COLORED HAIL-NETS AS A TOOL TO IMPROVE VINE WATER STATUS: EFFECTS ON LEAF GAS EXCHANGE AND BERRY QUALITY IN ITALIA TABLE GRAPE

Authors:Laura de PALMA[1*], Patrizio LIMOSANI[1], Vittorino NOVELLO[2]

[1]*University of FOGGIA-SAFE, Via Napoli 25, I-71122, Foggia, Italy*
[2]*University of Turin-DiSAFA, Largo Braccini 2, I-10095, Grugliasco (TO), Italy*

*Corresponding author: *laura.depalma@unifg.it*

Abstract:

Context and purpose of the study - Protecting table grape vineyards with white hail-nets is a common practice in Southern Italy. Hail-nets result in shading effects of 10-20%, depending on their density and type of weave, thus they act as a low shading nets and modify the vineyard microclimate. Darker nets are more opaque to solar radiation, increasing the shading effects. Colored nets have been introduced in horticultural crops aiming to alter the amount and composition of light available at canopy level, in order to getparticular light-induced effects on microclimate, plant physiology, growth and production. Yellow and red nets are among the most studied. However, by now, results of different studies are not always consistent with each other. The present study aimed at assessing the performance of Italia table grape grapevine under yellow and red hail-nets, with a particular interest to the chance of modulating the microenvironment to support the vine water status under the semi-arid conditions of Southern Italy, evaluating also the effects exerted on the grape quality.

Material and methods - The study was run in 2014 and 2015, in the BT province of Apulia region, on Italia covered with white, yellow and red nets, all having mesh of about 3x5 mm. PAR, air temperature and RH were monitored in warm hours of typical days of mid- and late- July and August. Leaf gas exchange and stem water potentials were measured. Leaf area was assessed ceptometrically. At harvest, berry fresh weight, skin color, juice total soluble solid concentration (TSS) and titratable acidity (TA), main skin and pulp phenol contents, and berry antioxidant activity (AA) were determined.

Results – Respect to the white net,the colored ones reduced the PAR available for canopy (especially the red net) and increased air temperature and RH (especially the yellow net). On average, they lowered the air VPD along the canopy profile by ~10% and improved the vine water status from 33% (yellow net) to 38% (red net). However, this improvement did not enhance the leaf gas exchange measured at maximum PAR interception (~1450 $\mu mol/m^2/s$); on the contrary, the leaf transpiration, and even more the net CO_2 uptake, tent to be lowered by yellow net, but not, or at a little extent, by the red net. The leaf area did not change. According to literature, yellow color depresses the transmissivity of red and blue wavelengths, active on photoreceptors that stimulate stomata opening and PSII efficiency. At harvest, on average, the patterns of berry and bunch weight were similar to those of leaf gas exchange (especially to the transpiration one); the yellow component of the skin color decreased with both colored nets; the TSS/TA ratio increased. The skin phenol contents were lowered by the red net but not, or a very little extent, by the yellow one; the berry antioxidant activity progressively decreased passing from the white to the yellow and to the red net. In conclusion, under the trial conditions, the yellow and red hail-nets did not influence the performance of Italia grapevine in univocal way. Some responses seemed more related to their low shading effects, while others to their spectrometric effects. They rose significantly the vine water status compared to the white net, but this improvement did not enhance other physiological parameters or any berry quality attributes.

Keywords: Grapevine, Microenvironment, Ecophysiology, Maturity indices, Phenol contents, Berry antioxidant activity.

1. Introduction

Protecting table grape vineyard with white hail-nets is very common in Southern Italy. Hail nets have also 10-25% shade effect depending on density and type of weave (Castellano et al., 2008). These porous screens may decrease or increase air temperature depending on whether the effect of limiting light entry or of reducing air circulation prevails (Iglesias and Alegre, 2006); same shifts occur for relative humidity (Solomakhin and Blanke, 2010; Bogo et al., 2012; Bosco, 2018). Colored cover materials absorb, reflects and transmit specific wavelengths of solar radiation, changing both amount and composition of light available for foliage, hence, "ColorNets" were introduced in horticultural crops to get particular light-induced effects on microclimate, plant physiological activity, growth and production (Shahak et al., 2008). However, by now, results of different research are not always consistent with each other.

The present study aimed at assessing the performance of cv. Italia table grape protected by white, yellow and red hail-nets, with a particular interest to the chance of modulating the microenvironment in order to support the vine water status under the semi-arid conditions of Southern Italy, and to evaluate the effects exerted on leaf functioning and grape quality. The richness in the main grape phenolic compounds was also assessed since, due to their well-known relationship with antioxidant activity, they are recognized to be relevant for human health as potential agents that prevent several types of diseases related to oxidative stress (Xia et al., 2010).

2. Material and methods

Plant material and growing conditions

Plant materials - The study was conducted, in 2014 and 2015, at a 15-year old vineyard of cv Italia/1103 P located in Trinitapoli (Laporta Farm, BT province, Apulia, Italy). Vines were planted 2.4 x 2.4 m apart on clay-loam soil, trained to *tendone* trellis, and pruned to 3 canes with 10 buds/cane. The vineyard was managed with standard practices including cluster thinning (1.5 bunch/cane), leaf thinning, sub-irrigation and fertigation. During the growing cycle the vineyard was protected with white hail-net, except for a group of central rows covered with yellow or red hail-nets. All nets had 3x5 mm mesh size. For the trial, each treatment (net color) consisted of a plot of 3 rows and 39 vines. Five one-vine replicates per treatment were considered.

Microenvironment and plant measurements – Photosynthetic active radiation (PAR), air temperature and relative humidity (RH) were monitored at mid-morning of typical days of mid- July and late August; vapor pressure deficit (VPD) was calculated. Rates of leaf gas exchange, as net photosynthesis (PN), stomatal conductance (CD) and transpiration (TR) at max. PAR interception (IRGA LC ProPlus Analytical Development Corporation) and stem water potentials (pressure bomb, Soilmoisture Equipment Corp.) were measured (3 mature leaves per replicate). Leaf area index was assessed ceptometrically (AccuPAR PAR/LAI LP-80 Decagon Dev. Inc). At harvest (1st week of September), the following parameters were determined (10 bunch/treatment): bunch and berry weight, skin color (chroma meter CR400 Konica Minolta), juice total soluble solid concentration (refractometer VM-7 Atago), titratable acidity (TA, Titralyzer T11-107 Laboratories Dujardin-Salleron), main skin phenol contents (protocol by Di Stefano and Cravero, 1991), berry antioxidant activity (protocol by Re et al., 1999).

Statistical analysis - Data of PAR interception, LAI, leaf gas exchange, stem water potential and all parameters of berry quality were analyzed using procedures of SAS software (SAS Institute, Cary, NC, USA). One-way ANOVA was performed considering the year as random factor; hence, per each parameter, the average value of the two-year trial was finally taken into account for discussion. When the effect of treatments was significant at $p \leq 0.05$, means were compared by applying the Duncan test. Relationships between bunch or berry weight and leaf gas exchange were assessed testing correlations and calculating regression equations.

3. Results and discussion

3.1. *Yellow and redhail-nets impact on vineyard microclimate more than white net*

White, yellow and red hail-nets reduced PAR available for canopy by about 11%, 14% and 19%, respectively; differences were significant. According to Al-Helal and Abdel-Ghany (2010), brighter colors enhance light scattering and thus total light transmission. Microclimate under net tended to be slightly warmer (from +2.00 °C with white net to +0.75 °C with red net) and more humid (from + 0.72% with white net to +3% with red net) than in open air. The yellow net performed intermediately between the others. Air VPD was 2.89 kPa under white net, 2.58 and 2.53 kPa under yellow and red nets, respectively, hence, the two ColorNets lowered VPD by about 11-12%. LAI did not change (4.8 with white net, 4.6 with yellow and red nets).

3.2. *Yellow and red hail-nets improve vine water status, but not photosynthetic rates*

Average stem water potentials varied from about -1.0 MPa in vines under white net to -0.7 and -0.6 MPa in vines under yellow and red net, respectively. Hence, vine under ColorNets significantly improved their water status by 33% (yellow) and 38% (red), likely due to the lower VPD experienced.According to Van Leeuwen et al. (2009), vine water deficit ranged from moderate (white net) to weak (ColorNets). Despite to this result, leaf gas exchange tended to decrease under yellow net (CD -2%, TR -10%, PN -17%), and PN tended to decrease under red net (-4%). However, red net tended to increased CD by +10% and TR by +5%. Only the difference of transpiration rates under yellow and red nets achieved statistical significance. Photosynthetic water use efficiency (PN/TR) was not enhanced (Figure 1). Basing on literature, white nets are almost neutral in light transmission; yellow nets, respect to red ones, favor transmissivity of yellow light but penalize that of red and blue light, while red nets do the opposite. Both yellow and red nets reduce the transmittance to UVB radiations (Schettini, 2011). Plant photoreceptors are sensitive to amount and ratio of red and blue light. Blue light stimulates stomata opening, chlorophyll photon absorption, and PSII efficiency; red light has similar effects, but at lower and more variable extent (Aasmaa and Aphalo, 2016). In this trial, leaf functioning under yellow net seemed more influenced by spectral limitations than by the improvement of vine water status, while, with red net, spectral limitations of leaf gas exchange seemed compensated or overcome by the improvement of vine water status.

3.3. Yellow and red hail-nets do not increase bunch weight and penalize berry skin color, phenol content and antioxidant activity

General features of 'Italia' grape reflected those found in other trials carried out in Apulia vineyards managed with traditional cultural practices (Novello *et al*., 1999). Bunch weight (about 600 g with white net) decreased slightly with yellow net (-8%) and red net (-2%). Berry weight was 9.2 g with white net, decreased by -8% with yellow net, while increased by +3% with the red one; the difference of berry weight between yellow and red treatments (11%) was significant. The pattern of differences of bunch and berry weight was quite similar to patterns of leaf gas exchange. Testing statistical relationships between bunch or berry weight and leaf gas exchange, positive significant correlations emerged (Table 1): more than 50% of the changes in bunch or berry weight might be explained by changes in rates of leaf gas exchange. The colored nets significantly decreased the yellow component of berry shin color (by 13%-14%). Yellow skin color is mainly linked to evolution of carotenoids that is stimulated by great availability of PAR and UVB radiation (Joubert et al., 2016). Juice TSS concentration was high (around 18 °Brix) in all treatments.
The indices of phenol concentration of 'Italia' berry skin tended to decrease passing from white, to yellow and to red net (Figure 2), in order of increasing net shading. The differences between white and red nets ranged from -22% for total proanthocyanidins to -24% for total polyphenols, and were significant. Pattern of differences in skin phenols reflected those found in previous trials (de Palma et al., 2012). Light availability and quality are involved in biosynthesis of skin phenol compounds and related precursors, especially with

regard to UV radiation (Koyama *et al*. 2012). Vine water status affects berry phenol content in many ways (Deluc *et al*., 2009). In the present experiment, the comparison of patterns of differences in skin phenol contents, PAR interception under nets, and vine water status suggests that this latter had a minor effect on skin phenols, possibly due to the moderate or weak water deficit experienced by vines. Antioxidant activity of 'Italia' grapes was clearly influenced by concentration of phenols in berry skin, as expected (Xia et al., 2010).

4. Conclusions

Colored hail-nets were able to improve vine water status likely due to their relatively higher shade effect compared to that of traditional white net of same mesh size. However, this benefit was not able to increase net photosynthetic rates or bunch weight. This limitation was probably due to a lower transmissivity of relevant light wavelengths for leaf functioning, such as red and blue ones, that is typical of these colored nets.

Under the trial conditions, colored nets decreased berry skin color, phenol content and antioxidant activity of 'Italia' grape, parameters affected by the amount of available PAR and UV radiation. The red nets, that was the most shading, induced the most pronounced decrease.

5. Acknowledgments

Authors thank Laporta farm for the assistance in this study.

6. Litterature cited

AASAMAA K., APHALO P.J., 2016. Effect of vegetational shade and its components on stomatal responses to red, blue and green light in two deciduous tree species with different shade tolerance. Environmental and Experimental Botany, 121, 94–101.

AL-HELAL I.M., ABDEL-GHANY A.M., 2010. Responses of plastic shading nets to global and diffuse PAR transfer: optical properties and evaluation. NJAS-Wageningen Journal of Life Scioence, 125-132.

BOGO A., CASA R.T., AGOSTINETO L., GONÇALVES M.J., RUFATO L., 2012. Effect of hail protection nets on apple scab in 'Royal Gala'and 'Fuji'apple cultivars. Crop Protect., 38, 49–52.

BOSCO L.C., BERGAMASCHI H., CARDOSO L.S., AIRES DE PAULA V., BETTIO MARODIN G.A., CORREA BRAUNER P.,2018. Microclimate alterations caused by agriculturalhail net coverage and effects on apple tree yield in subtropical climate of Southern Brazil. Bragantia, 77(1). doi.org/10.1590/1678-4499.2016459.

CASTELLANO S., SCARASCIA MUGNOZZA G., RUSSO G., BRIASSOULIS D., MISTRIOTIS A, HEMMING S., WAAIJENBER D.G., 2008. Design and use citeria of netting systems for agricultural production in Italy. J. Ag. Eng., 3, 31-42.

de PALMA L., TARRICONE L., VOX G., LIMOSANI P., DE MICHELE M., NOVELLO V., 2012. Semiforzatura precoce con film colorati: fisiologia delle viti e qualità del prodotto. Rivista di Frutticoltura, 1-2, 32-38.

DELUC L.G., QUILICI D.R., DECENDIT A., GRIMPLET J., WHEATLEY M.D., SCHLAUCH K.A., MERILLON JM., CUSHMAN J.C., CRAMER G.R., 2009. Water deficit alters differentially metabolic pathways affecting important flavor and quality traits in grape berries of Cabernet Sauvignon and Chardonnay. BMC Genomics, 10, 212.

DI STEFANO R., CRAVERO M.C., 1991. Metodi per lo studio dei polifenoli dell'uva. Riv.Vitic.Enol., 2, 37-45.

IGLESIAS I., ALEGRE S., 2006. The effect of anti-hail nets on fruit protection, radiation, temperature, quality and profitability of 'Mondial Gala' apples. J. Appl. Hortic. 8, 91-100.

KOYAMA K., IKEDA H., POUDEL P.R., GOTO-YAMAMOTO N., 2012. Light quality affects flavonoid biosynthesis in young berries of Cabernet Sauvignon grape. Phytochemistry, 78, 54–64.

JOUBERT C., YOUNG P.R., EYÉGHÉ-BICKONG H.A., VIVIER M.A., 2016. Field-grown grapevine berries use carotenoids and the associated xanthophyll cycles to acclimate to UV exposure differentially in high and low light (shade) conditions. *Front. Plant Sci*. 7, 786 fpls.2016.00786.

NOVELLO V., de PALMA L., TAMBORRA P., MONTEMURRO P., 1999. Variazioni del contenuto in lina¬lolo in Vitis vinifera L. cv 'Italia' in relazione al sistema di gestione del suolo. Quad. Vitic. Enol. Univ. Torino, 23, 271-278.

RE R., PELLEGRINI N., PROTEGGENTE A., PANNALA A., YANG M., RICE-EVANS C., 1999. Antioxidant activity applying an improved ABTS radical cation decolorization assay. Free Radical Biology & Medicine, 26(9/10), 1231-1237.

SCHETTINI E., 2011. Nets for peach protected cultivation. J. Ag. Eng. – Riv. Ing. Agr.,4, 25-31.

SHAHAK Y., GAL E., OFFIR Y., BEN-YAKIR D., 2008. Photoselective shade netting integrated with greenhouse technologies for improved performance of vegetable and ornamental crops. *Acta Hortic*., 797, 75–80.

SOLOMAKHIN A., BLANKE M., 2010. The microclimate under coloured hailnets affects leaf and fruit temperature, leaf anatomy, vegetative and reproductive growth as well as fruit colouration in apple. *Ann. Appl. Biol*., 156, 121-136.

VAN LEEUWEN C., TREGOAT, O., CHONE X., BOIS B., PERNET D., GAUDILLERE J.P., 2009. Vine water status is a key factor in grape ripening and vin¬tage quality for red Bordeaux wine. How can it be assessed for vineyard management pur¬poses? J. Int. Sci. Vigne Vin, 43 (3), 121-134.

XIA E.Q., DEN G.F., GUO Y.J., LI H.B., 2010. Biological activities of polyphenols from grapes. Int. J. Mol. Sci., 11, 622–646.

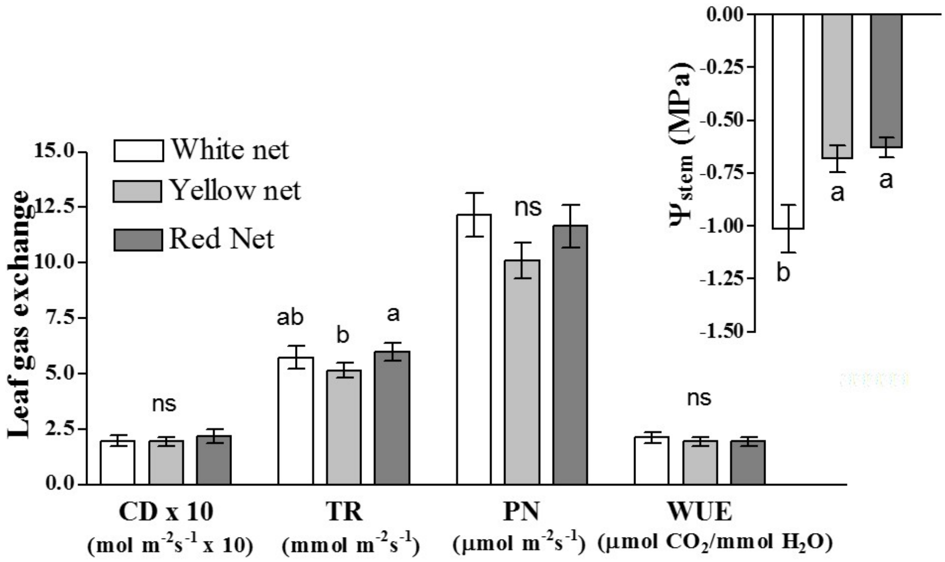

Figure 1 - Average rates of stomata conductance (CD), transpiration (TR), net photosynthesis (PN), leaf water use efficiency (WUE) measured, at mid-morning of typical days of mid-July and late August, on mature leaves of 'Italia' vines covered with white, yellow and red hail-nets (3x5 mm mesh), exposed to PAR irradiance around 1450 umol m^{-2} s^{-1}. Different letters indicate statistical differences at $p \leq 0.05$; ns = not significant differences.

Table 3 – Statistical relationships between bunch or berry weight and leaf gas exchange in 'Italia' vines covered with white, yellow and red hail-nets (3x5 mm mesh).

Association	*R*	*p* value	Equation	R^2
CD-Bunch weight	0.71089	0.0030	Bunch weight= 0.387646 + 0.943496*CD	0.5054
CD-Berry weight	0.82482	0.0002	Berry weight= 6.59372 + 12.27528*CD	0.6803
TR-Bunch weight	0.81064	0.0002	Bunch weight = 0.245381 + 0.059351*TR	0.6571
TR-Berry weight	0.94617	<0.0001	Berry weight = 4.716869 + 0.776793*TR	0.8952
PN-Bunch weight	0.73878	0.0017	Bunch weight = 0.321221 + 0.022763*PN	0.5458
PN-Berry weight	0.77276	0.0007	Berry weight = 6.060422 + 0.26699*PN	0.5972

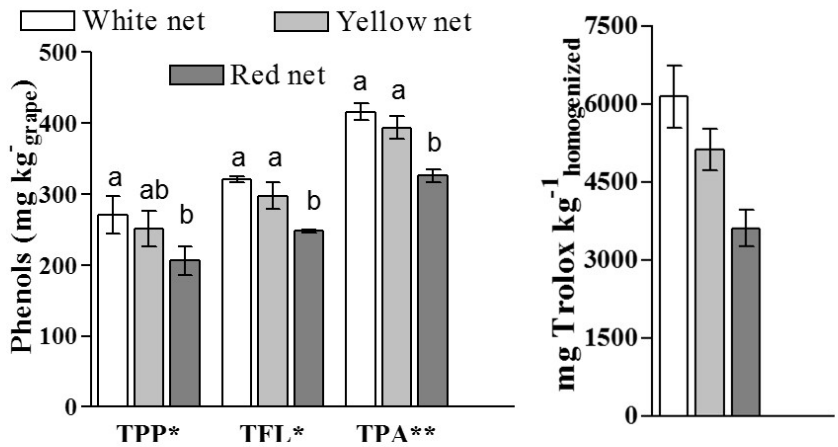

Figure 3 – Indices of berry skin concentration (left) in total polyphenols (TPP), flavonoids (TFL), proantocyanidines (TPA), and index of berry antioxidant activity (AA, right) of 'Italia' grapes produced in vineyard covered with white, yellow and red hail-nets (3x5 mm mesh). Different letters indicate statistical differences at $p \leq 0.05$. *expressed as (+)catechin ; **expressed as cyanidin chloride.