The importance of pruning to the quality of wine grape fruits (*Vitis vinifera* L.) cultivated under high-altitude tropical conditions

Importancia de la poda en la calidad del fruto de vid (*Vitis vinifera* L.) cultivada bajo condiciones del trópico alto

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ABSTRACT

Since 1998, the Ain-Karim Vineyard has been growing different grape varieties for the production of high-altitude tropical wines in the municipality of Sutamarchan, located in the Alto Ricaurte region of Boyaca (Colombia). Pruning is used to limit the number and length of branches, generating a suitable balance between plant vigor and production; thereby, regulating fruit quantity and quality and ensuring reserves for the subsequent production. This study aimed to evaluate the effect of three pruning types (short = two buds on two spurs; long = five buds on three spurs and mixed = combination of short and long pruning types) on the fruit quality of *V. vinifera*, Cabernet Sauvignon and Sauvignon Blanc varieties. To accomplish this, a completely randomized two-factor design was used. Physicochemical variables of fruit quality (fresh cluster weight, water content, total soluble solids (TSS), total titratable acidity (TTA), technical maturity index (TMI), and pH) were determined at harvest. The long pruning type presented the highest values for the fresh cluster weight and TSS of the fruits from both varieties and a higher TMI in the Cabernet Sauvignon variety. These results indicate that, under the conditions of the vineyard, long pruning is the most suitable.

Key words: tropical viticulture, altitude, grape harvest, organoleptic quality.

RESUMEN

En la Región del alto Ricaurte desde 1998, en el municipio de Sutamarchán, Viñedo Ain-Karim, Boyacá (Colombia), se cultivan diferentes variedades de uva para la producción de vinos tropicales de altitud, con la práctica de la poda se busca limitar el número y longitud de los pámpanos, para generar un balance adecuado entre el vigor y la producción, regulándola en calidad, cantidad de frutos y reservas que aseguren la siguiente producción. El objetivo de este estudio fue evaluar el efecto de tres tipos de poda (corta = dos yemas en dos pulgares; larga = cinco yemas en tres pitones y mixta = combinación de poda corta y larga), sobre la calidad del fruto *V. vinifera*, variedades Cabernet Sauvignon y SauvignonBlanc. Para tal fin, se realizó un diseño estadístico completamente al azar en forma bifactorial, en la vendimia (cosecha), se determinaron variables fisicoquímicas de calidad del fruto (peso fresco de racimo, contenido de agua, sólidos solubles totales (SST), acidez total titulable (ATT), pH e índice de madurez técnica (IMT). La poda larga presentó en los frutos, para las dos variedades, los valores más altos en peso fresco de racimo y SST y en la variedad Cabernet Sauvignon un IMT más alto. Estos resultados implican que para las condiciones del viñedo, la poda larga es la más apropiada.

Palabras clave: viticultura tropical, altitud, vendimia, calidad organoléptica.

Introduction

The growing vine in Colombia is being developed in the departments of Boyaca, Antioquia, Santander and Nariño at altitudes above 2,000 m a.s.l., in zones known for cold tropical viticulture (Almanza, 2008). Under these conditions and thanks to the intense light received from sunny days that are followed by cold nights, the resulting fruits have aromas, colors, and flavors that are suitable for the production of wines with quality tropical characteristics (Almanza *et al*., 2012). The Alto Ricaurte region of Boyaca is included in these regions, with an altitude of 2,100 m a.s.l. and with grape cultivation since 1985 (J. Herzberg, 2014, personal communication). The Ain-Karim Vineyard in the municipality of Sutamarchan started cultivating different grape varieties for the production of wines in 1998. In 2011, Boyaca had the third highest production of wine grapes in the country, with 11 ha and a harvest of 47 t, providing 4.27 t ha^{-1} (Walteros *et al*., 2013). The production of wines requires grapes that are harvested with the appropriate organoleptic compounds that guarantee quality must that can be turned into wine (Almanza-Merchán, 2012; Walteros *et al*., 2012). For this, it is necessary to maintain a balance between vegetative growth and reproduction (Fischer *et al*., 2012) that

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guarantees production, quality, and sustainability for the vineyard over time, benefitting the organoleptic potential of the fruit (Almanza-Merchán *et al*., 2014). According to Fischer *et al*. (2012), pruning is a method that is used to influence the activities of sources and sinks.

According to Aliquo *et al*. (2010), one of the objectives of pruning is obtaining quality through the elimination of plant parts (canes, shoots, suckers, buds, etc.) with the goal of modifying the natural growth habit of the strain to make it suit the needs of viticulture. Therefore, this study sought to find the optimal light for the plants, to secure good aeration and light for the branches (Almanza *et al*., 2012), and to form the architecture of the plants according to the space they occupy, the vineyard density, and the selected conduction system with the quantity of buds according to the productive capacity of the strain (Almanza-Merchán *et al*., 2014). According to Casierra-Posada and Fischer (2012), when pruning, it is important to recognize which branches and structures have vegetative or productive buds in order to ensure quality and continuous production. Taking into account the fact that the wine grape bears fruit on the shoots (branches with the most recent growth) growing from the wood of the previous year, pruning seeks to limit the number and length of these shoots in order to create an adequate balance between vigor and production, regulating the quality and quantity of the fruits and the reserves that will ensure the subsequent production (Hidalgo, 2006; Almanza-Merchán *et al*., 2014). Furthermore, pruning reduces the aging of strains by renewing their vegetative and productive structures (Aliquo *et al.,* 2010).

Leaves are responsible for synthesizing photosynthates and exporting them to developing fruits (Fischer *et al*., 2012). The leaves that are closer to developing fruits display a higher photosynthetic capacity as compared to other leaves (Urban *et al*., 2003). Therefore, these leaves are the source of the most photosynthates which are translocated to the fruits. Any growth, storage, or active metabolizing tissue can be a source or the destination of sap (Salisbury and Ross, 2000). In the case of the wine grape, in the active growth stage, the developing fruits and young leaves are the larger sinks (Hidalgo, 2006), but when engustment begins, the roots, trunk and branches become the larger sinks (Almanza *et al*., 2012). Therefore, according to Agusti (2004), the translocation of carbohydrates starting with bud break is apical (acropetal) and, when the maturation of the leaves begins, the photoassimilates are translocated toward the fruits, ending with basipetal transport. This means that adequate pruning is needed to guarantee fruit quality that translates into must that ensures good wine (Almanza-Merchán *et al*., 2014).

Balanced pruning seeks an equilibrium for the number of buds that are left and the capacity of the plant, maintaining a balance between production and vegetative growth (Hidalgo, 2006). Each plant has a certain internal maturation capacity for a certain number of branches and for supporting a certain number of buds, beyond which the balance is broken. This characteristic is proportional to the total growth potential (Aliquo *et al*., 2010). Winter pruning regulates the vigor; that is to say, the development capacity of the vineyard for the vegetative-production concept. When a vineyard uses very severe pruning, a very high vigor can be produced that generates a vegetative misbalance and a reduction in fruit quality (Yuste, 2005).

Furthermore, Hidalgo (2006) indicated that, of all the cultivation activities, pruning and the conduction method are the more decisive ones for the establishment of vegetative equilibrium in the plants and organoleptic quality of the berries in order to produce fruits with the characteristics that are typical of the variety. Therefore, the present study aimed to evaluate the effect of pruning on quality of wine grapes quality of the Cabernet Sauvignon and Sauvignon Blanc varieties growing in Sutamarchan-Boyaca.

Materials and methods

This study was carried out at the Ain-Karin the Marques of Villa de Leyva Vineyard, located in the municipality of Sutamarchan, Boyaca (Colombia). The vineyard has the coordinates of 5º39' N and 73º 35' W, with an altitude of 2,110 m a.s.l. It has a lime soil and a microclimate that is characterized by high solar radiation, with 5.5 h d^{-1} (García *et al*., 2013), and an average temperature during the research of 16.9ºC, where the maximum was 25.1ºC and the nighttime temperature was 7.6ºC; the relative humidity was between 80 and 90% (Walteros *et al*., 2012). The vineyard has an area of 12 ha that is planted with Cabernet Sauvignon and Sauvignon Blanc varieties imported from France (Camacho, 2014, personal communication). The plants, cultivated at a distance of 1.5 x 1.0 m, are 9 years old, and are found in bilateral royat or cordon conduction systems.

A completely randomized 2x3 two-factor design was used; in which, the first factor corresponded to varieties and the second factor corresponded to the pruning type (short, mixed, and long). The short pruning was the control and left two buds in three spurs (the traditional method of the vineyard); the long pruning left five buds in three spurs;

and the mixed pruning combined these two methods. Each treatment was replicated four times for a total of 24 experimental units, with two plants per experimental unit for a total of 48 evaluated plants.

The fruits were collected when they reached maturity and, following the enological technical criterion, all of the clusters were taken from each plant and taken to the plant physiology laboratory of the Universidad Pedagogica y Tecnologica of Colombia (Tunja), where they were weighed using a 0.01 g precision balance. The water content of the fruits was established through the percentage ratio between the dry mass and fresh mass of the fruits. Subsequently, 10 mL of must was obtained in order to establish the chemical variables of: total soluble solids (TSS) by measuring the Brix degrees using a digital refractometer (Hanna Instruments, Rhode Island, USA) with a range of 0 to 85% and a precision of 0.1°Brix; total titratable acidity (TTA) following the AOAC methodology (1990) with calculations using the volume data of 0.1N NaOH incorporated into 5 g of must and three drops of phenolphthalein in a potentiometric titration up to a pH of 8.2, expressed as tartaric acid; technical maturity index (TMI), determined following the methodology proposed by Parra and Hernández (1997) using the TSS/TTA ratio; and pH, using a Schott Handylab pH 11 pHmeter (Schott, Mainz, Germany) that was calibrated using 7.0 and 4.0 pH buffer solutions.

For the statistical analysis, the data of the evaluated variables were analyzed with the statistics program SAS® v. 9.2 and, to compare the treatments, the Tukey comparison test was used ($P \leq 0.05$), which allowed for the determination of the existence of significant differences between the treatments.

Results and discussion

Fresh mass clusters

With statistically significant differences ($P \leq 0.05$), the clusters of the Cabernet Sauvignon variety with long pruning had the highest fresh mass with values of 72.16 g, while the clusters with the lowest fresh mass were harvested from the 'Sauvignon Blanc' plants with short pruning at a weight of 34.91 g (Fig. 1). According to the data obtained in this study, the long pruning presented the highest fresh mass of the clusters for both varieties, as compared to the short and mixed pruning. Howell *et al.* (1987) and Howell (2001) indicated that long pruning is more productive because the buds found between the 3-10 nodes bear more fruit. Also, Almanza *et al.* (2012) stated that, for the case of the varieties grown in Boyaca (Pinot Noir, Riesling, Riesling x Silvaner, Cabernet Sauvignon, and Sauvignon Blanc, among others), the production is found between nodes 4 and 5, which would influence which type of pruning would be ideal. Keller *et al.* (2004) reported that the number of berries per cluster and the average cluster weight decrease as the number of clusters per plant increases, contrary to the values obtained in the present study, in which the long pruning, between the treatments and as compared to the level of individual factors, generated the highest cluster weight with values of 63.585 g, followed by short pruning with 45.79 g and mixed pruning with 38.11 g (Fig. 2). In this sense, De la Fuente *et al.* (2007) and Almanza-Merchán *et al.* (2014) indicated that the amount of photosynthetically active area is dependent on the pruning type, which explains the results seen with long pruning, generating the highest number of canes and, therefore, leaves.

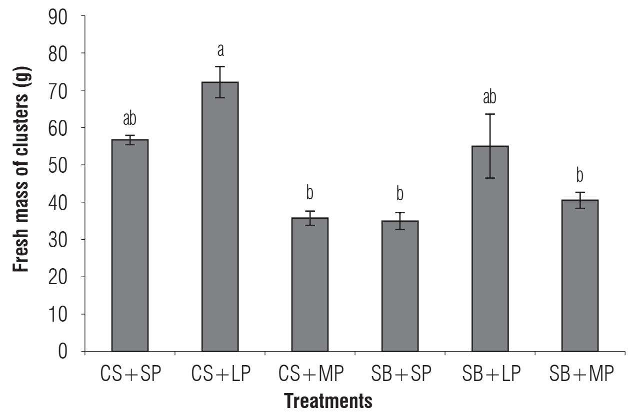

FIGURE 1. Effects of the pruning type and variety on the cluster fresh weight of wine grapes. CS, 'Cabernet Sauvignon'; SB, 'Sauvignon Blanc'; SP, short pruning; LP, long pruning; MP, mixed pruning. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) ($n = 4$). Bars indicate standard error.

For its part, the Cabernet Sauvignon variety produced a higher cluster weight (54.85 g) than the Sauvignon Blanc variety with 43.48 g. According to Rivera and Devoto (2003), the weight of the berries is determined by the number of cells, their volume and their density. This is consistent with Salazar and Melgarejo (2005), when the final weight appears to be highly determined by cellular division before anthesis and cellular elongation after anthesis. Different data were found by Ortega-Farias *et al.* (2007), in which the pruning with the highest number of buds resulted in the highest number of clusters, but with lower weights. This result was possibly due to the fact that the integral productivity of plants is determined by the capacity of the plant cover and especially by the photosynthetically active foliar surface with a capacity to fix carbon, as well as by the competition between the vegetative development and yield (De la Fuente *et al.*, 2007).

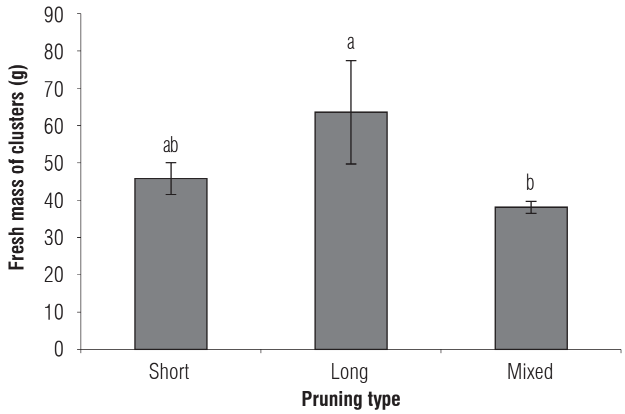

FIGURE 2. Effect of the pruning type on the cluster fresh mass of wine grapes. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) (n = 8). Bars indicate standard error.

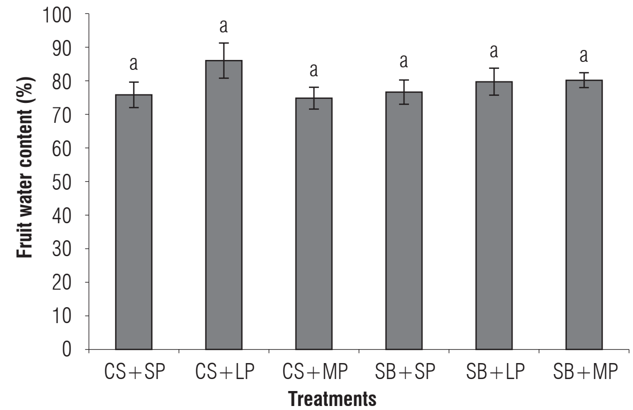

FIGURE 3. Effect of the pruning type and variety on the fruit water content of wine grapes. CS, 'Cabernet Sauvignon'; SB, 'Sauvignon Blanc': SP, short pruning; LP, long pruning; MP, mixed pruning. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) (n = 4). Bars indicate standard error.

Fruit water content

There were no significant differences between the treatments; however, the highest fruit water content was seen in the 'Cabernet Sauvignon' variety with long pruning (86.02%) and the lowest was seen in the same variety with mixed pruning (74.80%); the short pruning of the 'Sauvignon Blanc' variety tended to have the lowest fruit water content (76.61%) for this variety (Fig. 3). These values agree with those found by Hidalgo (1993), who stated that grapes for wine production have a water content of 70 to 85% (Fig. 4). Taking into account the fact that the final destination of the grapes is wine production, the fruit water content plays a vital role (Almanza *et al*., 2012). The factor levels did not present significant differences when separated. According to Fischer *et al*. (2012), plants with a high leaf/fruit ratio form fruits that have a higher amount of spongy tissue, which implies that they will have a higher capacity of water accumulation in the their cells and, therefore, the fruits will be bigger, which was confirmed by Medrano and Flexas (2004) when they reported that cellular growth depends on cellular turgor, which in turn depends on the cellular water pressure potential. The hydration of tissue is therefore an essential requirement for the growth and final size of the fruit. Reynier (1995) mentioned that, during the growth and development of wine grapes, with the vegetative and reproductive cycles being simultaneous, the organs constantly compete for the photoassimilates; therefore, the distribution of glucosides influences the quantity and quality of the current and subsequent harvests.

Total soluble solids

The accumulation of total soluble solids in the fruits presented statistically significant differences ($P \leq 0.05$). The fruits that tended to have the highest total soluble solids, with values of 22.76°Brix, were harvested from the Sauvignon Blanc variety with long pruning, followed by fruits of the same variety with mixed pruning with values of 22.66°Brix and with short pruning with values of 22.08°Brix. The TSS for the Cabernet Sauvignon variety was at low levels, with short pruning presenting the lowest value of 20.5°Brix (Fig. 5), which means sugar would have to be added to the must. According to Ryugo (1993), the grape varieties that will be used for quality wine production must accumulate a TSS content of between 22 and 28°Brix, which was demonstrated by Almanza e*t al*. (2012), who indicated that the content, in Brix degrees and under cold tropical conditions, presents values close to 23°. Blouin and Guimberteau (2004) explained the importance of high TSS contents in the production of quality wine.

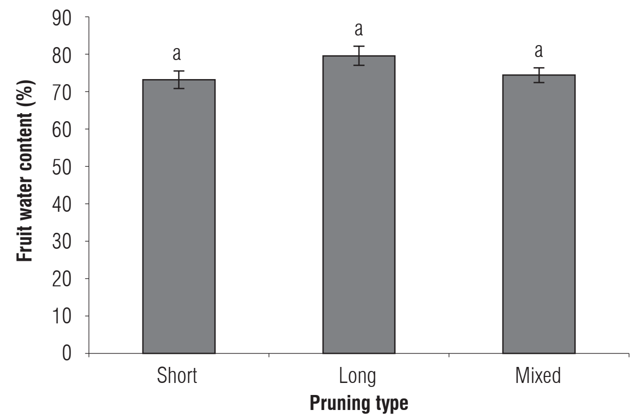

FIGURE 4. Effect of the pruning on the fruit water content of wine grapes. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) (n = 8). Error bars indicate standard error.

The Sauvignon Blanc variety presented the fruit with the highest TSS content with a value of 22.50°Brix. Salazar and Melgarejo (2005) confirmed that the content of the substances present in grapes will depend in large part on the variety type from which they come and on the edaphoclimatic conditions, because light, temperature, and water quantity of the soil are decisive for the formation of enological substances, which are of vital importance to the quality and microbiological stability of wine production. Lizana (1983) confirmed that the principal sugars present in the grape are glucose and fructose; the quantity found in mature berries is 150 to 250 g $L^{-1}$of juice, which corresponds to a value of 15 to 25°Brix. Martínez de Toda (1991) emphasized the importance of the pruning type due to the fact that, during the grape maturation process, acids lose ground to the sugars that come from the photosynthetic activity exercised by the leaves. The trunks of the strain also contribute to the accumulation of TSS during the herbaceous stage of the fruits because they accumulate sugar during this resting period and, once the filling starts, they act as a source (Almanza-Merchán *et al.*, 2014). According to Coombe (1960), the enrichment in the sugar of the clusters during veraison is due, in part, to the rapid and temporary mobilization of the reserves of the trunk and canes towards the fruits.

Statistical differences were observed for the short pruning; the higher TSS values were obtained with the long and mixed pruning types, with values of 22°Brix, while the short pruning presented the lowest value at 21.28°Brix (Fig. 6). Similar data were found by Poni *et al.* (1994), who confirmed that, with mixed pruning, grape production depends on an optimal equilibrium between the growth of leaves and buds, which is necessary for the production of sufficient carbohydrates for the optimal maturation of the clusters. This means that it is vital to control the foliar surface in order to have the correct maturation of the berries (Zufferey and Murisier, 2006), which can be achieved with the pruning type. Sánchez de Miguel (2007) stated that, due to the relationships between sources and sinks, there appears to be movements of photoassimilates between the different organs that allow for the establishment of translocation models which vary throughout the vegetative and reproductive cycles.

Total titratable acidity

There were no statistical differences at the treatment level (pruning and variety). The highest value tended to occur in the Sauvignon Blanc variety with mixed pruning (7.63 g L^{-1}) and the lowest value with the Cabernet Sauvignon variety with long pruning (6.43 g L^{-1}) (Fig. 7). The pruning type level, in an independent manner, did not present differences either (Fig. 8). According to the value of the wine

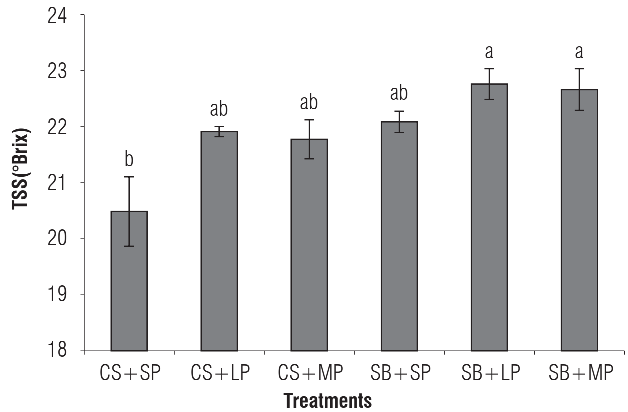

FIGURE 5. Effect of the pruning type and variety on the total soluble solids (TSS) in wine grape fruits. CS, 'Cabernet Sauvignon'; SB, 'Sauvignon Blanc'; SP, short pruning; LP, long pruning; MP, mixed pruning. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) (n = 4). Bars indicate standard error.

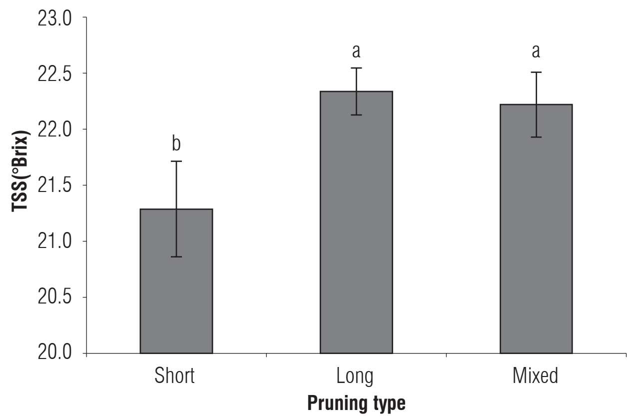

FIGURE 6. Effect of the pruning type on the total soluble solids (TSS) of wine grape fruits. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) (n = 8). Bars indicate standard error.

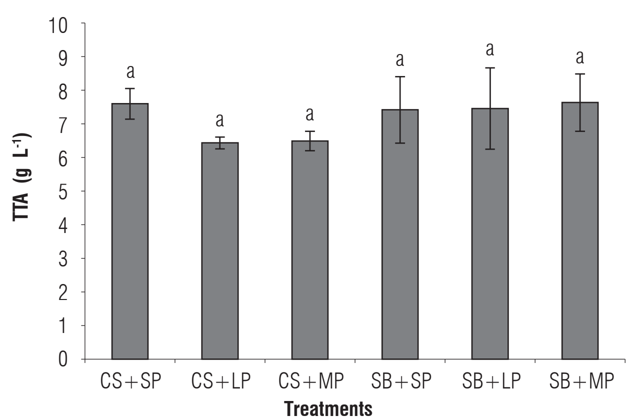

FIGURE 7. Effect of the pruning type and variety on the total titratable acidity (TTA) of wine grape fruits. CS, 'Cabernet Sauvignon'; SB, 'Sauvignon Blanc'; SP, short pruning; LP, long pruning; MP, mixed pruning. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) (n = 4). Bars indicate standard error.

acidity, known as total acidity and expressed as the most important acidity content, which in the case of the grape is tartaric acid, the total acidity was established between 4.5 and 7.0 g L^{-1}, which is approximately equivalent to a pH range of 3.2 and 3.7 (Pérez, 2003) or, as found by García *et al*. (2002), between 6.5 and 7.0; values that agree with those of the present study.

Reynier (1995) related the acidity of the grape to three basic factors: the most important appears to be temperature, which can cause decreases in acidity that favor respiratory combustions; vigor, which can favor the production of organic acids during the growth period and reduce the possibility of degradation during maturation; and water contribution, which can cause dilution when the contribution is made at the end of maturation or which can favor synthesis during the growth period of the fruit.

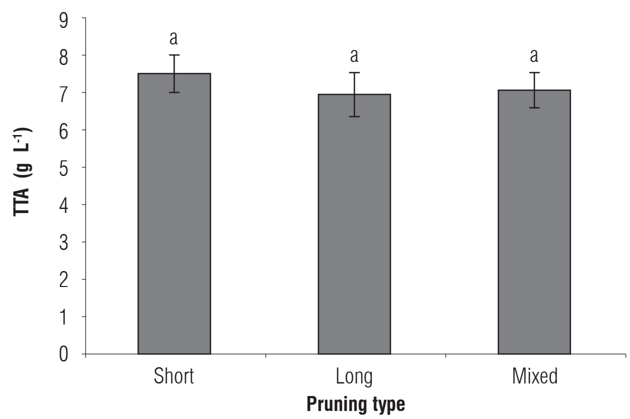

FIGURE 8. Effect of the pruning type on the total titratable acidity (TTA) of wine grape fruits. Means with different letters indicate significant differences according to the Tukey test ($P\leq0.05$) (n = 8). Bars indicate standard error.

Technical maturity index

The short pruning in the Cabernet Sauvignon variety presented the lowest value ($P\leq0.05\%$) among the treatments with an index of 2.74 (Fig. 9), while the highest value (3.40) was seen with the long pruning in the same variety, in agreement with the research of García *et al*. (2002), who reported ideal values between 2.79 and 3.62. All of the treatments presented technical maturity indices that guarantee the production of good quality wines. Almanza *et al*. (2012) suggested that TMI values between 3.0 and 3.5 are suitable for deciding the opportune moment of the harvest. According to Almanza (2011), this is the most used indicator by wine grape producers in the department of Boyaca because it allows for the determination of the optimal harvest point (Hidalgo, 1993; Reynier, 1995) and is defined as the TSS/TTA ratio. According to Gris *et al*. (2010) and Morlat and Bodin (2006), the maturity index represents a balance between sugars and acids, which is important for the quality of wines because it confers a balanced flavor in wines.

Between the pruning types, there were no significant differences (Fig. 10). The long pruning obtained the highest value with an index of 3.34, while the lowest value corresponded to the short pruning (2.94). Taking into account the fact that the balance between sugars and organic acids is a determinant factor for wine quality (Walteros *et al*., 2012), the values obtained in this study fit within the suggested values for the production of wines with tropical characteristics.

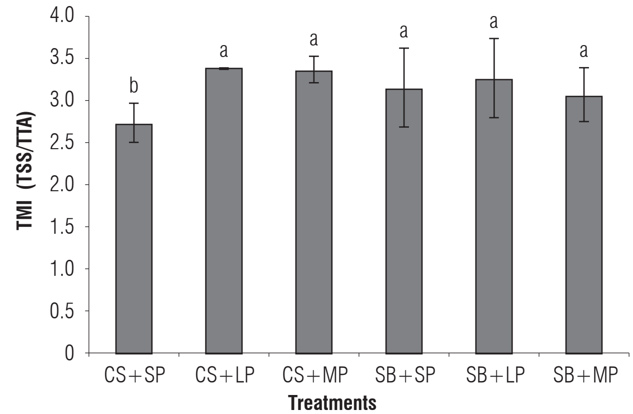

FIGURE 9. Effect of the pruning type and variety on the technical maturity index (TMI) of wine grape fruits. CS: 'Cabernet Sauvignon'; SB, 'Sauvignon Blanc'; SP, short pruning; LP, long pruning; MP, mixed pruning. Means with different letters indicate significant differences according to the Tukey test ($P\leq0.05$) (n = 4). Bars indicate standard error.

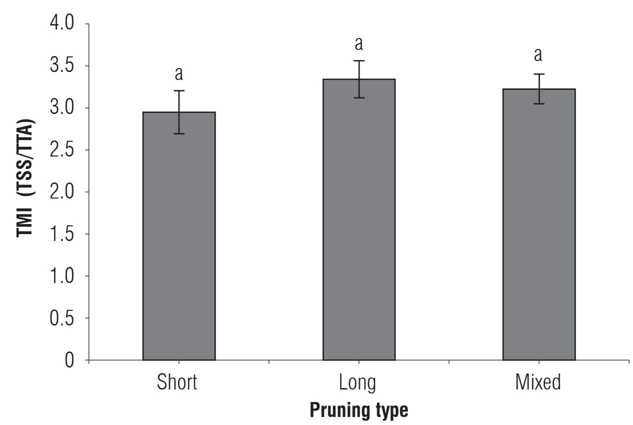

FIGURE 10. Effect of the pruning type on the technical maturity index (TMI) of wine grape fruits. Means with different letters indicate significant differences according to the Tukey test ($P\leq0.05$) (n = 8). Bars indicate standard error.

pH

The higher pH values ($P\leq0.05$) were obtained with the fruits of the Cabernet Sauvignon variety, independent of the pruning type (Fig. 11). The highest value corresponded to the mixed pruning type with a pH of 4.68. In the Sauvignon Blanc variety with all three pruning types, the pH values were lower, with 3.11 being the highest value. The factorial analysis did not reveal significant differences for the pruning type (Fig. 12). The behavior for the three pruning types was similar; the long and mixed pruning presented the highest value of 3.87 and the short pruning generated the lowest value (3.84). The high pH values seen in the present study were possibly due to a high K^+ content, which was associated with the shaded microclimates that are characteristic of long and mixed pruning types that contain a higher foliage quantity. Boulton (1980) mentioned that shaded clusters result in a higher accumulation of K^+ in the buds and mature fruits. Catalina *et al.* (1982) stated that an increase in pH has three causes: a) salinization of the fruit acids, caused by potassium salts; b) respiratory combustion, especially by the consumption of malic acid; and c) dilution due to fruit growth.

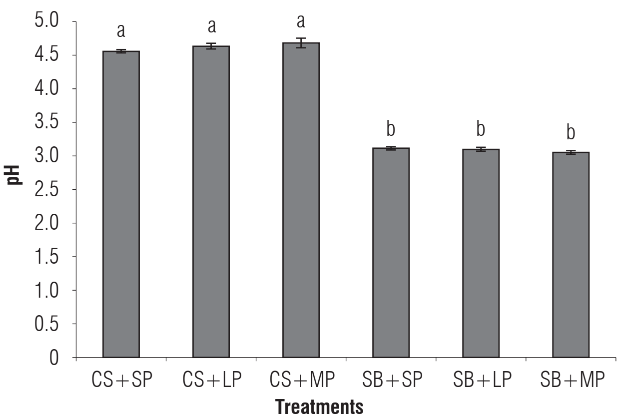

FIGURE 11. Effect of pruning type and variety on the pH of wine grape fruits. CS: 'Cabernet Sauvignon'; SB, 'Sauvignon Blanc'; SP, short pruning; LP, long pruning; MP, mixed pruning. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) ($n = 4$). Bars indicate standard error.

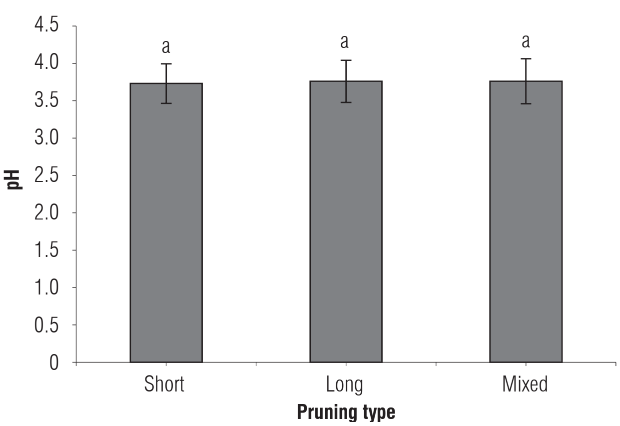

FIGURE 12. Effect of pruning type on the pH of wine grape fruits. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) ($n = 8$). Bars indicate standard error.

Conclusions

The long pruning type was the most suitable for both varieties growing under the agroecological conditions of the Ain-Karim Vineyard due to it having the highest values of fresh mass of the clusters and TSS and TMI of the fruits. The Cabernet Sauvignon variety surpassed the 'Sauvignon Blanc' variety in terms of fresh mass of clusters and pH, but it had a lower TSS.

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