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Phenology, production, and fruit quality of blackberry cultivars under greenhouse in southern Brazil

Fenologia, produção e qualidade de frutos de cultivares de amoreira-preta em estufa no sul do Brasil

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Knowing the phenology, production, and fruit quality of blackberry cultivars grown in greenhouses enables growers to develop and/or improve assertive orchard management. The aim of this study was to investigate whether phenology, production, and fruit quality differ among blackberry cultivars grown under greenhouse. The treatments were four blackberry cultivars (‘BRS Cainguá’, ‘BRS Tupy’, ‘BRS Xavante’, and ‘BRS Xingu’), arranged in a randomized block design, with four replications and three plants per plot. Phenology, production, and fruit quality were assessed. ‘BRS Xingu’ had an earlier start than all the phenological stages assessed, proving to be the earliest to achieve fruit harvest stage. ‘BRS Cainguá’ was the latest to harvest. ‘BRS Xingu’ showed the highest total production values, followed by ‘BRS Cainguá’, with the largest longitudinal diameter, and ‘BRS Tupy’, with the largest transverse diameter. Fruit quality was not influenced by the cultivars. In conclusion, the four blackberry cultivars differ in terms of phenology and fruit production potential under greenhouse. This allows production to be staggered around 15 days in terms of the start and end of the harvest.
Keywords: *Rubus* sp., phenological stages, yield.

Conhecer a fenologia, a produção e a qualidade de frutos de cultivares de amoreira-preta em estufa possibilita aos produtores desenvolver e/ou aprimorar manejos assertivos em relação ao estabelecimento de pomares. Assim, o trabalho objetivou investigar se a fenologia, a produção e a qualidade de frutos diferem entre cultivares de amoreira-preta em estufa. Os tratamentos foram quatro cultivares de amoreira-preta (‘BRS Cainguá’, ‘BRS Tupy’, ‘BRS Xavante’ e ‘BRS Xingu’), dispostos no delineamento de blocos casualizados, com quatro repetições e três plantas por parcela. Avaliou-se a fenologia, a produção e a qualidade de frutos. ‘BRS Xingu’ teve antecipação do período inicial de todos os estádios fenológicos avaliados, mostrando-se a mais precoce para a colheita de frutos. ‘BRS Cainguá’ foi a mais tardia quanto à colheita. ‘BRS Xingu’ apresentou os maiores valores de produção total, seguida de ‘BRS Cainguá’, com o maior diâmetro longitudinal, e ‘BRS Tupy’, com o maior diâmetro transversal. A qualidade de frutos não foi influenciada pelas cultivares. Em conclusão, as quatro cultivares de amoreira-preta diferem quanto à fenologia e potencial produtivo de frutos em estufa. Isso permite o escalonamento da produção em torno de 15 dias quanto ao início e final de safra.
Palavras-chave: *Rubus* sp., estádios fenológicos, rendimento.

1. INTRODUCTION

The annual fruit production in Brazil is approximately 37 million tons, with the country occupying third place in the ranking of the world’s largest producers, behind only China and India [1]. Blackberry (*Rubus* sp.) cultivation is on the rise on a global scale [2] due to the low cost of establishing orchards, the good crop profitability, the quick return on investment, and the benefits that blackberries provide to consumers through the activity of anthocyanins, flavonoids, and cinnamic acid derivatives [3].

As a temperate climate fruit tree, blackberries need to accumulate a certain number of hours of cold below 7.2ºC or 13.0ºC in winter, depending on the cultivar, so that productivity is not compromised [4]. Therefore, in addition to production systems, new blackberry cultivars are being adapted to the soil and climatic conditions and biogeography of the producing regions. The development of cultivars is controlled by complex environmental interactions, which mainly include temperature. Thus, studies on plant development are necessary to understand the adaptability of cultivars in relation to growing conditions and to scale up fruit production [5].

In a scenario where climate change is constant [6], crops with more rustic characteristics and management are gaining ground, as they can withstand adverse climatic conditions, such as frosts and periods of drought [7]. In addition to its hardiness and the high nutritional value of its fruit, blackberry has phenological characteristics that allow it to harvest two crops in one year, depending on pruning management, especially if the crop is grown in a greenhouse [8].

Various factors can affect phenology and production potential. However, there has been little research into the phenology and fruit production of blackberry cultivars grown in greenhouse in southern Brazil. This fact, as well as limiting the adoption of greenhouse cultivation by producers, makes it difficult to choose cultivars for the establishment of commercial orchards with more productive materials and that have contrasting phenology to allow for the scaling of cultivars.

Greenhouse cultivation can protect plants from frost, hail damage, and prevent the occurrence of diseases caused by excessive rainfall, which would compromise the crop's productive potential [7]. In addition to the micro-meteorological advantages that favor production, producers who use this system in regions with higher winter temperatures can obtain earlier harvests, with the possibility of producing in the months of August, September, and October, when blackberry prices rise due to a lack of product on the market [9].

The blackberry market still has gaps due to the lack of specific marketing channels. However, the increased interest of producers in cultivation could generate new business opportunities and make the cultivation and marketing of fruit more accessible. Therefore, the choice of the cultivar to plant commercial orchards is fundamental, since the particularities related to fruit production and quality vary from material to material [8].

Therefore, the aim of this study was to investigate whether phenology, production, and fruit quality differ among blackberry cultivars grown under greenhouse in the Brazilian subtropics. Our results will make it possible to develop a portfolio of cultivars for growers, which could contribute to establishing commercial greenhouse orchards in southern Brazil, allowing them to be scaled up.

2. MATERIAL AND METHODS

2.1 Plant material

The experiment plant material were plants of different blackberry cultivars from the Frutplan nursery (31º 46' 34" S; 52º 21' 34" W), Pelotas, Rio Grande do Sul (RS), Brazil. The work was carried out in the municipality of Passo Fundo (28º 15' 41" S; 52º 24' 45" W), RS, Brazil, from August (winter) to December (summer) 2021, in a greenhouse.

The semicircular metal roof structure was installed in a northeast-southwest direction, with dimensions of 9 m x 39 m and a ceiling height of 2.5 m. The roof was covered with low-density polyethylene (LDPE) with a 150 micron anti-UV additive. The greenhouse front parts were covered with 50% shading and the sides with wire mesh to prevent birds from entering.

2.2 Experimental design

The treatments were four blackberry cultivars ('BRS Cainguá', 'BRS Tupy', 'BRS Xavante', and 'BRS Xingu'), arranged in a randomized block design, with four replications and three plants per plot.

All the cultivars studied originated from the Embrapa Clima Temperado Breeding Program in Pelotas, RS, and are intended for fresh consumption or agro-industrial processing. The cultivars were launched in the following order: ‘BRS Tupy’ (1988), ‘BRS Xavante’ (2004), ‘BRS Xingu’ (2015), and ‘BRS Cainguá’ (2019). ‘BRS Tupy’ is the most widely used cultivar in orchards worldwide and ‘BRS Xavante’ is the only cultivar in the study without thorns. All four cultivars require 200 to 300 hours of winter chilling.

2.3 Cultivation procedures

The blackberry daughter plants were planted in August (winter) 2019, with a spacing of 0.70 m between plants and 2.00 m between rows (7,143 plants ha^{-1}), with a manually operated drip irrigation system. The plants were managed in a single espalier system, with a height of 1.70 m and four rows of wire equidistant from each other (Figure 1).

Figure 1: Internal view of the greenhouse with blackberry cultivation indicating the line, on the left, that was evaluated in the experiment.

The plants were initially trained with a stem from the root system of the blackberry daughter plants, which was cut off about 40 cm from the ground to induce the formation of three stems. The stems were guided until they reached around 25 cm above the last wire, when they were removed 15 cm after the wire. To avoid excessive growth, the secondary branches emitted laterally from the three main stems, in the direction of the planting line, were cut back to 15 to 20 cm, with 3 to 5 buds. The shoots pointing in the direction of the inter-row were also cut back, maintaining a length of 10 to 15 cm. These prunings were carried out monthly until growth stopped at the end of April.

The fertilizer supplied to the plants was made according to the crop’s needs, in accordance with the fertilization and liming manual for the states of Rio Grande do Sul and Santa Catarina [10]. Forage peanuts (*Arachis pintoi* Krapov. & W.C. Gregory) were used as a living mulch between the rows. Phytosanitary treatments were only carried out during the vegetative growth phase of the stems.

A mini weather station was used to monitor the temperature (minimum, average, and maximum) inside the greenhouse during the experiment (Table 1).

Table 1: Temperatures recorded inside the greenhouse during the experiment.

Month	Minimum (ºC)	Average (ºC)	Maximum (ºC)
August	2.20	17.50	39.60
September	5.60	19.17	39.70
October	6.20	19.21	34.80
November	11.80	22.43	37.50
December	11.10	24.40	37.50

2.4 Phenology

Phenology was characterized based on the scale proposed by Antunes et al. (2000) [11]. Evaluations were carried out every two or three days, starting in August 2021, to determine: the date when budbreak began; the start and end dates of each phenological stage, from the start of flower buds (stage 0) to ripe fruit (stage 9); the duration of each stage; the time interval between budbreak and flower opening (stage 2) and from the start of stage 2 to the start of harvest (stage 9); the duration of flowering and harvest. Phenological data was collected by observing the average behavior of each cultivar along the entire planting line.

2.5 Fruit production

Productive aspects were assessed by determining the number of fruits produced per plant (TNF, number per plant), the average fresh fruit mass (AFFM, grams), the longitudinal diameter (LD, mm), and transverse diameter (TD, mm) of the fruits and the total production per plant (TP, kg plant^{-1}). TNF was determined when the fruit was still green, 15 days before the harvest start. TP was calculated using TNF multiplied by AFFM. LD and TD were measured using a digital caliper. An analytical scale was used to assess the average fruit mass.

2.6 Fruit quality

In November (summer), from samples of 20 fruits from each treatment and repetition, the total soluble solids content (TSS, %) was determined in an analog refractometer, the total titratable acidity (TTA, % of citric acid), and the TSS/TTA ratio (fruit flavor), according to the standards of the Adolfo Lutz Institute [12].

2.7 Data analysis

Due to the nature of the variables, the phenological data was presented in descriptive form, characterizing, and comparing the cultivars. The data obtained regarding the productive potential and fruit quality were subjected to analysis of variance (Anova) and the differences between means were compared using the Scott-Knott test at a 5% probability of error, using the Sisvar® program [13].

In addition, to illustrate the relationship among the four blackberry cultivars in terms of phenology and fruit production and quality attributes, dendrograms were used to analyze clusters using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) calculated by the Mahalanobis distance. Subsequently, dendrograms were constructed which obtained the greatest consistency of grouping for the cultivars, using the cophenetic correlation coefficient (CCC), distortion and stress as validation criteria [14].

In addition, the relative contribution of blackberry production and quality attributes to divergence among cultivars was investigated [15], and Person's correlation analysis was carried out. The *'ggplot2'* package in RStudio [16] was used for the multivariate analyses.

3. RESULTS AND DISCUSSION

3.1 Phenology

The natural leaf fall during the hibernation period, especially in greenhouse conditions, which were less influenced by low temperatures and frosts, was only of the basal leaves, which had to be removed with scissors at the end of August (25/August) to encourage the emission of new shoots. Sprouting began in the greenhouse on 19/August for 'BRS Xingu' and 'BRS Xavante' and around three days later (22/August) for 'BRS Tupy' and 'BRS Cainguá'. The time elapsed from the start of sprouting to the start of flowering (stage 2) was shorter for 'BRS Xavante' (20 days), while for 'BRS Tupy' it was 27 days, 'BRS Xingu' 36 days, and 'BRS Cainguá' 39 days (Table 2).

Table 2: Period and duration (days) of phenological stages of four blackberry cultivars in a greenhouse.

Phenological stages[1]	'BRS Tupy'		'BRS Xavante'		'BRS Xingu'		'BRS Cainguá'	
	Period[2]	Days	Period	Days	Period	Days	Period	Days
Budding	22/Aug	-	19/Aug	-	19/Aug	-	22/Aug	-
0	06/Sept-06/Oct	30	02/Sept-02/Oct	30	29/Aug-05/Oct	37	02/Sept-16/Oct	44
1	20/Sept-13/Oct	24	10/Sept-06/Oct	26	06/Sept-09/Oct	33	13/Sept-20/Oct	37
2	23/Sept-20/Oct	27	18/Sept-08/Oct	20	12/Sept-18/Oct	36	18/Sept-27/Oct	39
3	27/Sept-23/Oct	26	22/Sept-11/Oct	19	18/Sept-23/Oct	35	22/Sept-31/Oct	39
4	04/Oct-28/Oct	24	27/Sept-29/Oct	32	22/Sept-26/Oct	34	28/Sept-02/Nov	35
5	12/Oct-19/Nov	38	06/Oct-03/Nov	28	02/Oct-02/Nov	31	08/Oct-08/Nov	31
6	22/Oct-22/Nov	31	23/Oct-08/Nov	16	18/Oct-19/Nov	32	20/Oct-17/Nov	28
7	29/Oct-26/Nov	28	29/Oct-15/Nov	12	23/Oct-22/Nov	30	29/Oct-29/Nov	31
8	04/Nov-29/Nov	25	02/Nov-20/Nov	18	26/Oct-26/Nov	31	10/Nov-03/Dec	23
9	08/Nov-02/Dec	24	08/Nov-24/Nov	16	28/Oct-29/Nov	32	13/Nov-07/Dec	25
Mean		28		22		33		33

[1]Scale proposed by Antunes et al. (2000) [11]. Stage 0 = Closed bud; Stage 1 = Open bud; Stage 2 = Open flower; Stage 3 = Petal loss; Stage 4 = Fruit swelling with floral remains; Stage 5 = Fruit swelling without floral remains; Stage 6 = Change from green to reddish; Stage 7 = Full red; Stage 8 = Beginning of fruit darkening; Stage 9 = Full black. [2]Aug = August; Sept = September; Oct = October; Nov = November; Dec = December.

The duration of each phenological stage ranged from 24 to 38 days for 'BRS Tupy', between 12 and 32 days for 'BRS Xavante', between 30 and 37 days for 'BRS Xingu', and, for 'BRS Cainguá', from 23 to 44 days (Table 2). 'BRS Xavante' had the shortest average duration of each stage (22 days), especially from stage 3 and from stage 6 onwards. 'BRS Tupy' was the second shortest (28 days). 'BRS Xingu' and 'BRS Cainguá' had an average duration of 33 days (Table 2).

This variation in the duration of the stages among cultivars can be exemplified by highlighting the case of 'BRS Cainguá', which had the longest duration in six of the nine stages (stages 0, 1, 2, 3, 4, and 7). In the closed bud stage (stage 0), 'BRS Tupy' and 'BRS Xavante' remained for 30 days, 'BRS Xingu' for 37 days, and 'BRS Cainguá' for 44 days (Table 2).

The heterogeneity among the cultivars in terms of the start, end, and duration of the phenological stages was illustrated by the dendrograms generated by the UPGMA method (Figure 2), whose fits to the Mahalanobis distance matrix calculated by the CCC were 89% (start dates of the stages), 64% (end dates of the stages), and 62% (duration of the stages), indicating the suitability of the models. Thus, in all three cases (start, end, and duration), two groups were formed (Figure 2), showing the dissimilarity among the cultivars in terms of phenological stages.

Regarding the dates that marked the start of each phenological stage, one of the groups was made up of ‘BRS Xavante’, ‘BRS Cainguá’, and ‘BRS Tupy’ (Figure 2). The second group consisted only of ‘BRS Xingu’ (Figure 2). In the latter case, ‘BRS Xingu’ was the first cultivar to start all the phenological stages (Table 2).

As for the end dates of each phenological stage, group 1 brought together ‘BRS Tupy’, ‘BRS Xingu’, and ‘BRS Cainguá’ and group 2 consisted only of ‘BRS Xavante’ (Figure 2). With the exception of stages 4 and 5, ‘BRS Xavante’ was the first cultivar to complete the phenological stages (Table 2).

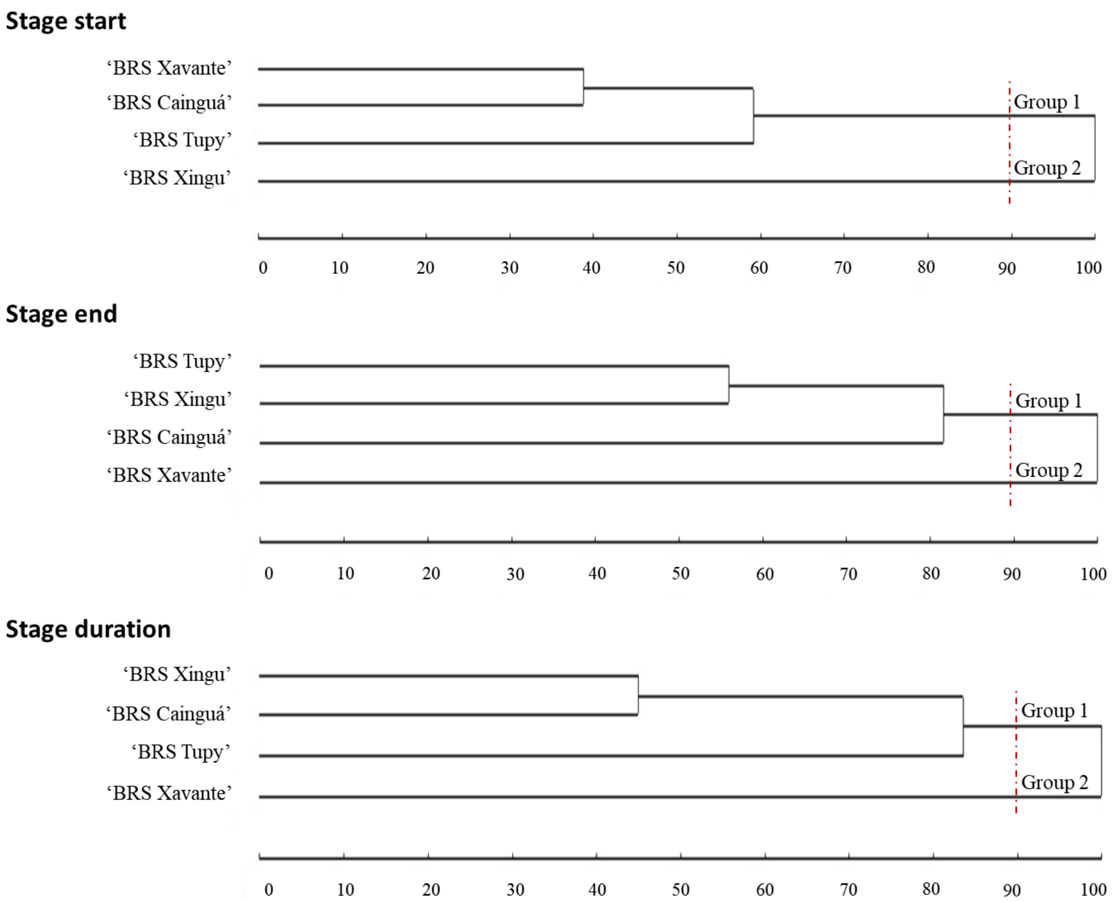

Figure 2: Dendrogram of dissimilarity among blackberry cultivars obtained by the UPGMA method based on the phenological stages. For stage start, CCC, distortion (%), and stress (%) were 0.89, 2.27, and 15.06, respectively. For stage end, CCC, distortion (%), and stress (%) were 0.64, 4.36, and 20.88, respectively. For stage duration, CCC, distortion (%), and stress (%) were 0.62, 0.84, and 9.20, respectively.

When we analyzed the duration of these stages, we found that ‘BRS Xingu’, ‘BRS Cainguá’, and ‘BRS Tupy’ were grouped together in group 1, while ‘BRS Xavante’ remained in group 2 (Figure 2). In this case, ‘BRS Xavante’ differed from the other cultivars in group 1, mainly due to the shorter average duration of each stage, which was 22 days (Table 2).

The blackberry is a temperate climate species and can be grown from regions with mild winters to regions with extreme cold. Changes in the average air temperature alter the cycle, especially the flowering season. The literature shows that the cultivation of temperate species in different conditions alters their phenological behavior, mainly due to variations in the accumulation of hours of cold during the dormant period and the occurrence of frosts. Subsequently, the phenological stages can be shortened in warmer regions due to more accelerated development [17] or due to the production system, which in our study was in a greenhouse, unlike the condition in which blackberry is traditionally grown, i.e., in the open field.

The characteristic of the blackberry tree to have long-lasting stages allows them to overlap (Figure 3). For example, 'BRS Tupy' had five phenological stages occurring simultaneously on 06/October, from stage 0 to stage 4; another five on 19/November, in the early harvest phase, from stage 5 to stage 9. Overlapping stages were observed in the other cultivars.

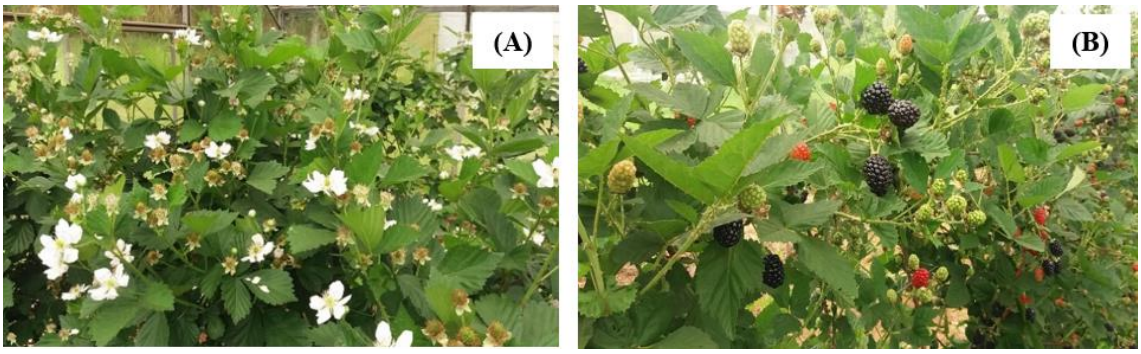

Figure 3: Superimposition of phenological stages in blackberry 'BRS Tupy'. A) Presence of stages 0 (closed bud), 1 (open bud), 2 (open flower), 3 (petal loss), and 4 (fruit swelling with floral remains). B) Presence of stages 5 (fruit swelling without floral remains), 6 (change from green to reddish), 7 (full red), 8 (beginning of fruit darkening), and 9 (full black).

In the initial phase of its development, 'BRS Cainguá' had more phenological stages occurring at the same time, due to the greater number of days it took to complete each one. However, in the final stage of development, this cultivar had shorter stages 8 and 9, characterizing more uniform fruit ripening.

The cycle of each cultivar, from sprouting to harvest, was 69 days for 'BRS Xingu', 77 days for 'BRS Tupy', 80 days for 'BRS Xavante', and 82 days for 'BRS Cainguá' (Table 2). This allows growers to stagger these cultivars, as 'BRS Xingu' proved to be the earliest in terms of fruit harvest.

'BRS Xingu' had an earlier start to all the phenological stages evaluated than the other cultivars and was therefore considered the earliest to start harvesting fruit (28/October). In addition, this cultivar remained in production for longer (32 days) (Table 2). Although 'BRS Tupy' required a longer period to start fruiting (stage 4), the cultivar with the latest harvest (stage 9) was 'BRS Cainguá', which started on 13/November. 'BRS Tupy' and 'BRS Xavante' were considered intermediate cultivars in terms of the start of fruit harvest (08/November) (Table 2). The phenological variations in terms of the start of sprouting and the other stages can be attributed, in addition to climatic factors (temperature, rainfall, and chill hours accumulated), to each cultivar and the management carried out [18].

Therefore, under greenhouse conditions, the cultivars began to be harvested between the end of October and the first half of November, concluding in the following sequence: 'BRS Xavante' (24/November), 'BRS Xingu' (29/November), 'BRS Tupy' (02/December), and 'BRS Cainguá' (07/December). The shortest harvest period was for 'BRS Xavante' (16 days), while it was 24 and 25 days for 'BRS Tupy' and 'BRS Cainguá', and 32 days for 'BRS Xingu'. These periods are similar to those found in the literature. Antunes et al. (2010) [19] showed that 'BRS Tupy' started harvesting in November, while Hussain et al. (2016) [20] showed that this cultivar also started harvesting in November, but with a duration of 49 days.

3.2 Fruit production

The analysis of variance indicated a significant effect for the cultivars in relation to the attributes TP, AFFM, LD, and TD. 'BRS Tupy' and 'BRS Xingu' produced blackberries with the highest AFFM, standing out with the highest TP. 'BRS Xavante', although its fruit had a lower fresh mass, did not differ from the aforementioned cultivars in terms of total production. These three cultivars had an average 47% higher total production than 'BRS Cainguá', which had the lowest production performance (Table 3). Fruits from 'BRS Tupy' had the highest TD, while blackberries from 'BRS Cainguá' had the highest LD (Table 3).

Table 3: Yield of four blackberry cultivars in a greenhouse.

Cultivars	TP (kg plant^{-1})[1]	AFFM (grams)	TD (mm)	LD (mm)
'BRS Tupy'	2.38±0.02 a	8.98±1.12 a	19.65±3.01 a	28.82±4.03 b
'BRS Xingu'	2.79±0.03 a	8.89±1.34 a	17.03±2.00 c	24.02±3.99 c
'BRS Xavante'	2.01±0.01 a	8.21±1.98 b	17.72±2.08 b	22.26±3.48 d
'BRS Cainguá'	1.26±0.01 b	7.66±0.98 b	16.48±2.14 c	33.81±4.57 a
Mean	2.10	8.43	17.72	27.24
CV (%)[2]	31.13	5.05	2.79	3.50

Data was presented as mean ± standard deviation. Means followed by the same letter in the column do not differ between each other by Scott-Knott test ($p \leq 0.05$). [1]TP = Total production (kg plant^{-1}); AFFM = Average fresh fruit mass (grams); TD = Transverse diameter of fruits (mm); LD = Longitudinal diameter of fruits (mm). [2]CV (%) = coefficient of variation experimental.

The yield results showed variability among cultivars. The most productive cultivar ('BRS Xingu') produced 2.2 times more than the least productive cultivar ('BRS Cainguá'). This indicates the influence of genotype on yield expression and the need to find cultivars that are more suitable for each growing region [21].

Blackberry production can vary depending on the choice of cultivars. In this study, 'BRS Cainguá' showed the lowest total production, but with the largest longitudinal fruit diameter, which gives it good potential for marketing *in natura* (Table 3). It should be noted that this is a low-growing cultivar, which does not require tutoring like the others, meaning that the choice of cultivation provides an important reduction in the costs of planting, managing, and harvesting.

'BRS Tupy', although it did not differ in terms of total production from 'BRS Xingu' and 'BRS Xavante', produced fruit with a larger transverse diameter, which reinforces its preference by producers in the domestic and foreign markets. It is one of the most widely planted cultivars in Brazil and worldwide because it has more suitable fruits for fresh consumption due to its size, uniformity, firmness, and flavor [8]. Although 'BRS Xavante' has erect, vigorous stems without thorns, which makes it easier to handle [22], this cultivar produced fruit with a smaller longitudinal diameter than the other cultivars (Table 3), which makes it more suitable for agro-industrial processing.

The literature reports that the staggering of cultivars with different phenological contrasts (Table 2) and different productive performances (Table 3) is strategic phytotechnical management, as it reduces the risk of losses and also makes it possible to distribute production throughout the crop cycle, which can dilute the labor involved in harvesting and allow the fruit to enter the market gradually [23].

3.3 Fruit quality

The analysis of variance for fruit quality indicated that there was no significant effect among the cultivars in relation to the attributes studied (Table 4).

Table 4: Summary of the analysis of variance, containing the sources of variation (SV), degrees of freedom (DF), mean squares (MS), and coefficient of variation experimental (CV, %) of variables related to the fruit quality of blackberry cultivars.

SV	DF	MS		
		TSS (%)[1]	TTA (%)	FLA
Blocks	3	0.0001[ns]	0.0002[ns]	0.0003[ns]
Cultivars	3	0.11[ns]	0.052[ns]	2.64[ns]
Residue	9	0.000000106	0.00000004	0.000000005
Total	15			
Mean		8.42	1.03	8.25
CV (%)		9.50	11.10	13.50

[1]TSS = Total soluble solids (%); TTA = Titratable total acidity (%); FLA = Flavor. [ns]Not significant ($p \geq 0.05$).

Sugars and organic acids are the main water-soluble substances in berries and have a great influence on the taste and ripeness of blackberries, even representing an index of consumer acceptability [24]. Thus, TSS and TTA levels (represented mainly by citric and malic acid) are constituents of fruit quality that determine its processability [25]. Alcohols, aldehydes, ketones, sulphur compounds, esters, furanones, and terpenoids are the main groups responsible for the taste of blackberries [26]. In addition, heptanol and *p*-cymen-8-ol are also important compounds in blackberry flavor, described as fruity-herbaceous and flowery-spicy, respectively [27].

The preference for blackberry consumption is not only attributed to its high nutritional value, characteristic flavor, and aroma, but also to its biomolecules with health-promoting potential [28]. For example, anthocyanins account for more than 50% of phenolic compounds and the high content of this pigment is the main cause of the black color formation in blackberries [24]. Researchers, industry, and producers should focus their studies and management on the phytochemical quality of blackberries to meet an increasingly demanding consumer market concerned with the acquisition and consumption of nutraceutical foods.

3.4 Multivariate contrasts

The multivariate analysis of fruit production and quality attributes showed that there was heterogeneity among cultivars studied. This dissimilarity was illustrated by the dendrogram generated by the UPGMA method (Figure 4), whose fit to the Mahalanobis distance matrix, calculated by the CCC, was 73%, indicating the model's suitability. Three groups were formed (Figure 4).

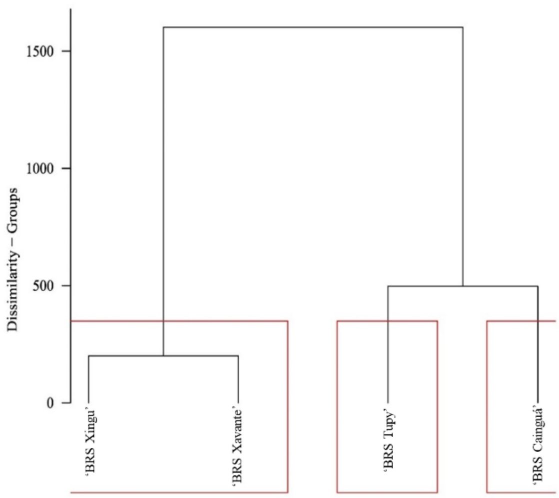

Figure 4: Dendrogram of dissimilarity among blackberry cultivars obtained by the UPGMA method based on the Mahalanobis distance matrix. CCC = 0.73. Distortion and stress (%) = 14.73 and 38.39, respectively.

One of the groups was formed by ‘BRS Xingu’ and ‘BRS Xavante’ (Figure 4). This group of cultivars showed similar performance in terms of phenology (start of sprouting) (Table 2). The second group consisted of ‘BRS Tupy’ and the third group ‘BRS Cainguá’ (Figure 4). ‘BRS Tupy’ had a particular characteristic in terms of the largest transverse fruit diameter (Table 3) and ‘BRS Cainguá’ had the most uniform fruit ripening (Table 2) and contrasted with the other cultivars, mainly in terms of longitudinal fruit diameter (Table 3).

The attribute that contributed most to the divergence among the cultivars (Figure 4) was TP, which explained 53.90% of the variability among the cultivars studied (Table 5). In addition, the attributes with the highest relative contribution to dissimilarity were TD, AFFM, and FLA, with 28.63%, 7.52%, and 5.33%, respectively. These attributes accounted for 95.38% of the total dissimilarity among the cultivars (Table 5).

Table 5: Relative contribution of the attributes to dissimilarity among blackberry cultivars.

Attributes[1]	Contribution (%)
TP	53.90
TD	28.63
AFFM	7.52
FLA	5.33
TTA	2.99
LD	1.60
TNF	0.00
TSS	0.00

[1]TP = Total production (kg plant^{-1}); TD = Transverse diameter of fruits (mm); AFFM = Average fresh fruit mass (grams); FLA = Flavor; TTA = Titratable total acidity (%); LD = Longitudinal diameter of fruits (mm); TNF = Total number of fruits (number per plant); TSS = Total soluble solids (%).

From the correlation matrix between fruit production and quality attributes, we found that eight associations were significant (Figure 5), five of which were positive (AFFM-TNF, TP-TNF, TSS-LD, AFFM-TD, and TP-AFFM) and three were negatively associated (FLA-TD, FLA-AFFM, and FLA-TTA).

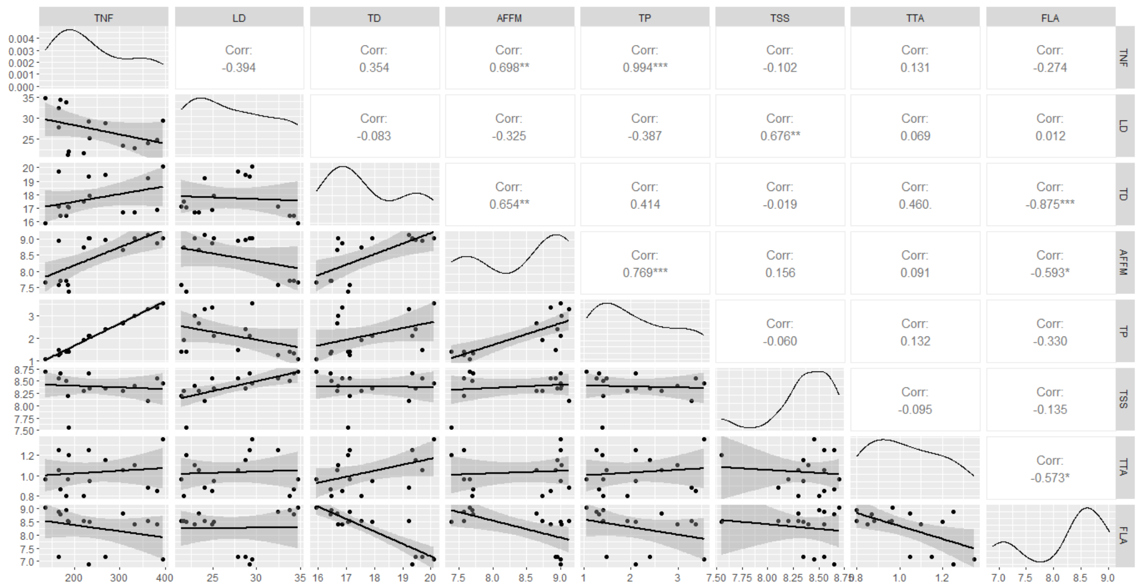

Figure 5: Correlation matrix among the attributes evaluated in the study. TNF = Total number of fruits (number per plant); LD = Longitudinal diameter of fruits (mm); TD = Transverse diameter of fruits (mm); AFFM = Average fresh fruit mass (grams); TP = Total production (kg plant^{-1}); TSS = Total soluble solids (%); TTA = Titratable total acidity (%); FLA = Flavor.

Greenhouse cultivation, commonly used for flower or vegetable production, has become a tool for the cultivation of some fruit trees. The use of plastic sheeting over the plant canopy partially or totally reduces rainfall on the leaves and fruit, reducing problems caused by diseases, hail damage or excessive wind, a practice that is already very common in some crops, such as grapes [29]. In addition to these advantages, growing in a greenhouse makes it possible to increase productivity compared to production outdoors. Due to the more favorable climatic conditions for accelerated crop development throughout the cycle, it can promote an earlier harvest [9]. Therefore, this technology deserves further study, as it can provide more or less physiological changes in plants and economic advantages depending on the region and specific growing conditions.

4. CONCLUSION

Blackberry cultivars grown under greenhouse in the Brazilian subtropics differ in terms of phenology and yield. Fruit quality is not influenced by the cultivars studied. ‘BRS Xingu’ anticipates the start of all phenological stages, is considered the earliest for fruit harvest and has the highest yield potential. ‘BRS Cainguá’ produces fruit with the largest longitudinal diameter and ‘BRS Tupy’ produces blackberries with the largest transverse diameter. The contrasting phenology of the four cultivars allows fruit production to be staggered around 15 days in terms of the beginning and end of the harvest. The long flowering period, which varies between 30 and 40 days, favors pollination and protects the plants from damage caused by late frosts, which can occur even when grown in a greenhouse.

5. REFERENCES

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