Yield Components, Vegetative Growth and Fruit Composition of 'Istrian Malvasia' (*Vitis vinifera* L.) as Affected by the Timing of Partial Defoliation

Marijan BUBOLA (✉)
Đordano PERŠURIĆ

Summary

The influence of partial defoliation performed at different grapevine growth stages on yield components, vegetative growth and fruit composition of 'Istrian Malvasia' ('Malvazija istarska') vines was investigated. During two consecutive seasons partial defoliation was performed manually at three grapevine growth stages; before bloom (BB), after bloom (AB), and at the beginning of bunch closure (BC). Three to four leaves on the basal part of primary shoots were removed in order to obtain moderately open grapevine canopy with good bunch exposure to sunlight. Control treatment without partial defoliation was also included. Partial defoliation did not significantly affect any of yield components of 'Istrian Malvasia' vines. The only consistent response to partial defoliation was the regrowth of laterals if partial defoliation was done early in the season, leading to the recovering of the removed leaf area from primary shoots. Less intensive regrowth of laterals occurred on BC treatment, resulting in the smallest leaf area per vine and the lowest leaf area/yield ratio, but the differences among treatments were not significant. Basic composition of 'Istrian Malvasia' grape juice (soluble solids, titratable acidity and pH) was not significantly affected by the timing of partial defoliation, but soluble solids tended to be higher in BB treatment and lower in BC treatment. It is concluded that the removal of three to four leaves per shoot at different grapevine growth stages did not considerably affect yield components and basic fruit composition of 'Istrian Malvasia' vines.

Key words

partial defoliation, 'Istrian Malvasia', yield, leaf area, fruit composition

Institute of Agriculture and Tourism, K. Huguesa 8, HR-52440 Poreč, Croatia
✉ e-mail: marijan@iptpo.hr

Received: April 15, 2011 | Accepted: July 22, 2011

Introduction

Partial defoliation in the fruit zone is a common canopy management practice in viticulture production. It is especially important if vegetative growth is too excessive, leading to dense grapevine canopies with unfavorable microclimate (Hunter and Visser, 1990a; Hunter et al., 1995). Partial defoliation improves sunlight exposure of clusters and remaining leaves, air circulation and pesticide penetration to the fruit zone, with benefits in improved fruit composition and lower disease incidence (Bledsoe et al., 1988; Dokoozlian and Kliewer, 1995; Hunter et al., 1995; Reynolds et al., 1996; Zoecklein et al., 1998; Austin et al., 2011).

If partial defoliation of basal leaves is done early in the season (around bloom), lower carbohydrate supply for the developing flowers or young berries is obtained and the result is lower fruit set (Coombe, 1959; May et al., 1969). Due to its negative effect on yield, it has traditionally been emphasized that leaf removal around bloom should be avoided on a practical basis (Poni et al., 2006). However, in recent years more attention is given to the achievement of high quality grapes and many studies have been focused on the effectiveness of early leaf removal as a tool for reducing crop potential and for inducing looser clusters that are less susceptible to rot (Poni et al., 2006, 2008, 2009; Intrieri et al., 2008; Tardaguila et al., 2010). In these studies usually six or eight basal leaves per shoot were removed before bloom or at fruit set. Owing to the reduced fruit set and higher final leaf area/yield ratio achieved with this technique, it is considered adequate for high-yielding cultivars marked by large, compact clusters, thus obviating the need for the costly and time-consuming technique of cluster thinning (Poni et al., 2006). Fruit composition improvement (higher Brix, pH, anthocyanins and phenolics and lower titratable acidity) was in most cases attained with early defoliation (Poni et al., 2006, 2009; Intrieri et al., 2008; Tardaguila et al., 2010).

Timing of partial defoliation impacts the vegetative response of grapevine. Hunter and Visser (1990a) found that the earlier defoliation was applied, the more lateral shoot length and the number of lateral shoots increased, resulting in higher total shoot length, while if performed at *véraison* it had no effect on lateral growth.

Partial defoliation is widely practiced in Istria, but it is sometimes done in inappropriate timing and intensity, leading to sunburn if bunches are suddenly exposed to direct sunlight during a period of high temperatures, or to inadequate ripening if too intensive partial defoliation is done in late phases of berry development, resulting in low leaf area/yield ratio during maturation period. 'Istrian Malvasia' (*Vitis vinifera* L.), locally known as 'Malvazija istarska', is a native white grapevine cultivar and the most widespread cultivar in Istria region (Croatia), where it is planted in about 57% of vineyard area and the second most widespread cultivar in Croatia, where it is planted on more than 10% of national vineyard area according to the Croatian main register of grape, wine and fruit wine producers, provided by the Institute of Viticulture, Enology and Pomology, Zagreb. As 'Istrian Malvasia' is characterized by high vigor (Mirošević and Turković, 2003; Vivoda, 2003), which is responsible for excessive vegetative growth and the formation of dense canopies, special importance is given to research concerning the manipulation of foliage in order to improve canopy microclimate.

The aim of this study was to assess the influence of partial defoliation of three to four leaves per shoot, performed at different grapevine growth stages (before bloom, after bloom and at bunch closure) on yield components, vegetative growth and fruit composition of 'Istrian Malvasia' vines.

Materials and methods

The experiment was performed in seasons 2009 and 2010 on *Vitis vinifera* L. 'Istrian Malvasia' vines (clone ISV 1) grafted on *Vitis berlandieri* x *Vitis rupestris* 1103P rootstock (clone VCR 107). The experimental vineyard was planted in 2006 and it is 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 x 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. Shoots thinning was performed manually at grapevine growth stage 15 according to the modified E-L system (Coombe, 1995), in order to attain approximately 15 shoots per meter of canopy. 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*).

A randomized block design was used in this experiment, with four canopy manipulation treatments: control treatment without defoliation; partial defoliation before bloom (BB), at grapevine growth stage 18 according to the modified E-L system (Coombe, 1995); partial defoliation immediately after bloom (AB), at grapevine growth stage 27; and partial defoliation at the beginning of bunch closure (BC), at grapevine growth stage 32. Each treatment was applied in three replications with five adjacent vines. Partial defoliation was performed manually by removing three to four leaves on the basal part of primary shoots in order to obtain moderately open grapevine canopy with good bunch exposure to sunlight. Laterals growing in the fruiting zone were removed after bloom in all investigated treatments.

Grapes were harvested when soluble solids in grape juice reached approximately 22° Brix and 6 g L^{-1} of titratable acidity (expressed as tartaric acid). In 2009 grapes were harvested on September the 11^{th} and in 2010 on September the 20^{th}. 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, when the vegetative growth has ceased. 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 value was determined with a MP220 pH-meter (Mettler Toledo, Germany). Weight of cane prunings was measured at winter pruning. Single cane weight was calculated from pruning weight and shoots per vine data.

The sum of growing-degree days in the period from April the 1st to September the 30th in season 2009 was 1950, while in season 2010 it was 1725. The sum of rainfall in season 2009 was 247 mm, while in season 2010 it was 591 mm.

Data were analyzed using the Mixed Model Procedure of the SAS statistical package (SAS Institute, Cary, North Carolina, USA). Analysis of variance was computed with treatment and growing season considered fixed. Mean differences were calculated using the LSD values if the F-test was significant at $P = 0.05$.

Results and discussion

Partial defoliation of three to four basal leaves performed before bloom, after bloom and at the beginning of bunch closure did not significantly affect any of yield components of 'Istrian Malvasia' vines, averaged over seasons 2009 and 2010 (Table 1). Although they had somewhat less berries per cluster compared to other treatments, BB and AB treatments did not significantly reduce the number of berries per cluster (Table 1), meaning that early defoliation did not lead to a substantial change in carbohydrate supply at anthesis, as a determinant of fruit set (Coombe, 1959). Bledsoe et al. (1988) found no impact of partial defoliation performed at fruit set on yield components of Sauvignon blanc vines, but several authors found that early defoliation reduces fruit set and consequently the number of berries per cluster (Coombe, 1959; Poni et al., 2006, 2008, 2009; Intrieri et al., 2008; Tardaguila et al., 2010). It should be emphasized that in these studies usually six or more basal leaves per shoot were removed, while in our study three to four leaves per shoot were removed. This intensity of leaf removal in our study was chosen because it is a typical intensity of leaf removal widely performed by grape growers of 'Istrian Malvasia' in Istria.

Berry weight did not vary significantly among treatments, implying that partial defoliation had no considerable impact on the assimilate availability for the developing berries following defoliation. In some previous investigations smaller berries developed following partial defoliation (May et al., 1969; Hunter and Visser, 1990b; Poni et al., 2006; Tardaguila et al., 2010), while in some other studies (Bledsoe et al., 1988; Guidoni et al., 2008; Intrieri et al., 2008) no differences among treatments were found, or berry weight was even increased on defoliated treatments (Poni et al., 2009).

No difference in number of clusters per shoot in the second season of investigation was attained among treatments, meaning that the difference in canopy microclimate following defoliation in the previous season did not impact the initiation of inflorescences in the buds. This finding is in accordance to Intrieri et al. (2008), who found that defoliation of six leaves per shoot, applied before or after bloom on 'Sangiovese' cultivar, does not affect bud fruitfulness.

If comparing the two growing seasons, it can be observed that cluster weight and berry weight were significantly higher in season 2010, while the number of clusters per shoot was significantly higher in 2009. Berry weight was higher in 2010 due to more rainfall during this season that enabled better conditions for cell division and enlargement. Although the number of berries per cluster was not significantly different between the two seasons, cluster weight was higher in 2010 as a result of higher berry weight. There was no significant interaction between treatment and growing season for any of yield components, indicating that treatments had similar impact on yield components in both years of investigation.

Due to the similar node number on primary shoots of all treatments, achieved with shoot trimming, leaf area on primary shoot (on a per shoot basis) was significantly larger on control treatment vines than on defoliated treatments (Table 2). Larger leaf area of primary shoots on control treatment in comparison to defoliated treatments was obtained even on non trimmed, pot-grown 'Sangiovese' vines, as well as on field-grown 'Trebbiano' vines (Poni et al., 2006). Leaf area of primary shoots on a per vine basis followed the same trend as on per shoot basis.

Leaf area of laterals per one primary shoot was significantly higher on BB treatment than on BC and control treatments. This indicates that early defoliation stimulated the growth of laterals. Lateral leaf area per shoot of AB treatment, although larger, was not significantly different if compared to BC and control treatments. Similar results were found for 'Cabernet Sauvignon' vines (Hunter and Visser, 1990a), where more total lateral shoot

Table 1. Effects of partial defoliation on yield components of 'Istrian Malvasia' vines

	Yield/vine (kg)	Clusters/ vine	Cluster weight (g)	Clusters/ shoot	Shoots/ vine	Yield/ shoot (g)	Berry weight (g)	Berries/ cluster
Treatment								
Control	3.22	17.2	190	1.52	11.4	283	2.21	86
BB	3.33	17.8	188	1.55	11.5	289	2.41	78
AB	3.51	18.3	197	1.49	12.2	288	2.36	83
BC	3.66	17.3	212	1.46	11.9	308	2.32	92
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Season								
2009	3.15	18.4	173	1.62	11.4	277	2.15	81
2010	3.71	16.9	220	1.40	12.1	307	2.50	88
Significance	n.s.	n.s.	*	**	n.s.	n.s.	**	n.s.
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

*, **, ***, n.s.: significant at $P = 0.05$, 0.01, and 0.001 levels, and not significant by the F-test, respectively.

Table 2. Effects of partial defoliation on leaf area components and leaf area/yield ratio of 'Istrian Malvasia' vines

	Leaf area of primary shoot (m^2)	Leaf area of laterals per shoot (m^2)	Total leaf area per shoot (m^2)	Leaf area of primary shoots per vine (m^2)	Leaf area of laterals per vine (m^2)	Proportion of laterals in total leaf area (%)	Total leaf area/vine (m^2)	Leaf area/ yield (m^2 kg^{-1})
Treatment								
Control	0.156 a	0.103 b	0.259	1.77 a	1.19 b	38 b	2.96	0.92
BB	0.109 b	0.175 a	0.284	1.26 b	1.99 a	61 a	3.25	0.87
AB	0.114 b	0.132 ab	0.246	1.41 b	1.61 ab	52 ab	3.02	0.99
BC	0.121 b	0.112 b	0.234	1.44 b	1.34 ab	47 ab	2.78	0.76
Significance	***	*	n.s.	*	*	*	n.s.	n.s.
Season								
2009	0.118	0.103	0.221	1.35	1.15	45	2.49	0.81
2010	0.132	0.158	0.290	1.60	1.92	54	3.52	0.96
Significance	n.s.	*	*	n.s.	*	n.s.	**	*
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

*, **, ***, n.s.: significant at $P = 0.05$, 0.01, and 0.001 levels, and not significant by the F-test, respectively; Means within column designated by different letters are significantly different by the LSD test at $P = 0.05$.

length per primary shoot, as well as the number of laterals per vine was increased if defoliation was implemented early in the season and no compensatory lateral growth occurred if defoliation was performed at *véraison*. Poni et al. (2009) found that compensatory lateral regrowth on pre-bloom defoliation treatment led to larger lateral leaf area per shoot than in control treatment for 'Barbera' vines, although laterals were removed in the defoliation zone. In some investigations no significantly higher regrowth of laterals occurred on defoliated field-grown vines in comparison to control vines, even if leaf removal was performed before bloom or at fruit set (Poni et al., 2006; Intrieri et al., 2008; Tardaguila et al., 2010). On a per vine basis, leaf area of laterals was significantly higher in BB treatment than in control treatment, while AB and BC treatments did not differ significantly with other treatments.

Total leaf area per shoot, as well as total leaf area per vine did not differ significantly among treatments. This was a result of compensatory growth of laterals on partially defoliated vines. Owing to less intensive regrowth of laterals on vines defoliated at the stage of bunch closure, BC treatment had the smallest total leaf area per shoot and per vine, but the difference with other treatments was not significant. In the investigation conducted by Poni et al. (2009), final leaf area per shoot between early defoliated and control vines of 'Lambrusco' was not significantly different owing to the regrowth of laterals, while early defoliated 'Barbera' vines had higher leaf area per shoot than control vines as a result of strong compensatory lateral regrowth.

The proportion of laterals in total leaf area was highest in BB treatment, it decreased if defoliation was performed during the latter stages (after bloom and at bunch closure) and was lowest in control treatment.

The leaf area/yield ratio did not differ significantly among investigated treatments. This was a consequence of similar leaf area per vine and similar yield per vine in all treatments. Other authors have reported higher leaf area/yield ratio in early defoliated treatments (Poni et al., 2006, 2009), or mostly no significant differences among treatments (Intrieri et al., 2008; Tardaguila et al., 2010), which depended on the impact of early defoliation on fruit set and lateral regrowth.

Intensive growth of laterals occurred during the vegetation period in 2010 due to abundant rainfall in this season. As a result, leaf area of laterals per shoot, total leaf area per shoot, leaf area of laterals per vine, total leaf area per vine and the ratio leaf area/yield were higher in 2010 than in 2009. Although the two seasons were quite different considering the meteorological data, no significant interactions between treatment and season occurred for leaf area components and leaf area/yield ratio, indicating that the treatment had similar effect on these variables in both seasons.

Partial defoliation treatments did not impact pruning weight per vine, single cane weight and yield/pruning weight ratio (Table 3). Similar results reported Hunter et al. (1990a) for 'Cabernet Sauvignon' vines and Bledsoe et al. (1988) for 'Sauvignon blanc' vines. Optimal yield/pruning weight ratio (crop load), as recommended by Kliewer and Dokoozlian (2005) is between 4 and 10 for single canopy training systems. Owing to high vigor of 'Istrian Malvasia' cultivar (Mirošević and Turković, 2003; Vivoda, 2003), yield/pruning weight ratio was on the lower range of recommended values (Table 3).

Significantly higher values of pruning weight per vine and single cane weight were present in 2010 comparing to 2009 due to higher vegetative growth in 2010, which is a consequence of high rainfall in this season. Since yield per vine did not considerably differ among treatments, lower yield/pruning weight ratio occurred in 2010, a season with more pronounced vegetative growth.

Grape composition is usually affected by the leaf area/yield ratio (Naor et al., 2002; Kliewer and Dokoozlian, 2005; Poni et al., 2006, 2009; Guidoni et al., 2008), as more assimilates are available per gram of fruit. As a result of similar values of leaf area/yield ratio among treatments in this research, investigated treatments did not significantly affect basic composition of 'Istrian Malvasia' grape juice, represented by soluble solids, titratable acidity and pH.

Nevertheless, soluble solids tended to be higher in BB treatment and to a certain extent in AB treatment, which is in accordance to Bledsoe et al. (1988), who found that timing of leaf removal did not significantly affect fruit composition, but earlier leaf removal tended to advance sugar accumulation.

Table 3. Effects of partial defoliation on pruning weight, yield/pruning weight ratio and basic composition of 'Istrian Malvasia' grape juice

	Pruning weight/ vine (kg)	Single cane weight (g)	Yield/ pruning weight (kg kg^{-1})	Soluble solids (°Brix)	Titratable acidity (g L^{-1})	pH
Treatment						
Control	0.78	68	4.31	22.1	6.1	3.49
BB	0.83	72	4.10	23.0	5.9	3.49
AB	0.91	75	3.93	22.6	5.9	3.47
BC	0.82	70	4.59	21.6	6.3	3.43
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Season						
2009	0.66	59	4.77	21.9	6.2	3.39
2010	1.01	83	3.69	22.8	5.8	3.55
Significance	***	**	**	n.s.	*	*
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

*, **, ***, n.s.: significant at $P = 0.05$, 0.01, and 0.001 levels, and not significant by the F-test, respectively.

Although not significant, BC treatment had slightly lower degree Brix and pH and higher titratable acidity, indicating delayed ripening. This reaction was expected because leaf removal in this treatment was performed late, so lateral regrowth was not sufficient to compensate the loss of leaves from primary shoots and, consequently, during the period of maturation it had slightly smaller leaf area per vine and lower leaf area/fruit weight ratio in comparison to other treatments.

According to Kriedemann et al. (1970) the production of organic acids declined with leaf age, while the production of sugars increased. As a larger leaf area from lateral shoots was developed on BB treatment in comparison to control treatment, it can be deduced that average leaf age was younger on BB treatment. However, no significant difference in grape juice composition occurred due to the fact that, although younger, laterals developed enough early in the annual cycle and they were already mature during the ripening period.

In other studies partial defoliation had no consistent impact (Zoecklein et al., 1992; Reynolds et al., 1996), had moderate impact (Bledsoe et al., 1988; Reynolds et al., 1995; Tardaguila et al., 2010) or had considerable impact (Intrieri et al., 2008; Poni et al., 2006, 2009) on basic constituents of grape juice (soluble solids, titratable acidity and pH). Such different responses are a consequence of differences in bunch zone microclimate, leaf area/fruit weight ratio, skin-to-pulp ratio of berries and photosynthesis capacity of the source leaves among investigated treatments.

Although season 2010 was characterized by lower growing-degree days and more rainfall than season 2009, significantly lower value of titratable acidity and higher pH was observed in 2010. Soluble solids content was higher in 2010, but the difference between two seasons was not statistically significant. The reason for this reaction was the larger leaf area per vine and higher leaf area/yield ratio in 2010 than in 2009, leading to better fruit ripening and consequently higher soluble solids content and pH and lower titratable acidity in 2010. Moreover, in season 2009 the harvest was anticipated for few days because of unfavorable weather forecast for the following period, thus not enabling the grapes to achieve the desired degree of maturity. No interaction between treatment and season was observed for soluble solids, titratable acidity and pH value of 'Istrian Malvasia' grape juice, indicating that treatments had similar impact on these variables in both years of investigation.

Conclusions

Partial defoliation of three to four leaves per shoot, performed before bloom, after bloom or at bunch closure, can not be considered as a yield regulation tool for 'Istrian Malvasia' cultivar. In this study the only consistent response to partial defoliation was the regrowth of laterals if partial defoliation was done early in the season. Although no significant differences in basic grape juice composition (soluble solids, titratable acidity and pH) occurred between the investigated treatments, Brix tended to be higher if defoliation was performed before bloom, and lower if performed at bunch closure. The question remains if other grape compounds, especially secondary metabolites such as aromatic or phenolic compounds were altered with partial defoliation due to different exposure of clusters to sunlight, at least in the grapevine growth stages following defoliation. Higher degree of defoliation performed before bloom and at fruit set is currently under investigation in order to find out if it will impact 'Istrian Malvasia' productive characteristics and grape composition.

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