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CROP PRODUCTION
Article

Agronomic performance of 'BRS Cora' grapevines grown under different training systems, rootstocks and growing seasons in a semi-arid region

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ABSTRACT: Producing grapes for juice has been gaining prominence in the Northeast region of Brazil with diversification of grape cultivars for juice production over the past decade. The aim of this study was to estimate the effect of different vine training systems and rootstocks on the vigor, yield, and morpho-agronomic traits of 'BRS Cora' grapes over six production cycles. The experiment was conducted in Petrolina, PE, Brazil, from 2017 to 2020. A randomized block experimental design was used with four replications in split-split plots in time, with evaluation of the espalier, pergola, and lyre training systems combined with the rootstocks IAC 572 and IAC 766. The variables studied were the following: bud fertility index; yield per plant; number of clusters per plant; weight, width and length of cluster and berry; soluble solids (SS); titratable acidity (TA); and ratio SS/TA. The response of the 'BRS Cora' vines were different depending on the training system, rootstock, production cycle, or interaction among them. The bud fertility index varied only as a result of the production cycle. The pergola training system increased yield in relation to espalier and lyre systems, also favoring a larger number and size of clusters. The IAC 766 rootstock increased berry size and TA, whereas IAC 572 favored higher sugar/SS content and SS/TA ratio. The fourth production cycle (harvest on 9 May 2019) led to the best agronomic performance of 'BRS Cora' grapevines under the conditions of the Submédio do Vale do São Francisco region.

Key words: *Vitis* spp., tropical vitiviniculture, hybrid grapes, yield, grape juice.

INTRODUCTION

Brazilian cultivars are used in the production of grape juices in Submédio do Vale do São Francisco region, such as 'Isabel Precoce', 'BRS Magna', 'BRS Carmem', 'BRS Cora', and 'BRS Violeta', which together represent annual production of around 8 million L of grape juice, with mean yield of 30 ton/ha/growing season, and yield of grapes into juice at around 60% (Lima et al. 2019). However, studies that evaluate the effects of different training systems and rootstocks on the yield performance and physical-chemical characteristics of 'BRS Cora' grapes have not been carried out in this semiarid tropical region yet.

Grape juice consumption has become more popular in Brazil along with the growing publicity of its beneficial effects on health. In 2023, grape juice production in Rio Grande do Sul, which is the center of most Brazilian production, increased by 7.8% compared to the 2022 season, for a total of 38,216,760.58 L. The highest production was for whole red grape juice and, after that, whole white grape juice (Azevedo 2023).

Global vitiviniculture under different environmental conditions has led to various types of vine training systems for grape growing, which seek to fulfill various objectives, mainly improvement of the local microclimate, favoring reduction in diseases; better ratio between leaf area and fruit exposure in intercepting solar energy; and reduction in labor and production costs through better positioning of the fruit, optimizing manual or mechanized practices (Zurowietz et al. 2022). Furthermore, the training system may be able to increase grape production (Leão and Chaves 2019, 2020), as well as affect the chemical composition of the fruit, including total soluble solids content, titratable acidity, anthocyanin, and volatile compound content, traits that affect juice quality (Costa et al. 2021, Ferreira et al. 2019, Leão et al. 2023, Liu et al. 2015).

Another factor that can directly affect grape yield and quality is the choice of the rootstock, since, although the rootstock is initially used as a source of resistance to attacks of soil-borne pests, it is known that it can affect vigor, yield components, and grape physical and chemical traits (Brighenti et al. 2021, Leão and Chaves 2019, 2020).

In Brazil, studies considering the combination of training systems and rootstocks in the 'BRS Cora' cultivar have focused only on the physical-chemical and antioxidant quality of the grapes over two production cycles in the dry and rainy seasons in the Submédio do Vale do São Francisco (Costa et al. 2020, 2021). Consequently, the agronomic performance of this cultivar is still unknown considering its cultivation under different training systems and rootstocks under semi-arid tropical climate conditions. Therefore, the aim of this study was to evaluate the effect of production cycles, training systems, and rootstocks on the yield, vigor, and physical and chemical traits of 'BRS Cora' grapes grown in the Submédio do Vale do São Francisco.

MATERIALS AND METHODS

Experimental site and vine management

The experiment was conducted over six production cycles from 2017 to 2020 at the Bebedouro Experimental Field, Embrapa Semiárido, in Petrolina, Pernambuco, Brazil (09°09'S, 40°22'W, and mean altitude of 365.5 m). The pruning and harvest dates are shown in Table 1. The harvest was carried out when the average soluble solids content determined in the field was above 18 °Brix. However, as shown in Table 1, the duration of production cycle was not the same among different growing seasons.

Table 1. Pruning and harvest dates of 'BRS Cora' grapevines over seven production cycles, 2017 to 2020.

Production cycle	Pruning date	Harvest date	Duration (Days)
1st: 2017.1	16/01/2017	03/05/2017	107
2nd: 2017.2	04/07/2017	31/10/2017	120
3rd: 2018.2	25/06/2018	09/10/2018	104
4th: 2019.1	23/01/2019	09/05/2019	104
5th: 2019.2	10/07/2019	01/11/2019	112
6th: 2020.1	10/02/2020	29/05/2020	109

This region is characterized by a semi-arid tropical climate, classified according to Köppen as Bswh type (Alvares et al. 2014). The climate variables [mean, maximum, and minimum temperatures (°C), global solar radiation (MJ/m^2), and rainfall (mm)] were recorded at the Automatic Agricultural Weather Station of the Bebedouro Experimental Field and are shown in Fig. 1. The soils in which the experiment was set up were classified as *argissolo vermelho eutrófico abrúptico plíntossólico*, with a moderate A horizon, medium texture, and flat topography (Cunha et al. 2008).

The grapevines were planted in 2015, using a spacing of 3 × 1 m (3,333 plants·ha^{-1}). Vine training pruning was performed in a unilateral cordon with six lateral branches in all the training systems. The fruit production prunings were of the mixed type with spurs at the base of the branches and canes (six or seven buds) and performed twice a year.

Irrigation and application of nutrients (fertigation) was performed by a drip irrigation system with two drippers per plant at every 0.50 m and a mean flow rate of 2.10 L·h^{-1}. The gross irrigation depth values were calculated daily, with evapotranspiration (ETo) determined by the Class A Tank method (Allen et al. 1998).

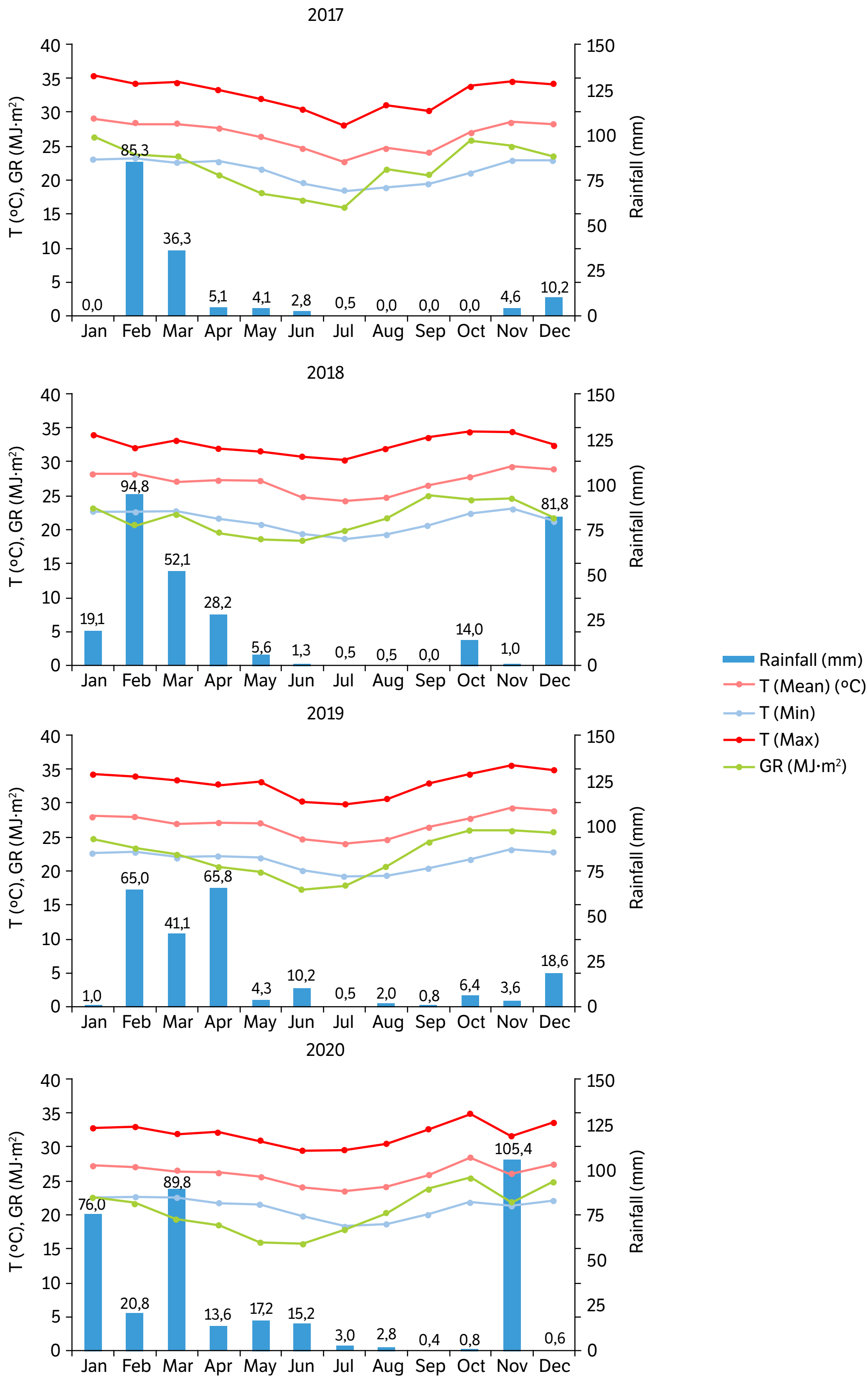

Figure 1. Seasonal variations of rainfall; mean, maximum, and minimum air temperature (T); and global solar radiation (GR) in the period 2017-2020, Petrolina, PE, Brazil.

Vineyard management included the following practices in the canopy: bud pruning, tying of branches and shoots, topping of branches, and minimal leaf removal in the region of the clusters. Mechanized mowing and alternating application of herbicides, as well as occasional hoeing, were performed for weed control. To control pests and diseases that affect the vines, they were sprayed weekly using chemical products registered for the crop.

Experimental design

Grapevines of the cultivar 'BRS Cora' were grown in three training systems: pergola (horizontal canopy growth orientation), lyre (oblique canopy growth orientation), and espalier (vertical canopy growth orientation); and they were grafted on the rootstocks IAC 572 and IAC 766. The experiment was carried out in split-split plots, in which the main plots were the production cycle, the split plots were the training systems, and the split-split plots were the rootstocks. A randomized block experimental design was used, with four replications, and plots consisted of five plants, identifying two plants to be used for data collection for evaluation of yield and collection of fruit samples.

Fruit and vine evaluations

Branches and leaves eliminated during pruning were weighed on a digital electronic balance, obtaining the fresh matter, which was expressed in $kg \cdot plant^{-1}$, a variable that indicates plant vigor.

At approximately 20 days after pruning and before shoots removal, buds, shoots, and clusters were counted on canes and spurs to determine the bud-burst percentage and bud fertility index using the Eqs. 1 and 2:

$$\text{Bud burst (\%)} = \text{no. of shoots} \times 100 / \text{no. of buds} \tag{1}$$

$$\text{Fertility (index)} = \text{no. of clusters} / \text{no. of shoots} \tag{2}$$

The harvest was carried out when the average soluble solids content determined in the field was above 18 °Brix. Then, the clusters from the plants used for data collection in the plot were counted and weighed on a digital electronic balance, obtaining yield per plant ($kg \cdot plant^{-1}$).

A sample of five clusters was collected for determination of the biometric measures of the clusters: cluster weight (g), cluster length (cm), and cluster width (cm). A sample of ten berries was separated from each cluster for evaluation of the physical and physical-chemical variables of the grapes: berry weight (g), berry length (mm), and berry diameter (mm), as well as soluble solids (SS) content and titratable acidity (TA).

The SS content was obtained from the must extracted from 50 berries used for the physical variables. Readings were taken using a digital refractometer with automatic temperature adjustment and expressed in °Brix. TA was determined in a sample prepared through dilution of 5 mL of grape pulp in 50 mL of distilled water, together with the 0.1 NaOH solution, using an automatic titrator and expressed in g of tartaric acid•100 mL-1 (AOAC, 2016) and the SS/TA ratio.

The agronomic and biometric variables of cluster and berry are not directly related to the production of grape juice, but they are correlated with vigor and yield and therefore with the economic viability of juice grape production. On the other hand, chemical variables (SS, TA, and ratio) have a significant influence on the sugar and acidity content and, consequently, on the flavor of the juice.

The Shapiro-Wilk's normality test was used on the mean values of all the variables. Upon meeting the requirement of normal distribution of the data, analysis of variance (F test, $p < 0.05$) was used on the mean values, considering the production cycles, training systems, and rootstocks as sources of variation, and the means were compared by Tukey's test at 5% probability. Shapiro-Wilk's normality test was used on the mean values of all the variables. The data for yield, TA, SS, and the SS/TA ratio did not follow a normal distribution and were adjusted using the $\sqrt{(X+1)}$ transformation, while for pruned material weight and cluster weight and width the $\sqrt{(X+0.5)}$ transformation was applied.

RESULTS AND DISCUSSION

The yield of 'BRS Cora' grapevines was affected by the production cycle associated with the training system. However, there was strong alternation between production cycles, where the second, and fourth cycles led to an increase in plant yield (Table 2), and significant statistical differences were not observed among training systems in these cycles. The second cycle (from July/2017 to Oct/2017) experienced the lowest rainfall accumulation (15.3 mm) along with increased temperatures and global solar radiation, a combination of factors that favoured plant health, higher photosynthetic rates, and carbohydrate accumulation, resulting in greater productivity (Keller 2015a). Unlike the second cycle, the factor that may have most contributed to the increased productivity in the fourth cycle was the longer rest period among production cycles (106 days). In the conditions of the Submédio do Vale do São Francisco, after harvest, vines tend to remain vegetative growth until the next production pruning, this period commonly varying between 30 and 60 days when opting for two harvests per year (Leão and Rodrigues 2009). During the rest period, as the main sink (clusters) was removed, most of the carbohydrates are exported and stored in the roots and trunks, to be used after production pruning for the development and initial growth of shoots, reestablishing the canopy and subsequently increasing the productive capacity of the grapevine (Keller 2015b). Alternation between growing seasons is a common feature in grape growing worldwide, as factors like excessive production depleting carbohydrate reserves, shortened rest periods, and unfavourable climate conditions during floral differentiation contribute to irregular yields across production cycles. Therefore, the cultivar 'BRS Cora', regardless of the training system or rootstock used, did not show yield stability over consecutive growing seasons.

Grapevine training systems can influence the light interception and improve environmental conditions such as temperature and humidity, which have an important influence on the yield and quality of grapes (Gregan et al. 2012). The pergola training system led to increases of 22 and 26% in yield compared to the espalier and lyre systems, respectively. The higher yield in this training system can be explained by the greater exposed leaf area, increasing interception of solar radiation, and the photosynthesis of leaves, which contributed to better fruit set resulting in a larger number of clusters (Stewart et al. 2003, Reynolds and Vanden Heuvel 2009).

Table 2. Mean values and standard error for yield per plant of 'BRS Cora' grapevines considering the production cycle × training system interaction, Petrolina, PE, Brazil*.

Growing Season	Yield per plant (kg)			Mean
	Espalier	Pergola	Lyre	
1st	3.29 ± 0.20 Ab*	2.59 ± 0.22 Acd	2.22 ± 0.16Abc	2.70 b
2nd	6.46 ± 0.49 Aa	7.08 ± 0.52 Aa	6.34 ± 0.43 Aa	6.62 a
3rd	1.66 ± 0.25 Bcd	5.11 ± 0.24 Aab	1.35 ± 0.17 Bbc	2.71 bc
4th	5.70 ± 0.31 Aa	6.37 ± 0.29 Aa	6.37 ± 0.38 Aa	6.14 a
5th	1.07 ± 0.13 Ad	2.16 ± 0.35 Ad	1.26 ± 0.08 Ac	1.50 c
6th	3.13 ± 0.33 ABbc	4.07 ± 0.17 Abc	2.72 ± 0.21 Bb	3.31 b

*Means followed by the same uppercase letters in the row and lowercase letters in the columns do not differ by Tukey's test at 5% probability. Data transformed into square root of x + 1.

Yield also varied according to the rootstock × training system interaction. Grapevines grafted on IAC 572 and trained in the pergola system were higher yielding (4.62 ton/ha) than in the espalier and lyre systems (3.32 and 2.99 ton/ha, respectively). The pergola system also led to significant gains compared to the espalier system when the IAC 766 rootstock was used; however, there were no differences in relation to the lyre system. Yield differences were not observed between rootstocks in the espalier and pergola training systems. However, when the grapevines were trained in the lyre system, the best performance was with the IAC 766 rootstock (Fig. 2).

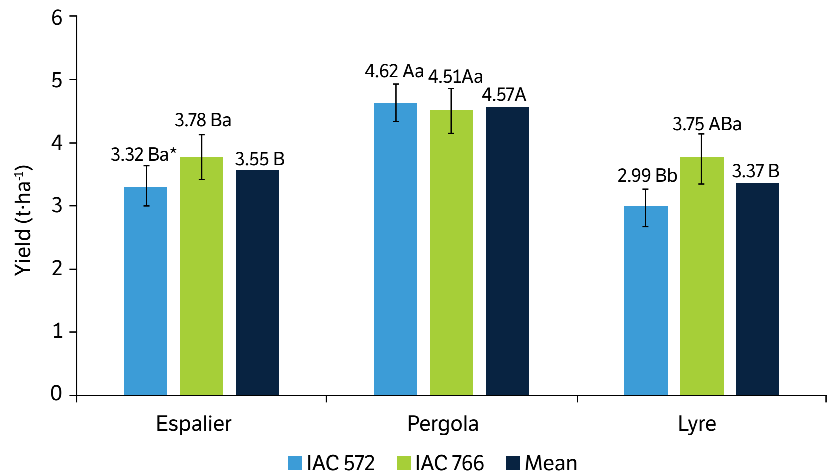

Figure 2. Overall mean and standard error of the yield of 'BRS Cora' grapevines grafted on different rootstocks and in different training systems. Uppercase letters compare the rootstock in different training systems, and lowercase letters compare rootstocks in the same training system. Means followed by the same uppercase and lowercase letter do not differ by Tukey's test at 5% probability. Data transformed into square root of x + 1.

The increase in mean yield of 'BRS Cora' grapevines grafted on IAC 766 corroborate the results obtained with this same cultivar and other grape juice and wine, such as 'BRS Carmem', 'Isabel Precoce', and 'IAC 138-22 Máximo' (Silva et al. 2018); 'IAC 138-22 Máximo', 'BRS Lorena', and 'Bordô' (Tecchio et al. 2020) in different regions of the state of São Paulo; as well as in the 'Syrah' (Dias et al. 2017) in the Submédio do Vale do São Francisco, similar results were found in the cv. BRS Magna, whose yields were higher on the IAC 766 rootstock in the pergola and lyre training systems (Leão et al. 2023). However, considering the pergola training system, there were no differences between the two rootstocks, obtaining maximum estimated mean yield of 16 ton/ha on the rootstock IAC 766 and pergola training system. This yield is below the mean yield achieved in other cultivars for grape juice, such as 'BRS Magna' (Leão et al. 2023) and 'Isabel Precoce' (Leão et al. 2018) grown in the Submédio do Vale do São Francisco.

There was a significant effect for the training system × rootstock interaction on canopy biomass (weight of branches and leaves eliminated in pruning), which is a variable associated with plant vigor (Fig. 3). Grapevines grown in the lyre and espalier systems had greater vigor than in the pergola system on both the rootstocks used; furthermore, grapevines grafted on IAC 572 and trained in the lyre system produced greater canopy biomass than in the pergola system, both of which did not differ significantly from the espalier system. The IAC 766 rootstock significantly reduced grapevine vigor in the pergola training system. These results differ from those found by Leão et al. (2023) in the BRS Magna cultivar in this same region, where the pergola and lyre systems led to an increase in the branch and leaf fresh matter compared to the espalier system. In contrast, the branch weight of Syrah grapevines grown in the Submédio do Vale do São Francisco was higher in the lyre training system than in the espalier system with grafting onto IAC 572 (Leão and Chaves 2019), which corroborates the results obtained in this study. IAC 572 is characterized as a high-vigor rootstock (Angelotti-Mendonça et al. 2018, Pimentel Junior et al. 2018), which is associated with the greatest root development observed in this rootstock (Embrapa 2023). In the Submédio do Vale do São Francisco, the branch weight of Syrah grapevines was higher in the lyre training system than in the espalier system with grafting onto IAC 572 (Leão and Chaves 2019), which corroborates the results obtained in this study. The IAC 766 rootstock significantly reduced grapevine vigor in the pergola training system. One of the main characteristics of the IAC 766 rootstock is its tendency to induce moderate canopy vigor, similar to the pergola training system, making this combination an effective alternative for controlling excessive vegetative growth (Fira et al. 2016, Embrapa 2023).

There was no effect of any of the factors studied (production cycle, training systems, and rootstocks) on bud fertility; however, 'BRS Cora' showed a mean of 1.7 clusters per shoot, that is, high bud fertility, confirming the trait of this cultivar (Camargo and Maia 2004).

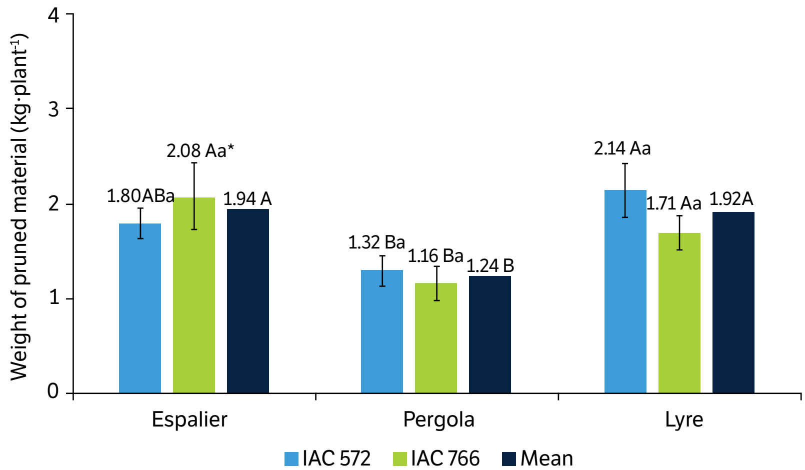

Figure 3. Overall mean and standard error of branch and leaf fresh matter collected after pruning in 'BRS Cora' grafted on different rootstocks and in different training systems. Uppercase letters compare rootstocks in different training systems, and lowercase letters compare rootstocks in the same training system. Means followed by the same uppercase and lowercase letter do not differ by Tukey's test at 5% probability. Data transformed into square root of x + 0.5.

Significant effects were observed for the training system × production cycle interaction on the number of clusters per plant, but there was no effect of the rootstock on this variable (Table 3). The largest mean value of the number of clusters was found in the second production cycle, without a significant difference among the training systems. Regardless of the production cycle, grapevines trained in the pergola system produced a larger number of clusters from the second to the sixth production cycle, with an overall mean of 62 clusters per plant. Production of a larger number of clusters in the pergola system can be explained by the horizontal architecture of the canopy, which allows greater vegetative growth and, consequently, a larger number of shoots and buds per square meter (Reynolds and Vanden Heuvel 2009, Yin et al. 2022). The results obtained agree with those observed in the Niágara Rosada cultivar, which produced a larger number of clusters in the pergola system than in the espalier system (Sanchez-Rodriguez and Spósito 2020).

Table 3. Mean values and standard error for number of clusters per plant of 'BRS Cora' grapevines considering the production cycle × training system interaction, Petrolina, PE, Brazil*.

Growing Season	Number of clusters per plant			Mean
	Espalier	Pergola	Lyre	
1st	72.04 ± 3.31 Aa	45.40 ± 2.91 Bc	53.87 ± 3.26 Bab	57.10 ab
2nd	66.44 ± 3.56 Aab	73.31 ± 3.07 Aab	69.94 ± 1.99 Aa	69.90 a
3rd	33.38 ± 4.86 Bde	83.44 ± 2.22 Aa	32.31 ± 3.46 Bbc	49.71 b
4th	49.44 ± 3.58 Bbcd	69.00 ± 3.62 Aab	59.63 ± 3.25 ABa	59.35 ab
5th	18.69 ± 1.85 Be	45.56 ± 5.82 Ac	23.31 ± 1.15 Bc	29.19 c
6th	58.06 ± 3.96 Aabc	54.69 ± 2.77 Abc	51.25 ± 1.65 Aab	54.67 ab

*Means followed by the same uppercase letters in the row and lowercase letters in the columns do not differ by Tukey's test at 5% probability.

Regarding cluster weight, there was significant interaction between the production cycle and the training system, with significant differences between training systems only the second and third production cycles. In the mean cluster values for the training systems, the pergola system was superior to the lyre system, while the espalier system had intermediate performance (Table 4). Just as observed for yield, the second and fourth cycles led to an increase in cluster weight, achieving the highest mean value (137.78 g) in the fourth production cycle, below the 150-g weight described for this juice grape cultivar evaluated in other regions of Brazil (Camargo and Maia 2004). Cluster weight, just as other yield components, is affected by the carbohydrate reserves stored in the roots, stem, branches, and leaves; therefore, the smallest cluster weight was observed in young grapevines in the first production cycle and also in the third, fifth, and sixth cycles, since they followed cycles with high yield. The effect of the rootstock, just as the rootstock × training system interaction, was not significant.

Table 4. Mean values and standard error for cluster weight of 'BRS Cora' grapevines considering the production cycle × training system interaction, Petrolina, PE, Brazil*.

Growing Season	Cluster weight (g)			Mean
	Espalier	Pergola	Lyre	
1st	45.72 ± 2.19 Ae	60.29 ± 6.08 Ad	41.66 ± 2.82 Ac	49.22 c
2nd	149.93 ± 8.20 Aa	112.34 ± 3.34 Bab	128.07 ± 8.42 ABa	130.11 a
3rd	74.58 ± 3.34 ABcd	93.33 ± 4.45 Abc	63.58 ± 4.70 Bbc	77.16 b
4th	133.99 ± 5.35 Aab	138.09 ± 9.36 Aa	141.26 ± 6.59 Aa	137.78 a
5th	63.39 ± 1.89 Ade	66.88 ± 2.81 Acd	71.19 ± 3.25 Ab	67.15 bc
6th	52.49 ± 3.32 Ade	76.22 ± 4.00 Acd	52.29 ± 3.07 Abc	60.33 bc

*Means followed by the same uppercase letters in the row and lowercase letters in the columns do not differ by Tukey's test at 5% probability. Data transformed into square root of x + 0.5.

The cluster size of 'BRS Cora' was affected by the production cycle × training system interaction; the grapevines trained in the pergola and espalier systems had shorter cluster length in the last two cycles, whereas shorter length in the lyre system was only in the fifth production cycle (Table 5). There were no significant differences in the width of the clusters of grapevines trained in the espalier and lyre systems in most of the cycles studied; whereas in the pergola system, clusters of smaller width were observed in the sixth cycle, though not differing from the previous cycle, which had an intermediate value similar to the previous production cycles. Cluster length and width were not affected by the rootstock either. The fourth production cycle favored the development of clusters with greater length and width in all the training systems. Therefore, the 'BRS Cora' cultivar when grown under suitable climate and management conditions had clusters of size similar to that of other juice grape cultivars, such as 'BRS Magna' (Leão et al. 2023) and 'Isabel Precoce' (Leão et al. 2018) grown in this same region, regardless of the training system and rootstock used.

Table 5. Mean values and standard error for cluster length and width of 'BRS Cora' grapevines considering the production cycle × training system interaction, Petrolina, PE, Brazil*.

Growing Season	Cluster length (mm)			Mean
	Training system			
	Espalier	Pergola	Lyre	
1st	45.72 ± 2.19 Ae	60.29 ± 6.08 Ad	41.66 ± 2.82 Ac	49.22 c
2nd	149.93 ± 8.20 Aa	112.34 ± 3.34 Bab	128.07 ± 8.42 ABa	130.11 a
3rd	74.58 ± 3.34 ABcd	93.33 ± 4.45 Abc	63.58 ± 4.70 Bbc	77.16 b
4th	133.99 ± 5.35 Aab	138.09 ± 9.36 Aa	141.26 ± 6.59 Aa	137.78 a
5th	63.39 ± 1.89 Ade	66.88 ± 2.81 Acd	71.19 ± 3.25 Ab	67.15 bc
6th	52.49 ± 3.32 Ade	76.22 ± 4.00 Acd	52.29 ± 3.07 Abc	60.33 bc
Mean	**11.04 B**	**12.12 A**	**11.21 B**	**11.46**
Growing Season	**Cluster width (mm)**			**Mean**
	Training system			
	Espalier	**Pergola**	**Lyre**	
1st	6.48 ± 0.27 Aab	7.30 ± 0.27 Aa	7.05 ± 0.37 Aab	6.94 a
2nd	6.58 ± 0.26 ABab	7.86 ± 0.65 Aa	6.51 ± 0.18 Bb	6.98 a
3rd	6.63 ± 0.21 Aab	7.30 ± 0.21 Aa	6.46 ± 0.25 Ab	6.79 ab
4th	7.40 ± 0.21 ABa	7.19 ± 0.29 Ba	8.69 ± 0.37 Aa	7.76 a
5th	6.17 ± 0.22 Aab	6.45 ± 0.11 Aab	6.17 ± 0.13 Ab	6.27 ab
6th	5.18 ± 0.17 Ab	5.40 ± 0.17 Ab	5.59 ± 0.16 Ab	5.39 b

*Means followed by the same uppercase letters in the row and lowercase letters in the columns do not differ by Tukey's test at 5% probability. Data on cluster length were transformed into square root of x + 0.5.

Berry weight was affected by the training system × production cycle interaction (Table 6). In the espalier and pergola training systems, there was significant variation among practically all the cycles; however, in the lyre system, the fourth cycle was superior to the others. The mean of the training systems in each cycle indicated that the fourth production cycle had berries with the greatest weight (2.88 g). However, in the overall mean of all the cycles, there was no variation among the training systems. Greater berry weight was obtained when 'BRS Cora' was grafted on IAC 766 (2.60 g) than when grafted on IAC 572 (2.46 g). The rootstocks IAC 572 and IAC 766 are characterized by enhanced rooting (Embrapa 2023), but other genetic intrinsic characteristics, such as vigor and nutrient uptake, can promote gains in yield components, leading to different responses in scion–rootstock combinations. Although the fourth cycle occurred during the wet season, which had lower temperature and sunlight, it resulted in an increase in berry weight and size, and other yield components. The carbohydrate reserves accumulated during the long rest time between the harvest of the third cycle and the production pruning of the fourth cycle may have contributed for the compensatory increase in the berry and cluster weight and size. However, in the overall mean of all the cycles, there was no variation among the training systems.

Table 6. Mean values and standard error for berry weight of 'BRS Cora' grapevines considering the production cycle × training system interaction, Petrolina, PE, Brazil*.

Growing Season	Berry weight (g)			Mean
	Training system			
	Espalier	Pergola	Lyre	
1st	2.33 ± 0.04 Ab	2.39 ± 0.05 Abc	2.40 ± 0.04 Ab	2.37 cd
2nd	2.60 ± 0.05 Bab	2.95 ± 0.05 Aa	2.60 ± 0.03 Bb	2.72 ab
3rd	2.51 ± 0.09 Ab	2.49 ± 0.03 Ab	2.26 ± 0.05 Ab	2.42 cd
4th	2.88 ± 0.06 ABa	2.67 ± 0.06 Bab	3.09 ± 0.17 Aa	2.88 a
5th	2.58 ± 0.10 Aab	2.60 ± 0.10 Aab	2.47 ± 0.04 Ab	2.55 bc
6th	2.27 ± 0.08 Ab	2.11 ± 0.07 Ac	2.35 ± 0.06 Ab	2.24 d

*Means followed by the same uppercase letters in the row and lowercase letters in the columns do not differ by Tukey's test at 5% probability.

There was a significant effect in the training system × production cycle interaction for the TA variable (Table 7). 'BRS Cora' grapes had greater acidity in the fourth cycle when grown in the pergola system (0.82 g tartaric acid·100 mL^{-1}) and lyre system (0.88 g tartaric acid·100 mL^{-1}), whereas in the espalier system the third and fourth production cycles favored an increase in TA of the grapes, reaching 0.81 and 0.89 g tartaric acid·100 mL^{-1}, respectively. There was no difference in the overall mean of all the production cycles for training systems; however, more acidic grapes were harvested from grapevines grafted on IAC 766 (Fig. 4A). In relation to the mean value of each cycle, regardless of the training system used, the fourth cycle was significantly higher than the others, with 0.86 g tartaric acid·100 mL^{-1}. According to Guerra et al. (2003), values ranging from 0.5–0.9 g of tartaric acid·100 mL^{-1} are necessary to produce high-quality juices. Thus, despite the variations observed in the training system and rootstocks, all the values observed in the 'BRS Cora' grapes are in accordance with those recommended to produce grape juice.

The SS content (°Brix) variable showed significant differences only for the separate effect of production cycles and rootstocks, and the highest values were obtained in the fourth and sixth cycles, with 21.38 °Brix and 20.38 °Brix, respectively. Despite the variation in the SS content, the mean value in each production cycle was higher than 17 °Brix. The effect of training systems was not significant for total SS content, obtaining an overall mean of 19.35 °Brix. However, a higher SS content was observed in grapes harvested from 'BRS Cora' grapevines grafted onto the IAC 572 rootstock (Fig. 4B). That shows that the higher total sugar content in the 'BRS Cora' cultivar was not directly associated with reduction in acidity, and other environmental factors were able to interfere in these chemical variables, such as the use of different rootstocks, as shown in this study.

Table 7. Mean values and standard error for titratable acidity and total soluble solids of 'BRS Cora' grapevines considering the production cycle × training system interaction, Petrolina, PE, Brazil*.

Growing Season	Titratable acidity (g tartaric acid·100 mL^{-1})			Mean
	Training system			
	Espalier	Pergola	Lyre	
1st	0.34 ± 0.01 Ad	0.37 ± 0.01 Ad	0.36 ± 0.01 Ad	0.36 e
2nd	0.70 ± 0.09 Ab	0.63 ± 0.06 Ab	0.70 ± 0.04 Ab	0.68 c
3rd	0.81 ± 0.02 Aa	0.71 ± 0.02 Bb	0.74 ± 0.03 ABb	0.75 b
4th	0.89 ± 0.01 Aa	0.82 ± 0.01 Aa	0.88 ± 0.01 Aa	0.86 a
5th	0.66 ± 0.04 Ab	0.72 ± 0.07 Ab	0.71 ± 0.06 Ab	0.70 c
6th	0.51 ± 0.01 Ac	0.53 ± 0.01 Ac	0.52 ± 0.01 Ac	0.52 d
Mean	**0.65** ^{ns}	**0.63**	**0.65**	**0.64**
Growing Season	**Total soluble solids (ºBrix)**			**Mean**
	Training system			
	Espalier	**Pergola**	**Lyre**	
1st	19.34 ± 0.17 Aabc	20.28 ± 0.14 Aab	19.20 ± 0.45 Aabc	19.60 bc
2nd	18.90 ± 0.28 Aabc	19.54 ± 0.20 Ab	18.66 ± 0.40 Abc	19.03 cd
3rd	18.01 ± 0.36 Abc	18.35 ± 0.29 Ab	18.26 ± 0.27 Abc	18.21 de
4th	21.38 ± 0.27 Aa	22.36 ± 0.32 Aa	20.41 ± 0.59 Aab	21.38 a
5th	16.80 ± 0.37 Ac	18.45 ± 0.18 Ab	17.20 ± 0.36 Ac	17.48 e
6th	19.90 ± 0.58 Aab	19.84 ± 0.54 Aab	21.40 ± 0.46 Aa	20.38 ab

*Means followed by the same uppercase letters in the row and lowercase letters in the columns do not differ by Tukey's test at 5% probability. Data transformed into square root of x + 1.

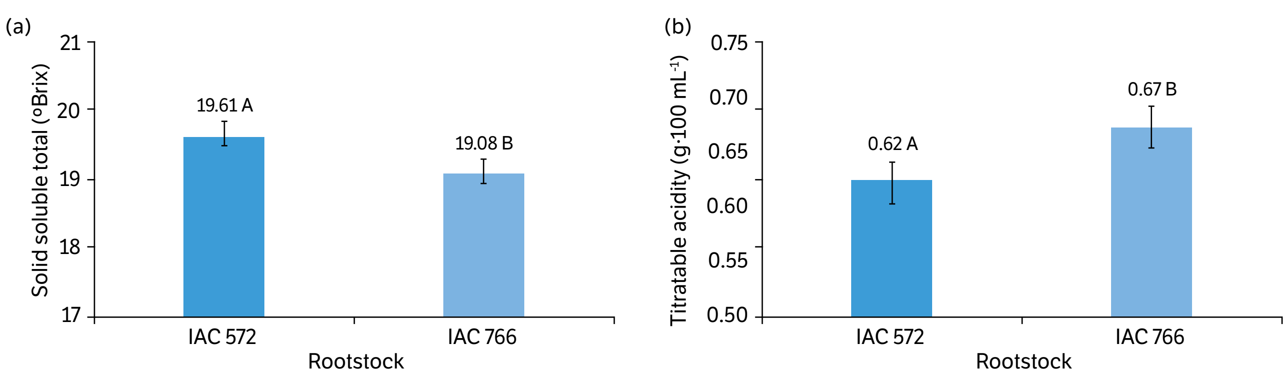

Figure 4. Overall mean and standard error of (A) total soluble solids and (B) titratable acidity of fruit from 'BRS Cora' grafted onto the rootstocks. Uppercase letters compare rootstocks in different training systems, and lowercase letters compare rootstocks in the same training systems. Means followed by the same uppercase and lowercase letter do not differ by Tukey's test at 5% probability.

The taste balance of grape juices is primarily based on the SS/TA ratio, which can be used as an index of grape maturity. However, as seen in this study, harvesting based solely on this index should be avoided, since an increase in berry sugar content does not necessarily correspond to a decrease in TA. For the SS/TA variable, there was significant interaction between the rootstock and production cycle (Table 8), and there were no differences among the training systems. According to Burin et al. (2010), the SS/AT ratio values should be between 15 and 45, as it can interfere in the juice quality. In both rootstocks, the SS/AT ratio values in the first production cycle was higher compared to the others, being considered inadequate (> 45), while the mean values of other cycles ranged from 24.44 to 39.47. The IAC 572 rootstock led to gains in the SS/TA ratio, since on that rootstock the 'BRS Cora' grapes had higher total SS content (Fig. 4B).

Table 8. Mean values and standard error for soluble solids/titratable acidity (SS/TA) of 'BRS Cora' grapevines considering the production cycle × training system interaction, Petrolina, PE, Brazil*.

Growing Season	SS/TA (ºBrix/acidity ratio)		Crude protein (mg/g)
	Rootstock		
	IAC 572	IAC 766	
1st	54.07 ± 1.02 Aa	56.27 ± 1.23 Aa	55.17 a
2nd	33.71 ± 0.85 Ac	24.88 ± 0.58 Bc	29.30 c
3rd	26.14 ± 1.48 Ad	22.75 ± 0.93 Ac	24.44 d
4th	25.65 ± 0.26 Ad	24.22 ± 0.25 Ac	24.93 d
5th	27.98 ± 1.16 Ad	23.96 ± 1.60 Bc	25.97 cd
6th	40.07 ± 1.00 Ab	38.88 ± 0.72 Ab	39.47 b

*Means followed by the same uppercase letters in the row and lowercase letters in the columns do not differ by Tukey's test at 5% probability. Data transformed into square root of x + 1.

CONCLUSION

Production components and vegetative vigor are influenced by the association of training systems, rootstocks or production cycles, but there are no effects of isolated factors.

Rootstock IAC 766 promotes an increase in TA, whereas IAC 572 favors greater sugar content (SS) and SS/TA ratio.

Growing 'BRS Cora' grapevines in the pergola system increase yield by around 22% and 26% compared to the espalier and lyre systems, respectively, also favors a larger number and size of clusters.

The choice of the vine training system must consider the characteristics of soil, climate, and rootstock of each vineyard.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

Conceptualization: Leão, P. C. S.; **Investigation:** Leão, P. C. S.; **Writing – Original Draft:** Leão, P. C. S. and Oliveira, C. R. S.; **Writing – Review and Editing:** Leão, P. C. S. and Oliveira, C. R. S.; **Funding Acquisition:** Leão, P. C. S; **Supervision:** Leão, P. C. S. ; **Final approval:** Leão. P.C.S.

DATA AVAILABILITY STATEMENT

All dataset were generated and analyzed in the current study.

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