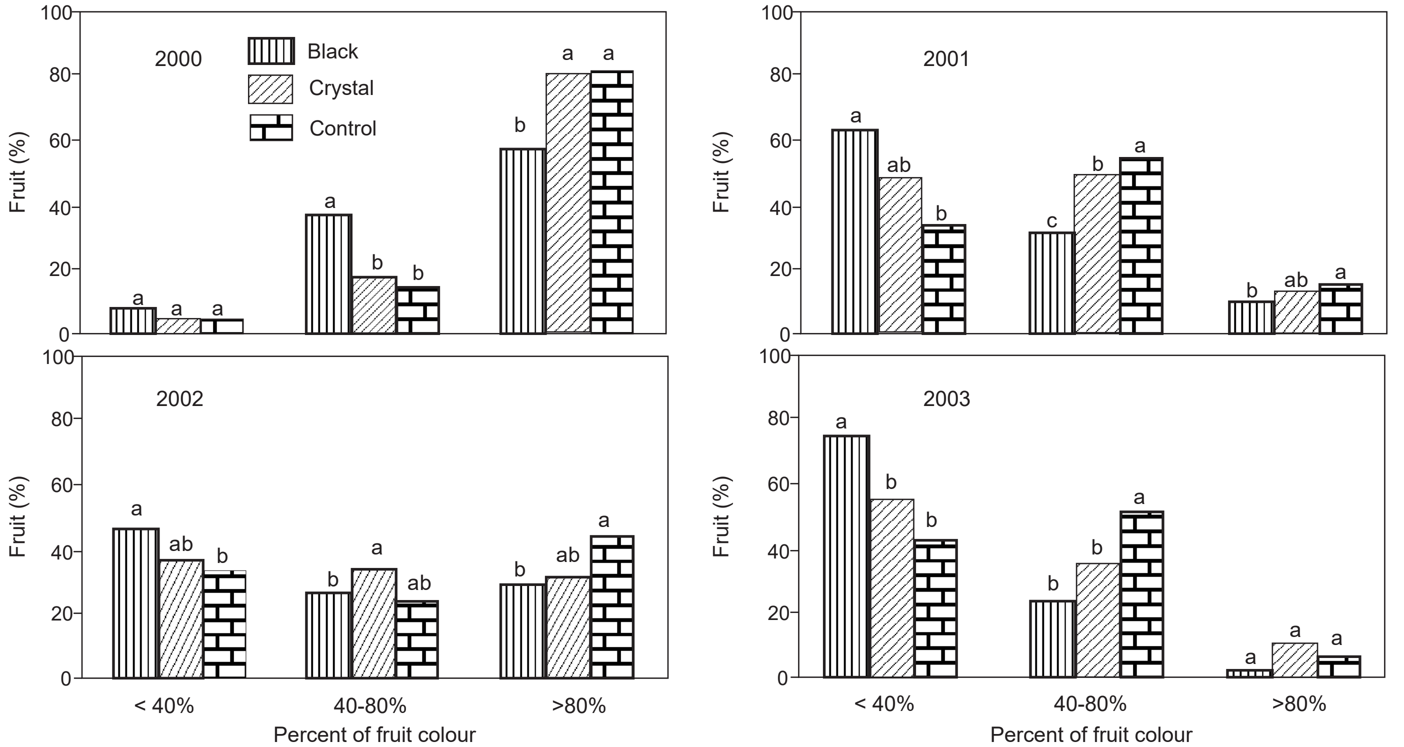

Fig. 5. The effect of two different coloured nets on the average of fruit colour for all the yield of ‘Mondial Gala’ apples at commercial harvest in the 2000, 2001, 2002 and 2003 seasons. Columns with the same letter for the same average colour and season were not statistically different according to the Tukey Test ($P<0.05$). (Season x treatment interaction for % of fruits for each different degree of colour was significant at $P<0.01$).

Crystal net provided similar values to the control, except in 2003 when reduced the averages of 40-80% and increased those of <40%, indicating a reduction of fruit colour (Fig. 5).

The total yield harvested at the first picking date (>70 mm size and >50% of coloured surface) revealed lower values associated with the use of the black net and similar values between the crystal net and the control in 2000, 2001 and 2002, and intermediate values for the control and use of the black net in 2003. Even in seasons favourable to fruit development, such as 2000, the black net reduced fruit colouration. Mean values for all seasons only indicated significant differences between the control and black net (Fig. 6). Important differences were observed between seasons, with higher average values being obtained in 2000 and lower values in 2003. For this reason, the interaction *season x treatment* was also significant with regard to average values associated with fruit harvested at the first picking.

All previously presented results relating to fruit colour confirm those reported by other authors working with bicoloured cultivars such as 'Royal Gala', 'Jonagold' and 'Elstar' (Reigne, 1997; Vercammen, 1999; Crété, 2000; Peano *et al*., 2001). They also illustrate the negative effect of the black net on fruit colour; in the case of the crystal net, similar values were obtained to the control for seasons with normal or optimum temperatures, and values between those obtained using the black net and the control were obtained in warm seasons, such as 2003. Dussi *et al*. (2005) working with the cultivar 'Fuji', in Argentina, and Gindaba and Wand (2006) working with 'Royal Gala' in South Africa, also reported a significant reduction in fruit colour under anti-hail nets. Red colour development was influenced by the season due to the direct effect of temperatures on anthocyanin biosynthesis in 'Mondial Gala' apples as reported by Iglesias *et al*. (2002).

Tree vigour and yield: No difference between treatments were observed at the end of the first season (2000) after the installation of the nets on tree vigour. The annual increase in TCSA showed greater values for trees under the black net in 2002 and 2003 and intermediate values for crystal net in 2001 (Table 2). Furthermore, annual shoot growth was significantly higher in all seasons when using the black net in comparison to the crystal net and the control, as reported by Peano *et al.* (2002). Shading by nets (specially black net) has effects similar to over-tree evaporative cooling; decreasing plant temperature and water stress, and reducing the incidence of sunburn. This has been widely documented by several authors (Parchomchuk and Meheriuk, 1996; Recasens *et al*., 1998; Gindaba and Wand, 2005, 2006; Iglesias *et al*., 2005). As discussed above, fruit colour was significantly reduced by net shading because of decreased direct sunlight on the fruits and consequently a reduction of anthocyanin bioshynthesis rate.

Table 2. The effect of two different coloured nets on tree vigor[z], measured as the trunk-cross-sectional-area (TCSA), of 'Mondial Gala' apples over 1999 to 2003 seasons

Treatment	TCSA (cm^2)**				
	1999*	2000	2001	2002	2003
Black	33.9a	43.2a	48.6a	55.6a	63.8a
Crystal	35.0a	41.9a	45.3ab	51.3b	57.9b
Control	35.2a	40.3a	44.1b	50.2b	56.1b
Significance (*P*)	0.353	0.080	0.031	0.009	0.001

[z] Different letters in the same column represent significant difference at $P \leq 0.05$ by Tukey range test if the F-test was significant in the ANOVA. (*): Initial TCSA, before installation of nets. **: TCSA mesured in November

The trial was located in a warm region with sunny days and high radiation levels (Fig. 2) over the most part of summer. In these conditions, light disponibility compared to cold regions of the North European countries, is not a limitation, even under black nets. For this reason the increase of vigour could be explained by the positive effect of shading (black net) which resulted in a significant reduction of both, the radiation reaching trees and consequently the level of evapotranspiration. This resulted in a reduction in plant water stress, an increase in photosynthesis and increased availability of carbohydrates: all of these circumstances are conducive to an increase in vigour, as observed in commercial orchards. The reduction in stress is also favoured by a reduction in maximum temperatures and increase in orchard humidity associated with the use of nets. In these conditions we suggest that this reduction is more important than the reduction in photosynthesis caused by the interception of radiation by the nets. Gindaba and Wand (2005) reported a down-regulation of photosynthetic capacity due to anti-hail net which resulted in reduced fruit size on 'Royal Gala' and 'Cripps Pink' apples. Furthermore, the greater humidity found under the nets leads to a decrease in plant water stress. This confirms the data presented by Crété *et al.* (2001), which indicated that it is possible to reduce irrigation needs by about 15% with respect to the control because of an 10% evaporation decrease.

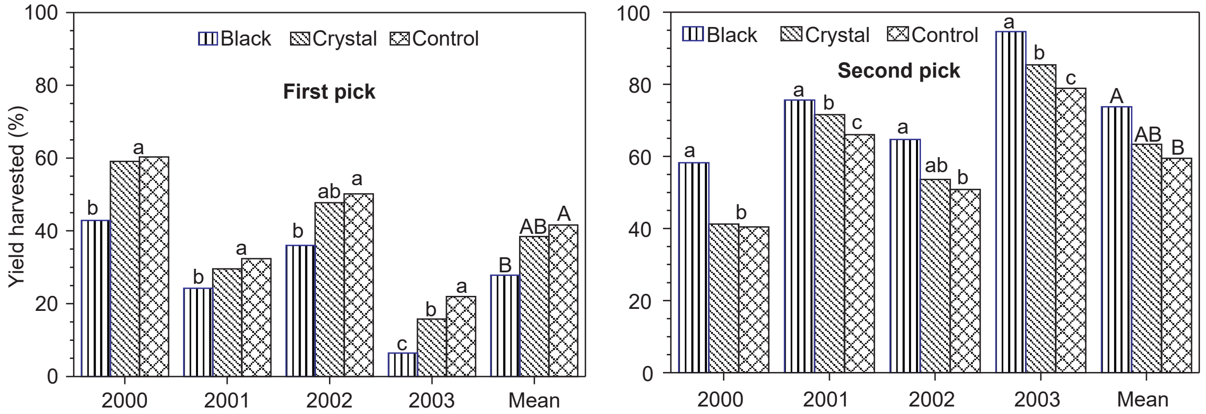

Fig. 6. Percentage of yield harvested by picking for 'Mondial Gala' apples for the period 2000-2003, as affected by the use of different coloured nets. Columns with the same letter for the same season and picking were not statistically different according to the Tukey Test (*P*<0.05). (Season x treatment interaction for % of yield harvested by picking was significant at P<0.01).

Table 3. Effect of two different coloured nets on mean yields, fruit size, quality parameters, starch index, incidence of cracking and sunburn and hail damage, for 'Mondial Gala' apples at commercial harvest in the 2000, 2001, 2002 and 2003 seasons.

Season	Treatment	Yield (kg tree^{-1})	Weight (g fruit^{-1})	Size mm (% yield) <70	70-80	>80	Firmness (lb)	SSCs (ºBrix)	T.A. (g L^{-1})	Starch index	Crack. (%)	Sunburn (%)	Hail affe. (%)
2000	Black	31.7	185.7 b	19.2	67.7	13.1 b	15.4	13.3	3.9	7.2 b	2.1	1.2 b	0.0
	Crystal	25.1	190.5 ab	11.7	67.2	21.1 a	14.9	13.1	3.3	7.1 b	3.7	1.8 b	0.0
	Control	30.6	198.0 a	14.1	70.7	15.2 b	15.6	13.2	3.0	8.6 a	3.9	4.9 a	0.0
2001	Black	38.1	144.0	36.9	52.4	10.6	16.5	11.8 b	2.8	8.2	4.2	2.3 b	0.0
	Crystal	39.9	155.0	23.8	64.2	11.9	16.3	12.8 a	2.5	8.1	6.1	4.3 b	0.0
	Control	37.9	141.0	37.0	49.1	12.9	16.9	12.7 a	2.8	7.4	6.4	7.5 a	0.0
2002	Black	28.1	168.5	27.1	52.9	19.9 a	16.7	10.6 b	5.4	7.4	0.0	0.0	0.0
	Crystal	26.4	161.7	31.2	52.9	15.9 ab	16.6	12.6 a	6.1	7.1	0.0	0.0	0.0
	Control	28.2	154.2	37.9	48.4	13.6 b	16.9	12.0 a	5.8	7.0	0.0	0.3	0.0
2003	Black	29.4	153.0	29.4	61.9	8.6	14.3	11.2 b	2.8 a	7.1 b	12.6 b	0.3 c	0.0 b
	Crystal	28.9	154.0	27.8	62.1	10.1	14.2	12.0 a	2.6 ab	7.4 b	15.8ab	3.8 b	0.0 b
	Control	29.4	152.0	24.7	61.8	13.3	14.7	12.4 a	2.5 b	8.8 a	20.5 a	12.0a	10.6 a

Columns with the same letter for the same season were not statically different according to the Tukey Test (P<0.05).

Mean yields (kg tree^{-1}) recorded during the period 2000-2003 were not significantly affected by the use of nets (Table 3). These results support those presented by Reigne (1997), but Peano *et al*. (2002) reported a decrease by the effect of anti-hail nets due to modifications in the plant physilogy.

The effect of nets on fruit size, fruit maturity and quality parameters: Fruit size distribution, fruit weight and fruit firmness were not significantly affected by the use of nets (Table 3). Similar observation have been reported by Borin and Saoncella (2000) and Crété (2000). Soluble solid content decreased when the black net was used, but values were similar for the crystal net and the control. These results agree with those reported by Coreau *et al*. (1997), Crété *et al*. (2001), Peano *et al*. (2001) on 'Gala' and 'Fuji' apples, and confirm that shading reduces the soluble solid content of fruits, delaying their ripening. In opposite, a better exposition of the leaves to light has been related with a better fruit sugar content (Jackson *et al*., 1977; Dussi *et al*., 2005). Nets had no effect either on titratable acidity or on fruit firmness, but maturity, expressed by starch conversion, was delayed by about a week in 2000 and 2003, but not in the other seasons. Similar results were reported by several other workers (Borin and Saoncella, 2000; Peano *et al*., 2001). However, Ghindaba and Wand (2006) did not find any differences in fruit firmness, soluble solid content and starch conversion when using a shade net with 'Royal Gala' apples.

According to Reigne (1997), the use of nets did not have any influence upon the incidence of pests (*Cydia*, *Aphis*, etc) or diseases (*Venturia*, *Podosphaera*, *etc.*). Demaria *et al*. (2006), reported a significant decrease of moth pest population and a reduction of fruit-damages with anti-hail nets.

The effect of nets on fruit sunburn and cracking: The use of nets had a positive effect on the reduction in number of fruits affected by sunburn, in spite of 'Mondial Gala' is not a very sensitive cultivar to this disorder compared with 'Fuji' or 'Granny Smith' (Carbó *et al*., 2004). Crystal net produced intermediate results between black net and the control (Table 3). The reduction of sunburn associated with the use of nets, especially the black net, and the increase in overall skin quality (but decrease of fruit colour) has been widely reported for the cultivars 'Golden', 'Gala', 'Granny Smith', 'Fuji' and 'Pink Lady' (Andrews and Johnson, 1996; Yuri *et al*., 1996; Crété, 2000; Peano *et al*., 2001; Dussi *et al*., 2005; Gindaba and Wand, 2005, 2006). This can be explained by both, the reduction in direct incident radiation on the fruit (Fig. 2), and by the reduction in fruit temperature under the net (Table 3). This finding is in agreement with most of the research indicating high temperatures and intense solar radiation as the main causes of sunburn in apples (Yuri *et al*., 1998). For this reason, shading by nets has been used in several parts of the world with high temperatures and intense solar radiation to reduce sunburn and increase skin quality in apples (Andrews and Johnson, 1996; Yuri *et al*., 1996; Dussi *et al*., 2005; Gindaba and Wand, 2005; 2006), specially on non coloured apples such as 'Golden' or 'Granny Smith'. As reported in warm areas, the reduction of fruit colour observed on bicoloured or red cultivars should be considered and the use of white or grey nets is recommended (Peano *et al*., 2001), in spite the minor protection against sunburn.

Fruit cracking was not affected by the nets, except in 2003 when greater values of fruit cracking were recorded, probably due to the unusually high summer temperatures, which also reduced fruit colour. In this season nets significantly reduced the averages of fruit cracking compared to the control (Table 3).

Efficiency of nets against hail protection: The only hail storm recorded took place in May 2003. The results obtained showed the efficiency of the nets in protecting fruit compared to the control (Table 3). The stability offered by this system in windy storms has also been reported by several researchers from different countries, working with the same system (Bru, 1996; Vercammen, 1999).

Economic evaluation

Installation costs: Beniagro-type GVM 2.5 x 3, crystal and black coloured nets were used in the trial. The total cost of net installation (nets, poles, poles anchorages, rented machinery, net installation, labours, *etc.*) was 14358 € ha^{-1}. The cost of the support structure for a planted orchard (poles + support cables) was 6625 € ha^{-1}. In the case of a new plantation, the same poles used to support the nets can support the trees and this makes it possible to share the cost of supporting trees, which is estimated at around 2000 € ha^{-1} (the cost of poles and their positioning).

Annual cost of nets and insurance: These costs have been calculated for the orchard where the trial was carried out in the region of Lleida (Mollerussa). Annual costs of using nets (nets, installation, structure, rented machinery, labour, fold and unfold the nets each year, *etc.*) were 1874 and 1612 € ha^{-1}, for crystal and black nets, respectively (Table 4). We consider a lifespan for the support structure (poles, support cables) of 24 years, and lifespans of 8 and 15 years, respectively, for the crystal and black nets. The annual cost of using nets was compared with the annual cost of insurance (only protection against hail) for the cultivar ‘Mondial Gala’, considering a mean yield of 50 tons ha^{-1} at the Mollerussa site. The final annual cost of insurance was 760 € ha^{-1} (Table 4) and was subsidised by ENESA (48%) and DARP-Generalitat de Catalunya (15%). The cost (€ kg^{-1}) of insurance was lower than that of covering the orchard with nets and directly depended on the yield insured: the cost increased as the yield increased. The greater cost of the crystal net was due to its lower life expectancy (8 years) than the black net (15 years). In contrast with the case of insurance, the cost associated with the use of nets (€ kg^{-1}) was inversely related to the yields obtained.

The effect of nets on gross income: As explained earlier, the use of nets influenced some parameters of fruit quality as fruit colour, damage by sunburn and cracking, and consequently fruit price. Furthermore, as the insurance (control), the installation of nets resulted in annual recurring cost. Both factors are considered to evaluate the effect of the nets on the gross income without considering the other costs of production -labour, inputs, irrigation, *etc.*-, because these are the same for the three treatments of 1 ha of ‘Mondial Gala’ apples. Considering the same yield for the three treatments and based on the mean data corresponding to the 2000-2003 period, shown in Fig. 5 (fruit colour distribution), Fig. 6 (yields harvest by the two harvests) and Table 3 (fruit size, damage by cracking and sunburn), the total income from fruit sale, the cost of protection against hail, and the benefit are presented in Table 4. Compared to the control (insurance without using net), the benefits (total gross profit) of using crystal net was lower than using black net. Crystal net reduced sunburn, without affecting negatively fruit colour, but the annual cost of its installation is more than two times compared to the insurance and greater than black net. The decrease of benefit when using black net, even after reduction of cracking and sunburn, is due to the decreased fruit color: average of yields on the first picking and increase of non marketing yield.

The results discussed above are from ‘Mondial Gala’, with a limited insurance price. In the case of new developed cultivars as ‘Pink Lady’, ‘Kanzi’, *etc.*, the fruitgrower price is greater (0.50-0.60 € kg^{-1}), but the price to insure is limited (0.31 € kg^{-1}) and can’t cover the value of the fruit. In this case the benefit of using crystal net (black net reduces colour) increase the benefit compared to the control which is nowadays used in the main areas of fruit production in Spain.

On the basis of the results presented, we can conclude that the system evaluated was very effective at protecting fruit against hail damage. A study of annual benefits shows similar benefits when the control and the crystal net are compared and the disadvantage of using black nets due to the reduction of fruit colour on ‘Mondial Gala’ apples. Net cost was higher for the crystal net than for the black one due to its shorter lifespan (8 and 15 years, respectively). This relative cost decreased when yields increased; just the opposite to what happened in the case of insurance. The use of nets offers greatest return in case of cultivars with high market values, due to the limits of maximum insurable value.

Table 4. Differences on gross profit due to the use of two coloured nets and control (without nets), over a 1 ha orchard surface of `Mondial Gala' apples at Lleida (Spain)

Concept per ha	Treatment			
	Control	t eCrystal net a 1 B		
Total yield (kg ha^{-1})*	52000	0	0 52000 2	5
% yield >70 mm*	26.9	28.1	23.6	
% affected by sunburn*	6.2	1.0	2.5	
% affected by cracking*	7.7	4.7	6.4	
Commercial yield (kg)	**30784**	**4**	**2 4 0 4 0 3 1**	**5**
Yield harvested at 1st picking ** (%) (diameter > 70mm and > 50% fruit	1	28	437	
Yield decrease at 1st picking with respect to the control (%)	_	3	1 -4	-
Harvest 1st picking (kg)	**12621**	**9**	**3 76 8 9 9**	**2**
Price 1st picking (€)***	0.34	4	3 0.34	0
Income 1st picking (€)	42913	3277.2	4415.6	
Yield 2nd picking** (%)	9	2	563	7
Harvest 2nd picking (kg)	18163	5	8 7 3 4 1 2 1	2
Yield <40% fruit colour * (%)b	9	6	231	4
Price industry (€)***	0.06	6	0 0.06	0
Income industry (€)	**7**	**9 5**	**5 6 2692**	**2**
Price 2nd picking (€)***	0.24	4	0.24	0
Income 2nd picking (€)	**3094.9**	**3212.2**	**3661.9**	
Total fruit income (€ ha^{-1})	**9982.9**	**9454.1**	**10769.5**	
Difference to control (€)	**-**	**-528.8**	**786.6**	
Insurance cost (€/year)	**760.0**	**-**	**-**	
Total cost of net (€/year)	**-**	**1611.6**	**1873.8**	
Difference to control (€ ha^{-1})	**-**	**851.6**	**1113.8**	
Total gross profit' (€ ha^{-1})	**9222.9**	**7842.5**	**8895.71**	

(*): data from Table 3; (**): data from Figure 6; (***): mean fruit grower prices from 2000 to 2003. (y) : without considering production costs (labour, inputs, irrigation, *etc.*).

For all of the factors studied, the black net always had a greater impact than the crystal net, resulting in a reduction of fruit colour, soluble solid content and sunburn, and causing a subsequent delay in maturity. It would therefore adivisible to use crystal nets in warm areas with poorly or medium coloured cultivars.

It would also be interesting to study the effect of using nets on plant hydric status and water needs and their influence upon tree vigour. These are considerations of potential interest due to the effects of nets on radiation, humidity, evapotranspiration and temperature.

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