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Hail Net Effect on Photosynthetic Rate and Fruit Color Developent of 'Starkrimson' Apple Trees

Alejandro Romo-Chacón[1,3], Jesús A. Orozco-Avitia[1], Alfonso A. Gardea[1], Victor Guerrero-Prieto[1] and Juan M. Soto-Parra[2]

Abstract

Photosynthetically active radiation (PAR) distribution, net photosynthesis (Pn) and fruit color were measured on 'Starkrimson Delicious' apple (*Malus* × *domestica* Borkh.) trees and fruits protected against hail by white or black nets, as well as unprotected controls. PAR levels were reduced by 45 and 63% by white and black nets respectively. Net color and canopy position showed a highly significant interaction for PAR distribution. The inner canopy of trees under black hail nets received the least PAR. PAR measured in the upper canopy was significantly higher than in the lower canopy. No significant differences in Pn were found between trees under white nets and controls, but both were higher than trees under black nets. Highly significant differences were found for canopy position; the lower-internal canopy position yielded the lowest Pn values. Fruit color followed the same pattern of influence of canopy position and orientation. Fruit color measurements L-value and hue angle (°h) were directly affected by hail nets. Fruits in the upper tree stratum had better color, with lower L and °h values. Fruit color was mostly defined by fruit position within the canopy.

Hailstorms are common in high-elevation, low-latitude apple (*Malus* × *domestica* Borkh.) production areas in Mexico. Therefore, hail nets are widely used by growers to protect both trees and crop (6). The most commonly used hail nets are made of light-trapping black polyethylene, and information regarding side effects is still lacking. Physiological processes directly affected by this net shadowing effect and uneven sunlight distribution within the canopy are: photosynthesis, mineral element distribution, carbohydrate and anthocyanin synthesis, soluble solids accumulation, and flower bud differentiation (7, 15). Such inefficient sunlight use causes losses of fruit quality and ultimately profits, since fruit quantity and quality are directly affected by light distribution within the tree canopy (3, 14). Light level is determined by several factors such as latitude, altitude, season, time of day and cloud presence. Use of solar radiation by tree foliage depends on leaf angle of exposure, sun position, and solar spectrum distribution, as well as foliage distribution and arrangement within the canopy (10). A strategy to increase solar radiation penetration is to train trees in a way in which solar radiation exposure can be optimized. When PAR increases above saturation point, a larger amount of this radiation penetrates towards inner canopy whorls, increasing photosynthetic rates (13). Light saturation points for maximum photosynthetic rates in 'Delicious' trees for outer, middle and inner foliage were 731, 468 and 427 µmol m^{-2} s^{-1}, respectively (1). This research was conducted to evaluate the effect of hail nets on sunlight penetration and distribution in the tree canopy, leaf photosynthetic rates and fruit color development.

Materials and Methods

We used 28 year-old 'Starkrimson' apple trees, grafted onto MM.106 in Cuauhtemoc, Chih., Mexico. The rows were oriented NW-SE, on a 5 x 4 m planting distance. Average tree height and canopy diameter were 4.9 and

[1] Centro de Investigación en Alimentación y Desarrolo A.C., Unidad Cuauhtémoc, P.O. Box 781, Cuauhtémoc, Chih., México 31570
[2] Facultad de Ciencias Agrotecnológicas, Universidad Autónoma de Chihuahua, Chihuahua, Chih., México 31310
[3] corresponding author: archacon13@ciad.mx

5.0 m, respectively and 0.51 m for average trunk circumference. Variables evaluated were PAR penetration and distribution within tree canopy (µmol m^{-2} s^{-1}), Pn (µmol $CO_2 m^{-2}$ s^{-1}), and fruit color (L, a, b scale). Treatments were established on trees protected by black and white hail nets and uncovered controls. Readings were taken on clear sunny days between 10:00 and 11:00 A.M. at several dates during August. Experimental plots consisted of four trees. Hail net material was made of high density polyethylene, with 0.12 mm grid diameter and a 5 x 3 mm on each individual grid. Sunlight passing through each net was determined independently. Tree canopies were divided into two height strata; the upper was at measured 2.6 m and lower at 1.0 m. Canopy volume was divided into three depths: external, middle and internal layers. PAR penetration and distribution within the tree canopy was measured by using a 1 m linear photometer LI 191 (Li-COR, Lincoln, Neb.) (8). Total PAR was obtained by adding soil and foliage-reflected light to incident sunlight. To perform these measurements, a leveled frame, which supported the photometer, was used (11). Twenty-four PAR readings were made on each plot. A non-dispersive, infrared gas analyzer (LI-6200, LI-COR, Lincoln, Neb.) equipped with a 1 L chamber was used to measure Pn (9) on 24 leaves at each canopy position. Fruit color was evaluated by taking two opposite readings per fruit, on 16 fruits per canopy position with a Minolta CR-300 colorimeter (Chroma meter, Minolta Co., Osaka, Japan) using the L, a, and b scale. The a and b values were transformed to hue angle (°h) values (arc tan [b/a]); if negative, they were transformed by: (arc tan [b/a] + 180). The colorimeter was calibrated with the white standard values Y= 93.2, X= 0.3133 and y= 0.9132.

The experimental design used was completely randomized with a 3 x 2 x 3 factorial arrangement. Factor A included black and white hail nets and uncovered controls; factor B considered two canopy strata, upper and lower; and factor C, including three canopy positions; external, middle and internal. Statistical analysis was performed using SAS™ (Statistical Analysis System, version 6.12, Cary, NC). Mean separation was according to interaction significance. When interactions were significant, difference among treatment means was done by standard errors. When interactions were not significant, but independent factors were, mean separations were done by Tukey's test (P = 0.05) (12).

Results and Discussion

PAR. There were highly significant differences in PAR, passing through hail nets and distributed throughout the tree canopy. Total PAR (full sun) received was 2 000 µE $m^{-2} s^{-1}$; white and black hail nets allowed the passage of 63 and 45%, respectively of incident sunlight. The inner canopy received the least amount of PAR, regardless of treatment (Table 1). PAR data showed the effect of hail net color and canopy position. It has been reported that tree structure and other support structures could intercept up to 60% of solar radiation,

Table 1. Photosynthetically active radiation (µmol•m^{-2}•s^{-1}) distribution as affected by hail net used and canopy position in 'Starkrimson' apple trees.

	Canopy position[z]		
Hail net type	Internal	Middle	External
Black	257 a[y]	307 a	461 a
White	238 a	392 b	670 b
Unprotected	367 b	438 b	823 c

[z] canopy position x hail net type showed significant interaction (SE = 49.53, n = 96).

[y] means within a column followed by the same letter are not significantly different (Tukey's test, P ≤ 0.05)

which could be diminished even further depending on foliage number and density (15). Apple trees require from 30 to 50% of total sunlight for maximum photosynthetic activity (1,5). According to our results, only the outer tree canopy positions receive such light levels; therefore, foliage in the other canopy positions lacks sufficient PAR to maximize photosynthetic rates. It becomes clear that light interception and absorption by hail nets is dependent upon their color. Overall light reductions were observed primarily under black nets, followed by white nets, while unprotected trees exposed to clear skies obtained the most sunlight.

Net photosynthesis (Pn). Average Pn values were in accordance with light exposure of the foliage, although no significant differences were found between uncovered controls and trees protected by white nets, yielding 12.0 and 11.7 µmol CO_2 m^{-2} s^{-1}, respectively. These were the highest rates attained. In comparison, foliage under black nets only reached 9.6 µmol CO_2 m^{-2} s^{-1}.

A significant interaction occurred between canopy position and tree strata. Pn decreased towards the canopy center regardless of strata (Table 2). Also, less variation was observed among the three positions in the upper canopy. The latter was likely caused by the extra energy provided by soil reflected light. Similar results have been reported on 'Stayman' and 'Delicious' apple trees, where outermost foliage showed the highest Pn rates, as compared to foliage located in the inner and middle positions of the tree canopy (1).

Hail net effect on fruit color. Interactions among hail net type and tree canopy position were found when fruit color was analyzed. Previous work (6) in which different types of nets were evaluated on 'RedChief Delicious' apple trees found lower values for L (48.4) and °h (53.0) for fruits on trees under black hail nets, as compared to those fruits under white nets and unprotected ones. Results for our work showed lower L values, with a less striped red color, for fruits located within the upper tree stratum, as compared to those in the lower tree stratum (Table 3). 'Delicious' apples were not commercially acceptable when PAR was reduced 63% (4), when fruit were evaluated on a 1 to 4 scale, with 2.5 and 2.7 scores for shaded fruits and 3.6 and 3.1 for exposed fruits. However, no significant differences in color were found on visually evaluated 'Delicious' apples on PAR conditions ranging from 5 to 95% (14). Our results, however, showed differences among the different tree canopy positions evaluated. Fruits in the outer position had lower L values, which translates into a more uniform, deep red color, than those in the inner canopy positions (Table 1). Similar values to these were reported for 'Starkrimson' apples, when 37 different 'Delicious' strains were analyzed (16). Crassweller et al. (2) evaluated different 'Delicious' apple strains under different geographical locations from 1985 to 1987, finding that 'Starkrimson' apples had the highest fruit color variability. Ferree (5) concluded that low fruit color and size are most common in the more shaded areas of trees, therefore requiring 30 to 50% of complete solar radiation to assure a good red color, with some 'Delicious' mutants developing good red color with as low as 9.0% of full sunlight.

Table 2. Net photosynthetic rate (µmol•m^{-2}•s^{-1}) as affected by canopy stratum and position in 'Starkrimson' apple trees. Data were pooled across all hail net treatments.

	Canopy position[z]		
Canopy stratum	Internal	Middle	External
Lower	3 a[y]	9 a	15 a
Upper	11 b	14 b	15 b

[z] canopy position x canopy strata showed significant interaction (SE = 0.64, n = 96).
[y] means within a column followed by the same letter are not significantly different (Tukey, P ≤ 0.05)

Table 3. Effect of canopy position and stratum and hail net use and their interactions on the mean L-value and hue angle of 'Starkrimson' apple fruit skin.

	L-value[z]	Hue angle (°h)
Hail net type		
Unprotected control	36.1 b	24.7 b
White net	38.9 a	25.3 b
Black net	38.7 a	27.3 a
Canopy stratum		
Upper	34.3 b	22.4 b
Lower	41.4 a	29.2 a
Canopy position		
External	37.1 b	24.2 b
Middle	37.9 ab	26.1 a
Internal	38.6 a	27.0 a
Source of variation in ANOVA	F value from ANOVA[y]	
Net color	28.96**	10.09**
Canopy stratum	459.50**	194.10**
Canopy position	7.38**	11.05**
Net color x canopy stratum	10.18** [x]	6.84** [w]
Net color x canopy position	0.32	1.31
Canopy stratum x canopy position	1.57	1.02
Net x stratum x position	1.51	1.36

[z] Means within a column and section that are followed by the same letter are not significantly different (Tukey, $P \leq 0.05$).
[y] **significant at $P \leq 0.01$
[x] standard error = 0.38
[w] standard error = 0.60

Conclusions. Tree structure and hail net color had an effect on penetration and distribution of solar radiation within tree canopy. Highest Pn was achieved on foliage of unprotected trees, followed by white nets, with similar results for foliage located in the tree's upper section and outermost position within the tree canopy. Fruits on unprotected trees had best fruit color characteristics than those protected by either white or black hail nets. Unprotected trees fruit had a more uniform and solid red color, while fruits from protected trees had an incomplete and less solid red color. Fruits under white nets had better color than those under black nets.

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