Fruit quality and production of *Vitis vinifera* L. Chardonnay affected by partial defoliation in tropical highlands

Producción y calidad del fruto en *Vitis vinifera* L. Chardonnay afectados por la defoliación parcial en los altiplanos tropicales

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Abstract. *Using a completely randomized design with two treatments (50% defoliation and a control without defoliation) and six replications per treatment, the fruit quality and production of grape plants subjected to early partial-defoliation in Villa de Leyva – Colombia were determined. Five-year-old* ***Vitis vinifera*** *L. 'Chardonnay' plants were used as the plant material, planted in a trellis system with distances of 2.1 x 1 m. The plants were partially defoliated biweekly, removing every other recently emerged leaf in each of the plants subjected to the defoliation treatment. 130 days after the start of the pruning, the number of harvested clusters was determined for each of the evaluated plants along with the number of berries per cluster, the fresh weight of the clusters, the average berry weight, the fruit pH and diameter, the total soluble solids (TSS), the total titratable acidity (TTA) and the fruit maturity index (MI). The average weights of the clusters and the berries were significantly higher in the plants subjected to a reduced foliar area. All of the fruit quality parameter values increased with defoliation with the exception of TTA, which was higher in the control plants. Therefore, it was concluded that partial-defoliation had a pronounced influence on the fruit quality and production of the 'Chardonnay' grapes.*

Key words: cluster weight, berry weight, total soluble solids, maturity index.

Resumen. *Utilizando un diseño completamente aleatorizado, con dos tratamientos (defoliación al 50% y control sin defoliación) y seis repeticiones por tratamiento, se determinó la producción y la calidad del fruto en plantas de uva sometidas a defoliación parcial temprana en Villa de Leyva – Colombia. Como material vegetal se utilizaron plantas de* ***Vitis vinifera*** *L. 'Chardonnay' de cinco años de edad, sembradas en un sistema de espalderas a una distancia de 2,1 x 1 m. Quincenalmente, se realizó la defoliación parcial a las plantas, retirando una de cada dos hojas recién emergidas en cada una de las plantas sometidas al tratamiento de defoliación. 130 días después de la poda de inducción, se determinó el número de racimos cosechados en cada planta evaluada, el número de bayas por racimo, el peso fresco de los racimos y el peso promedio de la baya, el pH del fruto, su diámetro, el porcentaje de sólidos solubles total (SST), la acidez titulable total (ATT) y el índice de madurez del fruto (IM). El peso promedio del racimo y el peso promedio de la baya, fueron significativamente mayores en las plantas sometidas a la reducción del área foliar. El valor de todos los parámetros de calidad del fruto aumentó con la defoliación, excepto la ATT, la cual fue mayor en las plantas control. Con lo anterior, se pudo concluir que la defoliación parcial tuvo una marcada influencia sobre la producción y la calidad del fruto de uva 'Chardonnay'.*

Palabras claves: peso del racimo, peso de la baya, sólidos solubles totales, índice de madurez.

The production of wine grapes in Colombia has suffered difficulties and restrictions of an agronomical and commercial nature. Imported wines vastly surpass the domestic offerings and also lead the way in terms of production technologies, fruit quality and, principally, wine quality (Peña and Casierra, 2013). The vineyards of Argentina and Chile, given their climatic conditions, have a lot of potential in the development of their vines, surpassing the production levels of Colombia and controlling the Latin American wine market (Lacoste *et al.*, 2010).

Tolima, Huila and Boyacá are among the principal departments with the appropriate edaphoclimatic conditions for the production of wine grapes in Colombia. In the latter, the conditions are optimal for the development of quality wine-growing (Almanza *et al.*, 2011) and can be compared with the better wine-producing regions of South America. Consequently, this department contains the majority of the vineyards that are better-known on the national level. It has an area of 10 ha designated for the cultivation of wine grapes, which produces close to 48 t with a yield of 4.8 t ha^{-1} (Agronet, 2012), making this department the largest producer of wine grapes in Colombia (Almanza *et al.*, 2012). However, these numbers place Colombia below countries such as Argentina and Chile, making it necessary to increase the cultivated area within the national boundaries in order to elevate berry production in a manner that will meet the domestic demand and compete in the global markets.

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A common practice in the cultivation of grapes in the principal wine-producing regions of the world that increases production and improves the quality of the grape is early partial-defoliation (Abd El *et al.*, 2010). However, this method has had contradictory results in various strains. That is, partial-foliar area reduction, manual or mechanical, can be an effective strategy to reduce yield and improve quality in extensively cultivated strains, as in 'Sangiovese' (Intrieri *et al.*, 2008). Furthermore, partial-defoliation is considered an important factor in the improvement of berry quality and production in 'Crimson Seedless' (Abd El *et al.*, 2010). In contrast, Main and Morris (2004) found that no level of defoliation affected the cluster weight of 'Cynthiana'.

Considering the above, the present study evaluated the production and quality of 'Chardonnay' grape plants subjected to early partial-defoliation under tropical highland conditions with the goal of motivating wine-grape producers to carry out this practice and, thereby, improve berry quality and production.

MATERIALS AND METHODS

The study was carried out in Villa de Leyva - Colombia (5°38'16.24"N; 73°31'57.42"W), at an altitude of 2,119 m a.s.l., an average temperature of 16.9°C and an average annual precipitation of 716.9 mm (Ideam, 2012) with sandy clay soils. A completely randomized design was used with two treatments (50% defoliation and a control without defoliation) and six replications per treatment. The evaluation was performed on five-year-old 'Chardonnay' grape plants that were cultivated with a trellis system at a distance of 2.1 x 1 m. The partial-defoliation was performed biweekly for 121 days, removing half of the new leaves from each of the vine plants in the defoliation treatment.

130 days after the start of pruning, the following parameters were determined: the number of clusters harvested per plant, the number of berries per cluster, the average fresh weight of the clusters and the average fresh weight of the berries using a high-capacity digital balance (Scout-Pro, OHAUS), the pH of the juice with a waterproof pHep potentiometer (Hanna Instruments), the fruit diameter with a dial caliper (Shock-proof), the percentage of total soluble solids (TSS) with an ATC/FG-711 portable refractometer (Zhifong), the total titratable acidity (TTA) based on the percentage of tartaric acid according to the methodology of Díaz *et al.* (2008) and the fruit maturity index (MI), calculated as the quotient between TSS and TTA.

It is important to note that the 2011 period, in which this study was carried out, had high rainfall; for this reason, the production and fruit quality values presented in this study are not comparable with other vine crops, but are comparable between the treatments because the study conditions were the same for all of the defoliated plants (Figure 1) (Ideam, 2012).

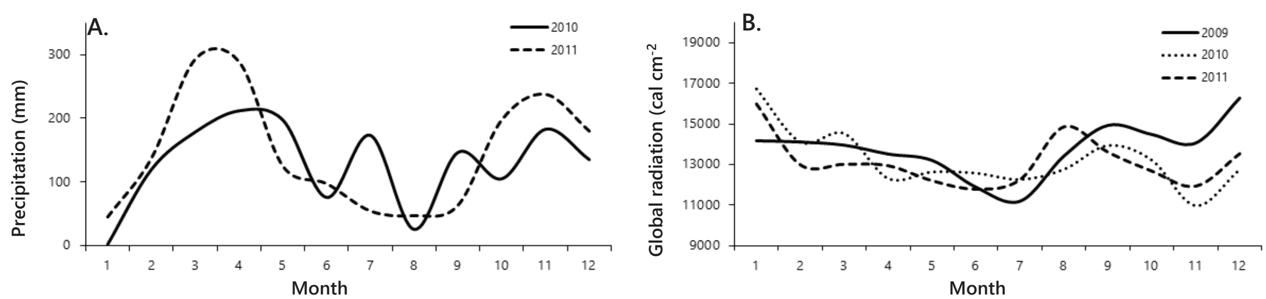

Figure 1. A. Precipitation (2010 and 2011) and B. global radiation (period 2009-2011) in Villa de Leyva, Colombia.

The data obtained were submitted to a classic analysis of variance ($p \leq 0.05$) and a Tukey separation of means test using PASW (Predictive Analytics Software) version 19.0.0 (30-07-2009; IBM Corporation.

RESULTS AND DISCUSSION

The number of clusters and the number of berries for the defoliated plants did not present significant differences with respect to those of the control plants; however, the average fresh weight of the clusters did. The defoliated plants presented an increase of 35.17% for the value of the latter parameter in comparison with the control plants. The average weight of the berries also presented significant differences between the treatments. The berries of the defoliated plants demonstrated an increase of 35.94% for this variable when compared with the control plants. For fruit diameter, statistically significant differences were seen, with the fruits of the defoliated plants having a diameter 6.27% greater than the fruits from the non-defoliated plants (Table 1).

Interestingly, Intrieri *et al.* (2008) found that the number of clusters per plant decreased when 'Sangiovese' plants were subjected to partial-defoliation, regardless of whether the defoliation was manual or mechanical. However, the number of clusters per plant appears to be an indicator of the cultivation practices carried out in the immediately prior cycle, due to the fact that the sprouting of the productive buds is related to, among other things, the pruning and induction and the photosynthetic behavior of the plant in the current season, led by the synthesis of growth regulators. Similarly, Mercader and Isaacs (2004) confirmed that *Vitis labrusca* 'Niagara' plants saw a reduction in the number of nodes per plant; however, this was induced by the defoliation of the previous season, which can affect the number of clusters.

Table 1. Characteristics of the clusters and berries of *Vitis vinifera* L. 'Chardonnay' plants submitted to partial-defoliation.

Source of variation	Number of clusters per plant	Number of berries per cluster	Average fresh weight of the cluster	Average fresh weight of the berries	Fruit diameter (mm)
			(g)		
Control	1.71±0.73 a	24.36±8.12 a	10.14±2.86 a	0.45±0.14 a	9.14±1.40 a
50% defoliation	1.92±0.53 a	23.19±5.24 a	13.71±3.42 b	0.61±0.14 b	9.72±1.32 b

Means with the same letter are not significantly different from each other ($p \leq 0.05$). (n=60).

Contrary to the findings of the present study, partial-defoliation induced a decrease of 86.37% in the number of berries per cluster in another study (Dunuyaali *et al.*, 1983) due to the fact that the loss of foliar area caused a shortage of carbohydrates in the rest of the plant in addition to the low nitrogen levels in the remaining levels as a consequence of the suppressed absorption of nutrient minerals by the plant roots. Added to this suppression, a problem was seen in the hormonal balance of the bound plants for the availability of growth promoters due to the fact that the removal of the leaves induced a lower synthesis and a lower flow of these hormones to the growth points. Intrieri *et al.* (2008) found that the number of berries per cluster decreased notably when manual partial-defoliation was carried out on 'Sangiovese' grape plants. Similarly, Poni *et al.* (2008) confirmed that the number of berries per cluster was reduced with the implementation of partial-defoliation in 'Sangiovese' plants, principally due to the limitation of carbohydrates induced by the defoliation. The average weight of clusters decreased in 'Sangiovese' plants that were subjected to mechanical partial-defoliation in comparison to control plants (Intrieri *et al.*, 2008). Similarly, Poni *et al.* (2008) saw a significant reduction in the cluster weight when 'Sangiovese' plants were submitted to partial-defoliation. It is possible that this reduction in fresh cluster weight is due to the decrease of growth regulators or their precursors, which are synthesized in the leaves and, therefore, are severely affected by reductions in foliar area, because these metabolites are closely related to the growth of the grape (Hunter and Visser, 1990b). Nevertheless, the present study saw a significant increase in the average fresh weight of the clusters, possibly due to the compensatory behavior of the plants, which occasioned a strong flow of photoassimilates from the reserve tissues towards the sink organs, such as the fruits. For example, from branches and trunk, which are reserve organs of the plant (Blouin, 2004).

Hunter and Visser (1990b) confirmed that the average weight of berries decreased when defoliation was carried out at the time of sprouting but increased when the defoliation was carried out during ripening on the vine, including severe defoliation (66%); due to the fact that the removal of a lot of foliar area leads to a growth delay throughout the plant, principally in the fruits, as a consequence of a general weakness in the plant (Koblet, 1984) and an exhaustion of reserves.

Furthermore, it is important to mention that a drastic change in the microclimate of berries, a decrease in the source : sink ratio and the interaction with the metabolic activity of the plant can directly influence the enzymatic activity of the plant, which can induce a redistribution of photoassimilates towards the berries. At the same time, the exposure of clusters to direct sunlight, as a result of a drastic reduction in foliar area, reduces the average weight of the berries due to the high transpiration rates that result from direct sunlight (Crippen and Morrison, 1986).

Meanwhile, Poni *et al.* (2008) did not find significant differences for the variable of average weight of 'Sangiovese' berries exposed to early defoliation. In the present study, the partial removal of leaves provoked an increase in the average fresh weight of the berries, which could be related to an increased demand for photoassimilates on the part of the outflow organs. This explanation was proposed by Candolfi *et al.* (1994), who confirmed that *Vitis vinifera* plants, stressed by a reduction in foliar area, can carry out the translocation of the carbohydrates contained in the reserve tissues to the fruits, resulting in an increased weight. In addition, studies carried out by Mercader and Isaacs (2003) showed that a reduction of foliar area in *Vitis labrusca* 'Niagara' significantly impacted the development of the roots, but that there were no differences in the behavior of the plants, which could allow one to infer that, with defoliation, the fruits of vine plants increase their potential as sink organs to a higher degree than roots because roots reduce their growth as a consequence of the reduction in the flow of photoassimilates towards them.

The size of fruits was not affected when *Vitis vinifera* 'Sangiovese' plants were subjected to partial-defoliation, manual or mechanical (Intrieri *et al.*, 2008; Poni *et al.*, 2008); however, the number of fruits per cluster decreased (Poni *et al.*, 2008), which led the authors to conclude that partial-defoliation is effective at decreasing the number of berries per cluster and, at the same time, plants compensate for this decrease with an increase in the size of the fruits, meaning that a lower number of berries per cluster results in larger-sized berries.

In the evaluation of the fruit quality, the juice pH variable presented significant differences between the treatments. The fruits of the defoliated plants increased the value of this variable by 0.11 units when compared to the fruits from the control plants. The total soluble solids content also demonstrated significant differences between the treatments. The fruits of the defoliated plants had 22.18% more total soluble solids than the fruits of the control plants. The total titratable acidity (TTA), based on the percentage of tartaric acid, presented significant differences between the two treatments. The fruits of the defoliated plants showed an average decrease of 0.56 units for the value of this variable when compared to the fruits from the control plants. The maturity index (MI) was significantly affected by the defoliation. The defoliated plant fruits displayed a 48.58% increase in the value of this quotient when compared to the control plant fruits (Table 2).

Hunter *et al.* (1991) found that partial-defoliation did not influence the pH value of 'Cabernet Sauvignon' fruits and further stated that there were no differences in the canopy temperature of defoliated plants and control plants due to the fact that an increase in the temperature induces changes in the pH values of the fruits because an increase in temperature leads to degradation of organic acids (Strydom, 2006). Intrieri *et al.* (2008) did not find statistically significant differences when evaluating the pH of fruits from defoliated plants in comparison with fruits from a non-defoliated control. Despite these results, Almanza *et al.* (2011) reported that the pH of the fruits decrease with defoliation. On the other hand, Lohitnavy *et al.*, (2010) found that defoliation before blooming caused an increase in pH from 3.97 to 4.01 in comparison with berries from non-defoliated plants.

Similarly, Poni *et al.* (2008) reported that the juice pH of fruits from defoliated 'Sangiovese' plants increased 0.13 units in comparison with the pH of fruits from non-defoliated plants. The authors related this finding to a drastic decrease in the total titratable acidity. Furthermore, they mentioned that this behavior of grape quality has all the characteristics of advanced maturation due mainly to the strong flow of carbohydrates from the source organs towards the sink organs.

It is important to note that the low TSS values of the grapes of the evaluated plants can be attributed to the climatic conditions during the period of the study. The conditions were not optimal for the development of the crops due to the notable influence of the La Nina phenomenon in the department of Boyacá (Colombia) during this period. This period was characterized by high precipitation in the first semester of 2011, when this study was carried out.

Intrieri *et al.* (2008) found that the fruits of defoliated plants presented a higher total soluble solids content in comparison to fruits from non-defoliated plants, regardless of whether the defoliation was manual or mechanical. Almanza *et al.* (2011) found that defoliation increased the TSS concentration in 'Riesling' x 'Silvaner' berries, possibly due to transpiration (Coombe and

Table 2. Chemical parameters of the fruit in *Vitis vinifera* L. cv. 'Chardonnay' plants subjected to partial-defoliation.

Source of variation	pH	TSS (°Brix)	TTA (tartaric acid %)	MI (TSS/TTA)
Control	3.54±0.15a	7.06±1.50a	3.29±0.43b	2.21±0.65a
50% defoliation	3.65±0.15b	8.62±1.40b	2.73±0.48a	3.28±0.88b

Means with the same letter are not significantly different from each other ($p \leq 0.05$). (n=60).

McCarthy, 2000), which could indicate a postharvest problem due to the rapid dehydration of the fruits (Almanza and Balaguera, 2009). Similarly, defoliation before blooming induced an increase in TSS content in 'Semillon' berries (Lohitnavy *et al.* 2010), possibly due to an increase in photosynthetic activity or an increase in the temperature of the fruit. Fruits on plants with leaf removal are exposed to higher solar radiation and, because higher illumination favors dry microenvironments in the clusters, experience improved grape quality (Almanza *et al.*, 2011; Muñoz *et al.*, 2002). In 'Sangiovese', the content of total soluble solids increased in fruits from defoliated plants by 11.36% as compared to the content of fruits from non-defoliated plants. This increase is principally due to the strong flow of photoassimilates from reserve organs which results from the stress of defoliation, unleashing a compensatory response in the plant that results in the advanced maturation of the fruits (Intrieri *et al.*, 2008).

Hunter *et al.* (1991) found that the TSS of 'Cabernet Sauvignon' grapes increased when defoliation was severe (66%) and carried out at the time of sprouting. The mobility of nutrients towards the fruits could explain this TSS behavior; however, the same authors mentioned that, when working with the same plants, they did not see evidence of said photosynthate mobility towards the buds of the plants and, therefore, did not share this appraisal (Hunter and Visser, 1988a). Nevertheless, they also confirmed that there were significant increases in the photosynthetic activity and photosynthetically active radiation (PAR) received by the remaining leaves in the foliage of the plant (Hunter and Visser, 1988b). Similarly, Peña and Casierra (2013) confirmed that a reduction in the foliar area modified the fraction of energy designated for photochemical and non-photochemical processes, which directly induces the photosynthetic process of the plants. Furthermore, the microclimate around berries, conditioned by the foliage density and in terms of the light intensity received by clusters, relative humidity and wind speed, improves with partial-defoliation (Hunter and Visser, 1990a, b). These factors may have contributed to the TSS increase in the 'Cabernet Sauvignon' plants.

Almanza *et al.* (2011) found that total titratable acidity increased when 'Riesling' x 'Silvaner' plants were subjected to partial-defoliation, which was probably related to the consumption of malic acid during the respiration of the fruit cells due to the fact that a lower solar exposure of clusters in dense foliage results in a lower respiration rate and so a lower consumption of organic acids. However, Intrieri *et al.* (2008) did not find statistical differences for the values of total titratable acidity of fruits from defoliated and non-defoliated plants. Similarly, Lohitnavy *et al.* (2010) did not observe significant differences in the total titratable acidity of 'Semillon' berries from defoliated and non-defoliated plants.

On the other hand, other studies found that a reduced foliar area induced a decrease in TTA values in grape fruits (Mota *et al.*, 2010; Keller *et al.*, 2005). Similarly, and in agreement with the results of the present study, Poni *et al.* (2008) registered TTA values that demonstrated significant differences between treatments when 'Sangiovese' grape plants were subjected to partial-defoliation. The fruits of the defoliated plants presented a decrease of 22.86% for TTA as compared to the fruits of the control plants, resulting in an advanced maturation process with elevated TSS and drastically decreased TTA as a consequence of the flow of sugars towards the sink organs of the plants. In addition, changes in the TTA are generally related to the respiration rate of the berries, which is a function of temperature (Lohitnavy *et al.*, 2010), which in turn is closely related to the solar radiation received by the berries.

In contrast to the results of the present study, Almanza *et al.* (2011) found that the MI of 'Riesling' x 'Silvaner' plants decreased by 7.36% when the plants were subjected to defoliation due to the fact that the TTA increased at a higher proportion than the TSS. Gris *et al.* (2010) and Mota *et al.* (2006) indicated that the MI represents a balance between sugars and acids, which is important to the quality of wines because it confers a balanced flavor to the drinks. Falcão *et al.* (2008) confirmed that the optimal values of the MI for the production of wine must be between approximately 30 and 38; however, the environmental conditions that the plants of the present study developed in markedly influenced the physicochemical properties of the berries due to the strong precipitation seen during the period of this study, as caused by the La Nina phenomenon in the region. Nevertheless, the defoliation induced a notable difference in the MI value, allowing for the conclusion that the partial removal of leaves influenced the quality of the 'Chardonnay' berries.

The changes induced by the partial-defoliation on the fruit quality evaluation parameters (pH, TSS, TTA, and MI) had a pronounced influence on the quality of the wine because, as stated by Peña *et al.* (2013) during an evaluation of wine produced from the same plants as the present study, the quality of wine is strongly favored by decreases in the foliar area of 'Chardonnay' grape plants.

CONCLUSIONS

The findings led to the conclusion that early partial-defoliation increases photoassimilates flow towards sink organs such as fruits, which in turn leads to an increase in the average fresh weight of clusters and in the average fresh weight of berries, which in turn modifies the yield of the crop. Partial-defoliation can be applied as a management practice in the cultivation of grapes, specifically for 'Chardonnay' and under the edaphoclimatic conditions of the present study, in order to improve the quality characteristics of the fruits because it increases the total soluble solids (TSS), reduces the total titratable acidity (TTA) and, at the same time, accelerates the fruit maturation process, as reflected by the maturity index.

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