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Pruning affects the vegetative balance of the wine grape (*Vitis vinifera* L.)

La poda afecta el equilibrio vegetativo de la vid (*Vitis vinifera* L.)

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ABSTRACT

Grape cultivation for wine production at altitudes between 2,200 and 2,600 m a.s.l. started in the department of Boyaca in 1982. Quality wines are produced by the AinKarim Vineyard in Ricaurte High. Wine grapes have to possess suitable organoleptic compounds at harvest in order to guarantee quality grape must that can be converted into wine. Therefore, it is necessary to maintain a suitable ratio between the sources and the sinks and to guarantee production, quality and vegetative sustainability over time, conserving the equilibrium and benefiting the productive potential of the vineyard. The aim of this study was to evaluate the productive and vegetative balance effect in the wine grape varieties Cabernet Sauvignon and Sauvignon Blanc in Sutamarchan-Boyaca, considering different pruning types (short, long, and mixed). A bifactorial, completely random statistical design was used. At the time of harvest, the fruit production and pruned wood were evaluated. The long-pruned vines showed the best behavior and the most balanced source/sink relationship, while Sauvignon Blanc demonstrated a better productive yield. Meanwhile, the short and mixed prunings had the better values for the Ravaz index (balance between fruit production and vegetative growth), indicating that they are more suitable for the conditions of the region, allowing for sustainability during the productive cycles of the wine grapes.

Key words: viticulture, vineyards, plant training, source/sink relationship, Ravaz index.

RESUMEN

El cultivo de la vid para elaboración de vino, en altitudes entre 2.200 y 2.600 msnm, se inició en el departamento de Boyacá, en el año de 1982. En el Alto Ricaurte se encuentra el Viñedo Ain Karim, donde se producen vinos de calidad. Para su elaboración, se requiere de vides cuyas cosechas tengan compuestos organolépticos adecuados para garantizar la calidad del mosto que se convertirá en vino. Para tal fin, es necesario lograr una adecuada relación entre las fuentes y los vertederos, y se garantice la producción, la calidad y la sostenibilidad vegetal en el tiempo, conservando el equilibrio y beneficiando el potencial productivo de la viña. El objetivo de la investigación consistió en evaluar el efecto del equilibrio productivo y vegetativo en las variedades de vid Cabernet Sauvignon y Sauvignon Blanc en Sutamarchán-Boyacá, considerando diferentes tipos de poda (corta, larga y mixta). Se realizó un diseño estadístico completamente al azar en forma bifactorial, en el momento de la vendimia se evaluó la producción frutal y madera podada. La poda larga de cepas presentó el mejor comportamiento y la relación fuente/vertedero más equilibrada. Los resultados permitieron determinar que Cabernet Sauvignon es la variedad más vigorosa del viñedo, mientras que Sauvignon Blanc, mostró un mejor rendimiento productivo. En tanto, que las podas corta y mixta, presentaron los mejores valores del índice de Ravaz (balance entre la producción de frutos y el crecimiento vegetativo), indicando que son los más adecuados a implementar bajo las condiciones de la zona, permitiendo la sustentabilidad durante el ciclo productivo de las vides.

Palabras clave: viticultura, viñedos, formación de la planta, relación fuente-vertedero, índice de Raváz.

Introduction

Grape cultivation for wine production at altitudes between 2,200 and 2,600 m a.s.l. started in Colombia in 1982 in Loma de Puntalarga, Valle del Sol, the department of Boyaca (Almanza *et al.*, 2012) and the Ricaurte High zone (Almanza, 2011), where there are currently four vineyards, two of which produced 47 t in 11 ha with a grape yield of 4.1 t ha^{-1} in 2011 (Walteros *et al.*, 2013).

Leaves constitute the principal source of transport material, having a high photosynthetic capacity, transforming light energy into chemical energy (Almanza, 2000), and removing carbohydrates for the harvest; in addition, leaves

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are the organs with the highest carbon uptake in the plants (Fischer *et al*., 2012). Meanwhile, any of the growth, storage, or active metabolic tissues can be a destination or sink for photosynthates (Salisbury and Ross, 2000). Therefore, it can be concluded that the assimilates are displaced from the source towards the sink (Salisbury and Ross, 2000). Fischer *et al*. (2012) reported that a number of methods exist for fruit cultivators to directly or indirectly influence photosynthesis and sink activity (the growth of the fruits), of which there are fruit thinning, pruning branches and roots, fertilizing, application of growth regulators, irrigation, and phytosanitary control. In the particular case of wine grapes, the ratio between source and sink is of vital importance and a good, balanced ratio should be a principal objective, allowing for quality production and also allowing for sustainability of the vines over time, which can be achieved with pruning (Almanza *et al*., 2012).

The pruning of wine grapes seeks to eliminate vine shoots, vine leaves, premature shoots, latent buds, leaves and roots in order to modify the natural growth of the vine, fitting the needs of the vine grower (Aliquo *et al*., 2010). This is used to obtain optimal lighting for the vines and to provide good aeration and lighting for the clusters (Almanza *et al.,* 2012). Furthermore, it is used to form the plants in accordance with the space they occupy, the density of the vineyard, the chosen conduction system, and the quantity of buds adjusted to the vigor of the vines, that is to say the growth potential that each plant possesses (Aliquo *et al*., 2010). Taking into account the fruit production habit wherein the plants produce clusters in the last growth branches (vine leaves) that originate in the development of the previous season (vine shoots), pruning is used to limit the number and length of said vine leaves, creating a balance between vigor and production, regulating the productive and vegetative potential and avoiding the aging of the vine (Aliquo *et al.,* 2010). Therefore, pruning allows for the distribution of load units in the plants (short-purned and long-pruned vines) according to their capacity (total quantity of obtained wood and fruits), regulating the number of buds and the number and size of the clusters (Hidalgo, 2003).

The growth and development dynamic of the wine grape starts with the initial growth of the vine leaves after pruning, which depends on the carbohydrate reserves accumulated in the trunk, limbs and roots (Almanza-Merchán *et al*., 2012). Williams (1996) reported that vine leaf growth depends on the reserves before flowering and depends on the level of reserves of the vine leaves and the number of leaves, with 50% of the final size being converted to assimilate exporters. Normally, the dry matter (DM) of the roots and trunk per vine decreases between budding and flowering (Gómez del Campo *et al*., 2002), when the DM of the renewable elements increases (vine shoots). During this period, the total DM of wine grape plants does not increase (Miller *et al*., 1996), indicating that the DM lost by the limbs, trunk and roots is used to sustain the growth of the renewable elements.

Depending on the agroecological conditions where the crop is developed and the variety planted, a group of possibilities exists that can enhance the growth and development of the wine grapes that is translated and integrated into a production capacity that is called "vegetative potential", giving rise to fruit and wood production, including all the parts of the vine but not including the fruit quality, in a vegetative balance of great interest to vine growers (Hidalgo, 2006). In a determined situation and in the same vine, the three partial production modals of the plant (fruit, wood, and quality) are intimately related to each other; therefore, an influence on one, impacts the others (Hidalgo, 2003). According to Hidalgo (2006), with compelling grape production, the weight of the vine shoots (wood) decreases, which is reflected in the vigor of the vine, in the fruit quality, and in the reserves for the subsequent production.

Dividing the development concepts into the understanding of the source/sink ratio and the balance it requires in order to guarantee the production quality of the plants, the Ravaz index allows for the determination of vineyard vigor, calculating the ratio that exists between the grape production per grape or per hectare and the pruned wood weight. The optimal values for this index are between 5 and 10; when they are over 10, they indicate excessive production, while low values indicate an overly elevated vigor in the vineyard (Hidalgo, 2006). This relationship between production and pruning weight indicates the balance between fruit production and vegetative growth. This ratio varies according to the variety and the environment. Optimal values translate into a plant equilibrium that should produce between 5 and 10 kg of grapes, approximately, per kg of pruned wood (Aliquo *et al*., 2010).

In the wine-grape growing region of Boyaca, research on the source/sink ratio is lacking. Therefore, this study aimed to evaluate the effect of the vegetative and productive balance on the wine grape varieties Cabernet Sauvignon and Sauvignon Blanc in Sutamarchan-Boyaca with the use of short, long, and mixed pruning.

Materials and methods

This research was carried out on the Ain-Karim vineyard in Sutamarchán at the coordinates of Greenwich 5°39' N latitude and 73°35' W longitude and an altitude of 2,110 m a.s.l. with a microclimate characterized by high solar radiation, representing 2,000 h of sun shine per year (García *et al*., 2013), with an average annual temperature of 18°C, daily highs of 23°C and night time lows of 10°C, and a relative humidity that oscillates between 80 and 90%, which contribute to quality wine-making grape production (Walteros *et al*., 2012). In an area of 12 ha, there is a cultivation of 9-year-old vines of the Cabernet Sauvignon and Sauvignon Blanc varieties, imported from France (Vargas *et al*., 2013). The plants are established at a distance of 1.5 x 1.0 m using a bilateral cordon or royat trellis conduction system.

The production was determined at the time of harvest using the direct measurement of the cluster weight per plant. The weight of the pruned wood was taken 2 months after the harvest using the results of the pruning and a Scout pro 0.01 g precision balance (Ohaus). The equation proposed by Hidalgo (2006) was used to calculate the Ravaz index (RI).

$$RI = \text{Harvest weight (kg ha}^{-1}\text{)/pruned wood weight (kg ha}^{-1}\text{)} \quad (1)$$

This index represents the difference between the harvest weight and the weight of the pruned vine wood. The optimal index level is determined based on the equilibrium table proposed by the same author.

A 2x3 bifactorial completely random design was used, in which the first factor was the Cabernet Sauvignon and Sauvignon Blanc varieties and the second factor was the pruning type (short, mixed, and long). The short pruning served as the control (traditional vineyard) and consisted in leaving two buds in three spurs. The long pruning left five buds in three spurs and the mixed pruning combined the two methods. The determination of the number of buds was done according to the criterion of the vineyard. Each of the treatments were repeated four times (24 experimental units), with two plants per experimental unit, for a total of 48 evaluated plants.

For the statistical analysis, the data of the evaluated variables were analyzed using the SAS® statistical program, v. 9.2 (SAS Institute, Cary, NC) and, to compare the treatments, a Tukey comparison test was used, which allowed for the determination of any significant differences between the treatments.

Results and discussion

Pruned wood

There were significant differences ($P \leq 0.05$) between the treatments. The highest quantity of pruned wood was seen with the Sauvignon Blanc variety in the short pruning treatment (0.56 kg/plant), followed by Cabernet Sauvignon with 0.46 kg/plant. On the other hand, the Cabernet Sauvignon plants had a value of 0.29 kg/plant with short pruning, generating the lowest value of pruned wood (Fig. 1). These results lead to the conclusion that the accumulation of pruned wood in the renewable organs of wine grape plants presents a behavior that is directly proportional to the vigor of the plant because the treatments that accumulated a lower quantity of pruned wood possessed higher Ravaz index values, which indicates that they were less vigorous and, therefore, the vines were more balanced, which, according to Poni *et al*. (2006), implies that a balanced vine is one that presents an inflow activity that allows for reaching an elevated productivity potential with the desired quality and that, at the same time, assures the correct maturation of the permanent woody parts (trunk, limbs, roots), responsible for the development and fertility of the subsequent harvest. For this, an increase in the fruit load can decrease the distribution of the organic assimilates towards the roots and other permanent organs of the plant and, also, a lack of assimilates can have negative effects on the fruit production of subsequent years (Lenz, 2009).

In addition, it should be taken into account that the production of DM in the canopy depends on the variety (Fernández *et al*., 1977; Gómez del Campo *et al*., 2002), on the root stock (Márquez *et al*., 2007), on the conduction system (González, 2003; Baeza *et al*., 2007), on the irrigation regime (Bartolomé *et al*., 1995; Yuste, 1995; Bota *et al*., 2004), and on the load (Miller and Howell, 1998; Fischer *et al*., 2012), among others.

According to Williams (1996), the quantification of the total (DM) produced by the plant is complicated due to the difficulty in valuing the biomass of the permanent parts. In practice, the measurement of the produced biomass is limited to the renewable elements, which, according to research, pose between 88 and 93% of the total DM produced annually. Yuste (1995) reported that the analysis of the biomass of the renewable organs of a plant, expressed as DM, is one objective method for evaluating growth and development and valuing the productive potential of the wine grape in determined conditions.

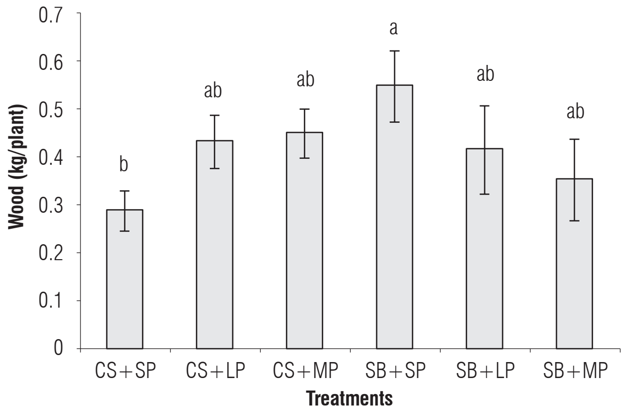

FIGURE 1. Effect of the pruning type and the variety on the quantity of pruned wood in wine grape plants. CS, Cabernet Sauvignon; SB, Sauvignon Blanc; SP, short pruning; LP, long pruning; MP, mixed pruning. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) ($n = 4$). Error bars indicate standard error.

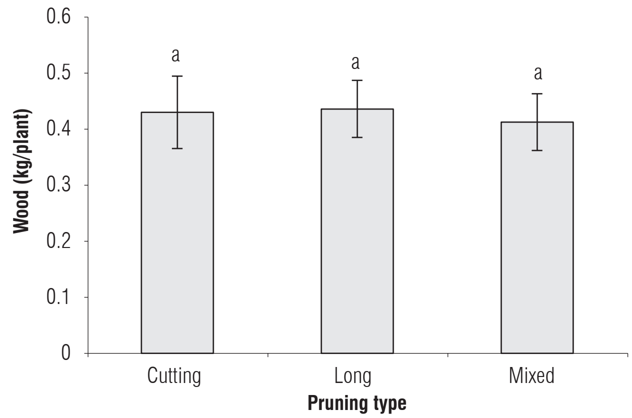

FIGURE 2. Effect of the pruning type on the quantity of pruned wood in wine grape plants. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) ($n = 8$). Error bars indicate standard error.

With the factorial analysis, statistical differences were not observed between the pruning types, obtaining the highest value with the long pruning (0.436 kg/plant) and the lowest value with the mixed pruning (0.41 kg/plant) (Fig. 2). These results differ from those of Smithyman *et al.* (2001), who observed that short pruning had higher weights for pruned wood. This could be due to the fact that, when limiting growth points, carbohydrate reserves and the substances supported by the roots are suitable for supporting the maximum growth rate in the shoots (Ortega-Farias *et al.*, 2007). However, a change in the degree of pruning could affect the total pruning weight per plant. And so, these results do not reflect the expected behavior according to this analysis for the Ravaz index variable where the long pruning was notable for being more balanced and where the pruned wood would be expected to be less. There were no significant differences between the varieties. The highest pruned wood weight (0.45 kg/plant) was obtained with Sauvignon Blanc. As seen in the pruning factor, this result did not fit with the quantity of expected pruned wood for Cabernet Sauvignon, where the value obtained for the Ravaz index demonstrated more vigor for this variety as compared to Sauvignon Blanc (Tab. 1).

This is why Reynier (1995) mentioned the need to take care in the selection of the pruning system; for example, determining a very low load of the buds could implicate a decrease in production with a consequent increase in the diameter of the shoots and a generalized increase in vigor, a situation that could accentuate itself even more with a curtailment of the roots and a misbalance in the plant, where the final production would be negatively affected. Reciprocally, an excessive load of the buds (long pruning) conduces a higher shoot density and foliar area (Walteros *et al.*, 2013), increasing the competition between the fruit and the shoots, which occasions a non-uniform maturation and low fruit quality along with insufficient lignifications and a weakness in the plant as explained by Lakso and Flore (2003) in their observation that the degree of competition between the organs is determined by the activity of the inflow and distance from the photoassimilates to the sink.

TABLE 1. Production and quantity of wood of wine grape plants for Cabernet Sauvignon and Sauvignon Blanc.

Variety	Pruning wood (kg/plant)	Production (t ha^{-1})	Ravaz index
Cabernet Sauvignon	0.40 NS	4.39 b	1.75 b
Sauvignon Blanc	0.45 NS	5.78 a	2.45 a

Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) ($n = 4$). NS, no significant differences.

Production

There were significant differences ($P \leq 0.05$) between treatments. The highest production was obtained with the Sauvignon Blanc variety and the mixed pruning (7.17 t ha^{-1}), followed by long pruning in the same variety with 6.47 t ha^{-1}. Meanwhile, the lowest production was seen with Cabernet Sauvignon with long pruning (5.93 t ha^{-1}), results that are explained by De la Fuente *et al.* (2007) in their observation that the quantity of photosynthetically active foliar area depends on the pruning type. The long pruning generated the highest production for the two varieties due to, among many factors, the quantity of radiation that each leaf was able to take advantage of and also because correct spatial distribution of the elements of the plant canopy increases production, increases the number of fertile nodes, and, therefore, results in a higher number of clusters (De la Fuente *et al.*, 2007).

Furthermore, the microclimatic conditions of good illumination translate into better results in subsequent years (Baeza *et al.*, 1999; Sommer *et al.*, 2000). Meanwhile, the lowest response was seen with the Cabernet Sauvignon variety and mixed pruning (2.91 t ha^{-1}) (Fig. 3); this behavior is considered contrary to that expected with the analysis of the Ravaz index, especially in Cabernet Sauvignon with the short pruning (Fig. 5). Fischer *et al.* (2012) explained that trees with a low fruit load have higher vegetative growth and form lower quantities of DM per unit of foliar area than plants without fruits.

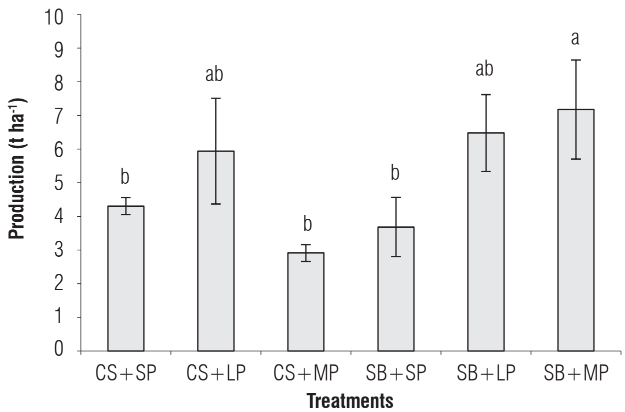

FIGURE 3. Effect of the pruning type and the variety on the production of wine grape plants. CS, Cabernet Sauvignon; SB, Sauvignon Blanc; SP, short pruning; LP, long pruning; MP, mixed pruning. Means with different letters indicate significant differences according to the Tukey test ($P \leq 5\%$) (n = 4). Error bars indicate standard error.

The factorial analysis indicates that the long pruning significantly favored production (6.20 t ha^{-1}), while the short pruning was responsible for a lower production with 3.99 t ha^{-1} (Fig. 4). Similar data were observed by Ortega-Farias *et al.* (2007) who stated that wine grapes that had a higher number of buds produced a higher number of clusters per plant, with a lower weight and a higher final yield in comparison to those that had short pruning. There were also statistical differences between the varieties. The highest production (5.78 t ha^{-1}) was obtained with the Sauvignon Blanc variety (Tab. 1). This result could possibly be due to the fact that the global productivity of the plant is determined by the total capacity of the vegetative cover, especially the exposed foliar surface, to fix carbon and by the competition between the vegetative development and the productive yield at harvest (De la Fuente *et al.*, 2007).

When relating the obtained yield behavior and the results found for the Ravaz index calculation, in general terms,

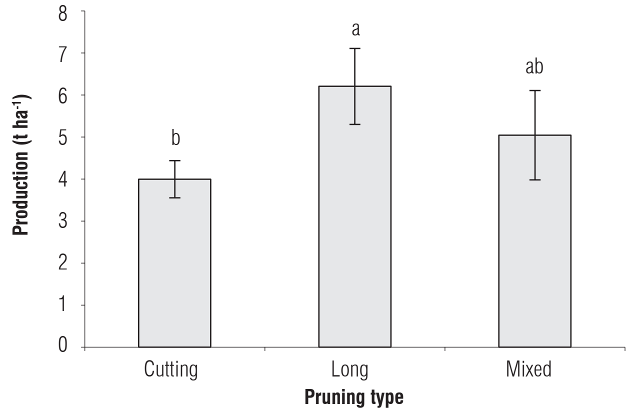

FIGURE 4. Effect of the pruning type on the production of the wine grape plants. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) (n = 8). Error bars indicate standard error.

it was verified that, when obtaining values close to productive and vegetative balance, the yield corresponds to the expected ideal for the production of wine. According to Walteros *et al.* (2013), table grape producers prefer to have high production per planted area unit, while, for the production of wine, it is necessary to sacrifice production, favoring the fruit quality that can obtain a maximum controlled production of 4 t ha^{-1} per crop cycle, possibly due in part to the fact that "over production" slows down the accumulation of sugar in the fruit when compared to fruits from plants with less yield. In this sense, when considering that the higher estimated productions in the research are found below this maximum expected value, it is predicted that, in the search for more balanced conditions, production will increase without surpassing this estimate, obtaining optimal yields that are sustainable for the vineyard.

Ravaz index

There were significant differences ($P \leq 0.05$) between the treatments. The highest Ravaz index was obtained with the mixed pruning in the Sauvignon Blanc variety with a value of 3.32; followed by long pruning with 3.01. The Cabernet Sauvignon variety with mixed pruning was responsible for the lowest index at 0.99; the highest value for this variety was seen with short pruning, 2.32. It is important to consider that, despite the fact that the indices for Cabernet Sauvignon were significantly lower than those of the Sauvignon Blanc variety, an inversely proportional relationship was seen between the prunings of the two varieties (Fig. 5). Contrary to the differences observed between the treatments, it was determined that, on average, the Ravaz index, for the two varieties, showed significantly low values with respect to those expected for a balanced source/sink ratio (Hidalgo, 2006). In agreement with Aliquo *et al.* (2010), these values, being below 5, reveal an overly elevated vigor in the vineyard, which favors the production of wood and, as a consequence, the exaggerated development of vine leaves to the determines of future producing-bud formations; in addition to their resulting excessive sowing, the subsequent production could be less, as confirmed by Hidalgo (2006), who stated that vines with excessive vigor can be less productive.

When analyzing the behavior of Cabernet Sauvignon separately, where the short pruning resulted in a higher Ravaz index value (2.32) with respect to the long and mixed prunings (Fig. 5), this value continued to be far below the expected value of a balanced vine. In this sense, it would be hoped that, when increasing the number of buds left in the short pruning of this variety (up from the three buds of the short pruning), the Ravaz index could increase enough to obtain a value equal to or superior to 5, resulting in an optimal state for the vegetative and productive ratio. These results agree with the observations of Farias *et al.* (2007), who found that plants that have a lower number of buds resulted in a higher weight and length for the vine shoots, generating an inferior Ravaz index, in accordance with Miller *et al.* (1996) and Smithyman *et al.* (2001), who observed the same tendency. This must be due to the fact that, when limiting the growth points, the carbohydrate reserves and substances supported by the roots are suitable for supporting the maximum growth rate of the shoots (Miller *et al.*, 1996).

For the Sauvignon Blanc behavior, the mixed pruning was responsible for a Ravaz index value (3.32) that was superior to those of the long and short pruning (Fig. 1); this value, despite being acceptable in the Ravaz index range proposed by Main *et al.* (2002), requires that, as suggested for Cabernet Sauvignon, the pruning be modified for the number of buds left (more than 2 for short and more than 5 for long) to find the expected optimal level. This was confirmed by Miller *et al.* (1996) when they stated that, when the number of growth zones increases, they start to compete for the available carbohydrates, water, nutrients, and cytokines, improving the final yield of the vine and, therefore, finding balance for the productive and vegetative ratio. In this case, care must be taken when modifying the number of buds for pruning; short pruning for Cabernet Sauvignon and mixed pruning for Sauvignon Blanc should be moderate, avoiding the contrary effect, which would result in a misbalance due to a lack of vigor and excessive production.

There were also statistical differences between the pruning types. The highest Ravaz index was generated with long pruning (2.46), followed by mixed pruning with

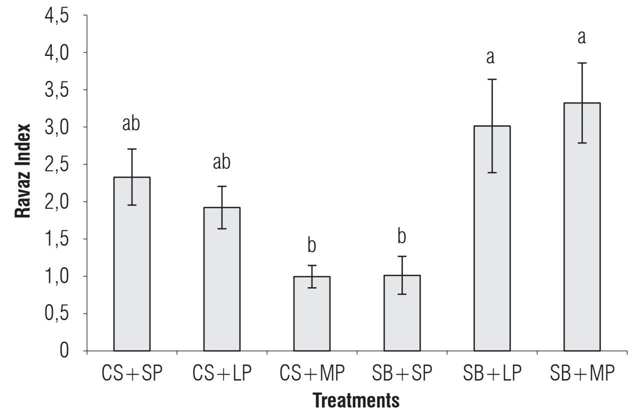

FIGURE 5. Effect of the pruning type and the variety on the Ravaz index. CS, Cabernet Sauvignon; SB, Sauvignon Blanc; SP, short pruning; LP, long pruning; MP, mixed pruning. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) ($n = 4$). Error bars indicate standard error.

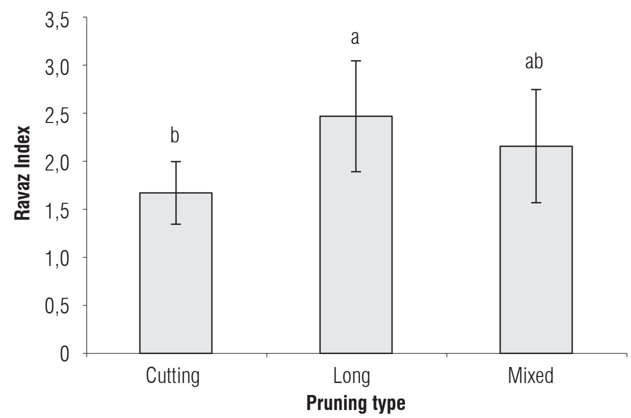

FIGURE 6. Effect of the pruning type on the Ravaz index. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$). ($n = 8$). Error bars indicate standard error.

2.15, and, finally, short pruning with 1.67 (Fig. 6), leading to the conclusion that the long pruning allowed for a suitable development of the shoots that benefitted the productive and vegetative ratio, advancing towards equilibrium in the plant. Despite this, if the index behavior of the Cabernet Sauvignon and Sauvignon Blanc is evaluated separately, the results appear to vary, with short pruning with Cabernet being the best system and mixed pruning for Sauvignon Blanc. This was explained by Aliquo *et al.* (2010) when they observed that the length of pruned vine shoots will vary according to the variety, which would be an important factor for the degree of fertility of the buds left behind; that is to say, the potential to form fructifications in the subsequent pruning. It is important to emphasize that fertility is a genetic characteristic of each variety. And so, Salazar and Melgarejo (2005) recommended that, in varieties with low fertility, long pruning should be used in order to obtain a high number of fructifying buds and that, in fertile varieties, short pruning should be used to avoid excessive fruit production and disproportionate increases in the foliar area.

For its part, when analyzing the behavior of the Ravaz index between the varieties without considering the pruning systems, it was observed that the Sauvignon Blanc variety significantly induced a high Ravaz index with a value of 2.45, implicating that Cabernet Sauvignon, with an index of 1.75 (Tab. 1), would be considered the most vigorous vine of the vineyard, taking into account the optimal index levels proposed by Hidalgo (2006). However, it is necessary to take into account that the index can present an increase with the aging of fruit trees and depends on many factors, such as the variety, pattern, agroecological conditions, and crop management (Fischer *et al*., 2012).

Conclusions

The Ravaz index for the two varieties showed values that were significantly low with respect to those expected for a balanced source/sink ratio, reflecting the fact that an elevated vigor exists in the vineyard that could negatively impact the yield and yet conserve the quality needed for wine production.

For the Cabernet Sauvignon variety, the pruning type that resulted in a productive and vegetative ratio that was closest to being balanced, presenting the best Ravaz index values, was the short pruning (control), but for the Sauvignon Blanc variety, it was mixed pruning.

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