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The Effects of Reflective Film on Fruit Color, Quality, Canopy Light Distribution, and Profitability of 'Mondial Gala' Apples

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ADDITIONAL INDEX WORDS. *Malus × domestica*, photosynthetically active radiation, PAR, soluble solids, firmness, maturity, costs, benefits

SUMMARY. The effects of covering the orchard floor with ExtendayTM or SolarmateTM reflective films on fruit color, fruit quality, canopy light distribution, orchard temperature, and profitability of 'Mondial Gala' apples (*Malus × domestica*) were evaluated over a 3-year period (2000–02) at Lleida (northeastern Spain). Reflective film was laid down 5 weeks before commercial harvest. Photosynthetically active radiation in the lowest part of the tree (1 m aboveground level) increased by 34% and 56%, for SolarmateTM and ExtendayTM films, respectively, compared with the control. Fruit color, measured with a portable tristimulus colorimeter, significantly increased on both sides of the fruit (with lower values of L* and hue) when using the film. A higher proportion of red blush over the fruit surface was observed for the fruit in the film treatments. Based on the fruit size and color required to meet European Union grade standards, the use of ExtendayTM or SolarmateTM resulted in an increase of 26% and 17%, respectively, when compared with the control, for the number of fruit picked at first harvest. Season clearly affected fruit color development, whereas harvest date, fruit firmness, fruit size, soluble solid concentration, titratable acidity, and maturity were not consistently affected by the use of reflective film. Despite the advance in fruit color, the starch score did not appear to be affected by the use of film. Based on current fruit prices for the study period, both types of film increased orchard profitability compared with the control, but the long-term benefit of this technique will largely depend on fruit prices.

For many red and bicolored apple cultivars, including Gala, Delicious, and Fuji, red color (the intensity and quality of red skin) and fruit size are important parameters within the grading standards for European Union (EU) countries (Diario Oficial de la Unión Europea,

2005). Even with adequate size, poor fruit color is an important factor that

can result in downgrading fruit and is generally associated with poor visual appearance and low consumer acceptance. Although red color does not affect eating quality (flavor, taste, and texture), it is an important factor for consumer acceptance, and it influences consumer decisions to buy apples (Crassweller and Hollender, 1989) and the profits of growers (Iglesias and Alegre, 2006).

'Gala' apple has become very popular in Europe where the high quality of this fruit is increasingly appreciated by consumers. In the commercial orchards of southern Europe (particularly Spain and Italy) that produce standard cultivars, such as Royal Gala or Mondial Gala, their warm and dry summers do not favor fruit color development, and this can have a negative effect on profitability (Iglesias and Alegre, 2006). Improvements in fruit quality can be achieved by improving management techniques, such as thinning and pruning to open up the canopy and allow more light to penetrate to otherwise shaded parts (Hirst et al., 1990). Fruit bagging improved red color in apples (Arakawa, 1988), but this practice is labor intensive. Cooling by sprinkler irrigation (evaporative cooling) to reduce fruit temperature also significantly improved fruit color and reduced sunburn in warmer areas of eastern Washington state and northeastern Spain with 'Delicious' and 'Gala' apples (Evans, 1993; Iglesias et al., 2000, 2003; Williams, 1993), but this practice is expensive. In such situations, the easiest way to counteract poor color development is to plant new strains that offer high coloring potential even under environmental conditions of hot climates or where there are low-light or shaded conditions (Iglesias et al., 2008; Rapillard and Dessimoz, 2000).

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
10	%	g·L ⁻¹	0.1
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
0.0929	ft ²	m ²	10.7639
0.2296	ft ² /acre	m ² ·ha ⁻¹	4.3560
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha ⁻¹	0.8922
4.4482	lbf	N	0.2248
28.3495	oz	g	0.0353
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

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The ideal conditions for red color development in apples are bright, clear days with temperatures of around 25 °C and cool nights (below 15 °C) during the preharvest period (2–3 weeks before harvest) (Chalmers et al., 1973; Iglesias, 1996). Under these conditions, as opposed to higher temperatures, plants are not stressed during the day, thereby increasing canopy photosynthesis, and respiration rates decrease at night (Carolus, 1971; Lancaster, 1992). Consequently, more substrate-type carbohydrates are provided and more raw material is available for the “pigment pool” (Williams, 1993). This is especially important in the preharvest period when the potential for accumulating anthocyanin is at its highest. Idaein, the main pigment responsible for red color, is derived from cinnamic acid (a precursor to anthocyanidin) by L-phenylalanine deamination, a reaction catalyzed by phenylalanine ammonia-lyase (PAL) and this is temperature sensitive but also light inducible. Temperatures below 25 °C promote this reaction (Arakawa et al., 1986; Blankenship, 1987; Faragher, 1983; Iglesias et al., 1999) and so the red pigmentation process mainly depends on temperature, although it is also influenced by light (Arakawa, 1988, 1991; Lancaster, 1992; Saure, 1990; Tan, 1980) and cultivar. The maximum capacity for anthocyanin synthesis is genetically controlled (Dickinson and White, 1986; Mancinelli, 1985) and the temperature threshold that determines PAL activity and maximum red color potential may differ from one cultivar to another (Curry, 1997).

Anthocyanin biosynthesis is a light-dependent process because the main enzymes involved in the biosynthetic pathway to anthocyanins are light inducible, as PAL and uridine diphosphate-galactose-flavonoid 3-O-galactosyltransferase (UFGaT). Increasing the light intensity within the tree canopy stimulates anthocyanin synthesis by accelerating the activity of UFGaT and PAL. UFGaT is an important enzyme involved in anthocyanin synthesis in apples and one that is light inducible (Ju et al., 1999a, 1999b). The use of reflective materials to increase light intensity and canopy absorption of photosynthetic photon flux (PPF) in the lower parts of the canopy by providing sup-

plementary illumination has been documented since the 1970s (Mancinelli, 1985; Miller and Greene, 2003; Moreschet et al., 1975; Proctor, 1974). This technique improved fruit coloration in red and bicolored apples and reduced the number of harvests required, without any adverse effects on fruit firmness, soluble solid content, starch score or acidity, as reported by Andris and Crisosto (1996), Green et al. (1995), Ju et al. (1999a), Layne et al. (2001, 2002), Li et al. (1994), Mathieu and D'Aure (2000), and Miller and Greene (2003) in different countries. Despite its potential interest and importance for improving apple color in warmer climates, this technique is relatively new in Spain and no references about its efficacy are available.

The work reported in this article summarizes a 3-year project carried out over the 2000, 2001, and 2002 seasons on ‘Mondial Gala’ apples. The objective was to determine the effect of covering the orchard floor with different types of reflective film on orchard temperature, skin-color development, fruit quality, light canopy distribution, and crop profitability.

Materials and methods

PLANT MATERIAL, CLIMATIC CONDITIONS, EXPERIMENTAL DESIGN, SAMPLE COLLECTION, AND FRUIT GRADING. The experiment was conducted in a commercial orchard of ‘Mondial Gala’ apple trees on East M.9 EMLA rootstock. This orchard was planted at the Institut de Recerca i Tecnologies Agroalimentàries (IRTA)-Estació Experimental de Lleida site

of Mollerussa (northeastern Spain) in 1994 and the tree rows had a north-south orientation. The trees were trained with a central leader system, spaced at 4 × 1.4 m, and grown on a Tipic Xerofluvent, coarse-silty soil, with an average depth of 0.85 m. This particular area of Spain typically experiences periods of high summer temperatures (>30 °C) and very low rainfall (456, 291, and 384 mm per season for 2000, 2001, and 2002, respectively). In the preharvest period (from 1 July to 15 Aug.), some differences were registered between seasons in terms of temperature (Fig. 1) and rainfall (42.5, 9.4, and 19.8 mm for 2000, 2001, and 2002, respectively). The average daily maximum and minimum temperatures (mean ± SE) for this period were 30.4 ± 0.44, 29.4 ± 0.59 and 30.2 ± 0.54 °C, and 14.8 ± 0.36, 15.7 ± 0.37 and 15.3 ± 0.33 °C, respectively, for 2000, 2001, and 2002.

Reflective film was laid on the orchard floor 5 weeks before the predicted harvest date and before the beginning of fruit coloration. Three treatments were evaluated: a no-film treatment (control), and two reflecting film treatments. The first treatment was ExtendayTM reflective plastic mulch (ExtendayTM New Zealand, Auckland, New Zealand), 300-cm-wide strips secured to trees with staples and elastic bands (ExtendayTM treatment). The reflective film was made by different pigments having high reflectance of ultraviolet (280–400 nm), visible (400–700 nm), and near infrared (700–800 nm) radiation, and allowing at least

Fig. 1. Daily maximum and minimum temperatures over the period preceding harvest (1 July–15 Aug.) for the 2000, 2001, and 2002 seasons; $(1.8 \times ^\circ\text{C}) + 32 = ^\circ\text{F}$.

part transmission of radiation of 800 to 2500 nm. The second film treatment was SolarmateTM, made of metalized silver (aluminum oxide), a high-density, polyethylene, ultraviolet-reflective film (Sonoco Products, Hartsville, SC), manufactured in rolls that were 155-cm-wide strips in overlapping sheets with a total width covered of 300 cm (SolarmateTM treatment) and secured to the ground with shovels full of soil every 2 m and covered with soil at rows ends.

The two types of film were centered in the interrow space covering 3.0 m of the total interrow distance (4 m). The experiment consisted of a randomized complete block design with the three treatments (control

and two film treatments) in each of four blocks or replications. Both films were randomly distributed over the bare soil between the tree rows of each block. Treatments within a given row were separated by at least four guard trees to prevent any lateral effects. Each treatment was randomized within the block and consisted of three rows with 12 trees (17 m) in each row. All measurements were taken from the central row only. Two trees per treatment were randomly selected from the middle of each block. A total of 160 fruit were selected per treatment (20 fruit/tree × 2 trees/treatment-block × 4 blocks). The fruit were selected and marked in the inner and outer canopy of each of the two

trees per treatment-block on 1 July. Ten fruit were selected on each of two sides of each tree (five fruit from the top part of the tree located from 1.2 to 2.3 m aboveground level, and five fruit from the bottom part of the tree located from 0.6 to 1.2 m). Fruit color measurements were taken four times from about the same points on both sides (exposed and shaded sides) of each fruit from 8 July through to harvest on 10 Aug. (Table 1) ± 3 d depending on the season. Harvest date was 138 d after full bloom, with flesh firmness 12%.

Fruit size distribution, based on fruit diameter categories of 5 mm and the percentage of the apple surface with red blush (<50%, 50% to 80%, and

Table 1. Fruit color (L^* and hue angle) of 'Mondial Gala' apples affected by SolarmateTM (Sonoco Products, Hartsville, SC) and ExtendayTM (ExtendayTM New Zealand, Auckland, New Zealand) reflective film treatments during preharvest period (8, 19, and 30 July) and at harvest (10 Aug.) in the 2000, 2001, and 2002 seasons.

Season	Parameter	Treatment	8 July		19 July		30 July		10 Aug.	
			ES ^z	SS ^y	ES	SS	ES	SS	ES	SS
2000	L^*	Extenday TM	56.5 ^x	70.0	53.3	66.2	51.5	65.5	43.3	60.3
		Solarmate TM	56.0	69.6	49.0	63.8	50.8	63.6	44.1	58.7
		Control	58.5	69.1	55.9	65.3	53.7	64.7	46.3	60.1
	Significance ($P \leq F$)		0.665	0.749	0.293	0.457	0.456	0.237	0.293	0.432
	Treatment × date		NS							
	Hue angle (°)	Extenday TM	71.4	104.9	67.7	101.3	49.4 b ^y	95.0 b	25.9 b	62.0 b
		Solarmate TM	70.7	107.6	65.7	104.6	51.8 ab	97.6 ab	25.1 b	65.3 ab
		Control	76.2	106.6	69.4	103.9	53.3 a	99.6 a	31.8 a	67.5 a
	Significance ($P \leq F$)		0.311	0.482	0.345	0.588	0.043	0.034	0.021	0.018
	Treatment × date		*							
2001	L^*	Extenday TM	62.7	71.3	59.2	70.9	50.9 b	67.4 b	47.4 b	65.2 b
		Solarmate TM	62.5	71.4	58.4	70.8	52.8 ab	70.4 ab	50.3 ab	69.8 ab
		Control	63.8	71.2	60.9	70.8	54.1 a	70.5 a	52.2 a	70.2 a
	Significance ($P \leq F$)		0.561	0.612	0.453	0.711	0.033	0.023	0.0181	0.0233
	Hue angle (°)	Extenday TM	89.9	114.6	71.6	114.2	48.7 b	91.8 b	38.6 b	83.7 b
		Solarmate TM	85.6	114.0	72.1	114.4	52.3 a	94.4 a	40.9 ab	86.8 ab
		Control	93.4	114.2	74.8	115.6	53.5 a	96.3 a	44.6 a	88.6 a
	Significance ($P \leq F$)		0.593	0.623	0.321	0.293	0.026	0.021	0.018	0.020
	Treatment × date (L^* and hue angle)		**							
2002	L^*	Extenday TM	65.3	71.8	63.5	73.4	53.5 b	68.1 b	49.1 b	67.3 b
		Solarmate TM	66.1	72.9	62.9	73.3	57.2 ab	71.9 ab	51.3 b	69.4 b
		Control	66.9	72.4	65.3	73.9	61.3 a	73.9 a	55.1 a	72.2 a
	Significance ($P \leq F$)		0.633	0.458	0.352	0.311	0.110	0.184	0.003	0.005
	Hue angle (°)	Extenday TM	91.1	111.9	79.3 ab	108.2 a	44.2 b	82.7 b	33.4 b	69.0 b
		Solarmate TM	92.2	112.0	77.0 b	108.3 a	52.4 ab	94.5 ab	35.7 b	71.7 b
		Control	95.2	111.8	82.7 a	107.3 a	64.8 a	104.3 a	43.5 a	81.8 a
	Significance ($P \leq F$)		0.421	0.586	0.019	0.016	0.002	0.004	0.009	0.011
	Treatment × date (L^* and hue angle)		**							
	Season × date, 2000–02 period (L^* and hue angle)		NS							
	Season × treatment, 2000–02 period (L^* and hue angle)		*							

^zEach value is the mean of 160 color measurements on the exposed side (ES) (4 blocks/treatment × 2 trees/block × 20 fruit/tree).

^yEach value is the mean of 160 color measurements on the shaded side (SS) (4 blocks/treatment × 2 trees/block × 20 fruit/tree).

Means followed by the same letter between treatments within the same row for the same color parameter (L^ or hue angle) and the same season do not differ at the 5% level of significance ($P \leq 0.05$) by Tukey's honestly significant difference (HSD) test. No letters means nonsignificant differences between treatments. Treatment × fruit side interaction was not significant.

NS, *, **Nonsignificant or significant at $P = 0.05$, $P = 0.01$, respectively.

>80%), was determined for the whole crop and for each of the two trees per treatment and block on which 20 fruit were marked for fruit color measurements, using an electronic grading calibrator manager (model S2010; Sammo, Cesena, Italy). In this case, all the fruit was harvested in only one harvest on 11 Aug. Four complementary trees per replication were also marked and their fruit were picked in two harvests. The criteria established for this first early harvest (EU extra premium crop) on 3 Aug. were fruit red blush >50% of fruit surface with a good red color and fruit size >70 mm. For the second harvest, on 14 Aug., the criteria established for the second category (EU commercial crop) were >40% of red blush and fruit size >65 mm. Fruit not meeting this criteria were considered noncommercial (Table 2).

FRUIT COLOR MEASUREMENT. Red color intensity was measured using a Minolta CR-200 portable tristimulus colorimeter (Minolta, Osaka, Japan) and recorded in Commission Internationale d'Eclairage (CIE) color space coordinates (L^* , a^* , and b^*). The colorimeter was

standardized by using the Minolta calibration plate CR.A43 before each measurement date. Hue angle was calculated as $\arctan(b^*/a^*) \times 57.3$ and expressed in degrees. L^* [lightness (0 = black, 100 = white)] was measured and hue angle was calculated on four dates for the 20 marked fruit on each of the two trees per treatment/block, at two equatorial points located 180° apart and corresponding to the reddest (exposed side = ES) and greenest (shaded side = SS) part on each side of the fruit.

ORCHARD TEMPERATURE AND RELATIVE HUMIDITY. The effects of the reflective film on orchard temperature and relative humidity were recorded with automatic sensors (HOBO H08.007.02; Onset Computer, Bourne, MA). These were installed 1.2 m aboveground level, within the canopy, and at the center of one block per treatment were fruit color (colorimeter) was measured.

LIGHT DISTRIBUTION WITHIN THE CANOPY. The effect of the reflective film on light distribution was assessed by measuring PAR reflected by the film or by the soil surface using a

ceptometer (Sun Scan Accu SS1-UM-1.05; Delta-T Devices, Cambridge, UK) with 64 sensor photodiodes arranged in a line along a 100-cm-long sword. The sword ceptometer was positioned so that it faced downward to measure the light reflected from the ground or from the reflective film. Measurements were taken in Aug. 2001, after shoot growth had stopped and at noon on bright sunny days with clear skies. Three cross-row readings were taken at each height and from the center of one alley to the center of the next and at different heights (30, 70, 120, 170, and 200 cm), always placing the end of the ceptometer in the center of the tree lines and perpendicular to the tree line, in one tree per treatment (15 readings in each replication of each treatment). The first measurements were made, at different heights, at the midpoint between trees in the row and the next was the trunk. Measurements in different replications were done in inverse order of treatments in each replication to minimize the change of radiation conditions. Values of radiation of each sensor of the ceptometer were recorded individually. Mean values of sensors in different ranges were assigned to the mean distance of the distance intervals, which were 6.25, 18.75, 31.25, 43.75, 56.25, 68.75, 81.25, and 93.75 cm.

YIELD AND FRUIT SIZE. Total yields per treatment, season, and block were recorded and electronically graded by fruit color and size for the two marked trees, as previously explained. In addition, four complementary trees per treatment-block were used to determine the average of yield obtained for each harvest, fruit size and fruit color distribution were calculated to assess the effects of using reflective film on the proportion of early harvested fruit.

FRUIT QUALITY PARAMETERS. Flesh firmness was determined with a penetrometer (Penefel; AgroTechnology, Tarascon, France) with an 11-mm tip. Two readings were taken from opposite peeled sides of 20 randomly selected fruit per block/treatment and data were measured in kilograms. Soluble solid concentration (SSC) was determined by the refractive index based on a composite sample of wedges from 20 unpeeled apples/block/treatment

Table 2. Differences in gross profit due to the use of Solarmate™ (Sonoco Products, Hartsville, SC) and Extenday™ (Extenday™ New Zealand, Auckland, New Zealand) reflective film treatments, over a 1-ha (2.5 acres) orchard surface of 'Mondial Gala' apples.

Yield, price, and income ^a	Reflective film treatment		
	Control	Solarmate™	Extenday™
Total yield (kg·ha ⁻¹)	50,600 ^y	53,300	52,300
Yield harvested at first harvest (%)			
(>70 mm diameter, >50% fruit color)	32 ^x	49	58
Yield harvested at first harvest (kg)	16,192	26,117	30,334
Yield increase at first harvest versus control (%)	—	17	26
Price first harvest (EUR/kg)	0.57 ^w	0.57	0.57
Income first harvest (EUR)	9,229.44	14,886.69	17,290.38
Yield harvested at second harvest (%)	68 ^x	51	42
Yield harvested at second harvest (kg)	34,408	27,183	21,966
Commercial yield at second harvest (%)			
(>65 mm diameter, >40% fruit color)	54	73	81
Price second harvest (EUR/kg)	0.41 ^w	0.41	0.41
Income second harvest (EUR)	7,617.93	8,135.87	7,294.91
Yield (kg·ha ⁻¹) [<65 mm diameter (no market), <40% fruit color]	15,828	7,339	4,174
Price yield no market (EUR/kg)	0.08	0.08	0.08
Income yield no market (EUR)	1,266.21	587.15	333.88
Total income (EUR/ha)	18,113.59	23,609.71	24,919.17
Difference versus control (EUR/ha)	—	5,496.13	6,805.59

^a1 kg·ha⁻¹ = 0.8922 lb/acre, 1 mm = 0.0394 inch, 1 kg = 2.2046 lb, 1 euro (EUR)/kg = 0.4536 EUR/lb, 1 EUR/ha = 0.4047 EUR/lb.

^yMean value of 2000, 2001, and 2002 seasons (data from Table 2).

^xMean value of 2000, 2001, and 2002 seasons (data from Fig. 3).

^wMean price of 2000, 2001, and 2002 seasons, for fresh market.

using a digital calibrated refractometer (Atago-Palette 100; Atago, Tokyo). Titratable acidity (TA) was determined on the basis of the same sample, which was titrated to a final pH of 8.2 with 0.1 N sodium hydroxide (NaOH); the result was expressed in grams per malic acid per liter. Starch degradation was analyzed using an iodine test developed by Center technique interprofessionnel des fruit et légumes (Ctifl) (Vaysse, 2002). The test, which stained starch blue on the tissue, was used on each of 20 fruit per treatment and replicate. The starch pattern was scored from 1 (full starch on the core and cortex areas and therefore immature) to 10 (low starch on the cortex and core and over mature).

DATA ANALYSIS. Analysis of variance was performed for fruit color values, yields, early harvest, fruit size, proportion red blush, and fruit quality according to a complete randomized block model with each block being a replication unit. This was done with SAS (version 6.12; SAS Institute, Cary, NC), and statistical significance was tested at $P = 0.05$. For fruit color values (colorimeter), data from each block represented the mean for two trees and 20 fruit per tree, for each fruit side: ES and SS. The plots were arranged in a randomized complete-block design. A General Linear Model procedure was used as a randomized complete block design to determine the statistical significance of the interactions. Season and treatment were designated as fixed effects, and blocks, trees, and fruit were designated as random effects. When the analysis was statistically significant (F-test), separation of means was carried out using Tukey's honestly significant difference (HSD) test at the $P \leq 0.05$ level of significance based on the mean square error for each sampling date and parameter evaluated. Differences between treatments and seasons were evaluated by analysis of variance. Season, treatment, block, tree height, and fruit were the main effects tested with each analysis.

Results and discussion

THE EFFECT OF REFLECTIVE FILM ON TEMPERATURE AND RELATIVE HUMIDITY. Orchard temperature and relative humidity were not consistently affected by the use of film. Average maximum temperature from

the period 1 July to 16 Aug. increased by 1.8 °C with reflective film and minimum temperature decreased by 0.5 °C. Relative humidity decreased slightly with the use of reflective film (data not shown). Similarly, Layne et al. (2001) reported an increase in air temperature of 1 to 2 °C during the daylight hours with respect to the control. Mathieu and D'Aure (2000) reported a decrease of 0.5 °C in minimum daily temperature at bloom associated with ExtendayTM, probably because of greater light reflection.

THE EFFECT OF REFLECTIVE FILM ON FRUIT COLOR DEVELOPMENT. For the first two dates (8 and 19 July) colorimetric values were the same for all treatments (Table 1). Fruit color intensity increased (diminution of L^* and hue values) over the measurement period, but especially in the last 11 d (from 30 July to 10 Aug.) when maximum values were recorded. Values of L^* and hue indicated that the reflective film increased red color formation (lowest values of L^* and hue) at harvest and before harvest (30 July) as a consequence of increasing color on both sides of the fruit (ES/SS). Color differences between both fruit sides were similar in the three seasons (Table 1). Bicolored appearance of the fruit depended mainly on the proportion of red blush covering the fruit surface (Fig. 2) rather than the intensity of red color, which is described in Table 1.

At harvest, the increase of color intensity was significant with both types of reflective film, but was greater with ExtendayTM than with SolarmateTM. This increase of fruit color did not affect fruit maturity as reported in Table 3. There were also significant differences between seasons: similar values of L^* and hue were recorded in 2001 and 2002, while lower values (better fruit color) were observed in 2000. These results were probably a result of the lower temperatures (Fig. 1) and greater rainfall throughout the period preceding harvest, which provided more suitable conditions for fruit red color development in all treatments in 2000. Therefore, it seems clear that season had a significant effect on the development of fruit color, which could explain the significance of the treatment $\times$ season interaction.

Average values for fruit color distribution for the total yield,

at commercial harvest, of each treatment are presented in Fig. 2. Both types of film significantly increased the proportion of red blush and reduced the average percentage of poorly colored fruit (80% red blush) increasing in comparison with the control. This provides evidence of the positive influence of reflective film on fruit color distribution, especially in the warmest seasons (2001 and 2002). As in the case of L^* and hue values, significant differences were observed between seasons and the interaction of season $\times$ treatment was also significant with respect to the average proportion of red blush on the fruit. The highest percentage of fruit with less than 40% red blush and the lowest percent of fruit with >80% occurred in 2001 (Fig. 2).

Because 'Mondial Gala' is an early season cultivar, any advance in harvest date for the fresh fruit market would increase its potential and profitability, but this would mainly depend on fruit color. In our experience, yields at the first harvest date or in early harvest (>70 mm size and >50% blushed surface) showed significant differences between treatments and seasons (Fig. 3). In 2000, more favorable climatic conditions resulted in better coloring for both treatments and the control. In 2001, the warmest season, both types of reflective film increased the proportion of early harvested fruit compared with the control. In 2002, also a year with warm conditions, the greatest values corresponded to ExtendayTM, with intermediate values being obtained with SolarmateTM and lower values with the control. For this reason, the interaction of season $\times$ treatment was also significant with regard to average values associated with fruit harvested at the first harvest date. Over the 3-year period (2000–02), average increases in the percentage of fruit harvested at the first picking were 26% and 17% compared with the control with ExtendayTM and SolarmateTM, respectively. Because only the fruit with better size and color were harvested in the early harvest, no consequences on fruit maturity were reported compared with those harvested 1 week later in the control (Table 3). Reflective film improved only fruit color without affecting maturity stage.

Fig. 2. The effect of using SolarmateTM (Sonoco Products, Hartsville, SC) and ExtendayTM (ExtendayTM New Zealand, Auckland, New Zealand) reflective film treatments on fruit color for 'Mondial Gala' apples at commercial harvest in the 2000, 2001, and 2002 seasons and mean values for this period. Columns/treatments with different letters for the same average color and season are significantly different at $P < 0.05$ (Tukey's least significant difference test). Season $\times$ treatment interaction for percentage of fruit for each different degree of color was significant at $P < 0.01$.

Different climatic conditions from season to season, and particularly differences in maximum and minimum daily temperatures, clearly affect the development of fruit color. They also affect fruit color responses to several techniques, such as orchard cooling and antihail nets, as reported by several authors (Gindaba and Wand, 2007; Iglesias et al., 2003; Iglesias and Alegre, 2006; Peano et al., 2001). Seasons that were favorable to fruit color development tended to mask the positive effects of the technique with respect to fruit color. Different responses to reflective film under different orchard conditions depended on the season, as reported by Andris and Crisosto (1996) using laminated aluminum foil and metalized polypropylene plastic strips laid down 1 month before the predicted harvest date. Reflective films induced an earlier harvest (35% more fruit picked and packed) on 'Fuji' apples, with a better and redder color, larger size, and higher external quality, without affecting fruit maturity. Mathieu and D'Aure (2000), using ExtendayTM reflective film on 'Mondial Gala' apples 1 month before harvest, reported a high intensity of coloration and an increase of 30% in the number of fruit harvested at the first harvest.

Ju et al. (1999a) tested the effects of covering the orchard floor with three types of reflective film for 8 weeks before harvest of 'Fuji' apples. Only the foil film and metalized film improved the percentage of red color of the fruit. Similar results were obtained by Li et al. (1994) using a reflective plastic film spread on the floor of a 'Starking' orchard in early August, before the beginning of fruit coloration; full-red fruit rate increased from 5.5% (control) to 27%. Layne et al. (2002) used metalized, high-density polyethylene reflective film on 'Imperial Gala' apples 4 weeks before the first commercial harvest date. They reported a 27% increase in the percentage of red surface compared with the control, without affecting fruit size. These findings are in accordance with those reported by us previously and evidenced clearly the positive effects of using film on increasing fruit color of 'Mondial Gala' apples.

LIGHT DISTRIBUTION WITHIN THE CANOPY. The reflective properties of

Table 3. Effects of Solarmate™ (Sonoco Products, Hartsville, SC) and Extenday™ (Extenday™ New Zealand, Auckland, New Zealand) reflective film treatments on yields and fruit quality of 'Mondial Gala' apples at harvest in the 2001, 2002 and 2003 seasons.

Parameter	Treatment	2000	2001	2002
		Mean ± SE		
Yield (kg/tree) ^z	Extenday™	28.5 ± 5.8 a ^y	34.2 ± 8.2 a	31.5 ± 7.5 a
	Solarmate™	29.1 ± 8.4 a	33.7 ± 7.8 a	33.1 ± 8.9 a
	Control	27.8 ± 5.4 a	32.4 ± 6.9 a	30.8 ± 7.4 a
	Significance ($P \leq F$)	0.25	0.31	0.19
Fruit weight (g) ^z	Extenday™	173.5 ± 6.1 a	157.6 ± 8.1a	140.6 ± 8.7 a
	Solarmate™	169.2 ± 7.3 a	160.5 ± 6.6a	134.0 ± 6.0 a
	Control	166.7 ± 6.9 a	158.5 ± 5.8 a	138.7 ± 7.2 a
	Significance ($P \leq F$)	0.59	0.86	0.16
Firmness (lbf) ^z	Extenday™	14.7 ± 0.48 a	15.1 ± 0.53 a	17.1 ± 0.66 a
	Solarmate™	14.5 ± 0.53 a	14.7 ± 0.67 a	16.9 ± 0.54 a
	Control	14.4 ± 0.41 a	15.4 ± 0.48 a	16.7 ± 0.37 a
	Significance ($P \leq F$)	0.94	0.39	0.87
SSC (%) ^x	Extenday™	13.4 ± 0.32 a	12.7 ± 0.29 a	12.8 ± 0.26 a
	Solarmate™	12.6 ± 0.63 b	12.2 ± 0.42 ab	11.3 ± 0.56 a
	Control	12.4 ± 0.51 b	11.7 ± 0.64 b	11.4 ± 0.67 a
	Significance ($P \leq F$)	0.0046	0.04	0.03
TA (g·L ⁻¹) ^w	Extenday™	3.0 ± 0.21 a	3.1 ± 0.29 a	3.5 ± 0.43 a
	Solarmate™	2.9 ± 0.33 a	3.2 ± 0.38 a	3.5 ± 0.41 a
	Control	2.8 ± 0.38 a	2.9 ± 0.31 a	3.4 ± 0.40 a
	Significance ($P \leq F$)	0.61	0.23	0.49
Starch index (1–10 scale) ^v	Extenday™	8.6 ± 0.41 a	8.4 ± 0.69 a	6.0 ± 0.20 a
	Solarmate™	8.4 ± 0.17 a	8.6 ± 0.58 a	5.7 ± 0.35 a
	Control	8.3 ± 0.39 a	8.7 ± 0.57 a	6.2 ± 0.19 a
	Significance ($P \leq F$)	0.15	0.30	0.26

^z1 kg = 2.2046 lbf, 1 g = 0.0353 oz, 1 lbf = 4.4482 N.

^yMeans followed by the same letter between treatments for the same season do not differ at the 5% level of significance ($P \leq 0.05$) by Tukey's honestly significant difference (HSD) test. Interaction season × treatment was not significant.

^xSSC = soluble solid concentration.

^wTA = titratable acidity, 1 g·L⁻¹ = 0.1%.

^v1 = immature fruit, 10 = overmature fruit.

Fig. 3. Percentage of 'Mondial Gala' apple crop harvested at first harvest (early harvest) as affected by Solarmate™ (Sonoco Products, Hartsville, SC) and Extenday™ (Extenday™ New Zealand, Auckland, New Zealand) reflective film treatments in the 2000, 2001, and 2002 seasons and mean values for this period. Columns/treatments with different letters for the same season are significantly different at $P < 0.05$ (Tukey's least significant difference test).

the materials used induced important differences in the intensity of the light inside the canopy as a consequence of the amount of PAR reflected by

the film (Fig. 4). Mean reflected PAR values in the control treatment were less than 100 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ for all measurements carried out in an area

measuring 2 m high × 1 m wide. Values of PAR reflected by the film in the same area reached 300 and 700 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ with the Solarmate™ and Extenday™ treatments, respectively. Moreover, radiation measurements made outside the canopy showed that Extenday™ reflected more radiation (86% of the incident radiation) than Solarmate™ (44%), at 1.5 m above the ground (data not shown). In the lowest part of the tree (1 m above the ground), Extenday™ and Solarmate increased PAR (visible wavelength 400–700 nm) by about 56% and 34%, respectively, compared with the control. The distribution of reflected PAR shown in Fig. 4 clearly shows that the effect of reflective film was limited to fruit located in the lower part of the tree (the first 1.2 m aboveground level) where the reflected PPF was at its maximum, although this effect would tend to depend on tree shape (Lancaster, 1992). Along the central axis, the lack of color mainly affects the lower and

Fig. 4. Distribution of PAR ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) within tree canopies of ‘Mondial Gala’ apple for 1) control, 2) Solarmate™ reflective film (Sonoco Products, Hartsville, SC), and 3) Extenday™ reflective film (Extenday™ New Zealand, Auckland, New Zealand) treatments, for incident radiation (A, B, and C, respectively) and reflected radiation (D, E, and F, respectively) radiation. Values are mean PAR readings of different measurements for tree blocks obtained at different tree heights (y-axis) and distances from the tree axis (x-axis) at midday on 4 Aug. 2001 (1 cm = 0.3937 inch).

most shaded parts of the tree where around 40% of total yield is located. It is in this bottom part of the tree that the benefits of using reflective film are

greatest because the potential for color improvement is also greatest, especially in poorly colored cultivars. The amount of fruit in this area

would also determine the relevance and profitability of using reflective film. Changes in fruit color varied according to their position and

location within the tree canopy because different points received different amounts of reflected light (Fig. 4), as the amount of sunlight received by the film was not uniform. Fruit on the exterior would tend to receive more radiation than that on the interior because the leaves and branches inside the canopy would absorb and reflect back part of the light.

On clear, bright days, light intensity inside the canopy remained relatively constant for 5 weeks after ExtendayTM application, but decreased progressively with SolarmateTM film. Reflectivity of SolarmateTM decreased over time by 15% after 7 d, 40% after 15 d, and 40% after 30 d, due to the damage to the film by machinery and wind and accumulation of dust and dirt. Layne et al. (2002) reported a lower reflective capacity (around 50%) when metalized high-density polyethylene reflective film remained on the orchard floor for 6 weeks. This loss of reflectivity could explain the lower efficiency of this film in fruit color improvement compared with ExtendayTM.

Our results are in agreement with those reported by Andris and Crisosto (1996), which reported that reflective film materials reflected 52% or more of the incident light at all wavelengths, which resulted in a significant increase in light inside the canopy compared with the control trees. Li et al. (1994) reported that using the film significantly increased the intensity of reflected light inside the tree canopy crown by 20% to 40% at 100 and 200 cm above the ground, respectively. Layne et al. (2001, 2002) reported that the spectral distribution of reflected solar radiation associated with the use of film was no different from that of incident sunlight; the film reflected visible and invisible (infrared) radiation. Incident sunlight at all measured wavelengths had a greater light intensity than that reflected from the film. Ju et al. (1999a), using different reflective film, were able to increase light intensity inside the tree canopy from 30% of daylight values to 68% and 50%, respectively, for foil film and metalized film.

The *PAR* (range of 400–700 nm) measured by the ceptometer shows the increase in light resulting from the introduction of either reflective films (Fig. 4). Enzymes in the

biosynthetic pathway to anthocyanins are light inducible. The relationship between light intensity and anthocyanin production has been confirmed by Bishop and Klein (1975). Siegelman and Hendricks (1958) considered radiation throughout the visible region of the spectrum to be effective, with the maximum proportion of anthocyanin synthesis in the red spectrum between about 640 and 670 nm, with a subsidiary maximum near 600 nm. Arakawa et al. (1986) showed that white light plus ultraviolet light at 312 nm produced four times the anthocyanin levels of white light alone. Based on the references above, the improvement in fruit color by the reflective film can be explained by the increase in light intensity inside the canopy at all wavelengths: infrared, *PAR* (visible), and ultraviolet radiation, increasing anthocyanin formation and accumulation in two ways: 1) It increased canopy photosynthesis and assimilation to the fruit, and thus indirectly stimulated anthocyanin synthesis by providing substrate/carbohydrates (Lancaster, 1992; Williams, 1993) without affecting SSC or fruit size. 2) The increase in light intensity within the tree canopy associated with the use of film accelerates *PAL* activity and *UFGalT* gene expression (*UFGalT* activity) and consequently stimulated anthocyanin synthesis. Both enzymes play an important role in anthocyanin synthesis in apples and are light inducible (Ju et al., 1995, 1999b). *UFGalT* also catalyzes the final reaction in the anthocyanin synthesis pathway, producing anthocyanin from cyanidin and UDP-D-galactose (Lancaster, 1992).

YIELD AND FRUIT QUALITY PARAMETERS. The total yields obtained for treatments and seasons were unaffected significantly by the reflective film, with a mean of 31.2 kg/tree per year (Table 3). In similar experiences with ‘Mondial Gala’ and ‘Fuji’ apples, using reflective film did not have a direct effect on yield (Andris and Crisosto, 1996; Layne et al., 2002) when the film was laid down from 5 to 7 weeks before predicted harvest. Fruit weight was not significantly affected by the use of reflective film. SSC increased with respect to the control when ExtendayTM was used, and SolarmateTM provided intermediate values, but

these were not consistent and depended on the season. Fruit firmness, TA, and starch scores were unaffected by the use of film (Table 3). Our results are consistent with previous findings reported by Li et al. (1994) for ‘Starking’ apples, Andris and Crisosto (1996) and Ju et al. (1999a) for ‘Fuji’ apples, and Layne et al. (2002) and Mathieu and D’Aure (2000) for ‘Imperial Gala’ (‘Mondial Gala’), where the use of reflective film laid 1 month before commercial harvest did not alter fruit size, firmness, SSC, or starch pattern index/fruit maturity. We can therefore conclude that although reflective films laid 5 weeks before commercial harvest increased fruit red color, they did not significantly affect fruit size, fruit maturity, and quality parameters (firmness, SSC, or TA) with respect to the control.

THE PROFITABILITY OF USING REFLECTIVE FILM. To calculate the profitability of the films, we considered the mean of the total yield obtained for each treatment over the period 2001 to 02 (Table 3). Both reflective films increased the yield of fruit harvested on the first two harvest dates and decreased the amount of fruit that was not marketable (Table 2). During the experimental period (2000–02), all the fruit from the first harvest were included in the EU extra premium ‘Gala’ crop. The prices and criteria used for the first and second harvest dates are presented in Table 2. Both types of reflective film significantly increased the yield harvested at the first harvest and the average commercial yield at the second harvest date, and reduced the noncommercial yield with respect to the control (Table 2). The cost of the reflective film and of the labor cost to lay it out and collect it in are presented in Table 4. The greatest annual cost was associated with the use of ExtendayTM film, but this film provided the best fruit color, was permeable to water, allowed access of machinery, provided the best stability with respect to wind, and showed excellent resistance to degradation by rain. We considered a lifespan of 10 years with only one use per season. On the other hand, SolarmateTM could only be used for one season and degraded much more easily and rapidly. The annual cost of using reflective film and the

Table 4. Set up costs, annual running costs, and net profit for the use of Solarmate™ (Sonoco Products, Hartsville, SC) and Extenday™ (Extenday™ New Zealand, Auckland, New Zealand) reflective film treatments for a 1-ha (2.5 acres) orchard surface of ‘Mondial Gala’ apples.

Concept ^z	Characteristics and cost/profit of film		Annual depreciation (EUR/ha) ^z	
	Solarmate™	Extenday™	Solarmate™	Extenday™
Lifespan (years)	10	1	—	—
Surface covered (m ² ·ha ⁻¹)	7,500	7,500	—	—
Cost of film (EUR)	895.00	6,175.20	1,050.00	682.50
Cost of film (EUR/m ²)	0.14	0.91		
Cost of anchorages, elastics, etc. (EUR)	60.20	756.00	60.20	75.60
Cost of folding and anchoring film (EUR)	360.00	680.50	—	—
Cost of unfolding the film (EUR)	70.70	340.30	—	—
A) Total cost of film (EUR/ha per year)	1,540.90	1,778.90	—	—
B) Increase in profitability versus control (EUR/ha per year)	5,496.13 ^y	6,805.59	—	—
Net profitability versus control = B – A (EUR/ha per year)	3,655.23	5,026.03	—	—

^z1 euro (EUR)/ha = 0.4047 EUR/acre, 1 m²·ha⁻¹ = 4.3560 ft²/acre, 1 EUR/m² = 0.0929 EUR/ft².

^yData from Table 3.

benefit accruing from the gain in fruit color and reduction of noncommercial yield gave respective net increases in profitability of EUR 5026 and EUR 3655 per hectare for Extenday™ and Solarmate™ respectively (Table 4). Extenday™ offered more advantages than Solarmate™ due to the associated increase in fruit color and the ease with which it could be used by growers. It offered the additional advantage of its potential use over several seasons and with more than one cultivar per season. In both cases, the economic potential of using film depended on the market value of the apple crop in question.

Conclusions

In recent years, the world apple industry has experienced a period of globalization and hypercompetition between hemispheres and producing countries in which consumer requirements have increased, especially in the case of global cultivars such as Gala and Fuji. This means that high standards of fruit quality are demanded in EU markets throughout the year, and that increased importance is being given to external appearance, internal quality, and packaging. At the same time, prices have tended to decrease because of increased supply and more and more saturated markets. EU growers are now obliged to produce similar levels of quality at reasonable prices to remain competitive. Selecting the reddest strains is now the best way to guarantee sales and commercial margins, and this is an important

consideration when planting new orchards in warm regions. Our experiment demonstrates that in established orchards, the use of reflective film (Extenday™ and Solarmate™) can efficiently increase the intensity of light within the tree canopy, improving fruit color in the shaded parts of the tree, reducing the average percentage of noncommercial fruit, and increasing profitability for growers, without affecting internal fruit quality. This color improvement is especially important in the early harvest and warm climate apple production areas of the southern EU (Spain, Italy, etc.) because of the difficulty in achieving the first class EU ‘Gala’ grade. Under these conditions, market price mainly depends on fruit color and harvest time, and the profitability of using reflective film will be directly influenced by the market price of the fruit.

Literature cited

- Andris, H. and C.H. Crisosto. 1996. Reflective materials enhance ‘Fuji’ apple color. *Calif. Agr.* 50:27–30.
- Arakawa, O. 1988. Characteristics of color development in some apple cultivars: Changes in anthocyanin synthesis during maturation as affected by bagging and light quality. *J. Jpn. Soc. Hort. Sci.* 57:373–380.
- Arakawa, O. 1991. Effect of temperature on anthocyanin accumulation in apple fruit as affected by cultivar, stage of fruit ripening and bagging. *J. Hort. Sci.* 56:763–768.
- Arakawa, O., Y. Hori, and R. Ogata. 1986. Characteristics of color develop-

ment and relationship between anthocyanin synthesis and phenylalanine ammonia-lyase activity in ‘Starking Delicious’, ‘Fuji’ and ‘Mutsu’ apple fruit. *J. Jpn. Soc. Hort. Sci.* 54:424–430.

Bishop, R.C. and R.M. Klein. 1975. Photo-promotion of anthocyanin synthesis in harvested apples. *HortScience* 10:126–127.

Blankenship, S.M. 1987. Night-temperature effects on rate of apple fruit maturation and fruit quality. *Scientia Hort.* 33: 205–212.

Carolus, R.L. 1971. Evaporative cooling techniques for regulating plant water stress. *HortScience* 6:23–25.

Chalmers, D.J., J.D. Faragher, and J.W. Raff. 1973. Changes in anthocyanin synthesis as an index of maturity in red apple varieties. *J. Hort. Sci.* 48:387–392.

Crassweller, R.M. and R.A. Hollender. 1989. Consumer evaluations of ‘Delicious’ apple strains. *Fruit Var. J.* 43:139–142.

Curry, E.A. 1997. Temperatures for optimum anthocyanin accumulation in apple tissue. *J. Hort. Sci.* 72:723–729.

Diario Oficial de la Unión Europea. 2005. Reglamento (CE) n° 1238/2005 de la Comisión, que modifica el Reglamento R(CE) n° 85/2004 por el que se establece la norma de comercialización aplicable a las manzanas. *Diario Oficial de la Unión Europea L 200:22–31.*

Dickinson, J.P. and A.G. White. 1986. Red color distribution in the skin of ‘Gala’ apple and some of its sports. *N.Z.J. Agr. Res.* 29:695–698.

Evans, R.G. 1993. Part one: Designing and operating overtree evaporative cooling

- systems for apples. *Good Fruit Grower* 6:23–27.
- Faragher, J.D. 1983. Temperature regulation of anthocyanin accumulation in apple skin. *J. Expt. Bot.* 34:1291–1298.
- Gindaba, J. and S.J. Wand. 2007. Do fruit sunburn control measures affect leaf photosynthetic rate and stomatal conductance in ‘Royal Gala’ apple. *Environ. Exp. Bot.* 59:160–165.
- Green, S.R., D.H. McNaughton, D.H. Greer, and D.J. McLeod. 1995. Measurement of the increased PAR and net all-wave radiation absorption by an apple tree caused by applying a reflective ground covering. *Agr. For. Meteorol.* 76:163–183.
- Hirst, P.M., D.S. Tustin, and I.J. Warrington. 1990. Fruit color responses of ‘Granny Smith’ apple to variable light environments. *N.Z.J. Crop Hort. Sci.* 18:205–214.
- Iglesias, I. 1996. Influencia del material vegetal y del riego por aspersión en la cloración de variedades rojas de manzana (*Malus domestica* Borkh.). University of LleidaLleida, Spain, PhD Diss.
- Iglesias, I. and S. Alegre. 2006. The effects of anti hail nets on fruit protection, radiation, temperature, quality and profitability of ‘Mondial Gala’ apples. *J. Appl. Hort.* 8:91–100.
- Iglesias, I., G. Echeverría, and Y. Soria. 2008. Differences in fruit colour development, anthocyanin content, fruit quality and consumer acceptability of eight ‘Gala’ apple strains. *Scientia Hort.* In Press.
- Iglesias, I., J. Graell, D. Faro, C. Larri-gaudiere, I. Recasens, G. Echeverría, and M. Vendrell. 1999. Efecto del sistema de riego en la coloración de los frutos, contenido de antocianos y actividad de la fenilalanina amonioliasa (PAL), en la variedad de manzana ‘Starking Delicious’. *Investigación Agraria Producción y Protección Vegetal* 14:157–172.
- Iglesias, I., J. Graell, G. Echeverría, and M. Vendrell. 2000. Orchard cooling with overtree sprinkler irrigation to improve fruit color of ‘Delicious’ apples. *Hort-Science* 35:1207–1208.
- Iglesias, I., J. Salvia, L. Torguet, and C. Cabús. 2003. Orchard cooling with over-tree microsprinkler irrigation to improve fruit color and quality of ‘Mondial Gala’ apples. *Scientia Hort.* 93:39–51.
- Ju, Z., C. Liu, and Y. Yuan. 1995. Activities of chalcone synthase and UDPGal: Flavonoid-3-glycosyltransferase in relation to anthocyanin shynthesis in apple. *Scientia Hort.* 63:175–185.
- Ju, Z., C. Liu, Y. Yuan, Y. Wang, and G. Liu. 1999b. Coloration potential, anthocyanin accumulation and enzyme activity in fruit of commercial apple cultivars and their F₁ progeny. *Scientia Hort.* 79:39–50.
- Ju, Z., Y. Duan, and Z. Ju. 1999a. Effects of covering the orchard floor with reflecting film on pigment accumulation and fruit coloration in ‘Fuji’ apples. *Scientia Hort.* 82:47–56.
- Lancaster, J.E. 1992. Regulation of skin color in apples. *Crit. Rev. Plant Sci.* 10:487–502.
- Layne, D.R., W. Jiang-Zheng, J.W. Ruhing, and Z.W. Jiang. 2001. Tree fruit reflective film improves red skin coloration and advances maturity in peach. *HortTechnology* 11:234–242.
- Layne, D.R., Z. Jiang, and J.W. Rushing. 2002. The influence of reflective film and ReTain on red skin coloration and maturity of ‘Gala’ apples. *HortTechnology* 12: 640–645.
- Li, Y.D., C. Zhao, Y.N. Lui, G.S. Zhang, Y.D. Li, C. Zhao, Y.N. Lui, and G.S. Zhang. 1994. Improving fruit quality of ‘Starking’ apple with silvery reflector film mulching. *Ningxia J. Agr. For. Sci. Technol.* 6:19–21.
- Mancinelli, A.L. 1985. Light-dependent anthocyanin synthesis: A model system for the study of plant photomorphogenesis. *Bot. Rev.* 51:107–157.
- Mathieu, V. and R. D’Aure. 2000. Pomme: Plus de lumière pour plus de couleur. *Fruit et Légumes* 183:52–54.
- Miller, S.S. and G.M. Greene. 2003. The use of reflective film and ethephon to improve red skin color of apples in the mid-Atlantic region of the United States. *HortTechnology* 13:90–99.
- Moreshet, S., G. Stanhill, and M. Fuchs. 1975. Aluminium mulch increases quality and yield of ‘Orleans’ apples. *HortScience* 10:390–391.
- Peano, C., G. Giacalone, A. Bosio, G. Vittone, and G. Bounous. 2001. Influenza delle reti antigrandine sulla qualità delle mele. *Rivista di Frutticoltura* 9:61–64.
- Proctor, J.T.A. 1974. Color stimulation in attached apples with supplementary light. *Can. J. Plant Sci.* 54:499–503.
- Rapillard, C. and A. Dessimoz. 2000. Différents mutants de ‘Gala’. *Revue Suisse de Viticulture et Horticulture* 32:233–237.
- Saure, M.C. 1990. External control of anthocyanin formation in apple. *Scientia Hort.* 42:181–218.
- Siegelman, H.W. and S.B. Hendricks. 1958. Photocontrol of anthocyanin shynthesis in apple skin. *Plant Physiol.* 33:185–190.
- Tan, S.C. 1980. Phenylalanine ammonia-lyase and the phenylalanine ammonia-lyase inactivating system: Effects of light, temperature and mineral deficiencies. *Aust. J. Plant Physiol.* 7:159–167.
- Vaysse, P. 2002. Outils qualité: Code amidon pomme. Centre technique interprofessionnel des fruits et légumes, Paris.
- Williams, K.M. 1993. Use of evaporative cooling for enhancing apple fruit quality. *Good Fruit Grower* 8:23–27.