TEMPORAL DYNAMICS OF PHOTOSYNTHETICALLY ACTIVE RADIATION IN THE FRUIT ZONE OF CV. ISTRIAN MALVASIA FOLLOWING EARLY DEFOLIATION

LA DYNAMIQUE TEMPORELLE DU RAYONNEMENT PHOTOSYNTHETIQUE ACTIF DANS LA ZONE DES GRAPPES DU CV. MALVASIE D'ISTRIE SUIVANT LA DEFOLIATION PRECOCE

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SUMMARY

The aim of this study was to investigate the impact of early defoliation on the temporal dynamics of the photosynthetically active radiation (PAR) in the fruit zone of Istrian Malvasia (*Vitis vinifera* L.) vines. Defoliation of six basal leaves per shoot was performed either pre-bloom or at berry set on vertically shoot positioned Istrian Malvasia vines. Control treatment without defoliation was also included. Fixed radiation sensors were used to intercept PAR in the fruit zone of each treatment as well as above the top of the canopy in order to measure total incident radiation. Berry set defoliation treatment had the highest mean daily PAR values inside the fruit zone from the phenological stage berries pea size until harvest, while control treatment vines had the lowest mean daily PAR values due to higher shading of leaves from the primary shoots. Pre-bloom defoliation treatment had higher PAR values than control treatment, although considerably lower than berry set treatment. Higher PAR values in berry set treatment in comparison to pre-bloom treatment is a consequence of later and less intensive lateral regrowth in berry set treatment. The highest PAR values in the fruit zone during the day were observed from 9 to 11 am and from 4 to 6 pm. During this period the differences in PAR among treatments were most expressed. From 12 am to 3 am PAR values in the fruit zone were lower and differences among treatments were less expressed. As PAR affects carbon assimilation of leaves and total dry matter production, the results of this study affirm the positive effects of early defoliation in the production of Istrian Malvasia grapes and indicate that this practice is suitable to avoid the formation of shaded canopies which are usual for this cultivar.

RÉSUMÉ

Le but de cette étude était d'étudier l'impact de la défoliation précoce sur la dynamique temporelle de l'intensité du rayonnement photosynthétiquement actif (RPA) dans la zone des grappes de la Malvasie d'Istrie (*Vitis vinifera* L.). La défoliation de six feuilles basales par rameau a été effectuée soit avant de la floraison ou à la nouaison. Traitement contrôle sans défoliation a été également inclus. Des capteurs de rayonnement fixes ont été utilisés pour intercepter RPA dans la zone des grappes de chaque traitement, ainsi que au-dessus de la vigne, afin de mesurer le rayonnement incident total. Traitement du défoliation à la nouaison était le plus élevé en les valeurs moyenne journalière du RPA dans zone des grappes, le traitement du défoliation avant la floraison avait le valeurs moyens, tandis que le traitement de contrôle avait le plus faibles valeurs moyennes quotidiennes du RPA. La plus élevée intensité du RPA dans la zone des grappes au cours de la journée a été observé du 9 à 11 h de la matin et de 4 à 6 heures de l'après-midi. Pendant cette période, les différences entre les traitements dans RPA ont été le plus exprimé. De 12 heures à 3 heures de l'après-midi l'intensité du RPA dans la zone des grappes etait le plus faible et les différences entre les traitements étaient moins exprimé. Ainsi que RPA affecte l'assimilation du carbone de feuilles et de production totale de matière sèche, les résultats de cette étude confirment les effets positifs de la défoliation précoce dans la production de la Malvasie d'Istrie et indiquent que cette pratique est appropriée pour éviter la formation des ombragés qui sont habituelles pour ce cultivar.

Key Words: Photosynthetically active radiation, Early defoliation, Istrian Malvasia

Mots clés: Rayonnement photosynthétiquement actif, défoliation précoce, Malvasie d'Istrie

INTRODUCTION

Photosynthetically active radiation (PAR) is the radiation utilized in photosynthesis. It comprises the visible wavelength range from 400 to 700 nm and it is expressed in μmol m^{-2} s^{-1} (Keller, 2010). At clear sky and full sunlight the photon flux of PAR can exceed 2000 μmol m^{-2} s^{-1}, while the light saturation for photosynthesis in leaves is achieved with 700 to 1200 μmol m^{-2} s^{-1}. Photosynthesis below light saturation is referred light limited (Keller, 2010), and this is often the case for interior leaves in dense grapevine canopies. The balance of PAR in grapevine canopies is in close relationship with total dry matter vine production and with qualitative characteristics of grapes.

Istrian Malvasia (*Vitis vinifera* L.), planted on about 57% of vineyard area in Croatian Istria, is characterized by high vigor (Bubola and Peršurić, 2012; Vivoda, 2003), which leads to excessive vegetative growth and the formation of dense canopies. Thus, special importance in its production is given to canopy management practices used to improve canopy microclimate. One of these practices is early defoliation, usually performed before bloom or at berry set, a technique widely studied in recent years owing to its positive effects on fruit quality (Bubola and Peršurić, 2012; Poni *et al.*, 2006; Intrieri *et al.*, 2008; Tardaguila *et al.*, 2010). Defoliation at fruit set increased cluster light exposure, as evidenced by the higher PAR values recorded on leaf removal vines than on control vines of the Nebbiolo variety (Chorti *et al*., 2010).

This study investigated the temporal dynamics of fruit zone PAR of Istrian Malvasia vines following early defoliation (pre-bloom, berry set and control treatments), with the goal to characterize mean daily values of PAR from the phenological stage berries pea size until harvest and the diurnal PAR trend among treatments.

MATERIALS AND METHODS

Vitis vinifera L. cv. Istrian Malvasia vines (clone VCR4), grafted on *Vitis berlandieri* × *Vitis riparia* SO4 rootstock (clone 102), were planted in 2006 in the experimental vineyard located at the Institute of Agriculture and Tourism in Poreč (West Istria winegrowing region, Croatia), 400 m distant from the Adriatic Sea. Rows in the vineyard were oriented in a direction NNE-SSW, with a declination of 26° from direction north-south. Row and vine spacing were 2.5 × 0.8 m, corresponding to 5000 vines per hectare. Vines were trained to Istrac training system, a bilateral spur cordon. From six to eight spurs with two nodes were left on vines at winter pruning. Shoots were vertically positioned and sustained with one pair of catching wires, positioned 40 cm above the basal wire. The basal wire was positioned 90 cm above the ground level. Two weeks after the end of bloom shoots were trimmed 35 cm above catching wires. Other viticultural practices were standard for the cultivar and region. The soil in the vineyard was typical, medium deep, anthropogenized red Mediterranean soil (*Terra rossa*).

During 2011 a defoliation trial of Istrian Malvasia vines was performed. Vines were defoliated either pre-bloom (May the 23rd), when inflorescences had single flowers separated, corresponding to grapevine growth stage 17 according to the modified E-L system (Coombe, 1995), or at berry set (June the 6th), when berries had a diameter from 2 to 4 mm, corresponding to grapevine growth stage 27 according to the modified E-L system. Defoliation consisted of the removal of six basal leaves from the main shoots, and only some highly developed lateral shoots. Control treatment without defoliation was also included, resulting in a total of three treatments. Each treatment was applied in three replications with six adjacent vines, distributed in a randomized block design.

The measurement of photosynthetically active radiation (PAR) was performed with fixed PAR photon flux sensors, model QSO-S, Decagon Devices, Pullman, Washington, USA. Sensors were located above the top of the canopy in order to measure total incident radiation and inside the fruit zone of the three treatments, 10 cm above the basal wire, and were connected with data loggers. For each treatment two sensors were used. PAR measurement was performed from 5:30 am to 8:30 pm, once every 15 minutes. Mean diurnal PAR patterns were generated from hourly means calculated from the raw data. The monitoring period lasted from berries pea size (grapevine growth stage 31 according to the modified E-L system), which occurred on June the 14th in 2011, until harvest (grapevine growth stage 38 according to the modified E-L system), which occurred on September the 7th.

Yield and number of clusters per vine were recorded at harvest. 200 berries were randomly chosen from each treatment replicate to determine mean berry weight. Mean cluster weight was calculated from yield and clusters per vine data, while number of berries per cluster was estimated from cluster weight and mean berry weight. Leaf area was determined as described by Smart and Robinson (1991) during the grape maturation period, after the vegetative growth has ceased.

Grapes were harvested on September the 7th 2011, when soluble solids in grape juice reached approximately 24 Brix and between 5 and 6 g L^{-1} of titratable acidity (expressed as tartaric acid). Samples for juice analyses were taken after crushing-destemming of grapes. Soluble solids (Brix) were assessed by HR200 digital refractometer (APT Instruments, Litchfield, IL, USA). Titratable acidity was analyzed by titration with 0.1 N NaOH to a pH 7.0 endpoint, using bromthymol blue as indicator and was expressed as g L^{-1} of tartaric acid. pH was determined with a MP220 pH-meter (Mettler Toledo, Germany).

Data were analyzed by the analysis of variance (ANOVA) using the software package Statistica 9. LSD test was used for post hoc comparison of significant treatment means.

RESULTS AND DISCUSSION

In this study, pre-bloom and berry set defoliation treatments reduced yield and affected other yield components of Istrian Malvasia vines, accordingly to the results of other early defoliation studies (Bubola and Peršurić, 2012; Poni *et al*., 2006; Intrieri *et al*., 2008; Tardaguila *et al*., 2010). The highest yield per vine was achieved with control treatment (2.59 kg), followed by berry set (2.21 kg) and the lowest yield of 1.92 kg/vine was achieved with pre-bloom defoliation treatment (Table I). Lower yield per vine obtained with defoliation treatments was a consequence of lower berry set due to lower carbohydrate supply at anthesis (Poni *et al*., 2006). In our study lower berry set resulted in lower number of berries per cluster in pre-bloom treatment (56 berries) and berry set treatment (63

Table I. Effects of early defoliation on Istrian Malvasia yield components, leaf area and basic composition of grape juice
Effets de la défoliation précoce sur les composants du rendement de la Malvasie d'Istrie, la surface foliaire et la composition du moût

Treatment	Cluster weight (g)	Berry weight (g)	Yield/vine (kg)	Leaf area/ vine (m^2)	Leaf area/ yield (m^2 kg^{-1})	Soluble solids (Brix)	Titratable acidity (g L^{-1})	pH
Control	161 a	2.27	2.59 a	4.20	1.66	23.6 b	5.4	3.53
Pre-bloom defoliation	131 b	2.25	1.92 c	3.80	1.98	24.7 a	5.5	3.56
Berry set defoliation	149 ab	2.29	2.21 b	3.50	1.59	24.6 a	5.5	3.54

Means within column designated by different letters are significantly different by the LSD test at $P = 0.05$.

berries) in comparison to control treatment, which had 68 berries per cluster. Consequently, cluster weight was highest in control treatment (161 g), followed by berry set (149 g) and pre-bloom defoliation treatment (131 g). Unlike the value of berries per cluster, berry weight was not affected by early defoliation treatments and it was in a range from 2.25 g (pre-bloom defoliation) to 2.29 g (berry set defoliation).

Total leaf area per vine ranged from 3.50 m^2 (berry set defoliation) to 4.20 m^2 (control treatment). Leaf area/yield ratio, as an important determinant of grape quality, was higher in pre-bloom defoliation treatment (1.98 m^2 kg^{-1}) than in control and berry set defoliation treatment, which had the leaf area/yield ratios of 1.66 and 1.59 m^2 kg^{-1}, respectively.

Early defoliation treatments positively affected the concentration of soluble solids, resulting with 24.7 Brix for pre-bloom defoliation treatment and 24.6 Brix for berry set defoliation treatment, while control treatment obtained 23.6 Brix. This difference was not very large because control treatment had rather high leaf area/yield ratio (1.66 m^2 kg^{-1}). Nonetheless, our results affirm the effectiveness of this practice in fruit composition improvement, previously found by other authors who investigated early defoliation with six to eight leaves per shoot removed (Poni *et al*., 2006; Intrieri *et al*., 2008). All treatments had very similar values of titratable acidity, which was in a range of 5.4 to 5.5 g L^{-1} and pH, which was in a range of 3.53 to 3.56.

Photosynthetically active radiation (PAR) was monitored in the fruit zone of control and defoliated treatments from the phenological stage berries pea size to harvest. During the first two weeks of the monitored period, berry set treatment had the highest values of mean daily PAR inside the fruit zone, followed by pre-bloom treatment, while control treatment vines had the lowest values of mean daily PAR (Figure 1).

Higher values of mean daily PAR for the berry set treatment in comparison to pre-bloom treatment in the first two weeks of monitoring was a consequence of later development of lateral shoots in berry set treatment due to later execution of defoliation. After the laterals of berry set treatment attain fully development, the difference between these two treatments diminished, although berry set treatment had a tendency of higher mean daily PAR than pre-bloom treatment throughout the rest of the monitored period. The reason of generally higher mean daily PAR for berry set treatment is a poorer development of lateral shoots in berry set than in pre-bloom treatment, which also had lower total leaf area (data not shown). Control treatment obviously had the lowest values of mean daily PAR throughout the monitored period due to higher shading of leaves from the main shoots. Higher PAR values following berry set defoliation than on control vines were evidenced also on Nebbiolo variety (Chorti *et al*., 2010).

If mean daily PAR for the investigated treatments on a daily basis is presented as percentage of total

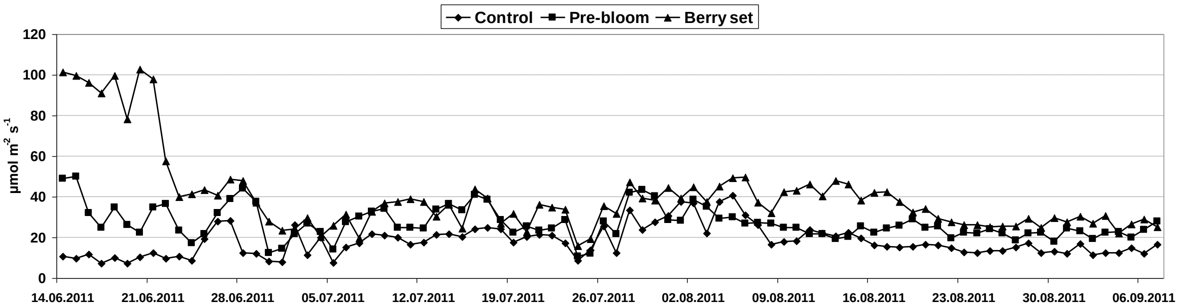

Figure 1 - Mean daily PAR values in the fruit zone (µmol m^{-2} s^{-1})
Moyenne quotidienne RPA dans la zone des grappes (µmol m^{-2} s^{-1})

incident radiation, in most cases it is below 4% (Figure 2). This is a consequence of the favorable development of Istrian Malvasia canopy even after defoliation.

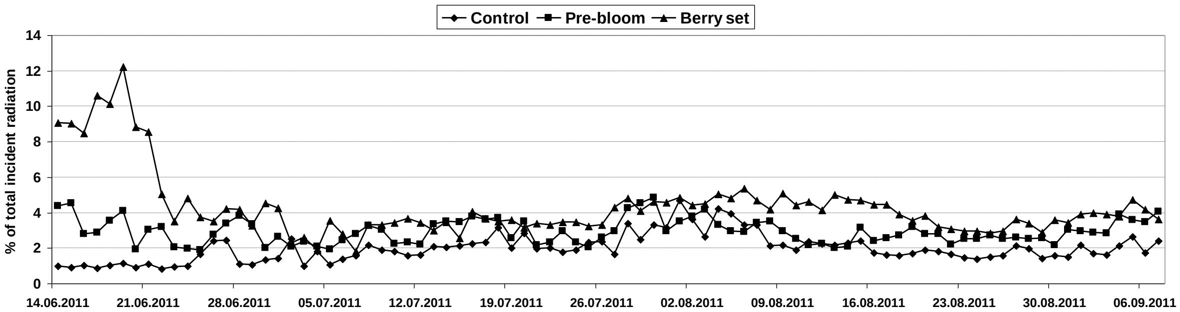

Figure 2. Mean daily PAR values in the fruit zone expressed as % of total incident radiation
Moyenne quotidienne RPA dans la zone des grappes exprimée en % du rayonnement incident total

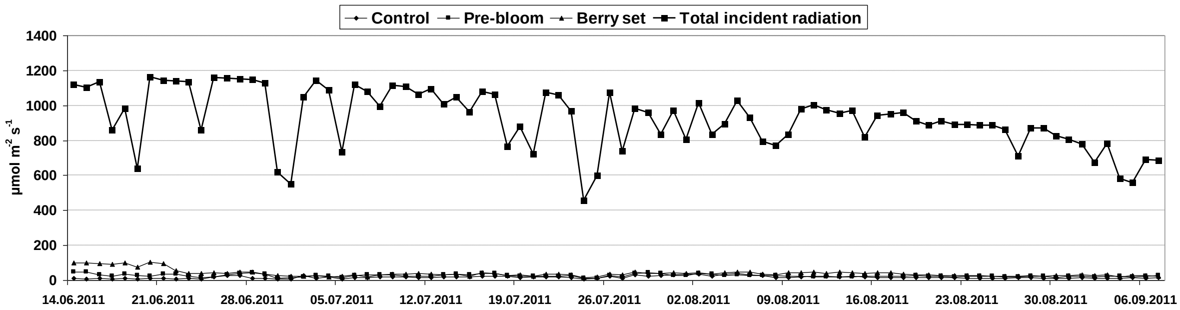

Figure 3. Mean daily PAR values in the fruit zone with total incident radiation included (µmol m^{-2} s^{-1})
Moyenne quotidienne RPA dans la zone des grappes avec le rayonnement incident total inclus (µmol m^{-2} s^{-1})

In Figure 3 mean daily PAR values for the investigated treatments are presented together with total incident radiation. Cloudy and rainy days are clearly indicated with lower values of total incident PAR. The constant decrease of total incident PAR from the beginning of July until the harvest is also perceived (Figure 3) and it is due to gradual shortening of day length.

Throughout the monitored period (from July the 14^{th} to September the 7^{th} and from 5:30 am to 8:30 pm each day) mean PAR resulted in 17 µmol m^{-2} s^{-1} or 1.9% of total incident radiation for control treatment, 28 µmol m^{-2} s^{-1} or 3.0% of total incident radiation for pre-bloom defoliation treatment and 38 µmol m^{-2} s^{-1} or 4.1% of total incident radiation for berry set defoliation treatment.

In this study PAR values recorded in the fruit zones of all treatments were far from light saturation point for photosynthesis, which is achieved with 700-1200 µmol m^{-2} s^{-1} (Keller, 2010). This fact implies that leaves inside the canopies of all treatments were not producing assimilates at their full capacity, although the situation was more favorable for defoliation treatments than for control treatment.

The highest PAR values in the fruit zone during the day in the monitored period were observed from 9 to 11 am and from 4 to 6 pm (Figure 4). These periods correspond to the time when the sunshine enters sideways the cluster zone, during the morning from the east side and during the afternoon from the west side. During these two periods the differences in PAR values among treatments were most expressed.

As rows in the vineyard were oriented in a direction NNE-SSW, with a declination of 26° from direction north-south, in the middle of the day and slightly afterwards (from 12 am to 3 am) PAR values in the fruit zone declined in all treatments and differences among treatments were less expressed (Figure 4). Although the sun radiation during this period was highest, the sunshine has to undergo through the entire VSP canopy before reaching the fruit zone, and a high portion of PAR was absorbed by above positioned leaves.

Although it had lower total leaf area and lower leaf area/yield ratio than other two treatments, berry set defoliation treatment obtained higher Brix than control treatment and almost the same Brix as pre-bloom treatment. This reaction was a consequence of better exposure of the canopy to the incident PAR thus allowing the interior leaves to produce more assimilates available for the developing berries.

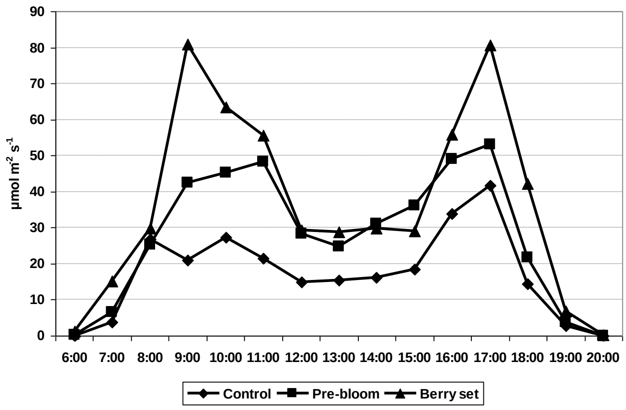

Figure 4 - Mean diurnal PAR values from berries pea size to harvest (µmol m^{-2} s^{-1})
RPA moyenne diurne dans la zone des grappes (µmol m^{-2} s^{-1})

CONCLUSIONS

Early defoliation improved fruit zone microclimate, as evidenced by higher PAR values recorded on vines of pre-bloom and berry set treatments than on control vines. Owing to higher PAR value inside canopy and consequently better photosynthetic activity of internal leaves, vines with the lowest leaf area and lowest leaf area/yield ratio (berry set treatment) obtained as high Brix as vines with the highest leaf area/yield ratio (pre-bloom treatment). Control vines had the lowest inside canopy PAR value from the phenological stage berries pea size until harvest, and on the diurnal basis, which resulted in lower Brix at harvest. The results of this study affirm the positive effects of early defoliation technique in the production of Istrian Malvasia grapes and indicate that this practice is suitable to avoid the formation of shaded canopies, which are usual for this cultivar. Moreover, if early defoliation at the severity of six leaves per main shoot is applied, the canopy microclimate remains favorable throughout the season and there is no any need for subsequent leaf removal (etc. at veraison).

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